9th INTERNATIONAL BLACK SEA MODERN SCIENTIFIC RESEARCH CONGRESS

August 1-3, 2026 / Düzce, Türkiye



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CONGRESS TITLE
9th INTERNATIONAL BLACK SEA MODERN SCIENTIFIC RESEARCH CONGRESS

DATE
August 1-3, 2026

PLACE
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Face-to-face & Online (Zoom)

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236	43	109	127
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İlgili makama;

9. Uluslararasi Karadeniz Modern Bilimsel Araştirmalar Kongresi, 1-3 Ağustos 2026 tarihleri arasında Düzce'de 32 farklı ülkenin (Türkiye 109 bildiri- Diğer ülkeler 127 bildiri) akademisyen/araştırmacılarının katılımıyla gerçekleşmiştir

Kongre 16 Ocak 2020 Akademik Teşvik Ödeneği Yönetmeliğine getirilen "Tebliğlerin sunulduğu yurt içinde veya yurt dışındaki etkinliğin uluslararası olarak nitelendirilebilmesi için Türkiye dışında en az beş farklı ülkeden sözlü tebliğ sunan konuşmacının katılım sağlaması ve tebliğlerin yarıdan fazlasının Türkiye dışından katılımcılar tarafından sunulması esastır." değişikliğine uygun düzenlenmiştir.

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Konu : Kongre Düzenleme ve Bilim Kurulu Görevlendirmesi

Sayın Dr. Öğr. Üyesi Mehmet TATOĞLU

İlgi : 29.06.2026 tarihli dilekçeniz.

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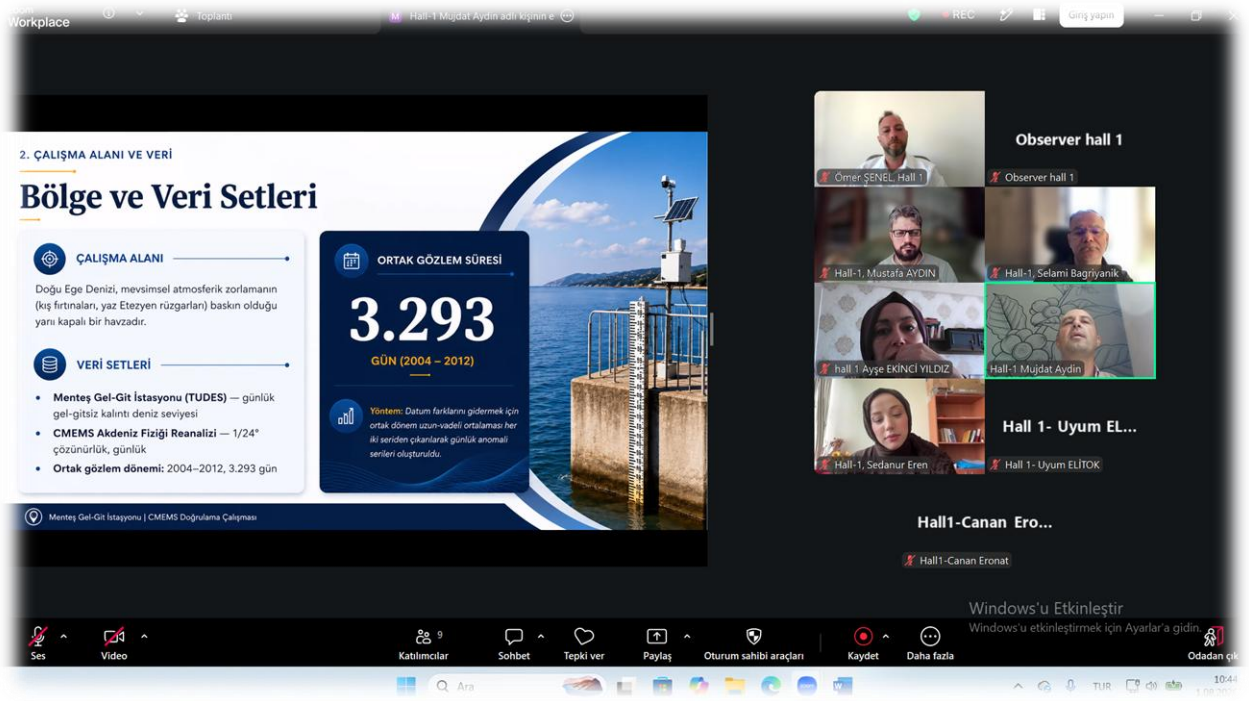

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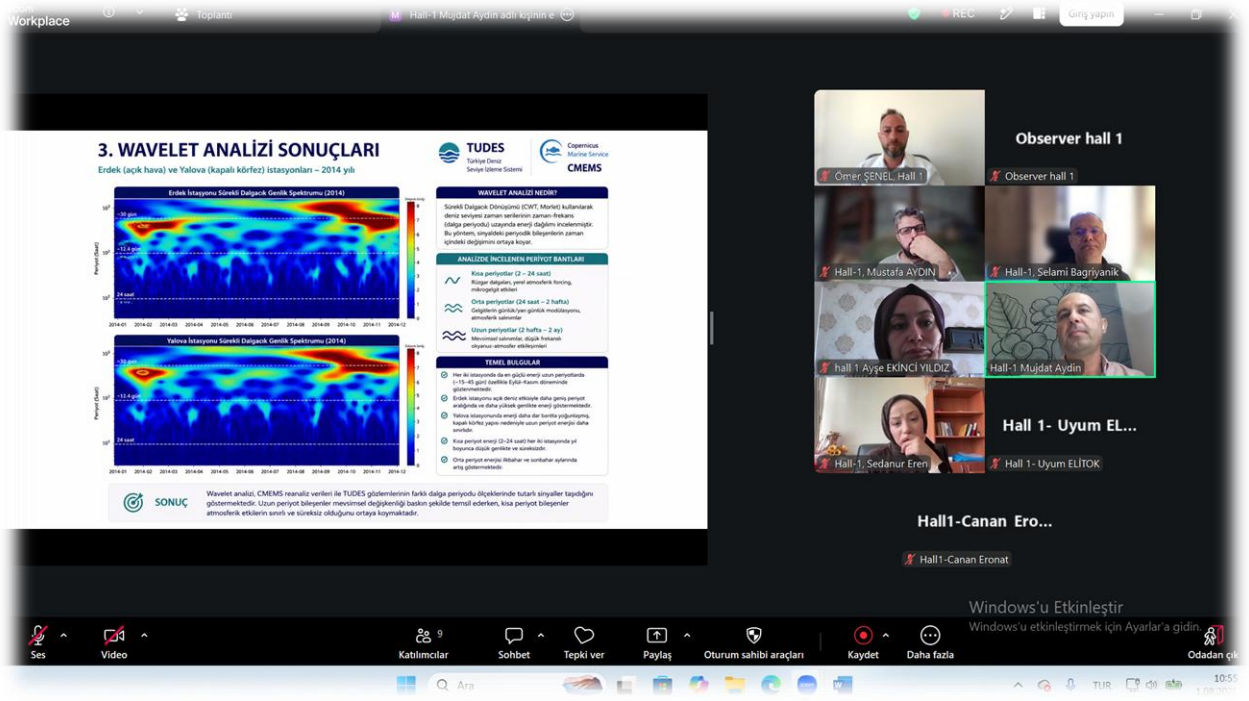

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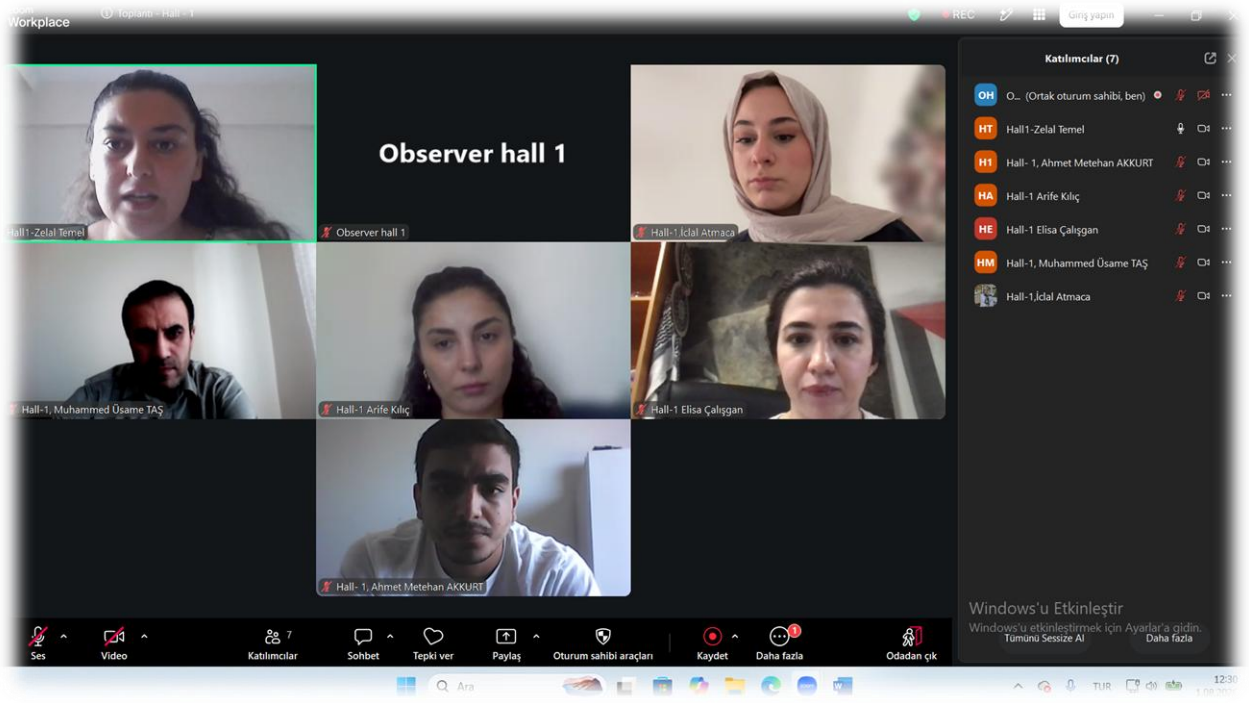

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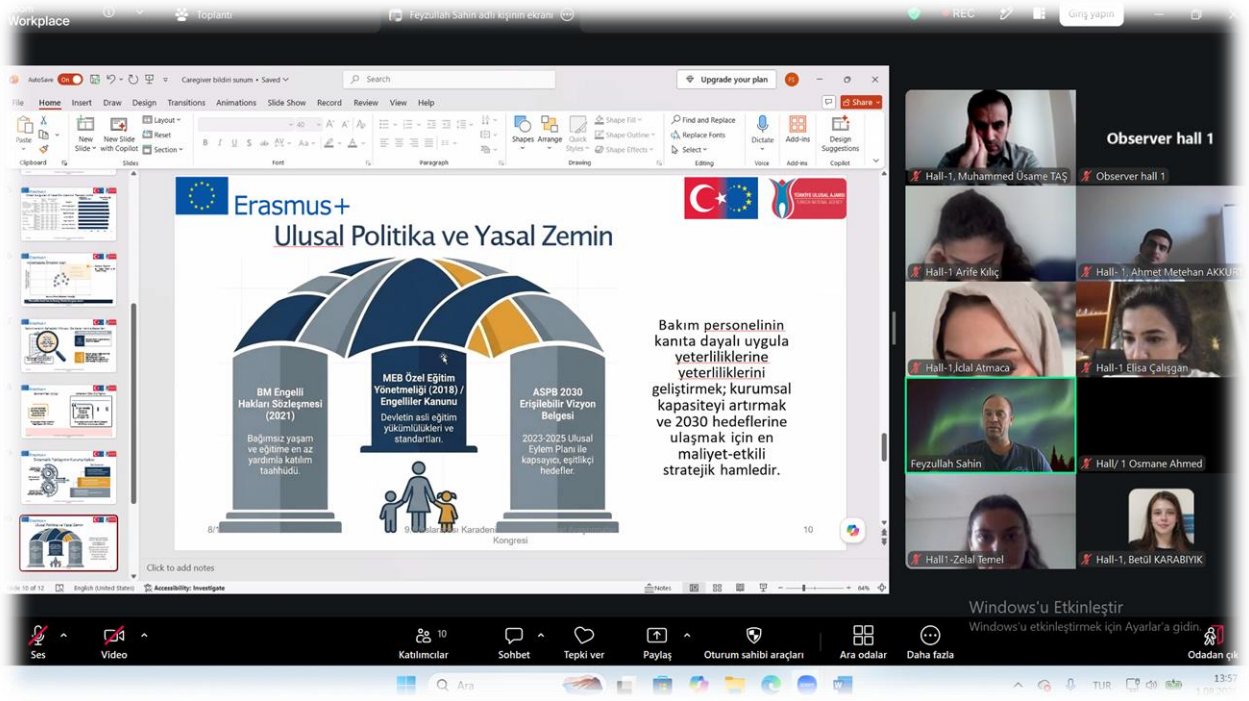

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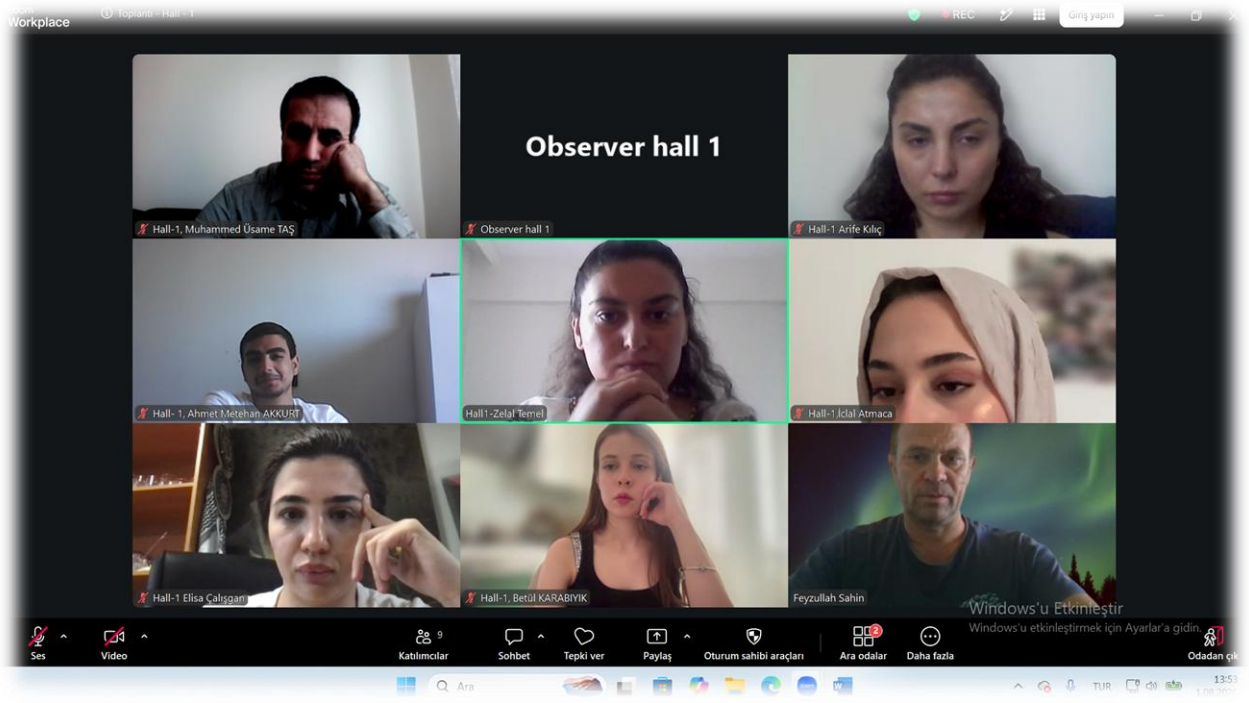

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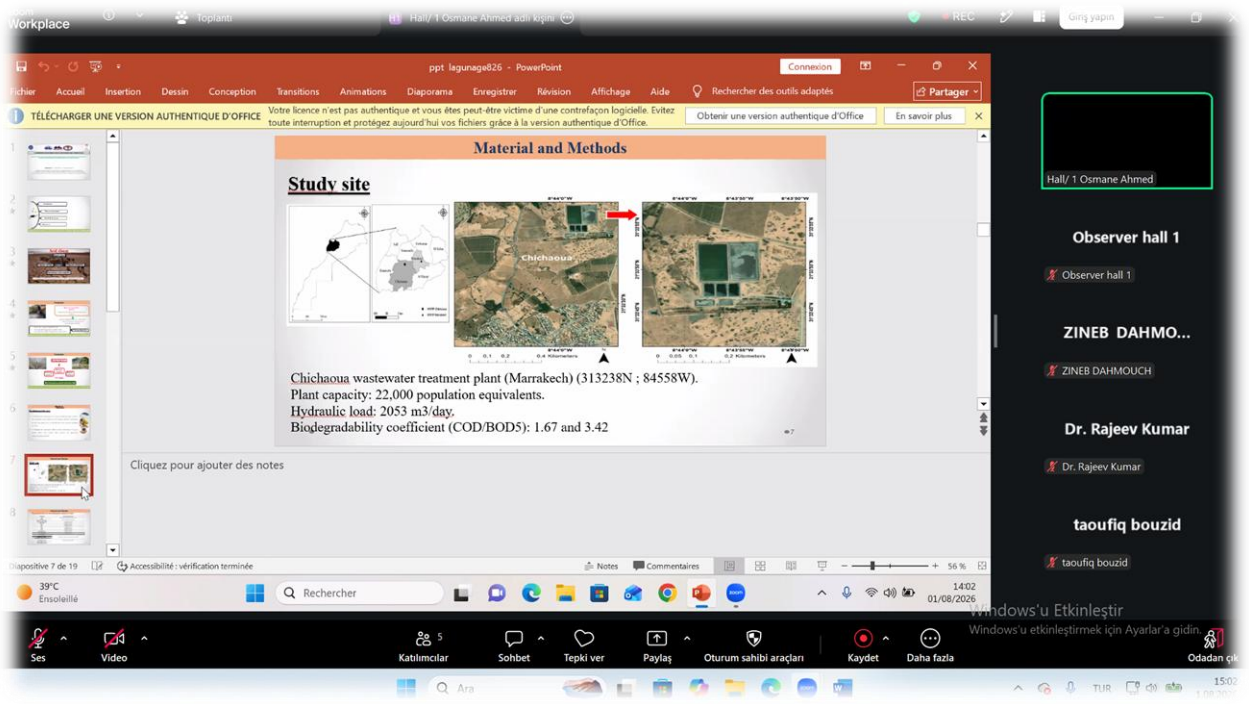

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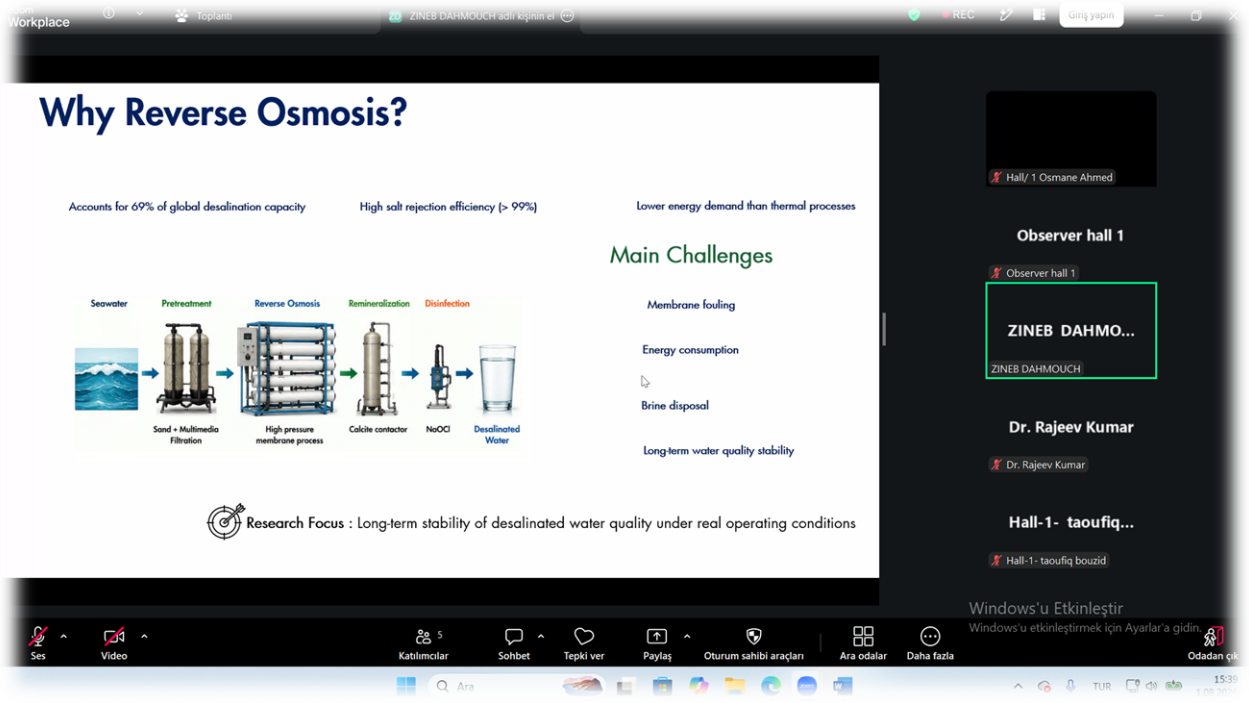

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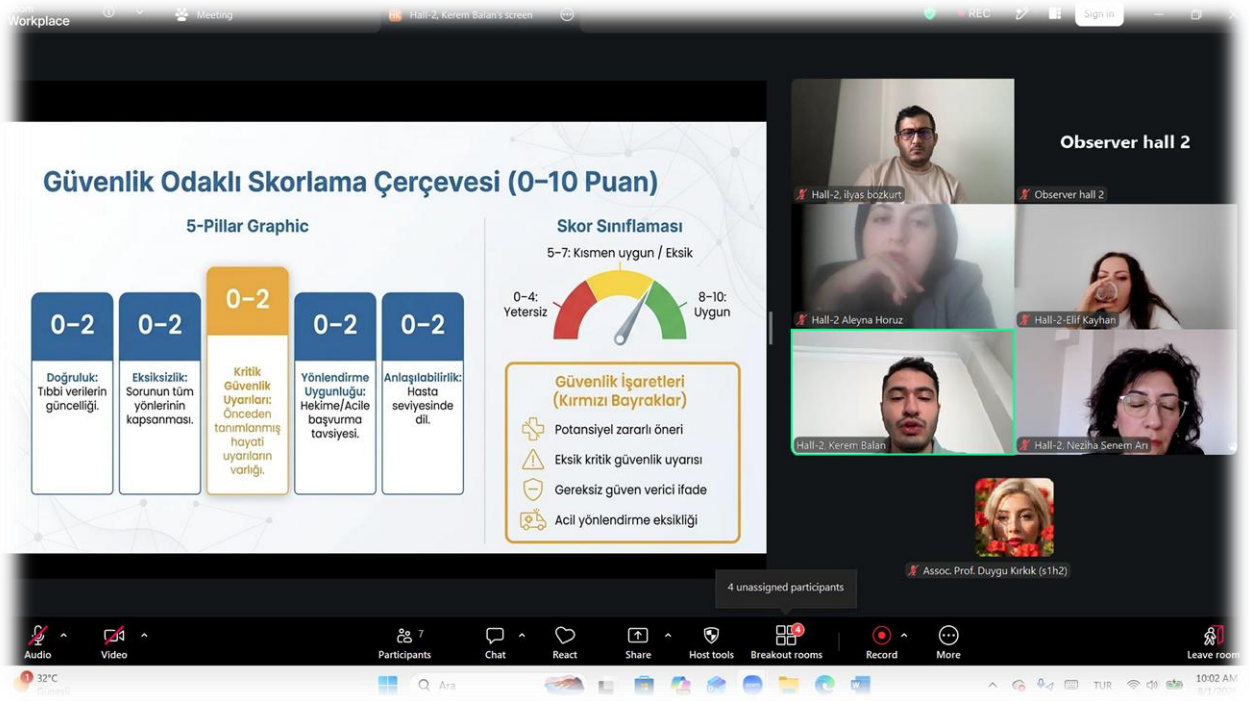

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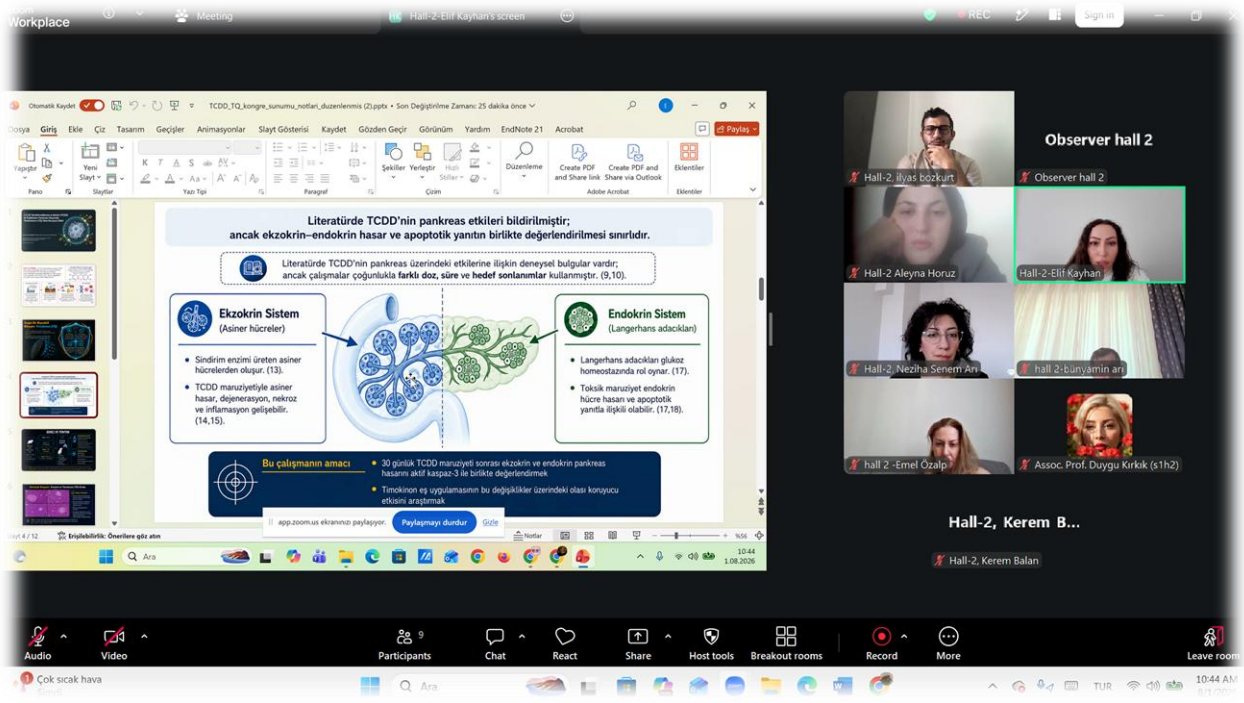

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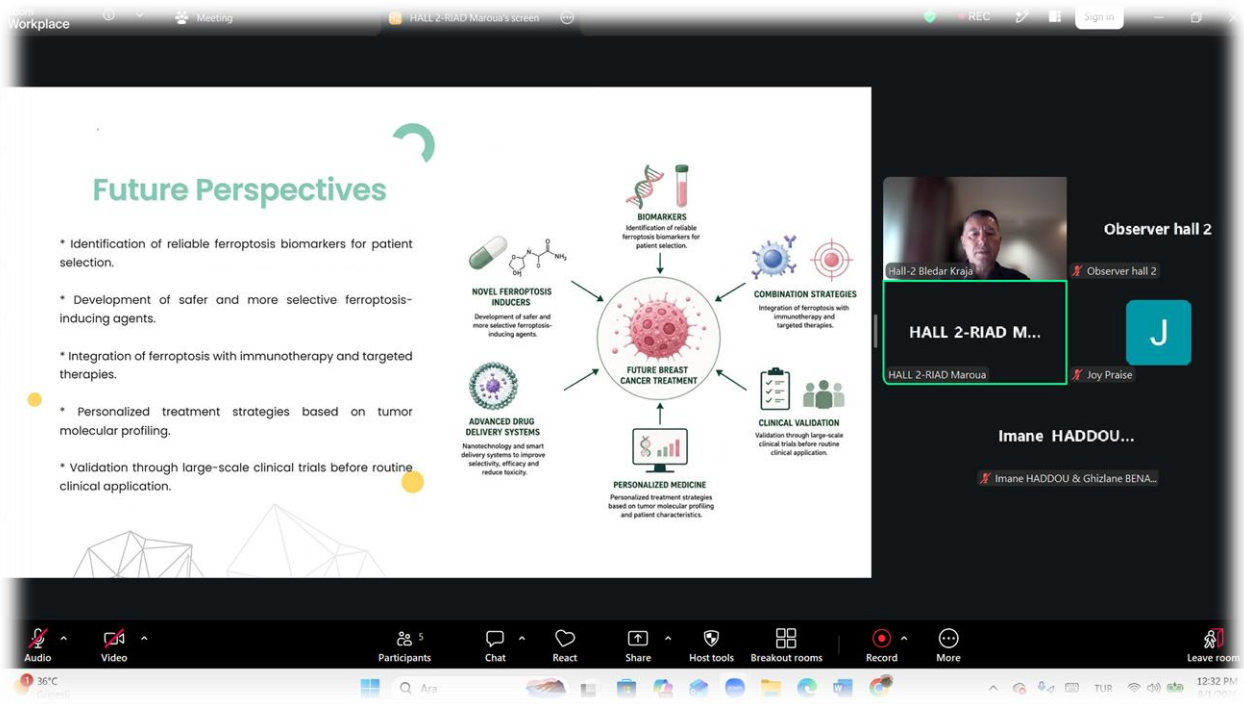

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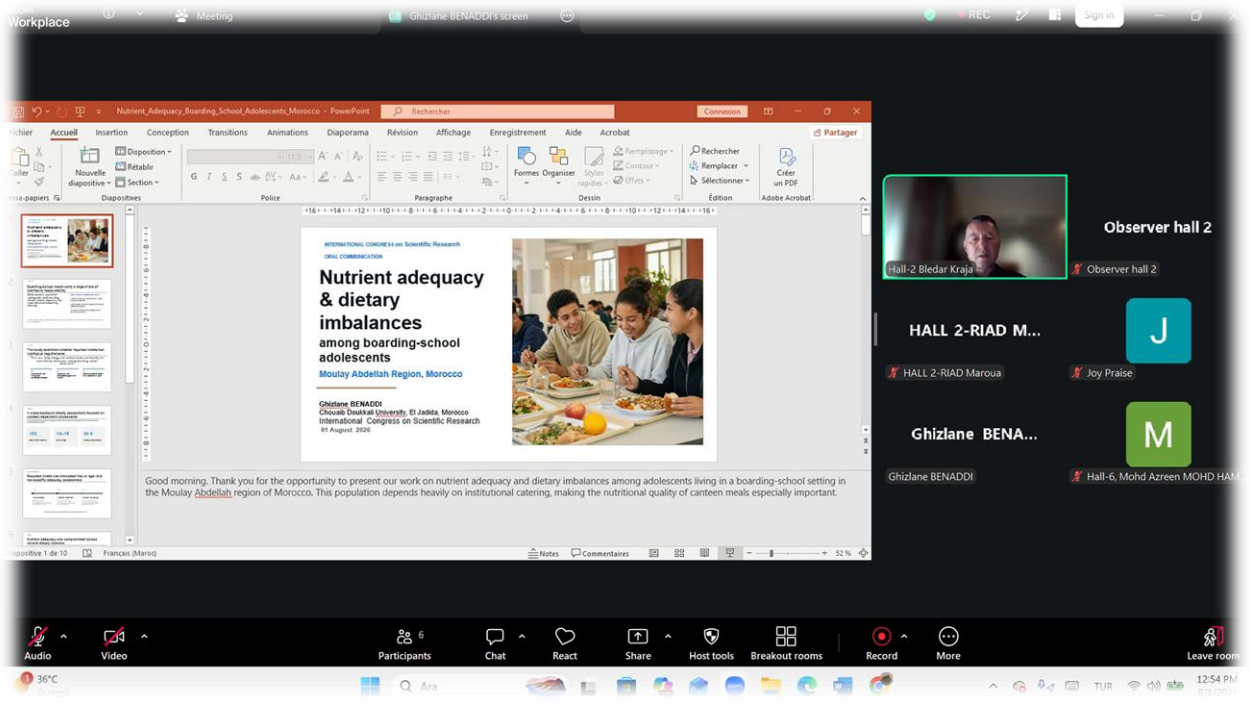

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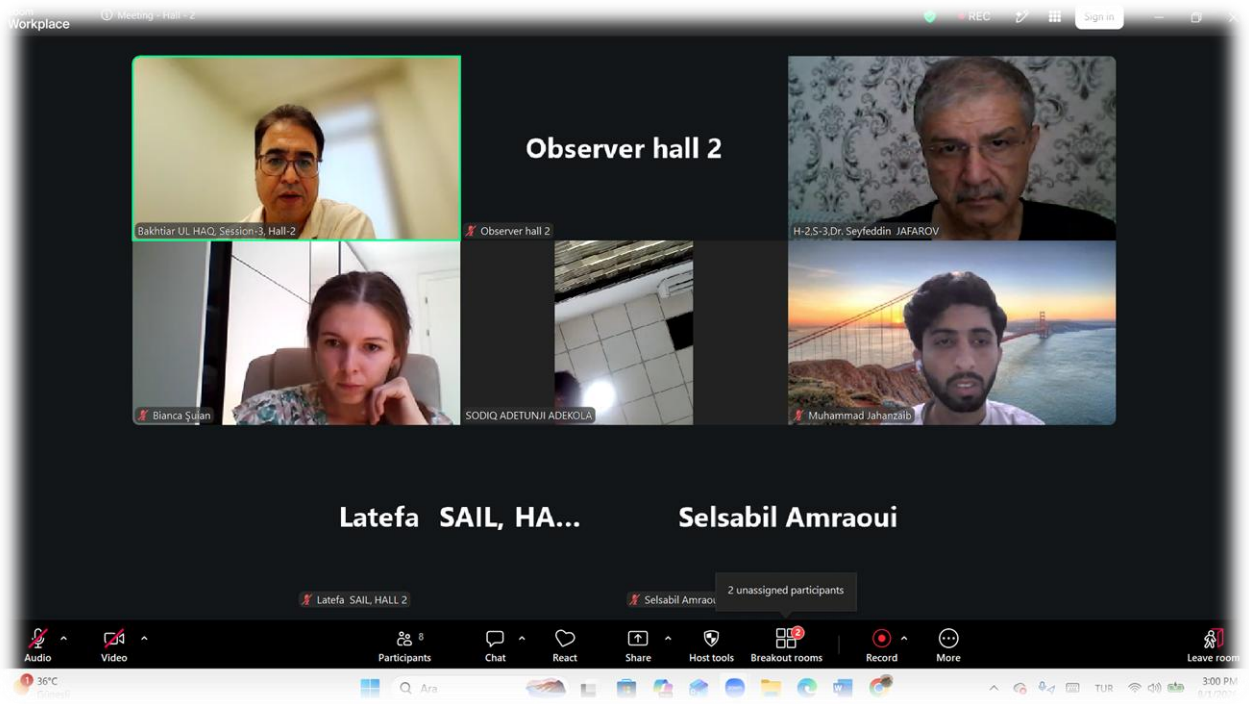

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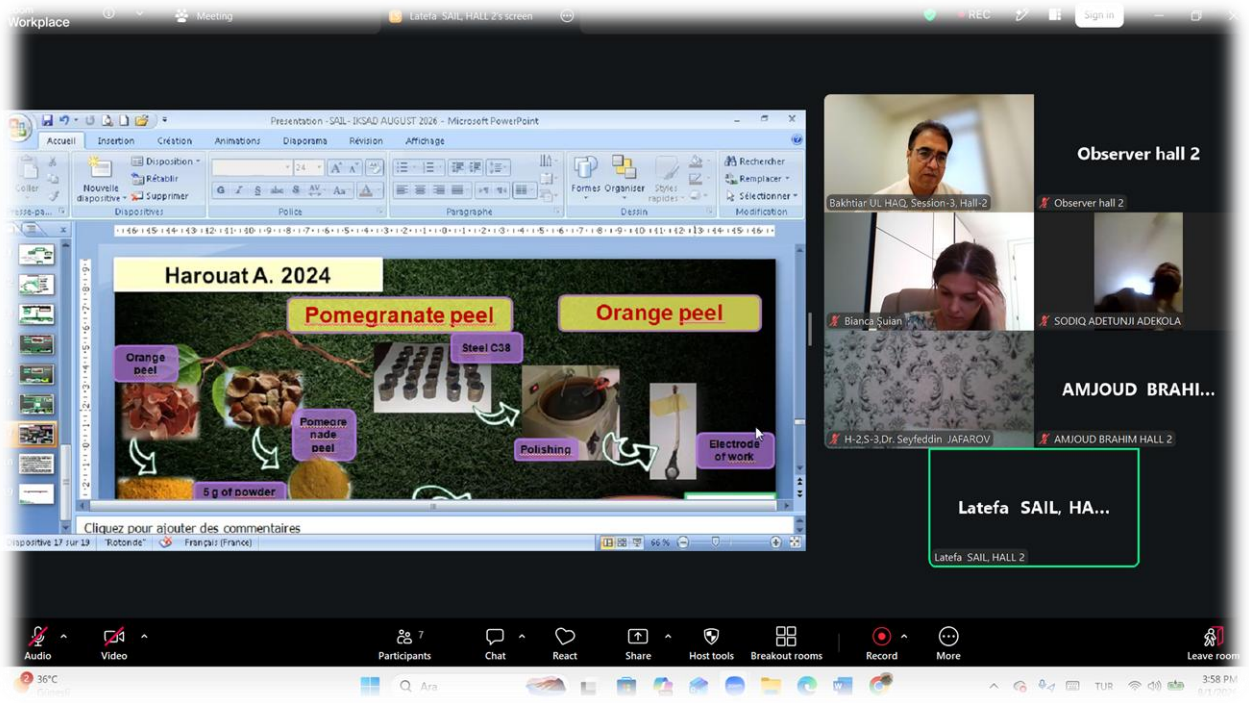

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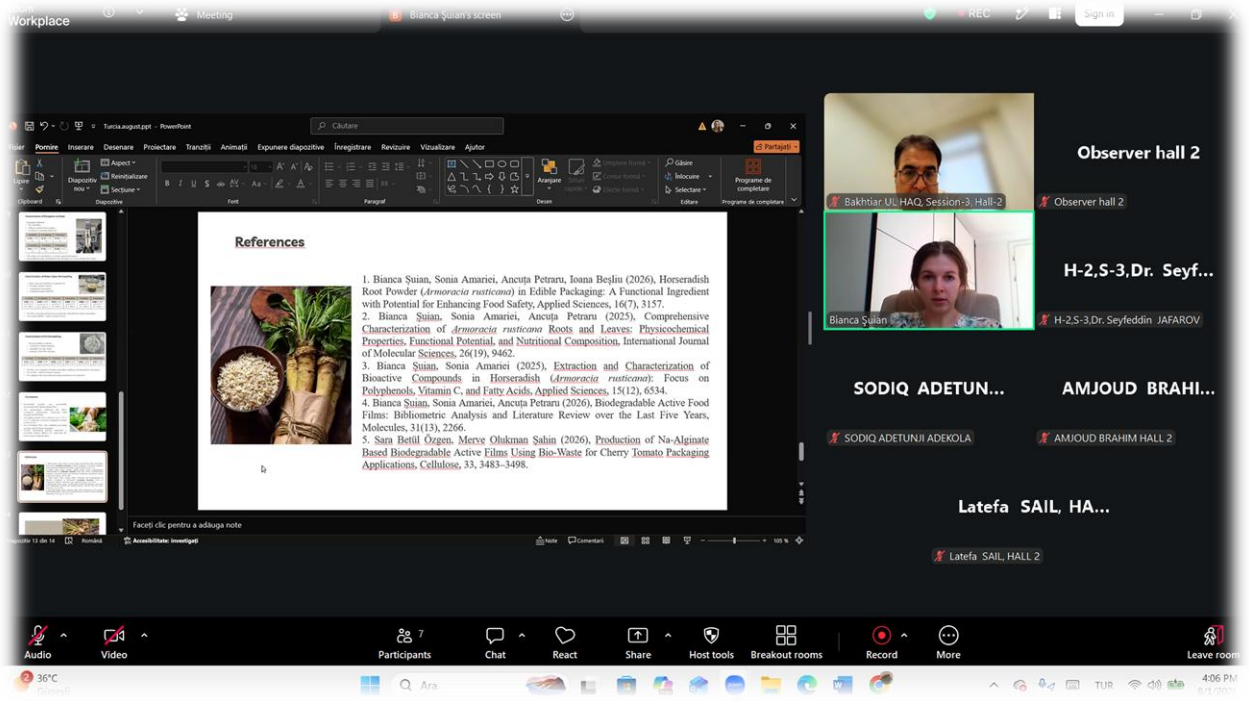

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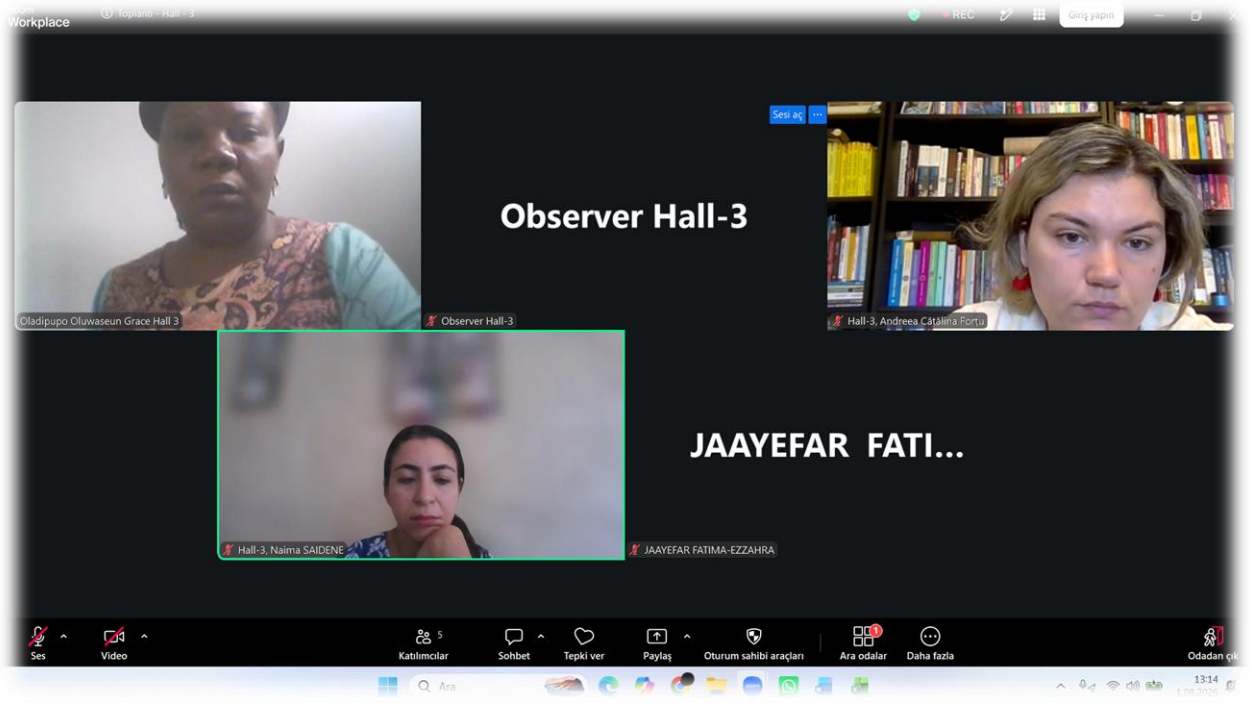

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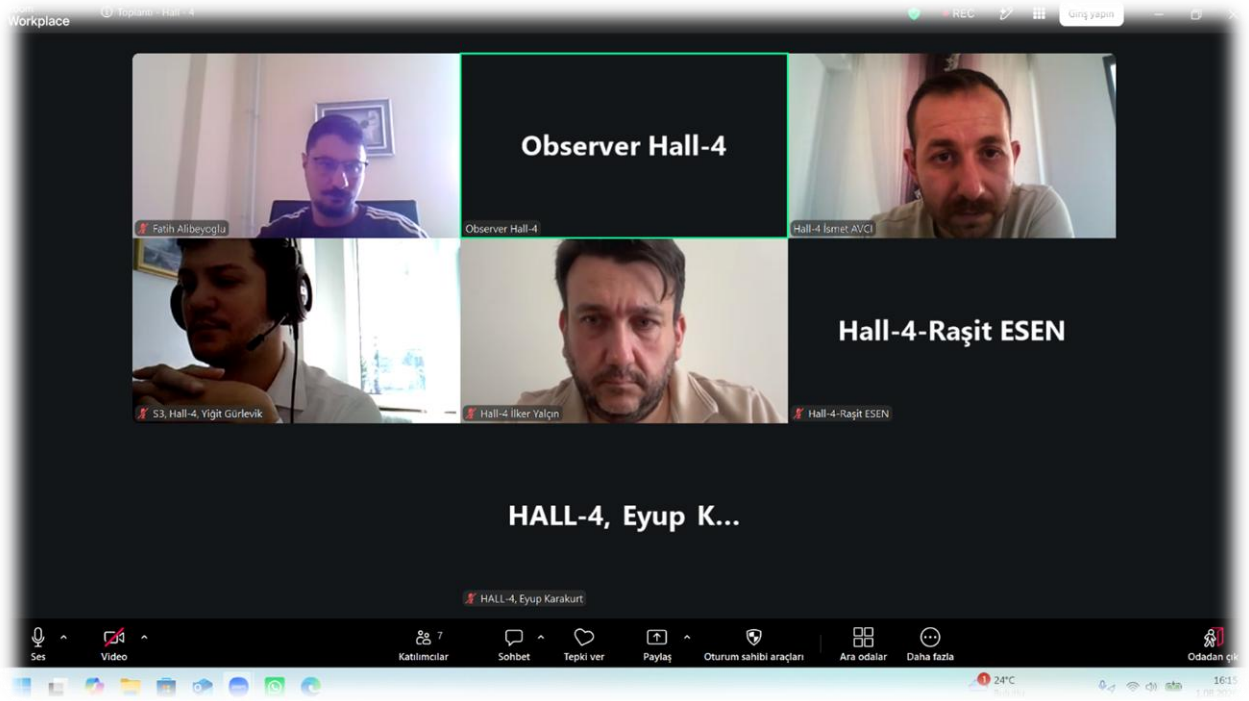

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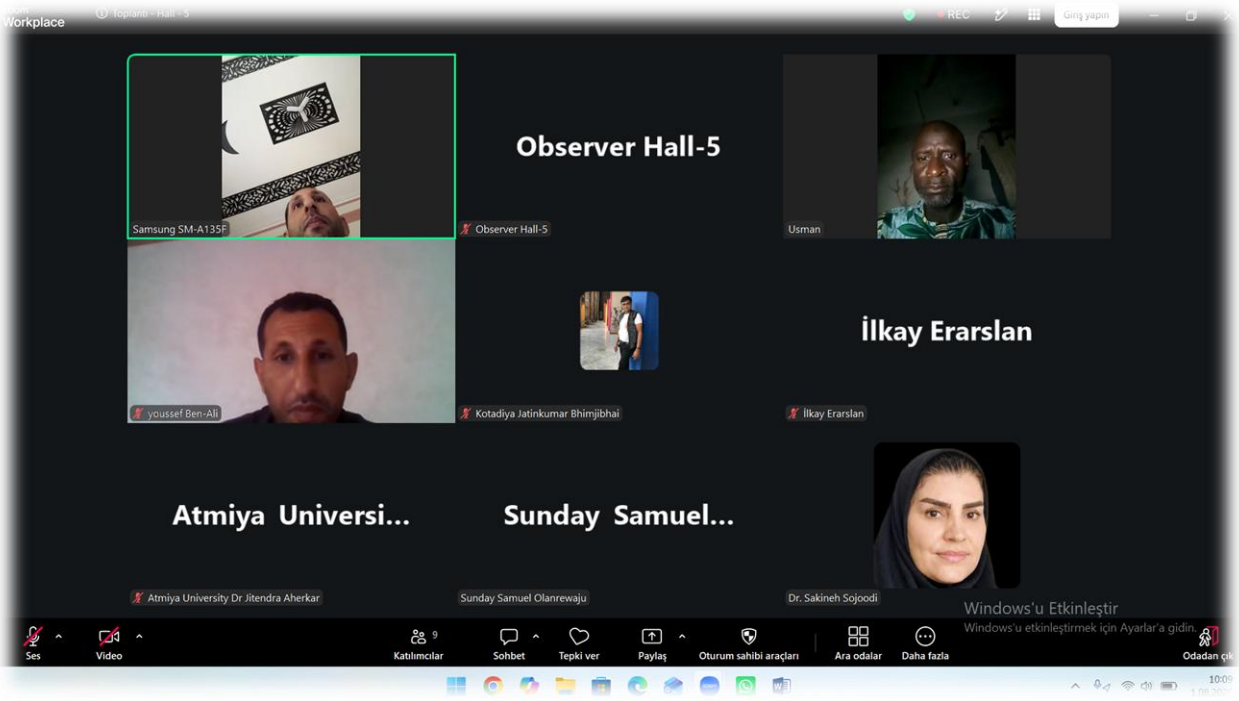

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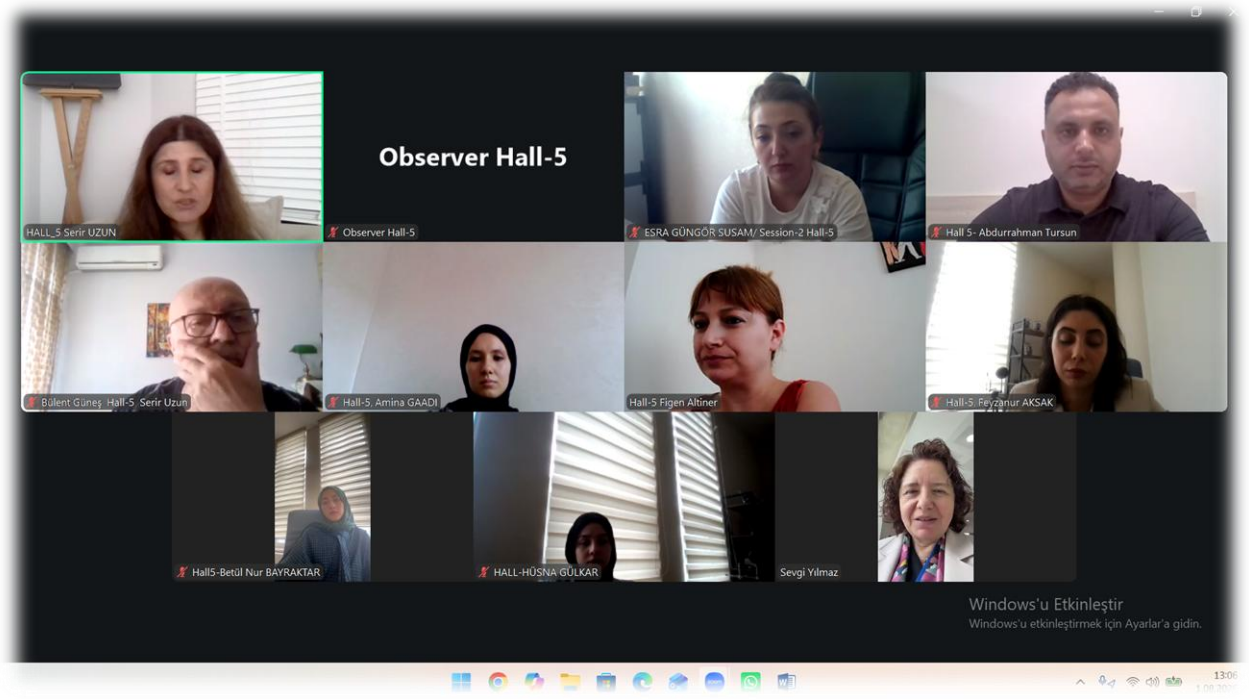

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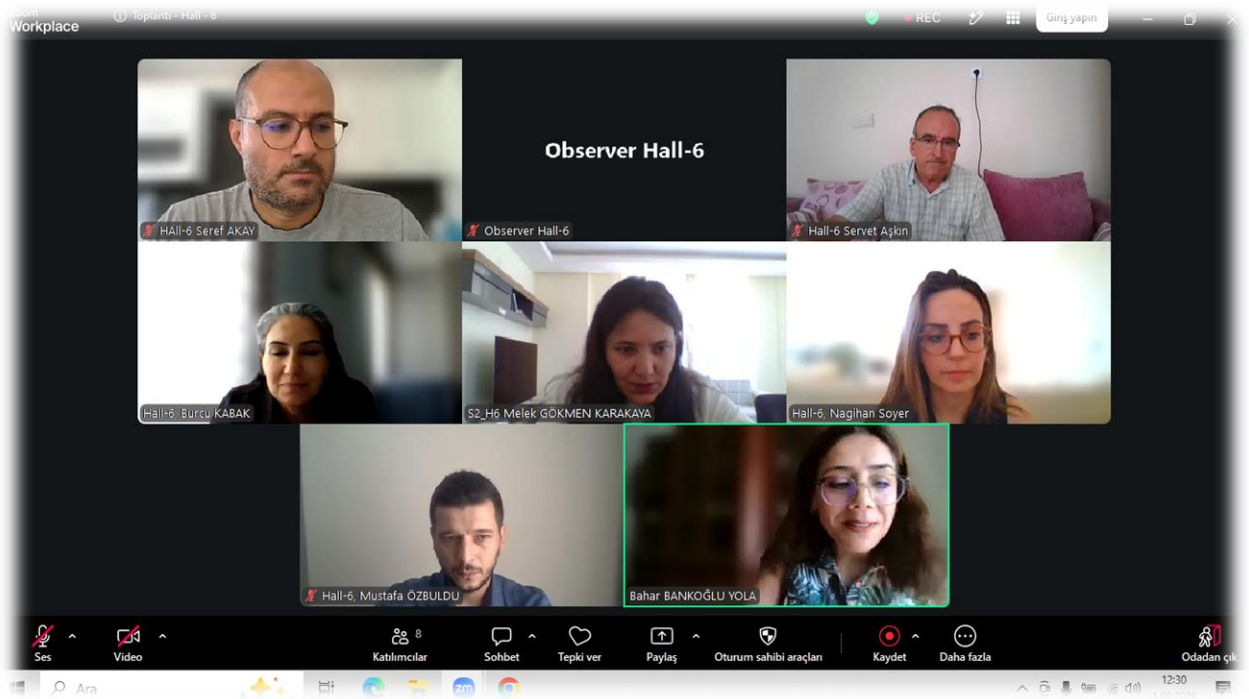

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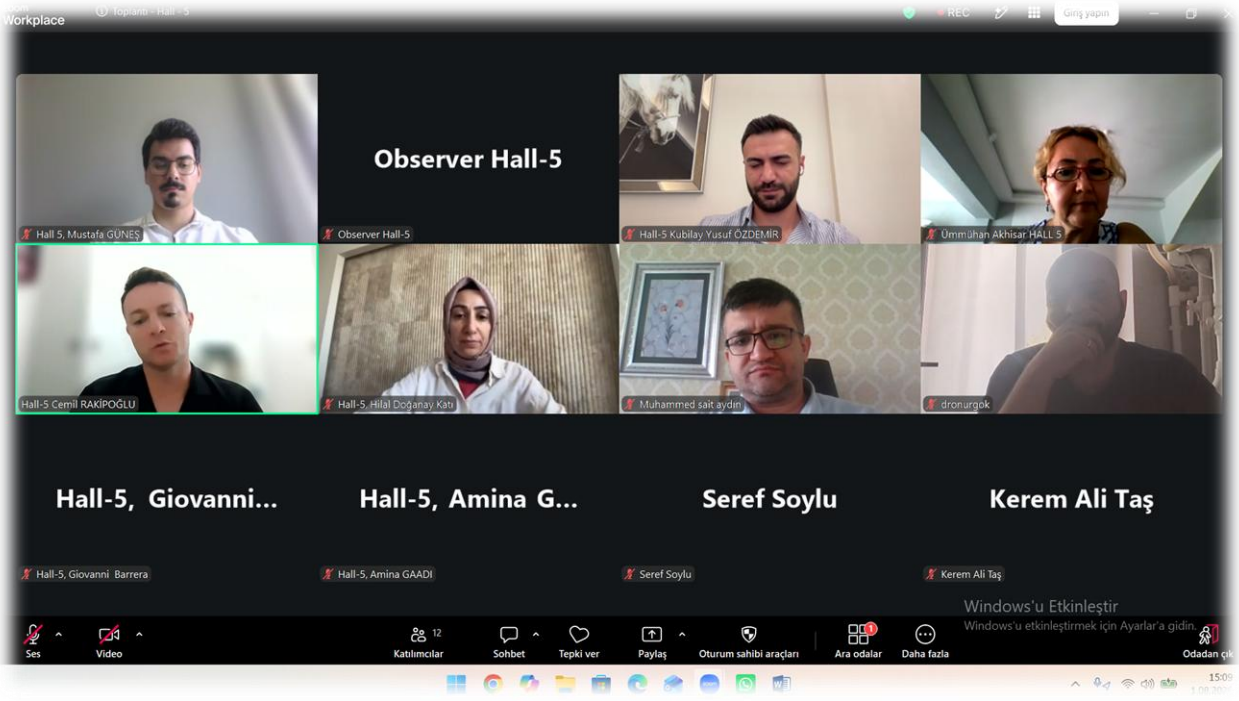

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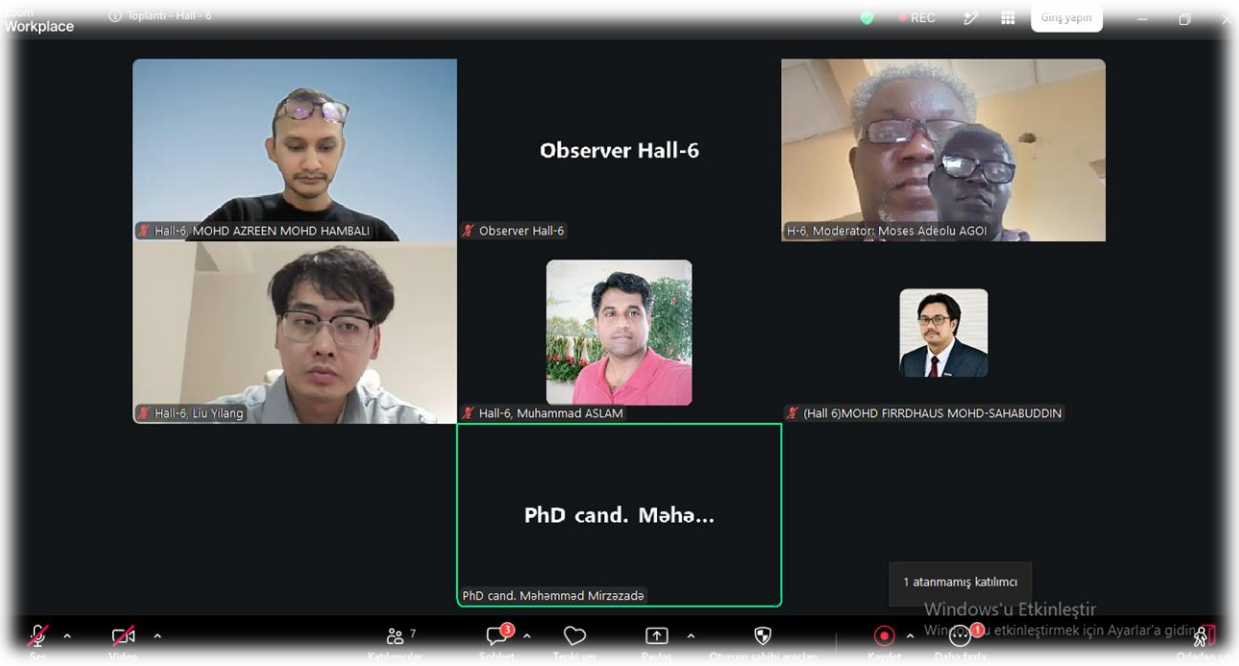

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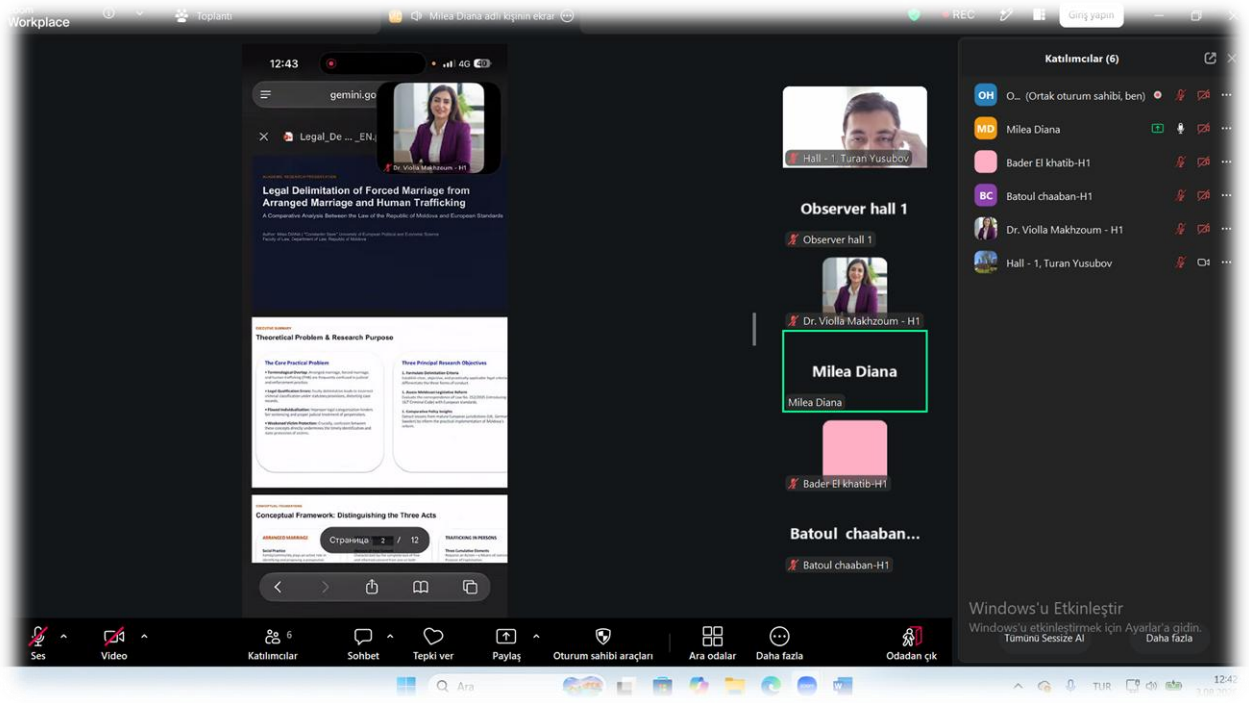

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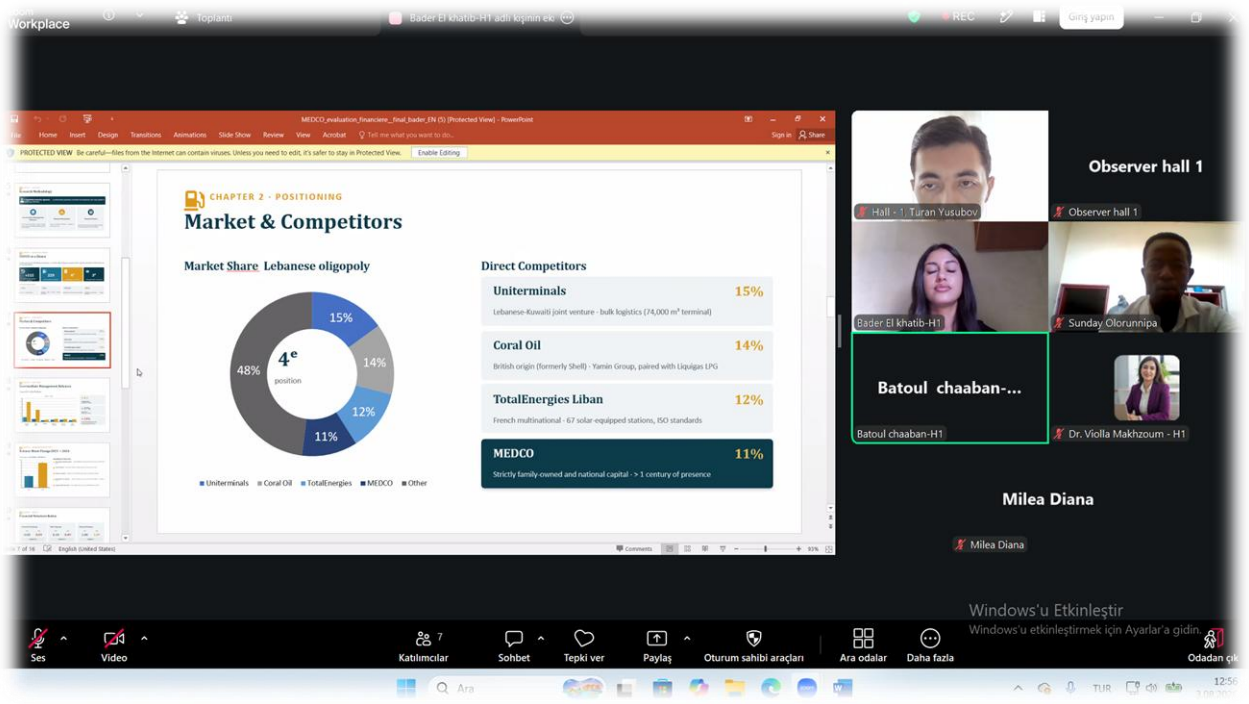

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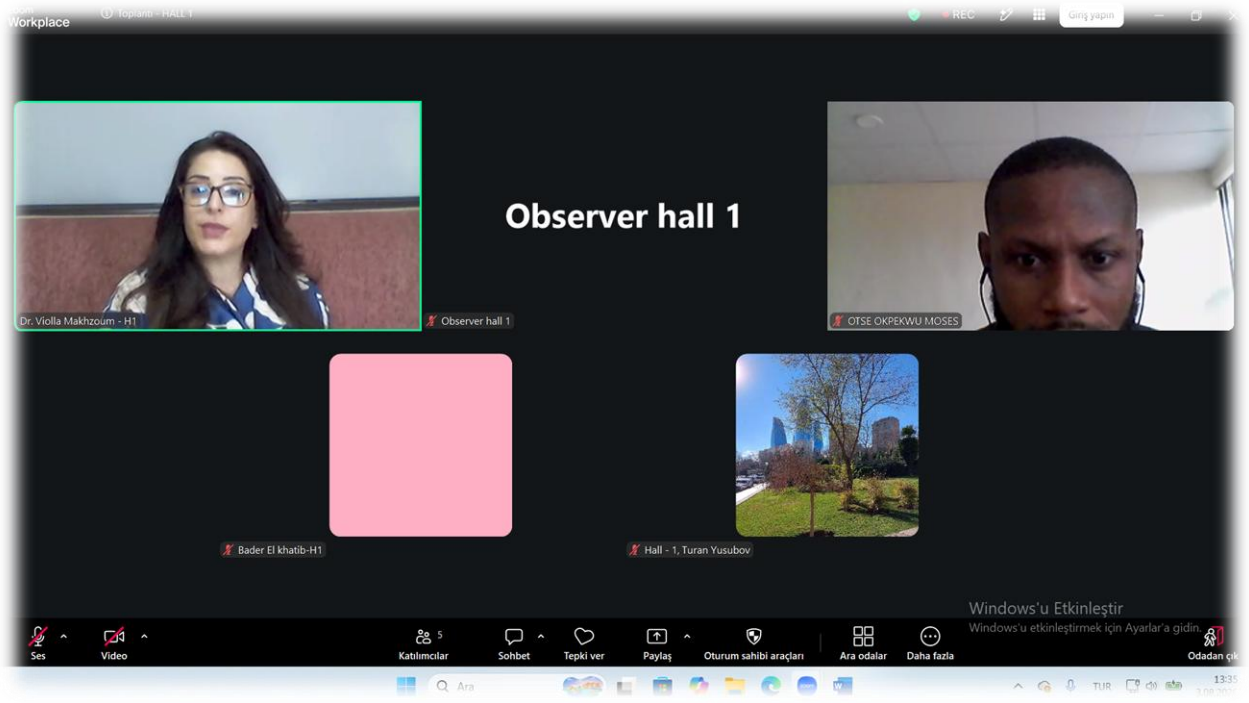

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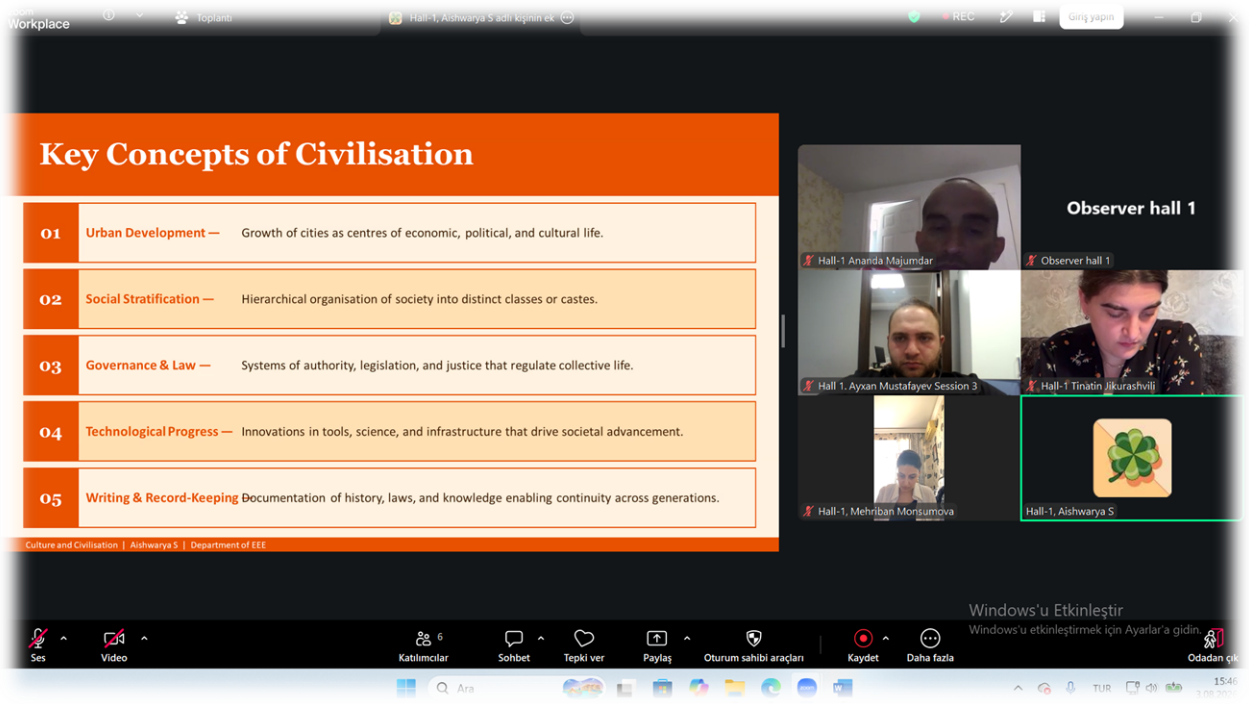

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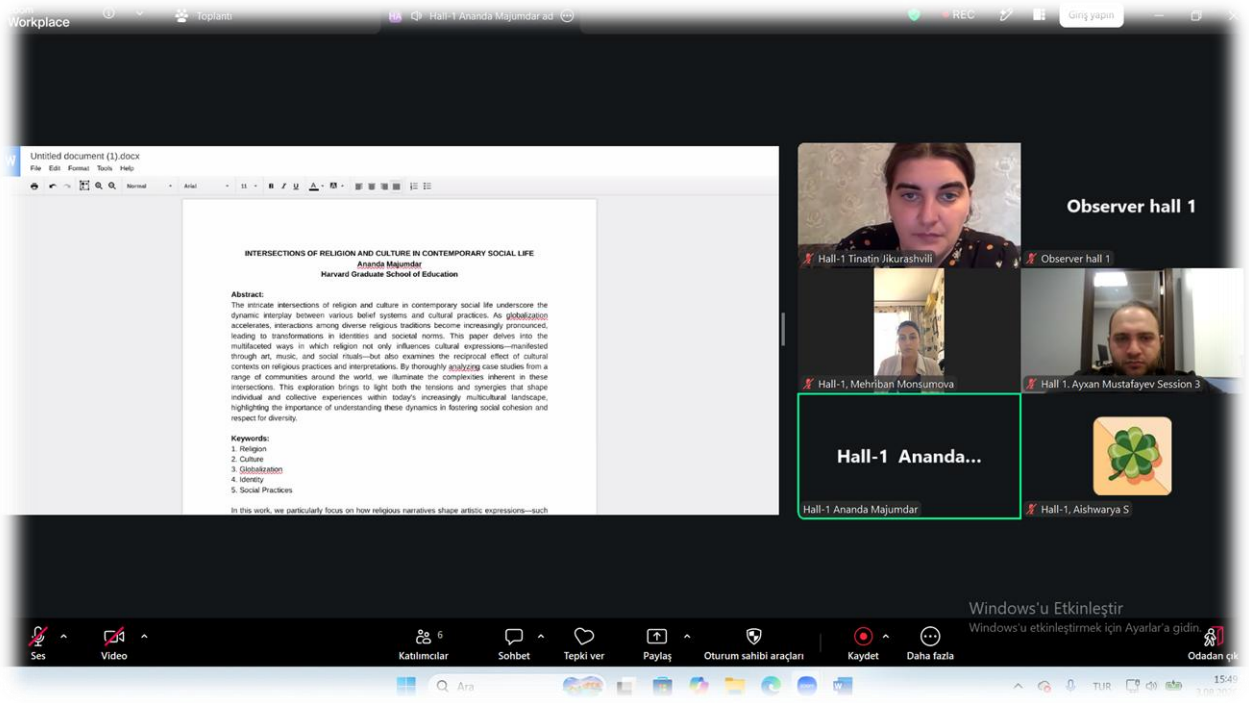

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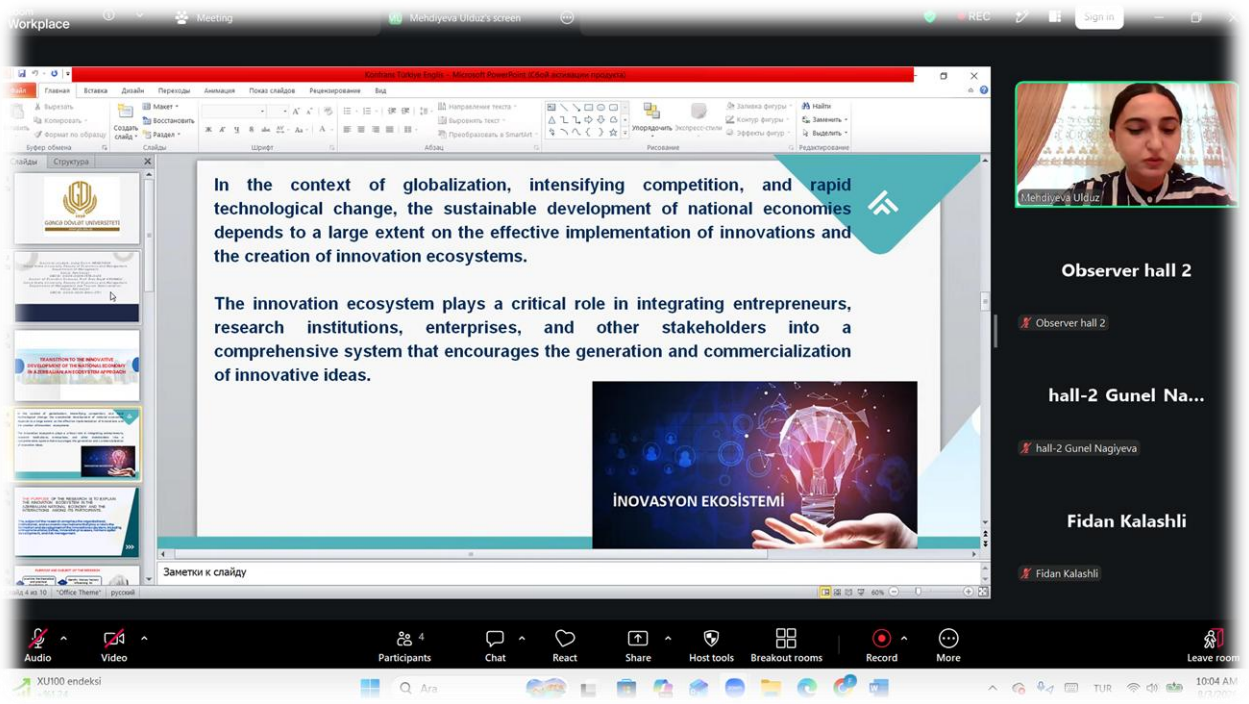

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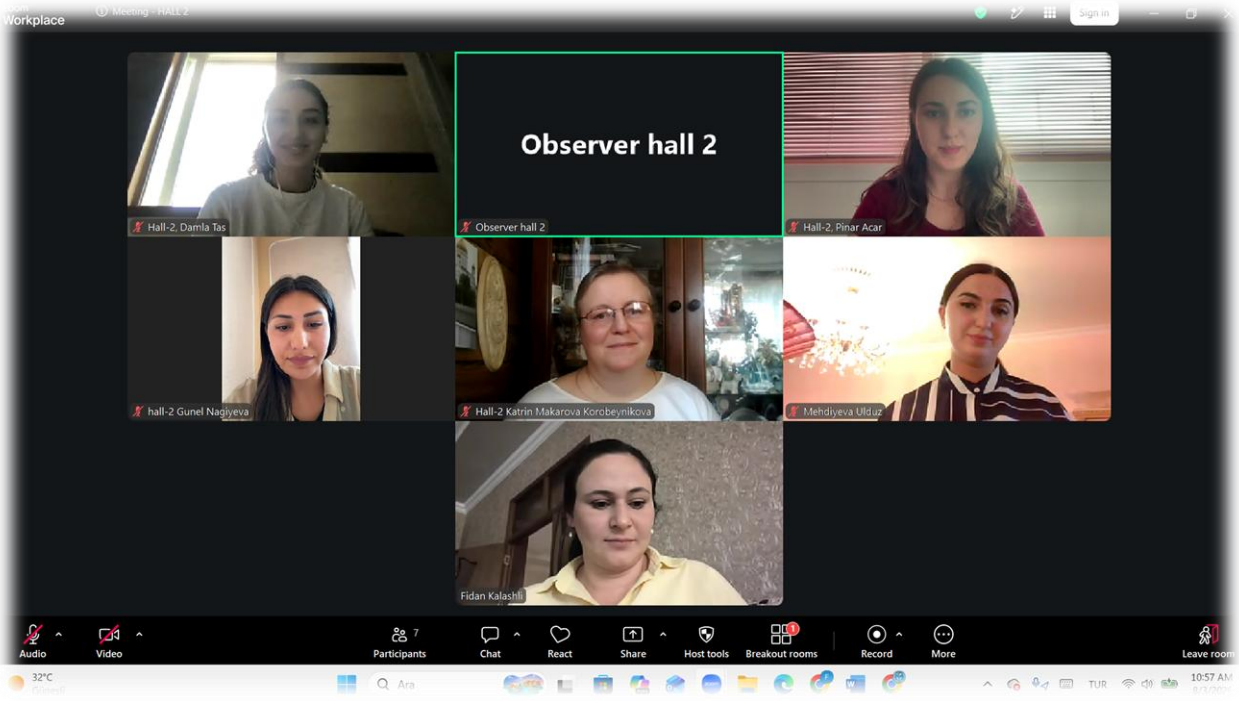

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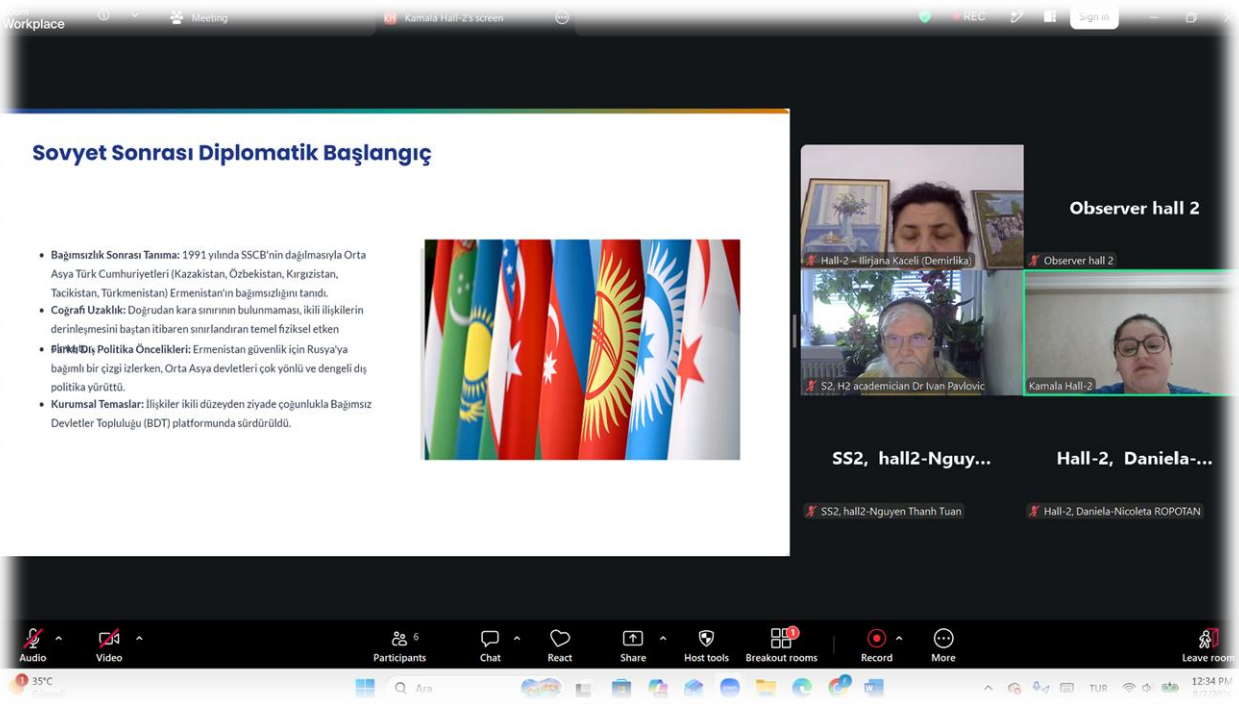

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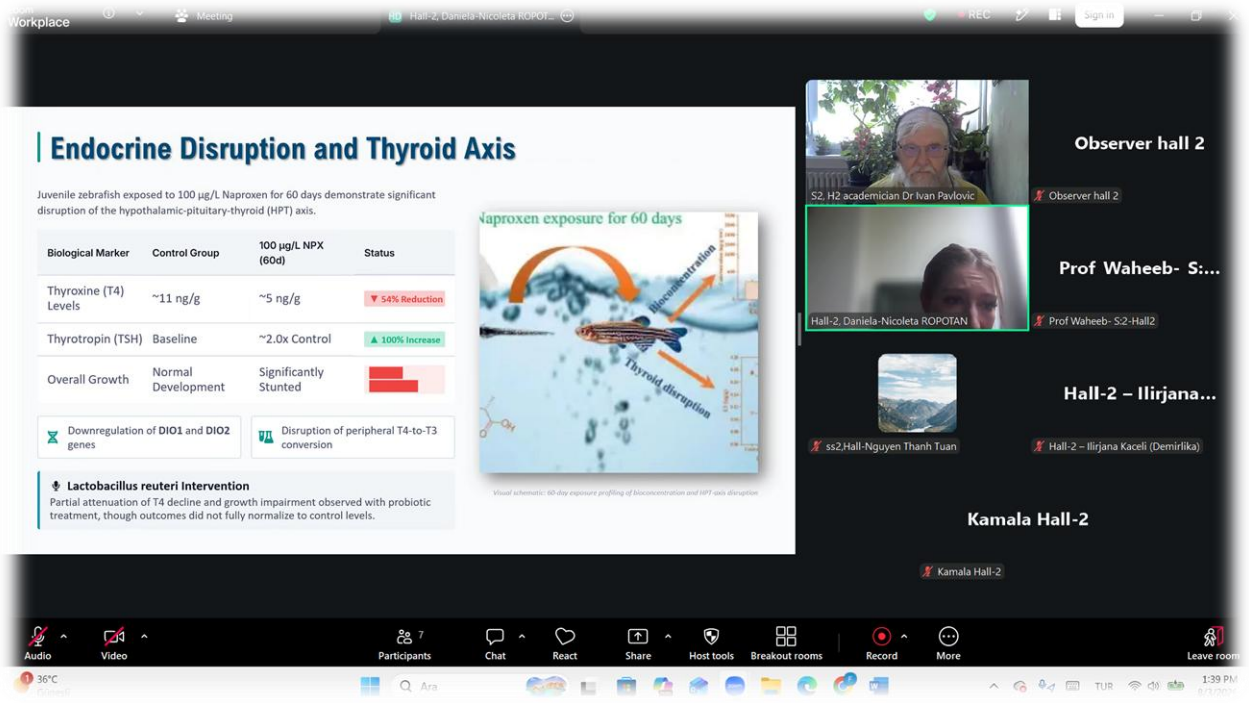

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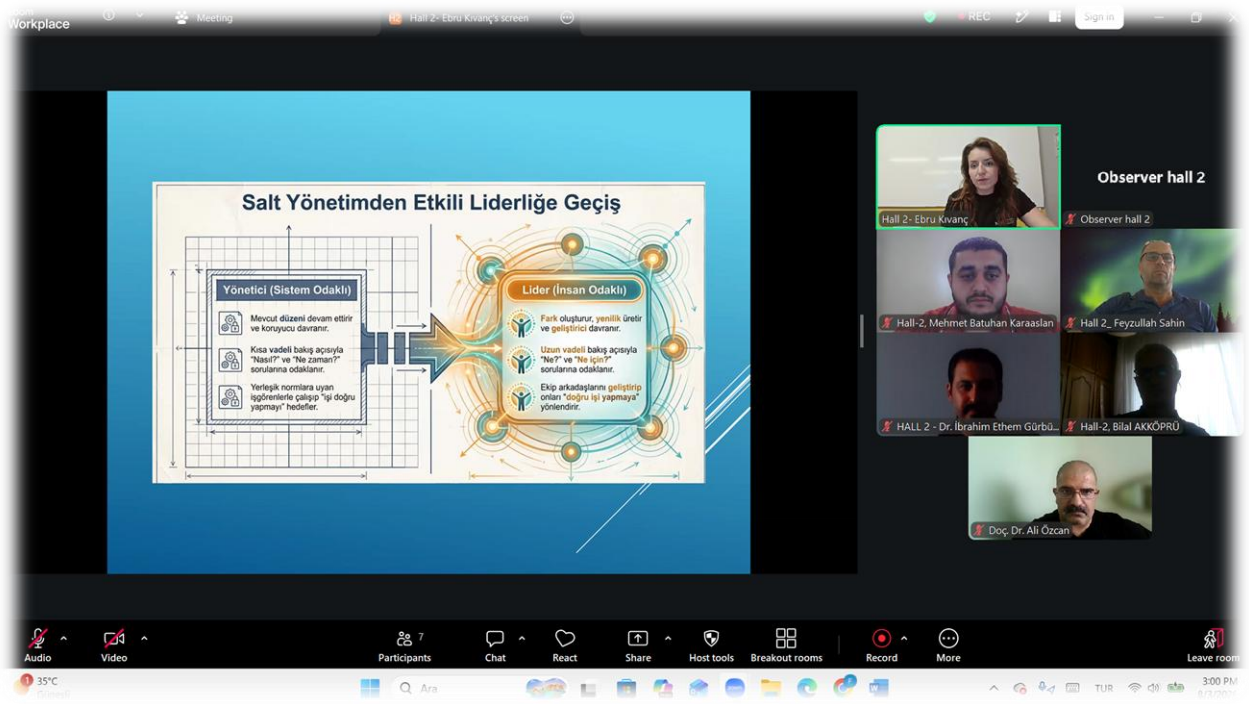

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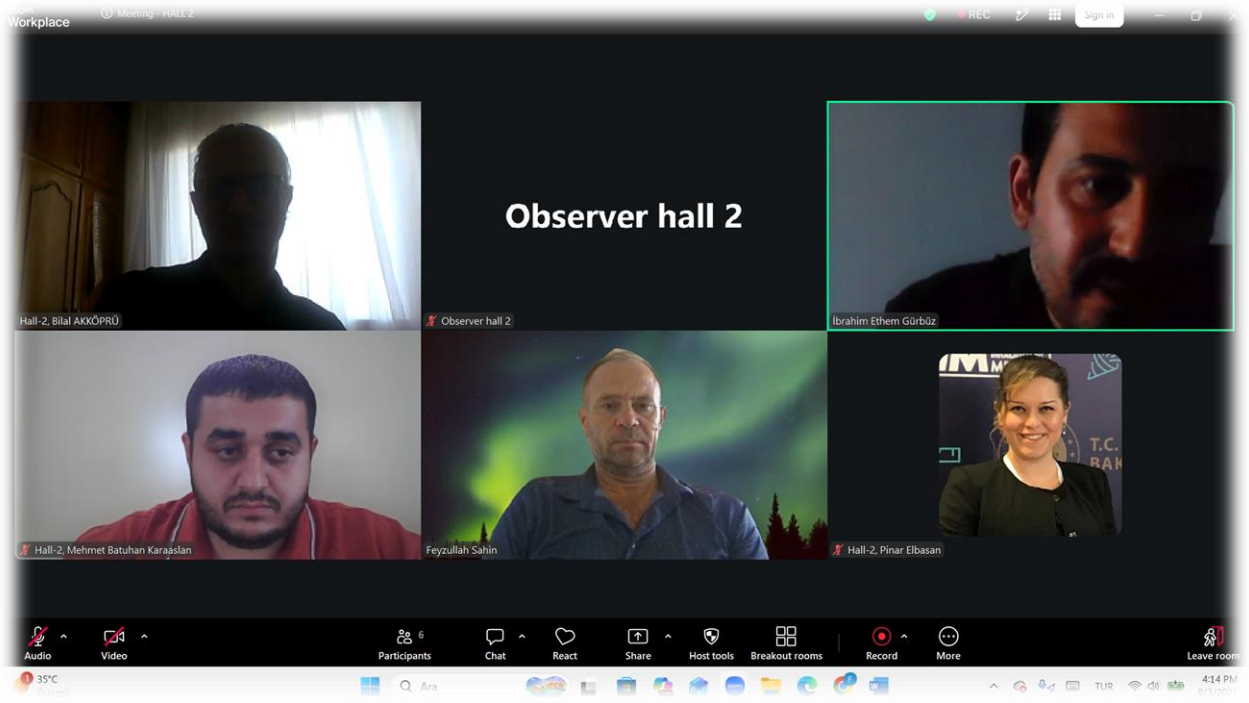

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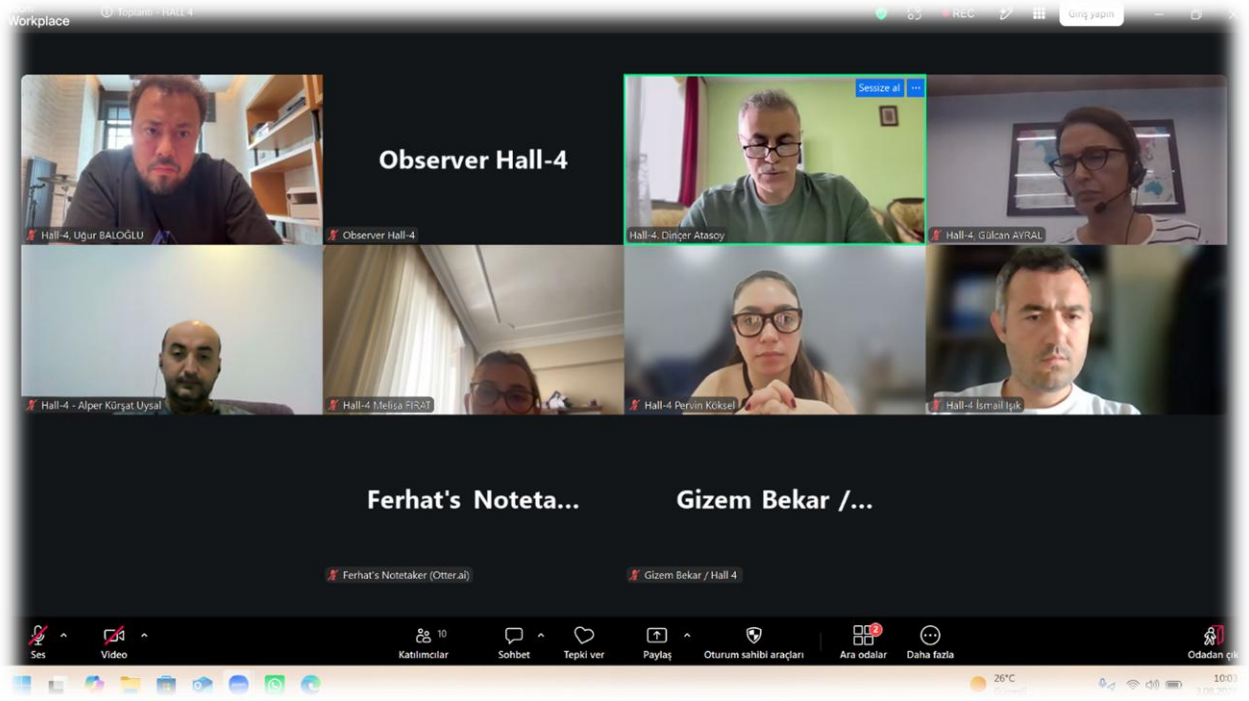

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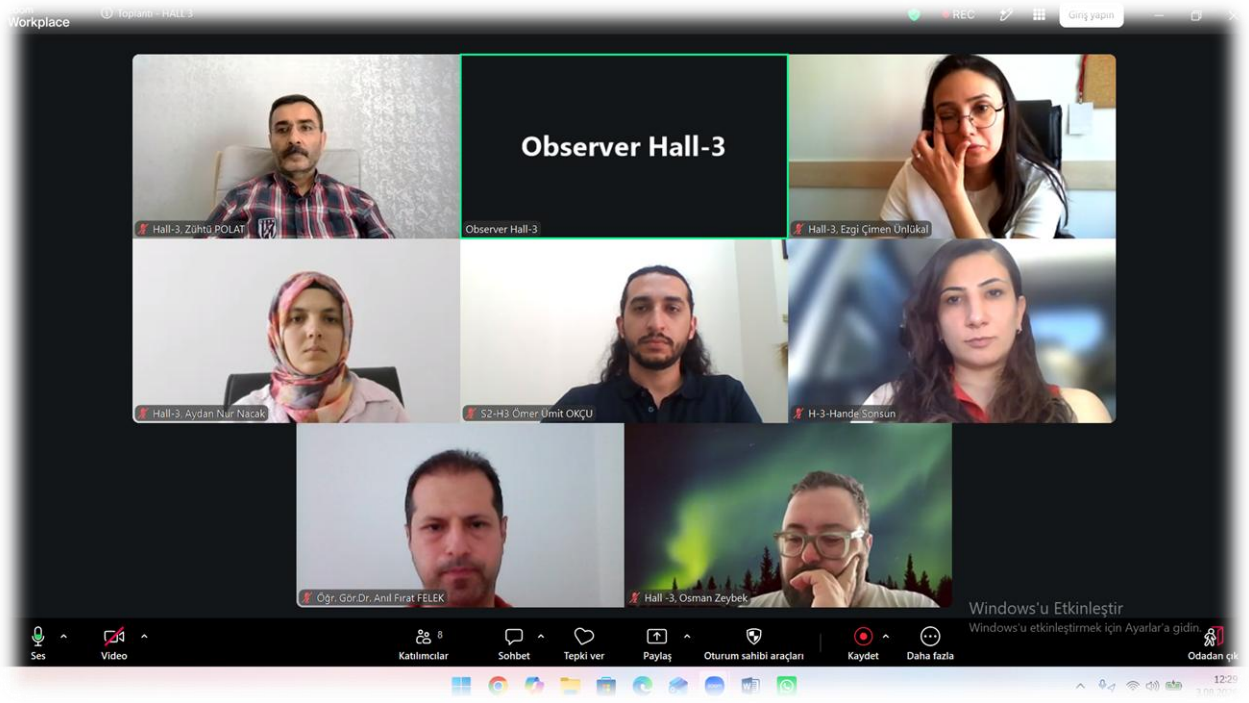


ONLINE SESSION • GALLERY 35



ONLINE SESSION • GALLERY 36

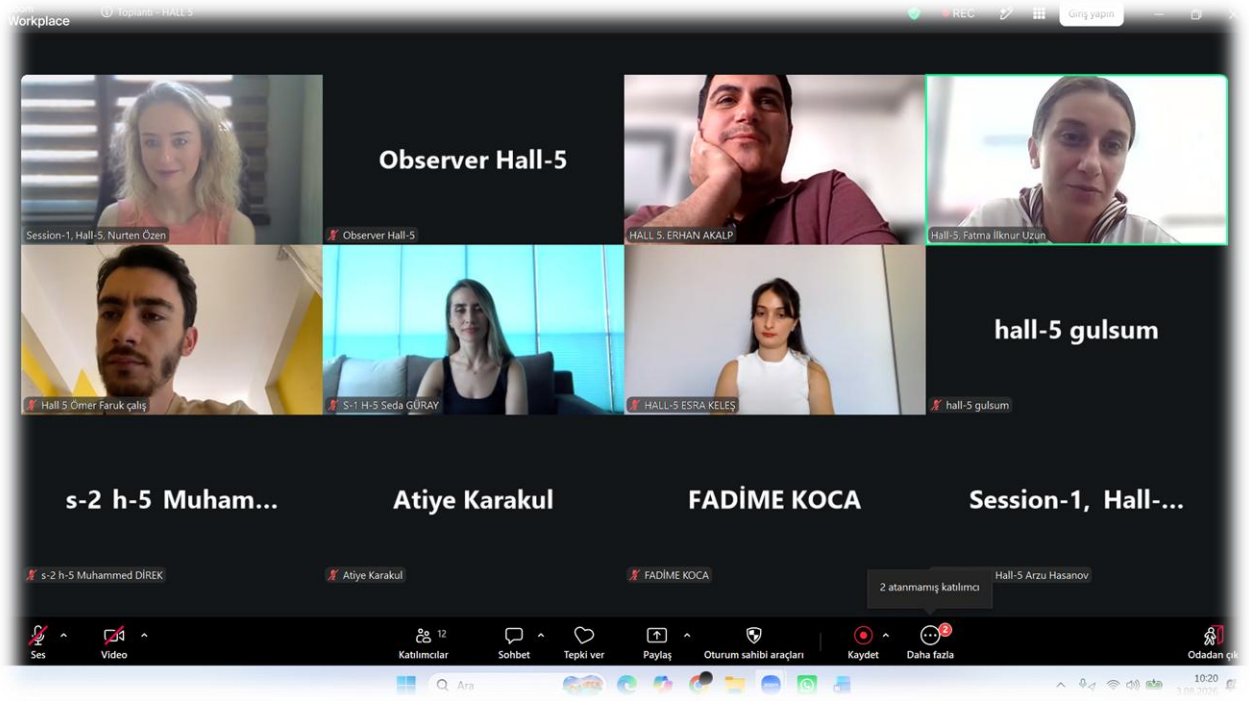
CONGRESS PHOTO GALLERY

9th INTERNATIONAL BLACK SEA MODERN SCIENTIFIC RESEARCH CONGRESS

AUGUST 1-3, 2026 • DÜZCE, TÜRKİYE • ONLINE SESSIONS



ONLINE SESSION • GALLERY 37



ONLINE SESSION • GALLERY 38

9th INTERNATIONAL BLACK SEA MODERN SCIENTIFIC RESEARCH CONGRESS



August 1-3, 2026

Düzce, Türkiye

"Exploring Ideas, Sharing Knowledge, Shaping the Future

CONGRESS PROGRAM

- INTERNATIONAL PARTICIPATION
- SCIENTIFIC SESSIONS
- ACADEMIC NETWORKING
- PROCEEDINGS PUBLICATION

9th INTERNATIONAL BLACK SEA MODERN SCIENTIFIC RESEARCH CONGRESS

August 1-3, 2026
Düzce, Türkiye

CONGRESS PROGRAM

Zoom Meeting ID: 862 6236 6905
Zoom Passcode: 010203
https://us02web.zoom.us/j/86262366905?pwd=Xb5K2NWx7acFFBBrsGpbDSroECaXnc.1

Participant Countries (32):

TÜRKİYE, ETHIOPIA, USA, VIETNAM, AFGHANISTAN, ALBANIA, ALGERIA, AZERBAIJAN, BOTSWANA, CHINA, COLOMBIA, GEORGIA, INDIA, INDONESIA, IRAN, ISRAEL, JORDAN, KOREA, KOSOVO, LEBANON, MALAYSIA, MOLDOVA, MOROCCO, NEW ZEALAND, NIGERIA, PAKISTAN, ROMANIA, RUSSIA, SAUDI ARABIA, SERBIA, UNITED KINGDOM, TRNC

ÖNEMLİ, DİKKATLE OKUYUNUZ LÜTFEN

IMPORTANT, PLEASE READ CAREFULLY

Önemli, Dikkatle Okuyunuz Lütfen

- ✓ Kongremizde Yazım Kurallarına uygun gönderilmiş ve bilim kurulundan geçen bildiriler için online (video konferans sistemi üzerinden) sunum imkanı sağlanmıştır.
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- ✓ Tüm kongre katılımcıları canlı bağlanarak tüm oturumları dinleyebilir.
- ✓ Moderatör – oturumdaki sunum ve bilimsel tartışma (soru-cevap) kısmından sorumludur.

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- ✓ All congress participants can connect live and listen to all sessions.
- ✓ Moderator is responsible for the presentation and scientific discussion (question-answer) section of the session.

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- ✓ Make sure your computer has a microphone and is working.
- ✓ You should be able to use screen sharing feature in Zoom.
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exp. Hall-1, Merve KIDIRYUZ

01.08.2026 / Session-1, Hall-1
Ankara Local Time: 10:00 – 12:00
Meeting ID: 862 6236 6905 / Passcode: 010203
Moderator: Dr. Ayşe EKİNCİ YILDIZ

Title	Author(s)	Affiliation
HILFER FRACTIONAL STOCHASTIC DELAYED DIFFERENTIAL SYSTEMS: A SUCCESSIVE APPROXIMATION PERSPECTIVE	Mustafa AYDIN	Van Yüzüncü Yıl University TÜRKİYE
STABILITY ANALYSIS OF INSTANTON SOLUTIONS IN THE 4D GURSEY SPINOR MODEL	Sedanur EREN Prof. Dr. Fatma AYDOĞMUŞ ŞEN	Karadeniz Technical University TÜRKİYE İstanbul University TÜRKİYE
A STUDY ON THE DYNAMIC STABILITY OF INSTANTON SOLUTIONS IN THE 2D THIRRING SPINOR MODEL	Sedanur EREN Prof. Dr. Fatma AYDOĞMUŞ ŞEN	Karadeniz Technical University TÜRKİYE İstanbul University TÜRKİYE
ASSESSMENT OF CMEMS SEA LEVEL REANALYSIS USING OBSERVATIONS FROM THE MENTEŞ TIDE GAUGE STATION IN THE AEGEAN SEA	Müjdat AYDIN Canan ERONAT	Dokuz Eylül University TÜRKİYE
WAVELET ANALYSIS OF SEA LEVEL VARIABILITY AT MARMARA SEA TIDE GAUGE STATIONS	Müjdat AYDIN Canan ERONAT	Dokuz Eylül University TÜRKİYE
DYNAMIC VIRTUAL CREDIT CARDS IN OTA B2B PAYMENTS: AN INDUSTRIAL CASE STUDY	Selami BAĞRIYANIK Behçet MUTLU	Wingie Enuygun Group, R&D İstanbul TÜRKİYE / İstanbul Health and Technology University TÜRKİYE Wingie Enuygun Group, R&D İstanbul TÜRKİYE
A STUDY ON CRISIS MANAGEMENT PRACTICES IN CHEMICAL, BIOLOGICAL, RADIOLOGICAL, AND NUCLEAR (CBRN) THREAT SITUATIONS	Ömer ŞENEL Uyum ELİTOK	Batman University TÜRKİYE

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01.08.2026 / Session-1, Hall-2
Ankara Local Time: 10:00 – 12:00
Meeting ID: 862 6236 6905 / Passcode: 010203
Moderator: Assoc. Prof. Duygu KIRKIK

Title	Author(s)	Affiliation
PATIENT SAFETY COUNSELING FOR ORAL ISOTRETINOIN USE: AN EVALUATION OF LARGE LANGUAGE MODEL RESPONSES	Kerem BALAN	Etimesgut Sehit Sait Erturk State Hostpital TÜRKİYE
AN ATYPICAL CYSTIC-POLYPOID INTRACAVITARY UTERINE LESION WITH BENIGN HISTOPATHOLOGY: A CASE REPORT	Emel ÖZALP	Ankara Etlik City Hospital TÜRKİYE
MEGALIN RECEPTOR AND ITS CLINICAL BIOCHEMICAL SIGNIFICANCE	Aleyna HORUZ Assist. Prof. Dr. Beyza SUVARIKLI ALAN Prof. Dr. Seyfullah HALİLOĞLU	Selçuk University TÜRKİYE
FROM OOCYTE TO IMPLANTATION IN ASSISTED REPRODUCTIVE TECHNOLOGIES: A STRUCTURED SYNTHESIS OF CURRENT INTERNATIONAL GUIDELINES IN TERMS OF EMBRYOLOGICAL DECISION POINTS	Assist. Prof. Dr. Neziha Senem ARI	Kütahya University of Health Sciences TÜRKİYE
PROTECTIVE EFFECT OF THYMOQUINONE AGAINST 2,3,7,8-TETRACHLORODIBENZO-P-DIOXIN-INDUCED PANCREATIC INJURY	Res. Assist. Dr. Elif KAYHAN Prof. Dr. Mehmet GÜL Lect. Birgül YİĞİTCAN	Malatya Turgut Özal University TÜRKİYE İnönü University TÜRKİYE
BORIC ACID ATTENUATES GLYPHOSATE-INDUCED NEPHROTOXICITY IN RATS BY MODULATING OXIDATIVE STRESS, PRO-INFLAMMATORY CYTOKINES, AND THE RENAL INJURY MARKERS KIM-1 AND NGAL	Assist. Prof. Dr. İlyas BOZKURT	Ardahan University TÜRKİYE
STRESS FRACTURES AND VITAMIN D DEFICIENCY IN THE MILITARY POPULATION: DIAGNOSIS, IMAGING AND PREVENTION STRATEGIES	Bünyamin ARI	Kütahya University of Health Sciences TÜRKİYE

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01.08.2026 / Session-1, Hall-3
Ankara Local Time: 10:00 – 12:00
Meeting ID: 862 6236 6905 / Passcode: 010203
Moderator: Dr. Suzana TURCU

Title	Author(s)	Affiliation
COGNITIVE EMOTION REGULATION STRATEGIES AND DIMENSIONS OF AGGRESSION IN ADULTS	Dr. Cornelia Rada Cristina Roxana IUREȘI Dr. Suzana TURCU	Romanian Academy ROMANIA Francisc I. Rainer Institute of Anthropology ROMANIA
FAMILY-PROMOTED FORGIVENESS AND EMPATHY, COGNITIVE EMOTION REGULATION, AND AGGRESSION IN ADULTS	Dr. Cornelia RADA Cristina Roxana IUREȘI Dr. Adela-Mihaela ȚĂRANU	Romanian Academy ROMANIA Technical University of Civil Engineering of Bucharest ROMANIA
THE RELATIONSHIP BETWEEN EMOTIONAL STABILITY, THE DARK TRIAD, AND AGGRESSION AMONG INCARCERATED INDIVIDUALS CONVICTED OF VIOLENT OFFENSES: EVIDENCE FROM A ROMANIAN SAMPLE	Andreea - Cătălina FORȚU Cornelia RADA	Romanian Academy ROMANIA
ASSOCIATIONS BETWEEN COPING STRATEGIES AND LENGTH OF DETENTION IN A SAMPLE OF PRISON INMATES FROM ROMANIA	Cornelia RADA Andreea - Cătălina FORȚU Suzana TURCU	Romanian Academy ROMANIA
PSYCHOPATHY, COPING STRATEGIES, AND THE PSYCHOLOGICAL ADJUSTMENT OF INCARCERATED VIOLENT OFFENDERS: A THEORETICAL FRAMEWORK	Andreea-Cătălina FORȚU Suzana TURCU Cornelia RADA	Romanian Academy ROMANIA
FINANCIAL DECISION-MAKING AUTHORITY AND FINANCIAL FREEDOM AMONG MARRIED COUPLES: EVIDENCE FROM A QUANTITATIVE STUDY	Assist. Prof. Dr. Asma Seemi Malik Lect. Dr. Anam Afzal Assist. Prof. Dr. Dr. Amjad Mahmood	Lahore College for Women University PAKISTAN Punjab College of Information Technology PAKISTAN
EXPLORING GENDER DIFFERENCES IN CAREER MATURITY AMONG SENIOR SECONDARY STUDENTS	Vasudha Mudgal	Swami Vivekanand Subharti University INDIA
AT THE END OF THE ACADEMIC YEAR, WHAT A DEGREE YOU'VE EARNED!	Dr. RAHMOUNI Hanane	University of Oran 2 Mohamed Ben Ahmed ALGERIA

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01.08.2026 / Session-1, Hall-4
Ankara Local Time: 10:00 – 12:00
Meeting ID: 862 6236 6905 / Passcode: 010203
Moderator: Dr. Youssef Ben-Ali

Title	Author(s)	Affiliation
THE IMPACT OF PARENT–SCHOOL COLLABORATION ON THE DEVELOPMENT OF STUDENTS WITH SPECIAL EDUCATIONAL NEEDS IN INCLUSIVE EDUCATION	Nagıyeva Gunel Azad	Baku State University AZERBAIJAN
THE IMPACT OF DIFFERENTIATED INSTRUCTION ON THE ACADEMIC ACHIEVEMENT OF STUDENTS WITH SPECIAL EDUCATIONAL NEEDS IN INCLUSIVE CLASSROOMS	Nagıyeva Gunel Azad	Baku State University AZERBAIJAN
DETERMINANTS OF TECHNOLOGY INTEGRATION AMONG SECONDARY SCHOOL MATHEMATICS AND SCIENCE TEACHERS IN LAHORE	Dr. Afshan Naseem Afshan Butt	University of Management and Technology INDIA
EMPLOYABILITY SKILLS IN THE ERA OF GENERATIVE ARTIFICIAL INTELLIGENCE: DEVELOPING A COMPETENCY FRAMEWORK FOR HIGHER EDUCATION	Natalia Bolgari	Academy of Economic Studies MOLDOVA
ENTREPRENEURSHIP EDUCATION MODELS FOR EMPOWERING THE AFRICA GIRL-CHILD	Prof. Ndubuisi-Okolo Purity Uzoamaka Grace Nwanonyigwe Akaegbobi Njideka Phina Onyekwelu	Nnamdi Azikiwe University NIGERIA
IMPACT OF TECHNOLOGY-INTEGRATED INSTRUCTION ON ENVIRONMENTAL RESPONSIBILITY AND ACADEMIC ACHIEVEMENT AMONG SENIOR SECONDARY GEOGRAPHY STUDENTS IN KATSINA STATE, NIGERIA	Dr. Aminu Salisu TSAURI Muhammad Nazir IBRAHIM Abdulkadir IBRAHIM	Umaru Musa Yar'adua University NIGERIA Federal University NIGERIA

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01.08.2026 / Session-1, Hall-5
Ankara Local Time: 10:00 – 12:00
Meeting ID: 862 6236 6905 / Passcode: 010203
Moderator: Dr. Jitendra Aherkar

Title	Author(s)	Affiliation
EXPLAINABLE HYBRID FRAMEWORK FOR STUDENT SENTIMENT PREDICTION IN LEARNING MANAGEMENT SYSTEMS USING ATTENTION-BASED TRANSFORMERS AND EDUCATIONAL DOMAIN KNOWLEDGE	Jatinkumar Bhimjibhai Kotadiya	Atmiya University INDIA
ADAPTIVE EXPLAINABLE FEDERATED LEARNING FRAMEWORK FOR PRIVACY-PRESERVING STUDENT PERFORMANCE PREDICTION USING MULTI-MODAL EDUCATIONAL DATA	Assist. Prof. Hetal Pravinsinh Jadeja Jatinkumar Bhimjibhai Kotadiya	Harivandana College INDIA Atmiya University INDIA
READINESS OF SECONDARY SCHOOL BUSINESS STUDIES STUDENTS FOR VIRTUAL OFFICE JOBS IN NIGER STATE NIGERIA	USMAN, Yahuza Alhaji El-Habib Haruna Abdullahi Hassan	Umaru Sanda Ahmadu College of Education NIGERIA
ECONOMIC FACTORS INFLUENCING STUDENT ACADEMIC DROPOUT IN NORTHWEST IRANIAN UNIVERSITIES: A SYSTEMATIC LITERATURE REVIEW	Faezeh Ostadi Sakineh Sojoodi	Tabriz University IRAN
DIGITAL EDUCATION AND SUSTAINABLE DEVELOPMENT GOALS IN INDIA	Dr. Jitendra Aherkar	Atmiya University INDIA
ENERGY DIVERSIFICATION: AN ENHANCEMENT OF TEACHING AND LEARNING PROCESS IN NIGERIA INSTITUTION OF HIGHER LEARNING	Sunday Samuel OLANREWAJU	Federal College of Education NIGERIA
THE IMPACT OF SOCIAL LEARNING IN PHYSICAL EDUCATION ON HEALTH-PROMOTING BEHAVIORS AMONG MIDDLE SCHOOL STUDENTS	Amina GAADI Abdelhak CHAKLI Youssef SEFRI	Hassan II University MOROCCO
ADAPTIVE FEDERATED DEEP LEARNING FRAMEWORK FOR PRIVACY-PRESERVING AND EXPLAINABLE INTRUSION DETECTION IN SMART IOT NETWORKS	Assist. Prof. Dharmendrakumar Jayantilal Ambani	Harivandana College INDIA

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01.08.2026 / Session-1, Hall-6
Ankara Local Time: 10:00 – 12:00
Meeting ID: 862 6236 6905 / Passcode: 010203
Moderator: Assoc. Prof. Hülya DEMİR

Title	Author(s)	Affiliation
NUTRITION AND COLORECTAL CANCER: CURRENT EVIDENCE ON RISK, PREVENTION, AND MANAGEMENT	Res. Assist. Yaren ARAY Prof. Dr. Elvan YILMAZ AKYUZ	Istanbul Esenyurt University TÜRKİYE / University of Health Sciences TÜRKİYE University of Health Sciences TÜRKİYE
FROM PREVENTION TO CLINICAL MANAGEMENT: STAGE-DEPENDENT EFFECTS OF THE MEDITERRANEAN, MIND, AND KETOGENIC DIETS IN ALZHEIMER'S DISEASE	Prof. Dr. Elvan YILMAZ AKYUZ Res. Assist. Yaren ARAY	University of Health Sciences TÜRKİYE Istanbul Esenyurt University TÜRKİYE / University of Health Sciences TÜRKİYE
THE PLACE OF WATER KEFIR AMONG FERMENTED BEVERAGES, ITS PRODUCTION AND THERAPEUTIC PROPERTIES	Mahdı FARSHADFAR Prof. Dr. İlkay KOCA	Ondokuz Mayıs University TÜRKİYE
EVALUATION OF NUTRITIONAL AND BEHAVIORAL ATTITUDES AND FOOD ADDICTION IN ADULTS SCHEDULED FOR BARIATRIC SURGERY	İbrahim KUTLU Assist. Prof. Dr. Hale AVŞAR ERDEKLİ	Independent Researcher TÜRKİYE Antalya Bilim University TÜRKİYE
THE SILENT DECLINE IN BREAST MILK: EFFECTS OF SMOKING AND LACTATION DURATION ON THE CULTURABLE MICROBIOTA	Ayşe Yaren TANIŞ Tuğçe OKUR Assist. Prof. Dr. Ebru ÖZTAŞ GÜLMÜŞ	Erzurum Technical University TÜRKİYE
EVALUATION OF DIFFERENT COATING MATERIALS FOR THE MICROENCAPSULATION OF LACTOBACILLUS ACIDOPHILUS ATCC 4356 AND ITS STABILITY UNDER SIMULATED GASTROINTESTINAL CONDITIONS	Lect. Dr. Kübra KORKMAZ AYSEL Prof. Dr. Yusuf TUNÇTÜRK	Batman University TÜRKİYE Van Yüzüncü Yıl University TÜRKİYE
EFFECT OF MICROENCAPSULATED LACTOBACILLUS ACIDOPHILUS ATCC 4356 ON VIABILITY AND MICROBIOLOGICAL QUALITY OF FUNCTIONAL LOR CHEESE DURING STORAGE	Lect. Dr. Kübra KORKMAZ AYSEL Prof. Dr. Yusuf TUNÇTÜRK	Batman University TÜRKİYE Van Yüzüncü Yıl University TÜRKİYE
EARLY CELLULAR RESPONSES TO PENTHIOPYRAD IN CHO-K1 CELLS: EVALUATION OF CELL VIABILITY, INTRACELLULAR ROS PRODUCTION, AND MITOCHONDRIAL MEMBRANE POTENTIAL	Assist. Prof. Dr. Merve ARICI	İstinye University TÜRKİYE

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01.08.2026 / Session-2, Hall-1
Ankara Local Time: 12:30 – 14:30
Meeting ID: 862 6236 6905 / Passcode: 010203
Moderator: Dr. Zelal TEMEL

Title	Author(s)	Affiliation
INVESTIGATION OF THE EFFECTS OF PLYOMETRIC TRAINING APPLIED TO MUAY THAI ATHLETES ON AGILITY	Ugur ÖDEK Ahmet Metehan AKKURT	Nevşehir Hacıbektaş Veli University TÜRKİYE
INVESTIGATION OF THE EFFECT OF INSTRUMENT-ASSISTED SOFT TISSUE MOBILIZATION TECHNIQUE AND FOAM ROLLER APPLICATION ON STRENGTH, FLEXIBILITY AND PAIN IN INDIVIDUALS WITH CHRONIC NON-SPECIFIC NECK PAIN: A RANDOMIZED CLINICAL TRIAL	Assist. Prof. Dr. Muhammed Üsame TAŞ Prof. Dr. Burcu TALU	Gümüşhane University TÜRKİYE İnönü University TÜRKİYE
INVESTIGATION OF THE EFFECT OF INSTRUMENT-ASSISTED SOFT TISSUE MOBILIZATION TECHNIQUE AND FOAM ROLLER APPLICATION ON FUNCTIONAL STATUS, RANGE OF MOTION AND QUALITY OF LIFE IN INDIVIDUALS WITH CHRONIC NON-SPECIFIC NECK PAIN: A RANDOMIZED CLINICAL TRIAL	Assist. Prof. Dr. Muhammed Üsame TAŞ	Gümüşhane University TÜRKİYE
THE ROLE OF ATTACHMENT STYLES IN DEPRESSION AND ANXIETY	Assist. Prof. Dr. Özlem Özden TUNCA İclal ATMACA	Fenerbahçe University TÜRKİYE
COMPARISON OF PREMENSTRUAL SYNDROME AND ANXIETY LEVELS AMONG WORKING AND NON-WORKING WOMEN AGED 18–55 IN TÜRKİYE	Arife KILIÇ	Near East University TRNC
PARENTAL PERMISSION FOR RISKY PLAY: ASSOCIATIONS WITH EMOTION REGULATION AND SELF-REGULATION IN PRESCHOOL CHILDREN	Res. Assist. Betül KARABIYIK Assist. Prof. Dr. Serap DEMİRİZ	Hasan Kalyoncu University TÜRKİYE Gazi University TÜRKİYE
THE NEEDS OF CAREGIVERS OF INDIVIDUALS WITH SPECIAL NEEDS REGARDING EVIDENCE-BASED PRACTICES: A CROSS-SECTIONAL STUDY	Prof. Dr. Feyzullah ŞAHİN Prof. Dr. Bekir Fatih MERAL Assoc. Prof. Dr. Dilek ŞAHİN	Düzce University TÜRKİYE Sakarya University TÜRKİYE Düzce University TÜRKİYE
YOUTUBE AS A SOURCE OF INFORMATION ON CHARCOT–MARIE–TOOTH DISEASE AND REHABILITATION: A CROSS-SECTIONAL EVALUATION OF VIDEO QUALITY, RELIABILITY, AND ACTIONABILITY	Assist. Prof. Dr. Elisa ÇALIŞGAN	Kahramanmaraş Sütçü İmam University TÜRKİYE

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01.08.2026 / Session-2, Hall-2
Ankara Local Time: 12:30 – 14:30
Meeting ID: 862 6236 6905 / Passcode: 010203
Moderator: Prof. Bledar KRAJA

Title	Author(s)	Affiliation
INVESTIGATING THE ASSOCIATION BETWEEN C-REACTIVE PROTEIN AND CHRONIC KIDNEY DISEASE IN PATIENTS WITH TYPE TWO DIABETES MELLITUS: A CROSS SECTIONAL STUDY	Akpah FAITH	Buea University CAMEROON
MEDICATION ADHERENCE AMONG PATIENTS WITH TYPE 2 DIABETES: FINDINGS FROM A MULTICENTER STUDY IN MOROCCO	Maryem ARRAJI	Hassan First University MOROCCO
DIGITAL HEALTH LITERACY AS A TOOL FOR STRENGTHENING PREVENTIVE HEALTH BEHAVIOURS AMONG YOUNG ADULTS	Sodiq Adetunji Adekola Suleiman Abeebat Abiola Iwueke Obinna Adonischris Towolawi Glory Omobowale Mohammed Abdulmueez Omotayo	National Open University NIGERIA Centre for Community Health and Systems Support NIGERIA
LIFESTYLE BEHAVIORS AND GASTROESOPHAGEAL REFLUX DISEASE: INSIGHTS FROM THE LITERATURE AND THE ALBANIAN POPULATION	Prof. Bledar KRAJA	Medicine University ALBANIA
BIOCHEMICAL AND METABOLIC BASIS OF BREAKING THE FAST WITH FRESH DATES (PHOENIX DACTYLIFERA): INTEGRATING PROPHETIC PRACTICE WITH CONTEMPORARY NUTRITIONAL SCIENCE	Ibrahim Sani Dikko	Umaru Musa Yar'adua University NIGERIA
FERROPTOSIS IN BREAST CANCER: EMERGING MECHANISMS AND THERAPEUTIC PERSPECTIVES	Maroua RIAD Souad Madani Chaimae Lamiri Jamal MABROUKI Ahmad AL-SHAMI	Mohammed V University MOROCCO
DESIGN AND IMPLEMENTATION OF AN INTEGRATED LIFESTYLE EDUCATION PROGRAM AMONG SCHOOL-GOING ADOLESCENTS IN EL JADIDA, MOROCCO	Imane HADDOU Halima DAIF Rekia BELAHSEN	Chouaib DOUKKALI University MOROCCO
NUTRIENT ADEQUACY AND DIETARY IMBALANCES AMONG BOARDING-SCHOOL ADOLESCENTS IN THE MOULAY ABDELLAH REGION, MOROCCO	Ghizlane BENADDI Halima DAIF Imane HADDOU Rekia BELAHSEN	Chouaib DOUKKALI University MOROCCO

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01.08.2026 / Session-2, Hall-3
Ankara Local Time: 12:30 – 14:30
Meeting ID: 862 6236 6905 / Passcode: 010203
Moderator: Umida MOVILYANOV

Title	Author(s)	Affiliation
DESIGN, SYNTHESIS, MOLECULAR DOCKING, AND ANTICANCER EVALUATION OF NOVEL THIOPHENE–1,3,4-OXADIAZOLE DERIVATIVES	Zainib Razzaq Samreen Gul Khan Mehr un Nisa	Government College University PAKISTAN Lahore University PAKISTAN
BIOTECNOLOGICAL METHODS FOR PRODUCTION OF POLYENE MACROLIDE ANTIBIOTICS: RECENT ADVANCES, SEARCH OF NEW DIRECTIONS FOR IMPROVEMENT AND DEVELOPMENT PROSPECTS	Dr. Valery V. Belakhov	Israel Institute of Technology ISRAEL
DATA CAPITALIZATION ON MEDICAGO SATIVA: PHYTOCHEMICAL COMPOSITION AND PHARMACOLOGICAL POTENTIAL	Jaayefar Fatima-ezzahra Jamila Dahmani	Ibn Tofail University MOROCCO
DATA CAPITALIZATION ON SCABIOSA ATROPURPUREA: PHYTOCHEMICAL COMPOSITION AND BIOLOGICAL ACTIVITIES	Jaayefar Fatima-ezzahra Jamila Dahmani	Ibn Tofail University MOROCCO
ASSESSMENT OF ANTIMICROBIAL ACTIVITY OF SELECTED EDIBLE MUSHROOMS EXTRACT AGAINST FOODBORNE PATHOGENS	Oladıpupo Oluwaseun Grace Awe Sunday Ajıboye Elızabeth Adeyınka	Kwara State University NIGERIA
VALORISATION OF UNDERUTILISED JACKFRUIT (ARTOCARPUS HETEROPHYLLUS) SEEDS INTO A SPREAD: EFFECTS OF PALM OIL ON PHYSICOCHEMICAL CHARACTERISTICS AND STORAGE STABILITY	Nur Alya Batrisyia binti Abd Hamid Nursabrina Munawar	MARA University of Technology MALAYSIA
IN VITRO ANTICOCCIDIAL EFFECTS OF OLIVE LEAF (OLEA EUROPAEA L. VAR. CHEMLAL) EXTRACT AGAINST BROILER CHICKENS EIMERIA OOCYSTS	Nedjima DEBBOU IOUKNANE Naima SAiDENE Amal OUATAH	Campus University ALGERIA
PROTEOMIC PROFILING, ANTI-PROLIFERATIVE AND ANTI-MIGRATORY ACTIVITY OF VENOM PEPTIDES FROM MOROCCAN SCORPION ANDROCTONUS MAURITANICUS AND COBRA NAJA HAJE: ION CHANNEL MODULATION IN HUMAN GLIOBLASTOMA CANCER CELL LINES	Reda Chahir Océane Pertegaz Salma Chakir Noureddine Hammani Hinde Aassila Marie Potier-Cartereau Naoual Oukkache	Hassan I University MOROCCO

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01.08.2026 / Session-2, Hall-4
Ankara Local Time: 12:30 – 14:30
Meeting ID: 862 6236 6905 / Passcode: 010203
Moderator: Assist. Prof. Anita Pandey

Title	Author(s)	Affiliation
DIVERSITY AND CONSERVATION OF THE ORCHIDACEAE OF THE TAZEKKA NATIONAL PARK (EASTERN MIDDLE ATLAS, MOROCCO)	BOUGUETTOUCHE Ismail ARROUD Hanane ZAABOUL Fatna ALAOUI MHAMDI Omar ISMAILI Brahim LIBIAD Mohamed HAMMANI Khalil KHABBACH Abdelmajid	Sidi Mohamed Ben Abdellah University MOROCCO Abdelmalek Essaadi University MOROCCO
FORTY YEARS OF LANDSAT AND SENTINEL-2 RETROSPECTIVE ANALYSIS REVEAL A SPECIES-DIFFERENTIATED DIEBACK SIGNAL IN THE ATLAS FORESTS OF BÉNI MELLAL-KHÉNIFRA (MOROCCO)	Yacine Laidi Nawfel El Bouchti	Sultan Moulay Slimane University MOROCCO National Agency of Waters and Forests MOROCCO
HARPETOFOUNAL DIVERSITY IN RAM JHARNA RIVERINE- FOREST ECOSYSTEM	Assist. Prof. Anita Pandey	Kirodimal Govt. Arts and Science College INDIA
SCIENTIFIC AND PRACTICAL FOUNDATIONS OF THE RECLAMATION OF TECHNOGENICALLY DISTURBED AREAS AND APPROACHES TO SOIL FERTILITY RESTORATION	Nargiz Hakimova Dayanat Bakhishov Nargiz Nasirli	Ministry of Science and Education of the Republic of Azerbaijan, AZERBAIJAN
THE IMPACT OF ENVIRONMENTAL POLLUTION CAUSED BY INDUSTRIAL PLANTS ON ECO-GEOGRAPHICAL CONDITIONS	Aysel KHUDAI	Ministry of Science and Education of the Republic of Azerbaijan, AZERBAIJAN
PHYSICOCHEMICAL, BIOLOGICAL, AND HEAVY METAL ANALYSIS AND ASSESSMENT OF WATER AND SEDIMENT AT THE LLUZHAN SPA, PODUJEVË, KOSOVO	Prof. Dr. Skender Demaku Msc. Arbnorë Aliu Msc. Donika Sylejmani Anita Ismajli Shqipe Berisha	Prishtina University KOSOVO
THE COST OF CONSERVATION: CROP NUTRITION AND HEALTH RISKS IN TRICKLING FILTER EFFLUENT-IRRIGATED MILLET	Ahmed Osmane Khadija Zidan Moustapha Belmouden	Cadi Ayyad University MOROCCO
TREATED WASTEWATER REUSE IN ARID AGRICULTURE: NUTRITIONAL AND HEALTH IMPLICATIONS OF TRICKLING FILTER EFFLUENT ON MILLET PRODUCTION IN NORTH AFRICA	Ahmed Osmane Khadija Zidan Moustapha Belmouden	Cadi Ayyad University MOROCCO

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01.08.2026 / Session-2, Hall-5
Ankara Local Time: 12:30 – 14:30
Meeting ID: 862 6236 6905 / Passcode: 010203
Moderator: Assoc. Prof. Serir UZUN

Title	Author(s)	Affiliation
ASSESSMENT OF PEDESTRIAN THERMAL COMFORT IN POCKET PARKS: A CASE STUDY OF ERZURUM, TÜRKİYE	Hüsna GÜLKAR Prof. Dr. Sevgi YILMAZ	Atatürk University TÜRKİYE
ANALYSIS OF TWO DIFFERENT URBAN PARKS IN URBAN AREAS IN TERMS OF ENVIRONMENTAL, PHYSICAL, VEGETATIVE, AND MICROCLIMATIC CHARACTERISTICS AND USER REQUESTS: THE CASE OF ERZURUM CITY CENTER	Betül Nur BAYRAKTAR Assoc. Prof. Dr. M. Akif IRMAK	Atatürk University TÜRKİYE
THE NECESSITY OF URBAN SQUARES IN THE CONTEXT OF URBAN CLIMATE RESILIENCE: AN ECOLOGICAL APPROACH TO THE CASE OF ERZURUM PALANDÖKEN	Feyzanur AKSAK Assoc. Prof. Dr. Hasan YILMAZ	Atatürk University TÜRKİYE
URBAN GREEN SPACES AS A REGULATING FACTOR IN THE RELATIONSHIP BETWEEN PARTICULATE MATTER POLLUTION AND OUTDOOR THERMAL COMFORT	Assist. Prof. Dr. Figen ALTINER	Balıkesir University TÜRKİYE
DILEMMAS IN THE PROCESS OF CONCEPTUALIZING URBAN DESIGN	Dr. Bülent GÜNEŞ	T.C. İstanbul Yeni Yüzyıl University TÜRKİYE
A DYNAMIC RUSLE-SYSTEM DYNAMICS FRAMEWORK FOR SOIL EROSION AND POLICY SIMULATION	Dr. Abdurrahman TURSUN Prof. Dr. Bernard A. Engel Prof. Dr. Günay ERPUL	Ankara University TÜRKİYE Purdue University USA Ankara University TÜRKİYE
THE RULE OF LAW PRINCIPLE AND URBAN TRANSFORMATION IN THE FACE OF THE REALITY OF EARTHQUAKES	Esra Güngör SUSAM	KTO Karatay University TÜRKİYE

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01.08.2026 / Session-2, Hall-6
Ankara Local Time: 12:30 – 14:30
Meeting ID: 862 6236 6905 / Passcode: 010203
Moderator: Asst. Prof. Melek GÖKMEN KARAKAYA

Title	Author(s)	Affiliation
RESEARCH TRENDS IN ANTIBIOTIC-FREE NANOMATERIALS: A BIBLIOMETRIC PERSPECTIVE	Dr. Şeref AKAY	Alanya Alaaddin Keykubat University TÜRKİYE
MULTI-CRITERIA SUSTAINABILITY EVALUATION OF WASTE-BASED ADSORBENTS FOR WATER TREATMENT	Assist. Prof. Dr. Nagihan SOYER	Sivas Cumhuriyet University TÜRKİYE
INVESTIGATION OF THE ADSORPTION OF ORIGINAL APRICOT RESIN FROM ARSENIC AND LEAD-CONTAMINATED WATERS	Assist. Prof. Dr. Servet AŞKIN	Iğdır University TÜRKİYE
QUERCETIN IMPRINTED QUARTZ CRYSTAL MICROBALANCE SENSOR FORTHE APPLICATION TO APPLE JUICE	Assist. Prof. Dr. Bahar BANKOĞLU YOLA	Gaziantep Islam Science and Technology University TÜRKİYE
FLUORESCENT DETERMINATION OF 17B-ESTRADIOL USING A COPPER- BASED METAL–ORGANIC FRAMEWORK	Lect. Dr. Burcu KABAK	Burdur Mehmet Akif Ersoy University TÜRKİYE
ANALYSIS OF LONG TERM SURFACE SOIL MOISTURE TRENDS IN THE ASİ BASIN USING SMAP SATELLITE DATA	Assist. Prof. Dr. Mustafa ÖZBULDU	Hatay Mustafa Kemal University TÜRKİYE

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01.08.2026 / Session-3, Hall-1
Ankara Local Time: 15:00 – 17:00
Meeting ID: 862 6236 6905 / Passcode: 010203
Moderator: Assoc. Prof. Rajeev Kumar

Title	Author(s)	Affiliation
SUSTAINABLE WATER RESOURCE MANAGEMENT: ASSESSMENT OF SALINE WATER TREATMENT USING OSMOSE INVERSE IN ARID REGIONS	Zineb Dahmouch Driss Azdem Prof. Dr. Jamal Mabrouki	Mohammed V University MOROCCO
STATISTICAL ANALYSIS OF LONG-TERM OPERATIONAL WATER QUALITY DATA IN A FULL-SCALE MOROCCAN SWRO PLANT	Zineb Dahmouch Driss Azdem Prof. Dr. Jamal Mabrouki	Mohammed V University MOROCCO
STUDY THE EFFECTIVENESS OF THE NATURAL LAGOONS FOR REMOVAL OF ORGANIC MATTER, NUTRIENTS AND FECAL COLIFORM FROM URBAN DOMESTIC WASTEWATER UNDER ARID CLIMATE (MOROCCO)	Ahmed Osmane Khadija Zidan Moustapha Belmouden	Cadi Ayyad University MOROCCO
PERFORMANCE ASSESSMENT OF NATURAL LAGOONS FOR ORGANIC MATTER, NUTRIENT, AND FAECAL COLIFORM REMOVAL FROM URBAN DOMESTIC WASTEWATER UNDER ARID CLIMATE CONDITIONS (MOROCCO)	Ahmed Osmane Khadija Zidan Moustapha Belmouden	Cadi Ayyad University MOROCCO
BIO-WASTE MATERIALS FOR WASTEWATER TREATMENT: A SUSTAINABLE SOLUTION	Assoc. Prof. Rajeev Kumar	Manav Rachna International Institute of Research and Studies INDIA
ECO-FRIENDLY SYNTHESIS OF A CHITOSAN@TiO_2 NANOCOMPOSITE USING GINGER EXTRACT: ENHANCED ADSORPTION OF DYES, REAL WASTEWATER TREATMENT, AND DFT INSIGHTS	Soukaina El Bourachdi Yassine Rakcho Ali Raza Ayub Abdelhay el Amri Mahdi Lechheb Amal Lahkimi	Sidi Mohamed Ben Abdellah University MOROCCO Cadi Ayyad University MOROCCO Beijing Institute of Technology CHINA Mohammed VI Polytechnic University MOROCCO Moulay Ismail University MOROCCO Sidi Mohamed Ben Abdellah University MOROCCO
APPLICATION OF ARTIFICIAL INTELLIGENCE IN DYNAMIC REMOVAL OF POLLUTANTS FROM WASTE WATER USING NOVEL MATERIALS PREPARED BY IN SITU POLYMERIZATION	Taoufiq Bouzid Abdelali Grich Aicha Naboulsi Hicham Yazid Ali Elbasraoui Mamoune El Himri Abdelmajid Regti Mohammadine El Haddad	Cadi Ayyad University MOROCCO
VALORIZATION OF OLIVE OIL BIOACTIVE COMPOUNDS VIA ADSORPTION ONTO POZZOLAN-ALGINATE COMPOSITE BEADS	Ahmed Osmane Khadija Zidan Khadija Zidan	Cadi Ayyad University MOROCCO

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01.08.2026 / Session-3, Hall-2
Ankara Local Time: 15:00 – 17:00
Meeting ID: 862 6236 6905 / Passcode: 010203
Moderator: Bakhtiar Ul Haq

Title	Author(s)	Affiliation
DEVELOPMENT OF CHITOSAN–ZNO–GHASSOUL CLAY BIOHYBRID BEADS FOR PHOTOCATALYTIC DYE DEGRADATION AND CU(II) PHOTOREDUCTION	Soukaina El Bourachdi Yassine Ballout Ali Raza Ayub Abdelhay El Amri Yassine Rakcho Amal Lahkimi	Sidi Mohamed Ben Abdellah University MOROCCO Mohammed VI Polytechnic University MOROCCO The Laboratory of Molecular Chemistry, Materials and Environment (LCM2E) MOROCCO Beijing Institute of Technology CHINA Mohammed VI Polytechnic University MOROCCO Cadi Ayyad University MOROCCO
NICKEL OXIDE-CONTAINING SPINEL NIAL2O4 NANOCOMPOSITE FOR ENHANCED SUPERCAPACITOR PERFORMANCE	Muhammad JAHANZAIB	Government Graduate College PAKISTAN
STUDY OF THE DIELECTRIC PROPERTIES OF SOLVOTHERMAL SYNTHESIZED CDSE:0.5%HO NANOCRYSTAL	Dr. Seyfaddin JAFAROV	Nakhchivan State University AZERBAIJAN
EXPERIMENTAL AND THEORETICAL INVESTIGATION OF 8-QUINOLINOL-5-AZOANTIPYRINE AS A CORROSION INHIBITOR FOR MILD STEEL IN 1.0 M HCL	Brahim Amjoud Soufiane zerraf Younes Abboud	Hassan II University MOROCCO
COPPER-BASED METAL–ORGANIC FRAMEWORK AS A CATALYST IN ORGANIC TRANSFORMATIONS	Sumayya Akram Prof. Dr. Matloob Ahmad Dr. Sana Aslam	Government College University PAKISTAN
STACKING-CONTROLLED ELECTRONIC STRUCTURE AND ANISOTROPIC OPTICAL RESPONSE OF TWO-DIMENSIONAL ZNO/SİC VAN DER WAALS BILAYERS	Bakhtiar Ul Haq Se-Hun Kim	Prince Mohammad Bin Fahd University SAUDI ARABIA Jeju National University KOREA
THE USE OF PLANT EXTRACTS TO INHIBIT CONCRETE REINFORCEMENTS CORROSION	Latefa SAIL Selsabil AMRAOUI	Aboubekr Belkaid University ALGERIA
EFFECT OF HORSERADISH ROOT POWDER ON THE MECHANICAL AND BARRIER PROPERTIES OF ALGINATE-BASED EDIBLE FILMS	Bianca ŞUIAN Prof. Dr. Sonia AMARIEI Dr. Ancuţa PETRARU	'Ştefan cel Mare' University ROMANIA

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01.08.2026 / Session-3, Hall-3
Ankara Local Time: 15:00 – 17:00
Meeting ID: 862 6236 6905 / Passcode: 010203
Moderator: Prof. Dr. Giovanni Barrera Torres

Title	Author(s)	Affiliation
BIOCOMPOSITE FROM BAMBOO (ARUNDO DONAX) FIBERS AND INDUSTRIAL POLYURETHANE WASTE	Prof. Dr, Giovanni Barrera Torres Prof. Wilson Sandova Niñol Prof. Dr . Edwin Yesid Gomez-Pachon	Institución Universitaria ITM, COLOMBIA Pedagogical and Technological University COLOMBIA
SUSTAINABLE INSULATION: NEW MATERIALS FOR FUTURE APPLICATIONS	Dr. Mrajji ouahiba Omar Cherkaoui	Hassan II University MOROCCO HigherSchool of Textile and clothing Industries MOROCCO
STRATEGIES FOR EMISSION REDUCTION IN INDUSTRIAL STEAM GENERATION SYSTEMS	Mohamed EL MORSY Prof. Dr. Laila AFIA	Ibnou Zohr University MOROCCO
ADVANCES IN SMART PACKAGING FOR REAL-TIME QUALITY MONITORING AND SHELF-LIFE EXTENSION OF MEAT PRODUCTS	Mir-Hassan Moosavy	Tabriz University IRAN
INTELLIGENT PROCESS CONTROL OF DUAL CONICAL TANK SYSTEMS THROUGH DEEP LEARNING-BASED LEVEL PREDICTION	ARULSELVAN K. SURESH PADMANABHAN T.	A.V.C. College of Engineering INDIA E.G.S. Pillay Engineering College INDIA
AI-DRIVEN SMART FAULT DETECTION AND PREDICTIVE MAINTENANCE IN RENEWABLE ENERGY SYSTEMS	Aboubaker Essaddiq MAZOUZ Said HASSAINE Hamid BOUMEDIENE Lallouani HELLALI Oussama MOUSSA Selma BAALI	Tiaret University ALGERIA Mohamed Boudiaf of Msila University ALGERIA Ghardaia University ALGERIA M'sila University ALGERIA

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01.08.2026 / Session-3, Hall-4
Ankara Local Time: 15:00 – 17:00
Meeting ID: 862 6236 6905 / Passcode: 010203
Moderator: Dr. Atabek MOVILYANOV

Title	Author(s)	Affiliation
DEVELOPMENT OF A B-RICH Ti–40Nb ALLOY THROUGH POWDER METALLURGY: MICROSTRUCTURAL CHARACTERIZATION	Assist. Prof. Dr. Eyyüp Murat KARAKURT	Osmaniye Korkut Ata University TÜRKİYE
SURFACE PATTERN FORMATION UNDER CONSTANT AVERAGE LASER POWER USING A PULSED SLS LASER SYSTEM	Dr. İbrahim ÜLKE	Gazi University TÜRKİYE
THERMAL CONDUCTIVITY OF DENSIFIED REINFORCED LAMINATED TIMBERS	Assist. Prof. Dr. İlker YALÇIN Assoc. Prof. Dr. Raşit ESEN	İzmir University of Economics TÜRKİYE Karabük University TÜRKİYE
ENHANCEMENT OF THE MECHANICAL AND TRIBOLOGICAL PROPERTIES OF ST37 STEEL USING NI-W COATINGS	Yiğit GÜRLEVİK Sezer TAN Mehmet UYSAL	Sakarya University TÜRKİYE
EFFECT OF THROUGH-THICKNESS ABS LAYER PLACEMENT ON THE TENSILE BEHAVIOR AND ENERGY ABSORPTION OF MULTI- MATERIAL FDM-PRINTED SILK PLA/ABS STRUCTURES	Assist. Prof. Dr. Arif BALCI Assist. Prof. Dr. Fatih ALİBEYOĞLU	Kafkas University TÜRKİYE
EFFECT OF PA6 POWDER-MODIFIED EPOXY ADHESIVE ON THE SHEAR STRENGTH OF FDM-PRINTED ABS SINGLE-LAP JOINTS	Assist. Prof. Dr. Fatih ALİBEYOĞLU Assist. Prof. Dr. Arif BALCI	Kafkas University TÜRKİYE
INVESTIGATION OF THE EFFECT OF UV CURING ON TEMPARARY DENTAL RESINS PRODUCED VIA PHOTOPOLYMERIZATION BASED STEREOLITHOGRAPHIC ADDITIVE MANUFACTURING IN DENTISTRY	Assoc. Prof. Dr. Çağın BOLAT İsmet AVCI	Samsun University TÜRKİYE

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01.08.2026 / Session-3, Hall-5
Ankara Local Time: 15:00 – 17:00
Meeting ID: 862 6236 6905 / Passcode: 010203
Moderator: Lecturer, PhD Ümmühan AKHİSAR

Title	Author(s)	Affiliation
EVALUATION OF NEW FLIGHT ROUTE SELECTION CRITERIA FOR AIRLINES USING BUCKLEY'S FUZZY AHP METHOD: INTEGRATION OF THE CONTRAIL EFFECT INTO THE DECISION MODEL	Kubilay Yusuf ÖZDEMİR Assoc. Prof. Dr. Eda ÇINAROĞLU	Erciyes University TÜRKİYE
AN ANALYSIS OF BIRD STRIKES AT JOHN F. KENNEDY INTERNATIONAL AIRPORT	Cemil RAKİPOĞLU Prof. Dr. Alper ASLAN	Erciyes University TÜRKİYE
SINGLE-CRITERION VS. MULTI-CRITERIA SKYHOOK GAIN SELECTION FOR OFF-ROAD VEHICLE SUSPENSION: A HALF-CAR ANALYSIS UNDER STOCHASTIC AND DETERMINISTIC EXCITATIONS	Assist. Prof. Dr. Hilal DOĞANAY KATI	Bursa Technical University TÜRKİYE
THERMODYNAMIC ASSESSMENT OF ORGANIC RANKINE CYCLE WORKING FLUIDS UNDER HEAVY DUTY DIESEL ENGINE OPERATING CONDITIONS	Mustafa GÜNEŞ Prof. Dr. Nurullah ARSLANOĞLU Cengizhan CENGİZ Prof. Dr. Şeref SOYLU	Bursa Uludağ University TÜRKİYE Bursa Uludağ University TÜRKİYE Ford Otosan, Eskişehir R&D Test Centre, TÜRKİYE Kocaeli University TÜRKİYE
NUMERICAL INVESTIGATION OF THE EFFECT OF SIMULTANEOUS ROUNDING OF INNER AND OUTER CORNER GEOMETRY ON DRAG AND PRESSURE LOSS IN AN IN-CHANNEL OBSTACLE ARRAY	Lect. Dr. Onur GÖK	Necmettin Erbakan University TÜRKİYE
SAFE DEEP REINFORCEMENT LEARNING–BASED VOLTAGE MANAGEMENT IN LV DISTRIBUTION NETWORKS	Muhammed Sait AYDIN	Siirt University TÜRKİYE
COMPUTATIONAL FLUID DYNAMICS-BASED AERODYNAMIC PERFORMANCE EVALUATION OF NACA 64A206 AIRFOIL USING ANSYS FLUENT	Kerem Ali TAŞ Assist. Prof. Dr. Kürşat TANRIVER Prof. Dr. Mustafa AY	Istanbul Healt and Technology University TÜRKİYE Istanbul Healt and Technology University TÜRKİYE Marmara University TÜRKİYE

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01.08.2026 / Session-3, Hall-6
Ankara Local Time: 15:00 – 17:00
Meeting ID: 862 6236 6905 / Passcode: 010203
Moderator: Moses Adeolu AGOI

Title	Author(s)	Affiliation
APPLICATION OF THE 'SMART VILLAGE' AND 'SMART CITY' CONCEPTS IN THE GREAT RETURN STRATEGY TO KARABAKH AND THEIR SOCIAL IMPLICATIONS	Mohammad MIRZEZADE	Azerbaijan Tourism and Management University AZERBAIJAN
INTELLIGENT VIRTUAL ARCHITECTURAL ENVIRONMENTS: ADVANCING SPATIAL PERCEPTION AND HUMAN EXPERIENCE THROUGH IMMERSIVE COMPUTING IN LAGOS STATE, NIGERIA	Moses Adeolu AGOI Olayemi Grace ABIMBOLA Rasheed Olatunde AJETUNMOBI Emmanuel Taiwo AGOI	Lagos State University of Education NIGERIA Loughborough University UNITED KINGDOM
THERMAL PERFORMANCE AND SOLAR REFLECTANCE OF GFRC AND ETFE COMPOSITE ENVELOPES IN TROPICAL CIVIC BUILDINGS	Mohd Firrdhaus MOHD SAHABUDDIN Mohd Azreen MOHD HAMBALI Muhammad ASLAM Yilang LIU	Universiti Malaya MALAYSIA Wenzhou University of Technology CHINA
AUTONOMOUS DESIGN SYSTEMS IN ARCHITECTURE: INTEGRATING EXPLAINABLE AI, LARGE LANGUAGE MODELS, AND DIGITAL TWIN TECHNOLOGIES	Moses Adeolu AGOI Akinyemi Edward AIYEGBUSI Yewande Adeyosola ODUNAYO Emmanuel Taiwo AGOI	Lagos State University of Education NIGERIA Loughborough University UNITED KINGDOM
SMART GEOTECHNICAL ENGINEERING FOR BLACK SEA COASTAL RESILIENCE: AN INTEGRATED IOT, EDGE AI, AND DIGITAL TWIN FRAMEWORK	Dr. Ali Akbar Firoozi Dr. Ali Asghar Firoozi	Botswana University BOTSWANA National University MALAYSIA
DIGITAL TWINS FOR REAL-TIME MONITORING OF PORT FOUNDATIONS AND COASTAL GEOTECHNICAL INFRASTRUCTURE IN THE BLACK SEA REGION	Dr. Ali Akbar Firoozi Dr. Ali Asghar Firoozi	Botswana University BOTSWANA National University MALAYSIA
REMOTE SENSING AND EDGE AI FOR DETECTING EROSION-INDUCED FOUNDATION INSTABILITY IN BLACK SEA COASTAL INFRASTRUCTURE A MULTI-SENSOR METHODOLOGICAL FRAMEWORK	Dr. Ali Akbar Firoozi Dr. Ali Asghar Firoozi	Botswana University BOTSWANA National University MALAYSIA
SMART BIO-ENGINEERED SLOPE STABILIZATION WITH EMBEDDED SENSORS FOR CLIMATE-RESILIENT BLACK SEA COASTLINES	Dr. Ali Akbar Firoozi Dr. Ali Asghar Firoozi	Botswana University BOTSWANA National University MALAYSIA

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03.08.2026 / Session-1, Hall-1
Ankara Local Time: 10:00 – 12:00
Meeting ID: 862 6236 6905 / Passcode: 010203
Moderator: Dr. Ali Akbar Firoozi

Title	Author(s)	Affiliation
GEOCHEMICAL AND STRUCTURAL EVALUATION OF MUD VOLCANISM AS AN INDICATOR OF DEEP-SEATED HYDROCARBON MIGRATION IN THE SHAMAKHI-GOBUSTAN DEPRESSION	Ismat MAMMADOV	Azerbaijan State Oil and Industry University AZERBAIJAN
PHYSICS-INFORMED MACHINE LEARNING FOR EARLY WARNING OF RAINFALL-INDUCED LANDSLIDES ALONG THE BLACK SEA COAST	Dr. Ali Akbar Firoozi Dr. Ali Asghar Firoozi	Botswana University BOTSWANA National University MALAYSIA
MULTI-SENSOR DATA FUSION FOR EARTHQUAKE-INDUCED LIQUEFACTION EARLY WARNING IN BLACK SEA COASTAL SETTLEMENTS	Dr. Ali Akbar Firoozi Dr. Ali Asghar Firoozi	Botswana University BOTSWANA National University MALAYSIA
EXPLAINABLE AI AND SATELLITE INSAR FOR COASTAL SUBSIDENCE MAPPING AND GEOTECHNICAL RISK ASSESSMENT IN BLACK SEA CITIES	Dr. Ali Akbar Firoozi Dr. Ali Asghar Firoozi	Botswana University BOTSWANA National University MALAYSIA
FEDERATED LEARNING FOR CROSS-BORDER LANDSLIDE RISK INTELLIGENCE ACROSS BLACK SEA COASTLINE COUNTRIES	Dr. Ali Akbar Firoozi Dr. Ali Asghar Firoozi	Botswana University BOTSWANA National University MALAYSIA
ARTIFICIAL INTELLIGENCE AND MACHINE LEARNING FOR EARLY PREDICTION OF BAYOUD DISEASE THROUGH SOIL MICROBIAL ACTIVITY IN DATE PALM CULTIVATION IN MOROCCO	Youssef El Hilali Alaoui Said Bouda Abdelmajid Haddioui Abdellatif Boutagayout Houria Ben Amar Hajar Mhammedi Adil Essarioui	Sultan Moulay Slimane University MOROCCO Moulay Ismail University MOROCCO National Institute of Agricultural Research MOROCCO
AI-BASED DECISION SUPPORT SYSTEMS FOR PRECISION DISEASE MANAGEMENT	Assist. Prof. Dr. K. VIGNESH	Agricultural College INDIA

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03.08.2026 / Session-1, Hall-2
Ankara Local Time: 10:00 – 12:00
Meeting ID: 862 6236 6905 / Passcode: 010203
Moderator: Prof. Arzu Najaf HASANOV

Title	Author(s)	Affiliation
TRANSITION TO THE INNOVATIVE DEVELOPMENT OF THE NATIONAL ECONOMY IN AZERBAIJAN: AN ECOSYSTEM APPROACH	Ulduz Elchin MEHDİYEVA Prof. Arzu Najaf HASANOV	Ganja State University AZERBAIJAN
PROBLEMS OF ENSURING ECONOMIC SECURITY OF ENTREPRENEURIAL SUBJECTS IN AZERBAIJAN	Fidan Faig KALASHLİ Prof. Arzu Najaf HASANOV	Ganja State University AZERBAIJAN
CHALLENGES AND INSTITUTIONAL–STRUCTURAL BARRIERS TO INDIVIDUAL MASTERY IN THE PATH OF IRAN'S POLITICAL ECONOMY UNDERDEVELOPMENT	Vorya Shabrandi Dr. Sajjad Bahrami Moghadam	Guilin University IRAN
HOUSEHOLD EXPENDITURE AND REGIONAL ECONOMIC WELFARE: EVIDENCE FROM WEST JAVA, INDONESIA	Ratna Septiyanti Harsono Edwin Puspita Doni Sagitarian Warganegara Agus Zahron Idris	Lampung University INDONESIA
THE ANALYSIS OF THE INNOVATIVE POTENTIAL OF RUSSIAN SMALL BUSINESS	Kristina AKOPYAN Ekaterina Petrovna MAKAROVA-KOROBEYNIKOVA	Russian Customs Academy RUSSIA
IMPROVING THE IMPLEMENTING INNOVATIONS MECHANISM ON THE EXAMPLE OF "REFORUM AWARDS" WINNING COMPANIES IN RUSSIA	Polina ALEXANDROVA Ekaterina Petrovna MAKAROVA-KOROBEYNIKOVA	Russian Customs Academy RUSSIA
BEYOND THE BOARDROOM: WOMEN'S CORPORATE LEADERSHIP AND FIRMS' ENVIRONMENTAL OUTCOMES ACROSS INSTITUTIONAL CONTEXTS	Pinar Acar Damla Tas	Korea University KOREA

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03.08.2026 / Session-1, Hall-3
Ankara Local Time: 10:00 – 12:00
Meeting ID: 862 6236 6905 / Passcode: 010203
Moderator: Dr. Edgar A Burns

Title	Author(s)	Affiliation
MEASURING THE PERFORMANCE AND EFFECTIVENESS OF CLOUD-BASED HRM SYSTEMS WITHIN ENTERPRISE RESOURCE PLANNING FRAMEWORKS	Shafiga RASULZADA	Azerbaijan Technical University AZERBAIJAN
STRATEGIC HUMAN RESOURCE MANAGEMENT AND ORGANIZATIONAL EFFECTIVENESS	Seifeslasie Asmamaw	Bahir Dar University ETHIOPIA
THE ROLE OF INTERNAL CONTROL SYSTEMS IN ENHANCING FINANCIAL PERFORMANCE AND AMONG SMALL AND MEDIUM ENTERPRISES (SMES)	Umar Baba Shaaba	Ahman Pategi University NIGERIA
THE ROLE OF FORENSIC ACCOUNTING IN COMBATING FINANCIAL FRAUD AND ENHANCING CORPORATE GOVERNANCE IN EMERGING ECONOMIES	Umar Baba Shaaba	Ahman Pategi University NIGERIA
IDENTIFYING ADMINISTRATIVE PROBLEMS USING PROBLEM-SOLVING TECHNIQUES AND THEIR ROLE IN DECISION-MAKING FOR CONTINUOUS IMPROVEMENT AND DEVELOPMENT: AN APPLIED STUDY ON THE PROPERTY INVESTMENT DEPARTMENT OF GREATER AMMAN MUNICIPALITY	Tahreer Farouk	Greater Amman Municipality JORDAN
ICT TOOLS AND E-COMMERCE AS AGENTS OF NIGERIA'S ECONOMIC DEVELOPMENT	Otse Moses Okpekwu Umoru, Rapheal Sunday Anyanwu Peter Chukwuemeka	Federal College of Agriculture NIGERIA Wesley University NIGERIA
NEW GLOBAL TRAMLINES: CENTRAL BANK CRYPTO-CURRENCIES	Dr. Edgar A Burns	Waikato University NEW ZEALAND

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03.08.2026 / Session-1, Hall-4
Ankara Local Time: 10:00 – 12:00
Meeting ID: 862 6236 6905 / Passcode: 010203
Moderator: Asst. Prof. Dinçer ATASOY

Title	Author(s)	Affiliation
ACOUSTIC SIGNATURES OF AI-GENERATED MUSIC: A REVIEW OF INTERPRETABLE AND DATA-DRIVEN DETECTION METHODS	Res. Assist. Dr. Uğur BALOĞLU	Ankara Music and Fine Arts University TÜRKİYE
DETECTION OF ATRIAL FIBRILLATION USING NONLINEAR HEART RATE VARIABILITY PARAMETERS WITHOUT ECG : A MACHINE LEARNING-BASED APPROACH	İsmail İŞİK Prof. Dr. Damla GÜRKAN KUNTALP	Dokuz Eylül University TÜRKİYE
DIGITAL TWIN-ASSISTED MULTIDISCIPLINARY CLINICAL DECISION SUPPORT SYSTEMS IN THE PERIOPERATIVE PROCESS: TRANSITION TO THE SMART OPERATING ROOM	Onur Eren KÖKSEL Assist. Prof. Dr. Pervin KÖKSEL Assoc. Prof. Dr. Ayşe TOPAL HANÇER	Harakani State Hospital TÜRKİYE Kafkas University TÜRKİYE Niğde Ömer Halisdemir University TÜRKİYE
EFFECTS OF SURGICAL SMOKE ON OCCUPATIONAL HEALTH AND ITS MULTIDISCIPLINARY MANAGEMENT	Onur Eren KÖKSEL Assist. Prof. Dr. Pervin KÖKSEL Assoc. Prof. Dr. Ayşe TOPAL HANÇER	Harakani State Hospital TÜRKİYE Kafkas University TÜRKİYE Niğde Ömer Halisdemir University TÜRKİYE
EVALUATING THE EFFECT OF ANNOTATION CONFIDENCE ON STRESS DETECTION PERFORMANCE	Prof. Dr. Alper Kürşat UYSAL	Alanya Alaaddin Keykubat University TÜRKİYE
INTEGRATING MANAGEMENT SYSTEM AND REGULATORY APPROACHES FOR ENTERPRISE GENERATIVE AI GOVERNANCE	Assist. Prof. Dr. Gülcan AYRAL	Üsküdar University TÜRKİYE
THE ROLE OF THE MANAGEMENT 3.0 APPROACH IN ENHANCING EMPLOYEE AGILITY	Assist. Prof. Dr. Gülcan AYRAL	Üsküdar University TÜRKİYE
THE AFFECTIVE MAP OF ALGORITHMS: DIRECTING ANGER, FEAR, AND CURIOSITY ON DIGITAL PLATFORMS	Assist. Prof. Dr. Ferhat ATİK Gizem BEKAR	Girne American University TRNC
ETHICAL DILEMMAS ENCOUNTERED BY HIGHER EDUCATION ACADEMIC STAFF DURING THE ADOPTION OF AI-SUPPORTED EDUCATIONAL ENVIRONMENTS: A QUALITATIVE STUDY	Melisa FIRAT Prof. Dr. Mehmet Ali AKIN	Mardin Artuklu University TÜRKİYE

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03.08.2026 / Session-1, Hall-5
Ankara Local Time: 10:00 – 12:00
Meeting ID: 862 6236 6905 / Passcode: 010203
Moderator: Asst. Prof. Erhan AKALP

Title	Author(s)	Affiliation
THE EFFECT OF AROMATHERAPY ON SLEEP QUALITY IN PATIENTS UNDERGOING DIALYSIS: A REVIEW OF POSTGRADUATE NURSING THESES IN TÜRKİYE	Prof. Dr. Nurten ÖZEN	İstanbul University TÜRKİYE
EXAMINATION OF GRADUATE THESES IN NURSING ON THE PREVENTION OF XEROSTOMIA IN DIALYSIS PATIENTS IN TÜRKİYE: A TRADITIONAL REVIEW	Prof. Dr. Nurten ÖZEN Assoc. Prof. Dr. Betül TOSUN	İstanbul University TÜRKİYE Hacettepe University TÜRKİYE
TELEPSYCHIATRY IN THE MANAGEMENT OF DEPRESSION AND THE ROLE OF MENTAL HEALTH NURSES: A NARRATIVE REVIEW	Assist. Prof. Dr. Fatma İlknur UZUN Güllü YAZKAN Feyza ACAR Assoc. Prof. Dr. Fatma BİRGİLİ	Biruni University TÜRKİYE Muğla Sıtkı Koçman University TÜRKİYE
EVIDENCE-BASED APPROACHES TO PAIN MANAGEMENT IN CHILDREN: PHARMACOLOGICAL AND NON-PHARMACOLOGICAL PRACTICES	Esra KELEŞ Assoc. Prof. Dr. Atiye KARAKUL Prof. Dr. Duygu SÖNMEZ DÜZKAYA	Tarsus University TÜRKİYE
DEVELOPMENTAL CARE IN THE NEWBORN: CURRENT APPROACHES AND NURSING PRACTICES	Esra KELEŞ Assoc. Prof. Dr. Atiye KARAKUL Prof. Dr. Duygu SÖNMEZ DÜZKAYA	Tarsus University TÜRKİYE
MIDWIFE-LED BREASTFEEDING SUPPORT: CURRENT EVIDENCE ON EFFECTIVE INTERVENTIONS AND THEIR CLINICAL IMPLICATIONS (I)	Res. Assist. Dr. Seda GÜRAY Assoc. Prof. Dr. Özlem KOÇ	Tarsus University TÜRKİYE
MIDWIFE-LED PREVENTION OF ALCOHOL USE DURING PREGNANCY: SCREENING, BRIEF INTERVENTION, AND EVIDENCE-BASED CLINICAL APPROACHES	Res. Assist. Dr. Seda GÜRAY Assoc. Prof. Dr. Özlem KOÇ	Tarsus University TÜRKİYE
ARTIFICIAL INTELLIGENCE AND DIGITAL APPLICATIONS IN DIABETES MANAGEMENT: A REVIEW OF CURRENT EVIDENCE	Ömer Faruk ÇALIŞ Assoc. Prof. Dr. Özlem CEYHAN	Erciyes University TÜRKİYE

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03.08.2026 / Session-2, Hall-1
Ankara Local Time: 12:30 – 14:30
Meeting ID: 862 6236 6905 / Passcode: 010203
Moderator: Assist. Prof. Dr. Dr. Violla Makhzoum

Title	Author(s)	Affiliation
THE DIGITAL STATE THROUGH THE PRISM OF A COMPARATIVE ANALYSIS OF TECHNOLOGICAL DETERMINISM AND SOCIAL CONSTRUCTIVISM	Turan Yusubov	Azerbaijan National Academy of Sciences AZERBAIJAN
A TURNING POINT: ARTIFICIAL INTELLIGENCE AND THE TRANSFORMATION OF CONTEMPORARY SOCIETY	Roxana Mihaela Moisoiu Prof Colegiul German Goethe	U.S.P.E.E. „C. Stere” MOLDOVA
CYBERSECURITY AND DATA PRIVACY COMPLIANCE IN ADMINISTRATIVE UNITS: CHALLENGES, RISKS, AND STRATEGIC SOLUTIONS FOR ORGANIZATIONAL SUSTAINABILITY	Sunday Olorunlogbon Olorunnipa	National Open University NIGERIA
ARTIFICIAL INTELLIGENCE AND AUTOMATION IN MANAGEMENT OF CROSS- BORDER ONLINE TRANSACTIONS: AUTOMATED FRAUD DETECTION, RISC SCORING, ETHICAL AND LEGAL IMPLICATIONS	Dr. Vatamanita MARIANA Dr. Marit ALEXANDRU	“Constantin Stere”University of European Political and Economic Science MOLDOVA
MONEY LAUNDERING IN REAL ESTATE AND CONSTRUCTION TRANSACTIONS: A COMPARATIVE ANALYSIS BETWEEN REPUBLIC OF MOLDOVA AND THE EUROPEAN UNION	Mariana VATAMANITA	“Constantin Stere”University of European Political and Economic Science MOLDOVA
LEGAL DELIMITATION OF FORCED MARRIAGE FROM ARRANGED MARRIAGE AND TRAFFICKING IN HUMAN BEINGS: A COMPARATIVE ANALYSIS BETWEEN THE REPUBLIC OF MOLDOVA AND EUROPEAN STANDARDS	MILEA Diana	'Constantin Stere' University of European Political and Economic Science MOLDOVA
ENFORCING WAR CRIMES UNDER INTERNATIONAL HUMANITARIAN LAW: NORMATIVE DEVELOPMENT, JURISPRUDENCE, AND STRUCTURAL LIMITATION OF INTERNATIONAL CRIMINAL JUSTICE	Roya Hussaini	Independent Researcher AFGHANISTAN
LEBANESE EDUCATIONAL LEGISLATION IN FACING THE CHALLENGES OF DIGITAL EDUCATION AND ARTIFICIAL INTELLIGENCE: AN ANALYTICAL STUDY FOR DEVELOPING CONTEMPORARY EDUCATIONAL LEGAL FRAMEWORK	Assist. Prof. Dr. Dr. Violla Makhzoum Dr. Mohamad Kanso	Islamic University LEBANON
FINANCIAL PERFORMANCE AND RESILIENCE OF MEDCO S.A.L. AMID LEBANON'S ECONOMIC CRISIS: A FINANCIAL EVALUATION (2023–2024)	Prof. Lina Bilani Dr. Yehia Zalzali Bader El Khatib Batoul Chaaban	Islamic University LEBANON

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03.08.2026 / Session-2, Hall-2
Ankara Local Time: 12:30 – 14:30
Meeting ID: 862 6236 6905 / Passcode: 010203
Moderator: Prof. Dr. Ivan PAVLOVIĆ

Title	Author(s)	Affiliation
THE DYNAMICS AND CHALLENGES OF ESTABLISHING DIPLOMATIC RELATIONS BETWEEN CENTRAL ASIAN STATES AND ARMENIA	Kamala Afandiyeva Allahverdi	Academician Ziya Bunyadov Institute of Oriental Studies of the Azerbaijan National Academy of Sciences AZERBAIJAN
THE ROLE OF THE ALBANIAN COLONY IN ISTANBUL IN RELATIONS BETWEEN ALBANIA AND THE ANKARA GOVERNMENT, 1920–1924	Assoc. Prof. Dr. Ilirjana KACELI (DEMIRLIKA)	"Luigj Gurakuqi" University ALBANIA
INTERNATIONAL HUMANITARIAN LAW AND THE REGULATION OF ARMED CONFLICT	Homaira Rezaie	Niswan Shohada Markez AFGHANISTAN
ECONOMIC INFORMATION NETWORKS AND THEIR ROLE IN THE OPERATIONS OF THE BANQUE DE L'INDOCHINE IN FRENCH INDOCHINA (1875 - 1945)	Nguyen Thanh Tuan	Vinh Nhuan Middle and High School VIETNAM
TRIANGLE OF TORMENT IN THE JORDAN VALLEY AND THE HIGHLANDS: A STUDY IN HISTORICAL GEOGRAPHY AND ARCHAEOLOGICAL SURVEYS OF THE CIVILIZATIONS OF LOT, MADYAN, AND ASHAAB AL-AYKAH	Mohammed Waheeb	Hashemite University JORDAN
ANALYSIS OF THE REPATRIATION PROCESS USING THE METHOD OF INFORMATIVE-SOCIOLOGICAL ANALYSIS	Khudaverdi GULIYEV	Azerbaijan National Academy of Sciences AZERBAIJAN
A CASE REPORT OF INFECTION OF A CAT WITH AELUROSTRONGYLUS ABSTRUSUS	Prof. Dr. Ivan PAVLOVIĆ Vlada ANTIĆ Nikola NEDELJKOVIĆ	Scientific Institute of Veterinary Medicine SERBIA Veterinary Ambulance "Djole & Prle" SERBIA
NAPROXEN AS AN EMERGING POLLUTANT IN THE AQUATIC ENVIRONMENT - A REVIEW ON TOXICOLOGICAL EFFECTS ON FISH	Daniela-Nicoleta ROPOTAN Assoc. Prof. Dr. Iulia Rodica GRECU Assoc. Prof. Dr. Angelica DOCAN Assist. Prof. Dr. Ion VASILEAN Prof. Dr. Lorena DEDIU	"Dunarea de Jos" University ROMANIA

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03.08.2026 / Session-2, Hall-3
Ankara Local Time: 12:30 – 14:30
Meeting ID: 862 6236 6905 / Passcode: 010203
Moderator: Dr. Nesrin KARATAŞ

Title	Author(s)	Affiliation
PREVALENCE AND PRE-HARVEST FRUIT INFECTION STATUS OF GRAY MOLD DISEASE AGENT (BOTRYTIS SP.) IN KIWIFRUIT ORCHARDS OF THE MARMARA REGION IN TÜRKİYE	Zühtü POLAT	Sakarya University of Applied Sciences TÜRKİYE
STATUS AND MANAGEMENT OF COMMON SMUT OF MAIZE (USTILAGO MAYDIS) AS A FUTURE THREAT TO MAIZE PRODUCTION IN KONYA PROVINCE	Aydan Nur NACAK Prof. Dr. Nuh BOYRAZ	Selçuk University TÜRKİYE
IN VITRO EGG HATCHING SUPPRESSION OF ROOT-KNOT NEMATODE MELOIDOGYNE LUCI BY PLANT GROWTH-PROMOTING ENDOPYTIC BACTERIA ISOLATED FROM HAZELNUT ROOTS	Dr. Anıl Fırat FELEK Assist. Prof. Dr. Şafak KALINDAMAR	Ordu University TÜRKİYE
IN VITRO ANTAGONISTIC EFFECT OF TRICHODERMA HARZIANUM AGAINST THE PEA WILT PATHOGEN FUSARIUM OXYSPORUM F. SP. PISI AT DIFFERENT SALINITY LEVELS	Res. Assist. Ömer Ümit OKÇU Mehmet Akif GÜLTEKİN Prof. Dr. Nuray ÖZER	Tekirdağ Namık Kemal University TÜRKİYE Atatürk Hortıcultural Central Research Instıtute TÜRKİYE Tekirdağ Namık Kemal University TÜRKİYE
EFFECTS OF ALTERNATIVE TREATMENTS AGAINST GRAPEVINE DOWNY MILDEW DISEASE ON THE ACCUMULATION OF STILBENE PHYTOALEXINS	Res. Assist. Ömer Ümit OKÇU Prof. Dr. Nuray ÖZER	Tekirdag Namık Kemal University TÜRKİYE
EVALUATION OF YIELD AND QUALITY CHARACTERISTICS OF BREAD WHEAT (TRITICUM AESTIVUM L.) GENOTYPES UNDER TOKAT ECOLOGICAL CONDITIONS	Yavuz BALMUK Cemal ŞERMET	Black Sea Agricultural Research Institute TÜRKİYE
POTATO PRODUCTION AND TRADE IN TÜRKİYE: CURRENT STATUS AND MAJOR CHALLENGES	Prof. Dr. Cuma AKBAY Ezgi ÇİMEN ÜNLÜKAL	Kahramanmaraş Sütçü İmam Universty TÜRKİYE
THE CALENDAR OF THE SKY AND THE WORK OF THE SOIL: A COMPARATIVE STUDY OF THE FUNCTIONS OF CELESTIAL INDICATORS IN AGRICULTURAL HISTORY	Res. Assist. Dr. Osman ZEYBEK	Bursa Uludağ University TÜRKİYE
PRELIMINARY GEOLOGICAL AND MINERALOGICAL FINDINGS FROM THE EASTERN EXTENSION OF THE KARAMADAZI FE-SKARN SYSTEM (YAHYALI, KAYSERI, CENTRAL TÜRKIYE)	Assoc. Prof. Dr. Nusret NURLU Dr. Emrah ŞİMŞEK Hande SONSUN	Çukurova University TÜRKİYE

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03.08.2026 / Session-2, Hall-4
Ankara Local Time: 12:30 – 14:30
Meeting ID: 862 6236 6905 / Passcode: 010203
Moderator: Asst. Prof. Murat SARI

Title	Author(s)	Affiliation
MATERNAL EMPLOYMENT, PARENTING PRACTICES, AND CHILD WELL-BEING: A COMPARATIVE ANALYSIS OF TURKISH AND BRITISH HOUSEHOLD SURVEY DATA	Neslihan ARAYİT Aybüke Zeliha ÖZDEMİR Merve KILIÇ Prof. Dr. Vilda PURUTÇUOĞLU	Middle East Technical University TÜRKİYE Middle East Technical University TÜRKİYE Health Sciences University TÜRKİYE Health Sciences University TÜRKİYE
WOMEN'S INTRA-HOUSEHOLD DECISION-MAKING POWER: COMPARATIVE STUDIES BETWEEN TÜRKİYE AND UNITED KINGDOM	Zeynep FENERCİOĞLU Muhammet Furkan KOÇ Merve KILIÇ Prof.Dr. Vilda PURUTÇUOĞLU	Middle East Technical University TÜRKİYE
AN EXAMINATION OF CRADLE BETROTHAL MARRIAGE AS AN OATH RITUAL WITHIN THE SOCIOLOGY OF EMOTIONS	Dr. Res. Assist. İlknur AĞTÜRK	Siirt University TÜRKİYE
SOCIAL PERCEPTIONS AND MEANINGS OF SECOND-HAND CLOTHING IN TURKIYE: A QUALITATIVE ASSESSMENT FROM A GENERATION Z PERSPECTIVE	Kerem ŞEKER Derya TURAN Ahmet SARIKAYA Özcan GARAN	İstanbul University TÜRKİYE
FROM EMPIRE TO FEDERATION: THE PARADOX OF KORENIZATSIYA AND CONSTRUCTIVIST NATION-BUILDING IN THE TRANSCAUCASIAN PERIPHERY (1922-1936)	Ufuk ÖZESMER	Middle East Technical University TÜRKİYE
THE INTERVENTION OF THE TURKISH FOREIGN AFFAIRS IN THE ENOSIS AMBITIONS ON THE ISLAND OF CYPRUS DURING THE NATIONAL STRUGGLE (1920-1923)	Dr. Elçin Gün CANİK Prof. Dr. Mehmet Yavuz ERLER	Ondokuz Mayıs University TÜRKİYE
REVILLING AND BESEYING BELIRMATS OF TERMS OF TRANSFORMING LEADERSHIP IN VASIR BİLKADİR ABDÜLHAMİD II'S POLICIES IN BAYT AL-MAQDIS	Lect. Murat GÖKMEN	Düzce University TÜRKİYE

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03.08.2026 / Session-2, Hall-5
Ankara Local Time: 12:30 – 14:30
Meeting ID: 862 6236 6905 / Passcode: 010203
Moderator: Assoc. Prof. Dr. Emine Ebru BOZÇELİK

Title	Author(s)	Affiliation
THE ROLE OF INTEREST RATES ON ECONOMIC GROWTH IN TÜRKİYE	Lect. Dr. Salih PARMAKSIZ	Isparta University of Applied Sciences TÜRKİYE
HOW DO SUSTAINABILITY (ESG) ACTIVITIES IMPACT FINANCIAL PERFORMANCE? A REVIEW OF THE S&P 500 HEALTH CARE SECTOR	Lect. Dr. Ersin YENİSU	Uşak University TÜRKİYE
FOREIGN OUTFLOW PRESSURE IN BORSA İSTANBUL: QUANTILE CONNECTEDNESS WITH DOMESTIC AND GLOBAL FINANCIAL RISKS	Assist. Prof. Dr. Halilibrahim GÖKGÖZ	Afyon Kocatepe University TÜRKİYE
COMPARATIVE ANALYSIS OF LOGISTICS COSTS IN MARITIME EXPORTS ON A GLOBAL BASIS: THE CASE OF TURKEY	Muhammed DİREK Assist. Prof. Dr. Yavuz ELİTOK	Batman University TÜRKİYE
THE AKHISM ORGANIZATION AND WELFARE THOUGHT: A CONCEPTUAL ANALYSIS THROUGH TITMUSS, MARSHALL, AND ESPING-ANDERSEN	Assoc. Prof. Dr. Emine Ebru BOZÇELİK	Kırşehir Ahi Evran University TÜRKİYE
TOTAL QUALITY MANAGEMENT IN THE HEALTHCARE SECTOR AND ITS RELATIONSHIP WITH PATIENT SAFETY	Saeideh BABAPOUR Assist. Prof. Dr. İlkay ERARSLAN	İstanbul Beykent University TÜRKİYE
RENEWABLE ENERGY INCENTIVES AND FIRM BEHAVIOR: A BIBLIOMETRIC ANALYSIS FROM MICROECONOMIC AND INSTITUTIONAL PERSPECTIVES	Assist. Prof. Dr. Faruk SEZER	Bayburt University TÜRKİYE
BEHAVIORAL NATURAL RESOURCE ECONOMICS: A BIBLIOMETRIC ANALYSIS OF CONSUMER CHOICE AND NUDGING IN NON-RENEWABLE RESOURCE CONSUMPTION	Assist. Prof. Dr. Faruk SEZER	Bayburt University TÜRKİYE

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03.08.2026 / Session-3, Hall-1
Ankara Local Time: 15:00 – 17:00
Meeting ID: 862 6236 6905 / Passcode: 010203
Moderator: Prof. Dr. Ananda Majumdar

Title	Author(s)	Affiliation
INTERSECTIONS OF RELIGION AND CULTURE IN CONTEMPORARY SOCIAL LIFE	Prof. Dr. Ananda Majumdar	Harvard University USA
THE EPISTEMOLOGICAL STATUS OF SYNTHETIC KNOWLEDGE: GENERATIVE ARTIFICIAL INTELLIGENCE, TRUTH, AND THE PROVENANCE OF KNOWLEDGE	Aykhan Mustafayev	Institute of Philosophy and Sociology (ANAS) AZERBAIJAN
READING DIVINE WILL: SORTES BIBLICAE IN HAGIOGRAPHIC NARRATIVE	Tinatin Jikurashvili	Tamaz beradze Institute of Georgian Studies GEORGIA
FROM MAGICIAN TO DEVIL'S DEACON: THE LOGIC OF TEMPTATION IN THE GREEK PREMETAPHRASTIC LIFE OF THEODORA OF ALEXANDRIA	Sophio Guliashvili	Georgia University GEORGIA
CULTURE AND CIVILIZATION	Aishwarya S. Reshma N. Tharunikaa P. Priyanka K. Varshana Deepa M.	R.M.K. Engineering College INDIA
THE ROLE OF ANATOLY LUNACHARSKY IN THE LATINIZATION OF THE ALPHABETS OF THE TURKISH PEOPLES	Elgun Gahramanov	Baku State University AZERBAIJAN
INSTITUTIONAL INDICATORS IN MEDIA DISCOURSE (ON THE EXAMPLE OF ECOLOGY MACRODISCOURSE)	Mehriban MONSUMOVA	Azerbaijan Sports Academy AZERBAIJAN

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03.08.2026 / Session-3, Hall-2
Ankara Local Time: 15:00 – 17:00
Meeting ID: 862 6236 6905 / Passcode: 010203
Moderator: Dr. İbrahim Ethem GÜRBÜZ

Title	Author(s)	Affiliation
THE EFFECTS OF SCHOOL PRINCIPALS' LEADERSHIP STYLES AND STRATEGIC PLANNING APPROACHES ON SCHOOL PERFORMANCE	Ebru KIVANÇ Assoc. Prof. Dr. Ali ÖZCAN	İstanbul Nişantaşı University TÜRKİYE
THE EFFECT OF MENTORING ON THE DEVELOPMENT OF CRITICAL THINKING SKILLS: A STUDY OF GIFTED STUDENTS	Prof. Dr. Feyzullah ŞAHİN Dr. Füsun TAŞTEPE	Düzce University TÜRKİYE Düzce Science and Art Center Directorate TÜRKİYE
EDUCATION DIPLOMACY AS A SOFT POWER INSTRUMENT: A CONCEPTUAL ASSESSMENT	Pınar ELBASAN Assoc. Prof. Dr. Buket ÖNAL	Kocaeli University TÜRKİYE
APPROACHES TO RENEWABLE ENERGY APPLICATIONS IN THE HOSPITALITY SECTOR: A CONCEPTUAL EVALUATION	Mehmet Batuhan KARAASLAN Prof. Dr. Abdullah KARAMAN Assoc. Prof. Dr. İlker IŞIK	Selçuk University TÜRKİYE
HYPER-LOCAL JOURNALISM: AN EXAMPLE OF JOURNALISM TYPES IN THE NEW MEDIA WHERE BOUNDARIES ARE BECOMING BROAD	Lect. Dr. Bilal AKKÖPRÜ	Van Yüzüncü Yıl University TÜRKİYE

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03.08.2026 / Session-3, Hall-3
Ankara Local Time: 15:00 – 17:00
Meeting ID: 862 6236 6905 / Passcode: 010203
Moderator: Assoc. Prof. Tülay YAZICI

Title	Author(s)	Affiliation
CHARACTERS IN THE DÎVÂN OF HASAN ZİYÂÎ FROM MOSTAR	Buket TOPATAN	Düzce University TÜRKİYE
CRITIQUING RATIONAL REASON IN ISLAMIC THOUGHT: TAHA ABDURRAHMAN AS A CASE STUDY	Mehmet KETME	Mardin Artuklu University TÜRKİYE
THE SCOPE OF MAQBUL AND SHÂDHQİRÂ'AT ACCORDİNG TO SAYYİD RİZQ AL-TAWİL: A STUDY OF A MODERN SCHOLAR	Mehmet Reşat ADIGÜZEL Dr. Bünyamin ARVASİ	Iğdır University TÜRKİYE
THE SACRED SOUND: MUSIC AS AN INSTRUMENT OF PROCLAMATION IN MYSTERY PLAYS	Ömür MUNZUR	Başkent University TÜRKİYE
STUDENT PSYCHOLOGY IN SINGING EDUCATION: THE EFFECT OF CRITICAL FEEDBACK PERCEPTION ON PERFORMANCE CONFIDENCE AND ARTISTIC AUTONOMY	Ömür MUNZUR	Başkent University TÜRKİYE
GASTRONOMY FROM THE PERSPECTIVE OF MUSIC EDUCATION: A REVIEW ON CREATIVITY, SENSORY PERCEPTION, AND CULTURAL TRANSMISSION	Abdullah Semih BİREL	Zonguldak Bülent Ecevit University TÜRKİYE
DEVELOPMENT OF TIMELESS DESIGNS THROUGH MINIMALIST AESTHETICS IN FASHION ILLUSTRATION	Assoc. Prof. Dr. Ahu Fatma MANGIR Rabia ASLAN	Selçuk University TÜRKİYE
THE ROLE OF LEGAL PROFESSIONALS IN TRANSITIONAL JUSTICE	Assist. Prof. Dr. Dilan MIZRAK	Atılım University TÜRKİYE

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03.08.2026 / Session-3, Hall-4
Ankara Local Time: 15:00 – 17:00
Meeting ID: 862 6236 6905 / Passcode: 010203
Moderator: Prof. Dr. Elman Quliyev

Title	Author(s)	Affiliation
HIGH-RESOLUTION SPECTROSCOPIC STUDY OF C IV ABSORPTION TOWARD Q1422+23	Satyajit Pal	Burdwan University INDIA
THE EVOLUTION OF THE CIRCUMGALACTIC MEDIUM ACROSS COSMIC TIME	Subhajit Pal	Jadavpur University INDIA
MASS EVOLUTION OF A SCHWARZSCHILD BLACK HOLE UNDER DARK ENERGY ACCRETION IN THE BISWAS-ROY-BISWAS EOS PARAMETERIZATION CONSTRAINED BY DIFFERENTIAL AGE DATA	Sukanya Dutta	Burdwan University INDIA
THE POETRY OF NAZIM HIKMAT	Prof. Dr. Elman Quliyev	Azerbaijan State Pedagogical University AZERBAIJAN

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THE ROLE OF THE ALBANIAN COLONY IN ISTANBUL IN RELATIONS BETWEEN ALBANIA AND THE ANKARA GOVERNMENT (1920–1924)

İSTANBUL'DAKİ ARNAVUT KOLONİSİNİN ARNAVUTLUK İLE ANKARA HÜKÜMETİ ARASINDAKİ İLİŞKİLERDEKİ ROLÜ (1920–1924)

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Özet

Birinci Dünya Savaşı'nın ardından Tiran'da millî kurumların güçlendirilmesiyle birlikte, İstanbul'da yaşayan Arnavutlar, Arnavut devletinin çıkarlarının korunması ve desteklenmesinde önemli bir rol oynamaya devam ettiler. Bu çalışma, İstanbul'daki Arnavut kolonisinin 1920–1924 yılları arasındaki faaliyetlerini, Arnavutluk hükümeti ile Ankara'daki millî hükümet arasında siyasi ve bilgi aktarımına dayalı bir aracı olarak üstlendiği işlev çerçevesinde incelemektedir. Koloni; millî cemiyetler, önde gelen şahsiyetler, Arnavutluk konsolosluk temsilciliğiyle kurulan bağlantılar ve Arnavutça yayımlanan basın organları aracılığıyla Türkiye'deki siyasi gelişmelere ilişkin bilgilerin aktarılmasına ve iki ülke arasında yakınlaşmaya elverişli bir ortamın oluşturulmasına katkı sağladı. Çalışmada özellikle İstanbul Arnavutluk Konsolosluğu ile Dışişleri Bakanlığı arasındaki yazışmalara, Mustafa Kemal hükümetinin Arnavut basınındaki yansımalarına ve 1923 yılında Arnavut heyetinin Türkiye ziyareti sırasında "*Paqja" (Barış)* ve "*E Drejta* "(Hak) gazetelerinin oynadığı role odaklanılmaktadır. Tarihsel yöntem ile arşiv, diplomatik belge ve basın kaynaklarının analizine dayanan çalışma, Arnavut kolonisinin resmî diplomasinin yerini almadığını; ancak gayriresmî temaslardan kurumsallaşmış ilişkilere geçişi kolaylaştıran iletişim, aracılık ve kamuoyu desteği kanalları oluşturduğunu ileri sürmektedir. Bu süreç, 15 Aralık 1923 tarihinde Türk-Arnavut Dostluk Antlaşması'nın imzalanmasıyla sonuçlandı. Bu bağlamda kolonin faaliyetleri, Arnavut diasporasının Osmanlı döneminden miras kalan millî bir örgütlenmeden, Arnavut devletinin dış politikasını ve diplomasisini destekleyen bir ağa dönüşümünü ortaya koymaktadır.

Anahtar kelimeler: İstanbul Arnavut kolonisi, Arnavutluk, Ankara Hükümeti, diaspora, diplomasi, Arnavut basını, Türk-Arnavut ilişkileri

ABSTRACT

Following the First World War and the consolidation of national institutions in Tirana, Albanians residing in Istanbul continued to play an important role in safeguarding and promoting the interests of the Albanian state. This study examines the activities of the Albanian colony in Istanbul between 1920 and 1924, focusing on its function as a political and informational intermediary between the Albanian government and the national government in Ankara. Through patriotic associations, prominent individuals, connections with the Albanian consular representation, and Albanian-language press organs, the colony contributed to the transmission of information concerning political developments in Turkey and to the creation of a favorable climate for closer relations between the two countries. Particular attention is devoted to the correspondence between the Albanian Consulate in Istanbul and the Ministry of Foreign Affairs, the representation of Mustafa Kemal's government in the Albanian press, and the role played by the newspapers "*Paqja"* (Peace) and "*E Drejta* "(The Right) during the visit of the Albanian delegation to Turkey in 1923. Drawing on the historical method and the analysis of archival, diplomatic, and press sources, the study argues that the Albanian colony did not replace official diplomacy. Rather, it established channels of communication, mediation, and public support that

facilitated the transition from informal contacts to institutionalized relations. This process culminated in the signing of the Albanian-Turkish Treaty of Friendship on 15 December 1923. In this respect, the activities of the colony illustrate the transformation of the Albanian diaspora from a national organization inherited from the Ottoman period into a network supporting the foreign policy and diplomacy of the Albanian state.

Keywords: Albanian colony in Istanbul, Albania, Ankara Government, diaspora, diplomacy, Albanian press, Albanian-Turkish relations.

GIRIŞ

Birinci Dünya Savaşı'nın sona ermesi ve Osmanlı İmparatorluğu'nun tedricen dağılması, Balkanlar ile Yakın Doğu'da yeni bir siyasî gerçeklik meydana getirdi. Savaştan kurumsal yapısı henüz yeterince sağlamlaşmamış ve uluslararası konumu belirsiz bir ülke olarak çıkan Arnavutluk, devlet otoritesini yeniden tesis etmeye ve bölge ülkeleriyle yeni ilişkiler kurmaya çalıştı. Aynı dönemde Anadolu'da Mustafa Kemal'in önderliğindeki Türk Millî Mücadelesi, işgal altındaki toprakların kurtarılmasını ve yeni bir Türk millî devletinin kurulmasını hedefliyordu. Dolayısıyla 1920'lerin başı, hem Arnavutluk hem de Türkiye bakımından köklü siyasî dönüşümlerin yaşandığı bir dönemdi.[1]

Bu süreçte İstanbul'daki Arnavut kolonisi özel bir rol üstlendi. Tüccarlar, aydınlar, eski Osmanlı memurları, siyasî failler ve uzun yıllardır Osmanlı başkentinde yaşayan Arnavut ailelerden oluşan koloni, millî örgütlenme konusunda önemli bir birikime sahipti. Bağımsızlığın ilanından önce İstanbul Arnavutları, Arnavut siyasî ve kültürel düşüncesinin gelişmesine, Arnavutça kitap ve süreli yayınların neşrine ve millî çıkarların Osmanlı makamları nezdinde savunulmasına katkıda bulunmuşlardı. 1912'den sonra da faaliyetlerini sürdürerek yeni siyasî şartlara ve Arnavut devletiyle bağların korunması ihtiyacına uyum sağladılar.[2]

Bu çalışma, İstanbul'daki Arnavut kolonisinin 1920–1924 yıllarında Arnavutluk ile Ankara Hükümeti arasındaki temasların gelişiminde oynadığı rolü incelemektedir. 1920 yılı, Loşna Kongresi sonrasında Arnavut kurumlarının güçlenmesi ve Türk Millî Mücadelesi'nin konsolidasyonu ile örtüştüğü için başlangıç noktası olarak seçilmiştir. 1924 ise 1923 antlaşmalarının imzalanmasının ardından diplomatik ilişkilerin kurumsallaştırılmasına yönelik ilk girişimlerle birlikte yakınlaşmanın ilk safhasının tamamlandığı yılı ifade etmektedir.

Çalışmanın temel tezi, İstanbul'daki Arnavut kolonisinin esas itibarıyla bilgilendirici, arabulucu ve destekleyici bir işlev gördüğüdür. Koloni, Arnavutluk veya Türkiye'nin dış politikasını belirlememiş ve 1923 antlaşmalarında karar verici olmamıştır. Bununla birlikte Türkiye'deki siyasî gerçekliğe ilişkin bilgisi, Arnavut makamlarıyla bağları ve Türk çevreleriyle temasları sayesinde iletişimin sürdürülmesine ve resmî yakınlaşmanın zemininin hazırlanmasına katkı sağlamıştır. Bu bakımdan kolonin faaliyetleri bir gayriresmî diplomasi biçimi olarak değerlendirilebilir.

Çalışma, Arnavutluk Devlet Merkez Arşivi ile Dışişleri Bakanlığı Arşivi'nde bulunan; Türkiye'deki Arnavut cemiyetleri, İstanbul'daki Arnavutluk konsolosluk temsilciliği ve Türk-Arnavut ilişkileriyle ilgili belgelere dayanmaktadır. Arnavut konsolosluk görevlilerinin raporları ve Dışişleri Bakanlığı ile yazışmaları özel önem taşımaktadır. Arşiv belgelerinin yanı sıra dönemin Arnavut ve Türk basını ile iki ülke ilişkilerine dair literatürden yararlanılmıştır. Halil Özcan, Selma Yel ve Hasan Bello'nun çalışmaları genel siyasî ve diplomatik çerçeveyi sunarken, arşiv malzemesi ve basın kaynakları İstanbul Arnavut kolonisinin somut rolünü ortaya koymak amacıyla kullanılmıştır.[3]

[1] Historia e Popullit Shqiptar, c. III: Periudha e Pavarësisë, 28 nëntor 1912–7 prill 1939 (Tiranë: Toena, 2007), s. 171, 205; Hikmet Öksüz, "Atatürk Dönemi Türk-Arnavut İlişkileri," Güney-Doğu Avrupa Araştırmaları Dergisi, sy. 12 (1998), s. 211.

[2] İlirjana Kaceli-Demirlika, "Türkiye'deki Arnavutluk Kolonisi ve Osmanlı İmparatorluğu ile İlişkileri," Kebikeç: İnsan Bilimleri İçin Kaynak Araştırmaları Dergisi, sy. 50 (2020), s. 435–439.

[3] AQSH, F. 101, D. 6, 1918–1924, fl. 40; AQSH, F. 151, D. 98, 1922, fl. 1–4; AMPJ, F. 151, 1924, D. 83, fl. 87, 195; D. 85, fl. 279; D. 301, fl. 48–49.

1920 Sonrasında İstanbul Arnavut Kolonisi

İstanbul Arnavut kolonisinin Arnavutluk ile Ankara Hükümeti arasındaki ilişkilerdeki rolünü değerlendirebilmek için öncelikle 1920'lerin başındaki siyasî ve toplumsal konumunu ele almak gerekir. İstanbul'daki Arnavut topluluğu uzun bir örgütlenme ve millî faaliyet geçmişine sahipti. XIX. yüzyılın ikinci yarısından itibaren şehir, Arnavut kültür ve siyaset hareketinin başlıca merkezlerinden biri olmuş; burada aydınlar, memurlar, tüccarlar ve tanınmış Arnavut ailelerinin temsilcileri faaliyet göstermiştir. Kültür cemiyetleri, yayınlar ve Osmanlı siyasî çevreleriyle temaslar aracılığıyla İstanbul Arnavutları, Arnavutçanın yaygınlaşmasına ve millî taleplerin şekillenmesine katkıda bulunmuşlardır.[4]

Birinci Dünya Savaşı sonrasında koloni yeni ve karmaşık bir durumla karşı karşıya kaldı. İstanbul İtilaf Devletlerinin işgal ve denetimi altındayken, saltanat hükümetinin otoritesi sürekli zayıflıyordu. Buna karşılık Mustafa Kemal'in liderliğindeki Türk Millî Mücadelesi Ankara'da giderek güçlenmekteydi. Bu ikili yapı, İstanbul Arnavutlarını iki siyasî merkez arasındaki ilişkiyi dikkatle izlemeye ve Türkiye'nin geleceğini hangi otoritenin belirleyeceğini değerlendirmeye yöneltti.[5]

Dönemin belge ve yazışmaları, koloninin faaliyetlerinin kültürel meseleler ve yurttaşlara yardımla sınırlı kalmadığını göstermektedir. Koloni temsilcileri Arnavutluk'taki siyasî gelişmeler, Türk makamlarının Arnavutlara yaklaşımı ve iki ülke arasında yeni ilişkiler kurulması ihtimaliyle de yakından ilgileniyordu. Böylece koloni, kimliğini ve anavatanla bağlarını korumanın yanı sıra, Arnavutluk ile Türk makamları arasında siyasî iletişimi sağlayan bir alan hâline geldi.

Arnavutluk ve Türk Millî Mücadelesi, 1920–1922

1920 başında Arnavutluk ile Türkiye farklı, ancak bazı yönlerden karşılaştırılabilir güçlüklerle karşı karşıyaydı. Loşna Kongresi kararlarının ardından Arnavutluk merkezî kurumlarını yeniden inşa etmeye, toprak bütünlüğünü korumaya ve uluslararası konumunu güçlendirmeye çalışıyordu. Anadolu'da ise Türk Millî Mücadelesi, yabancı işgallerine ve Osmanlı topraklarını parçalama planlarına karşı direnişi örgütlemekteydi. 23 Nisan 1920'de Türkiye Büyük Millet Meclisinin açılması, İstanbul'daki Osmanlı hükümetine karşı çıkan ve Türk milletinin iradesini temsil ettiğini ileri süren yeni bir siyasî merkez oluşturdu.[6]

Erken dönem Türk-Arnavut temaslarının en önemli göstergelerinden biri Selahattin Saip Bey'in faaliyetidir. Onun Arnavutluk'taki görevi sıradan bir diplomatik misyon niteliğinde değildi. Selma Yel ve Halil Özcan'a göre Arnavutluk Başbakanı İlyas Vrioni, emekli Albay Selahattin Saip Bey'e kurulmakta olan kabinede Harbiye Nazırlığı görevini teklif etti. Selahattin Saip Bey teklifi kabul etmeden önce Ankara'ya başvurarak Mustafa Kemal'in görüş ve onayını istedi. Mustafa Kemal, 9 Aralık 1920 tarihli cevabında Büyük Millet Meclisi Hükümetinin bu görevlendirmeden duyduğu memnuniyeti bildirdi.[7]

9 Aralık 1920 tarihli belge, bir subayın şahsî görevinin onaylanmasının ötesinde bir anlam taşımaktadır. Selahattin Saip Bey'e verilen talimatlarda Arnavutların iç birliğinin korunması, Arnavutluk ile Ankara Hükümeti arasındaki bağların güçlendirilmesi ve taraflar arasında kesintisiz temas kurulması gereği vurgulanmıştır. Ayrıca Arnavutluk'un Ankara'ya bir temsilci göndermesi tavsiye edilmiştir. Bu

[4] İlirjana Kaceli-Demirlika, "Türkiye'deki Arnavutluk Kolonisi ve Osmanlı İmparatorluğu ile İlişkileri," Kebikeç, sy. 50 (2020), s. 435–439.

[5] Hikmet Öksüz, "Atatürk Dönemi Türk-Arnavut İlişkileri," s. 211; Selma Yel, "Atatürk ve İnkılaplarının Arnavutluk'taki Tesirleri," Atatürk Araştırma Merkezi Dergisi, c. XIX, sy. 55 (Mart 2003), s. 108; AQSH, F. 151, D. 98, 1922, fl. 1–4.

[6] Historia e Popullit Shqiptar, c. III, s. 171, 205; Hikmet Öksüz, "Atatürk Dönemi Türk-Arnavut İlişkileri," s. 211; Atatürk'ün Millî Dış Politikası: Millî Mücadele Dönemine Ait 100 Belge, 1919–1923, c. I (Ankara: Kültür Bakanlığı Yayınları, 1994), s. 209–210.

[7] Selma Yel ve Halil Özcan, "Mustafa Kemal'in Selahattin Saip Bey'i Arnavutluk'ta Görevlendirmesinin Sebep ve Sonuçları (1920–1923)," Atatürk Araştırma Merkezi Dergisi, c. XXIV, sy. 70 (2008), s. 62–63; Vakit, "Müstakil Arnavutluk," 27 Nisan 1921, sy. 1216, s. 2.

hususlar, resmî diplomatik ilişkiler henüz kurulmamış olsa da Türk Millî Mücadelesi önderlerinin Arnavutluk hükümetiyle doğrudan bir iletişim kanalı açmak istediğini göstermektedir.[8]

Ankara'nın Arnavutluk'a ilgisi, Mustafa Kemal'in Türkiye Büyük Millet Meclisinin üçüncü çalışma yılını açarken 1 Mart 1922'de yaptığı konuşmada da açıkça ifade edildi. Mustafa Kemal, Arnavutluk'tan söz ederken iki halkın yüzyıllara dayanan ortak yaşantısına ve aralarında oluşan bağlara değindi; Arnavut halkı ile hükümetinin karşılaştıkları siyasî güçlükleri aşacağına inandığını belirtti.

İlirjana Kaceli, 1920–1922 yıllarındaki olumlu beyan ve temaslara rağmen Arnavut hükümetlerinin diplomatik ilişkilerin kurulması yönünde hemen belirleyici adımlar atmadığını vurgulamaktadır. Bunun başlıca sebepleri iç siyasî istikrarsızlık, sık hükümet değişiklikleri ve yabancı güçlerin Arnavutluk siyaseti üzerindeki etkisiydi. Bununla birlikte Ankara'nın konumunun güçlenmesi, Türk Millî Mücadelesi'nin askerî başarıları ve Türkiye'deki Arnavut topluluğunun baskısı, ilişkilerin kurumsallaştırılmasını giderek daha gerekli hâle getirdi.[9]

Bu çerçevede 1920–1922 temasları, resmî Türk-Arnavut yakınlaşmasının hazırlık safhasını oluşturdu. Diplomatik ilişkilerin kurulması 1923'te aniden ortaya çıkan bir gelişme değil; devlet çıkarlarının, siyasî ve askerî misyonların, kamuoyuna yönelik açıklamaların ve Türkiye'deki Arnavut kolonisinin teşvik edici faaliyetlerinin iç içe geçtiği tedricî bir sürecin sonucuydu. İstanbul bu süreçte Tiran ile Ankara arasında bir iletişim noktası olmayı sürdürdü ve koloni giderek daha görünür bir bilgilendirme ve aracılık işlevi üstlendi.

Tiran, İstanbul ve Ankara Arasında Aracı Olarak Koloni

İstanbul Arnavut kolonisi, 1920'lerden önce de Türkiye'nin çeşitli şehirlerindeki Arnavutlarla, Arnavut devlet kurumlarıyla ve İstanbul'daki yabancı temsilciliklerle bağlarını sürdürebilecek bir örgütlenme kurmuştu. Merkez Komitesi şubelerin faaliyetlerini eş güdümlüyor, Arnavutluk'la ilgili siyasî gelişmeleri izliyor ve Arnavutların taleplerini ilgili makamlara iletiyordu. Paris Barış Konferansı sırasında temsilciler göndermesi ve diğer Arnavut heyetleriyle iş birliği yapması, koloniye karar merkezleriyle temas kurabilecek bir siyasî tecrübe kazandırmıştı.[10]

18 Mayıs 1921'de Nezir Leskoviku, İstanbul Arnavut Kolonisi Komitesi adına Arnavutluk hükümetinden Osmanlı başkentinde bir diplomatik temsilcilik açılmasını talep etti. Temsilcilik görevine Halil Paşa Gjirokastra'nın getirilmesini ve uygun görülmesi hâlinde kendisine gerekli güven mektuplarının verilmesini önerdi. Aksi takdirde Tiran'ın Arnavut devletinin ve Türkiye Arnavutlarının çıkarlarını temsil edecek başka bir kişiyi göndermesini istedi. Bu girişim, koloninin yalnızca hükümet müdahalesini beklemediğini, devlet temsil mekanizmalarının oluşturulması için bizzat harekete geçtiğini göstermektedir.[11]

Arnavutluk hükümeti daha sonra temsilciliğin statüsünü yükseltmek için adımlar attı. 5 Ağustos 1921'de pasaport bürosunun, Nezir Leskoviku'nun başkanlığında ve Asaf Xhaxhuli'nin kâtipliğinde bir konsolosluğa dönüştürülmesine karar verildi. Dışişleri Bakanlığı, konsolosluk işlevinin tanınması için İngiliz, İtalyan ve Fransız temsilciliklerinden de yardım istedi. Nezir Leskoviku 20 Eylül'de Tiran'a gönderdiği yazıda bu girişimlerin sonuç verdiğini ve Arnavut temsilciliğinin statüsünün söz konusu devletlerin İstanbul temsilcileri tarafından kabul edildiğini bildirdi.[12]

Türkiye'de iki siyasî merkezin varlığı Arnavut temsilciliğinin çalışmalarını güçleştiriyordu. Saltanat hükümeti İstanbul'da faaliyetini sürdürürken, Türk Millî Mücadelesi Ankara'da otoritesi giderek artan

[8] Atatürk'ün Millî Dış Politikası, c. I, s. 209–210; Selma Yel ve Halil Özcan, "Mustafa Kemal'in Selahattin Saip Bey'i Arnavutluk'ta Görevlendirmesinin Sebep ve Sonuçları," s. 63–64.
[9] Türkiye Büyük Millet Meclisi Zabıt Ceridesi, Devre I, c. 18, 1 Mart 1922 tarihli oturum, s. 12.
[10] İlirjana Kaceli, "Kolonia Shqiptare e Turqisë dhe marrëdhëniet me Perandorinë Osmane," Studime Sociale, c. 15, sy. 3 (2021), s. 107–112; İlirjana Kaceli-Demirlika, "Türkiye'deki Arnavutluk Kolonisi ve Osmanlı İmparatorluğu ile İlişkileri," Kebikeç, sy. 50 (2020), s. 435–439.
[11] AQSH, F. 101, D. 6, 1918–1924, fl. 40, İstanbul Arnavut Kolonisi Komitesinin Arnavutluk hükümetine gönderdiği 18 Mayıs 1921 tarihli telgraf; İlirjana Kaceli, "Kolonia Shqiptare e Turqisë," s. 112–113.
[12] AMPJ, 1921, D. 4, fl. 118, 139, 170; İlirjana Kaceli, "Kolonia Shqiptare e Turqisë," s. 114.

yeni bir iktidar kurmuştu. 1922 sonuna kadar Arnavutluk siyaseti Mustafa Kemal Hükümetini resmen tanımamış ve Arnavut temsilciliği İstanbul hükümetinin kurumlarıyla muhatap olmayı sürdürmüştü.[13]

18 Kasım 1922 tarihli rapor, ilişkilerin gelecekteki yönelimini daha açık biçimde ortaya koydu. Nezir Leskoviku, İstanbul'daki yeni makamlarla yaptığı gayriresmî görüşmelerde Ankara Hükümetinin önceki Osmanlı idaresince verilen izin ve anlaşmaları kendiliğinden tanımayacağını öğrendi. Arnavut temsilciliği meselesinin Ankara'ya iletilmesi ve konsolosluk ilişkilerinin yeni esaslara göre düzenlenmesi gerekiyordu. Bununla birlikte Türk temsilciler, Arnavutluk'la anlaşmanın ciddi bir gecikme olmaksızın sağlanabileceğine inandıklarını ifade ettiler.[14]

Koloninin rolü dört başlık altında değerlendirilebilir. Birincisi, Türkiye Arnavutlarının taleplerini toplayıp ilgili makamlara iletmesi nedeniyle temsil işlevidir. İkincisi, Komite ve konsolosluk aracılığıyla İstanbul ve Ankara'daki siyasî gelişmeleri Tiran'a aktarması sebebiyle bilgilendirme işlevidir. Üçüncüsü, Arnavut ve Türk makamları arasında temas kurulmasını kolaylaştıran aracılık işlevidir. Son olarak koloni, Türkiye'de yaşayan Arnavutların hukukî, iktisadî ve toplumsal çıkarlarını koruyucu bir işlev üstlenmiştir.

Bununla birlikte koloninin faaliyetleri devlet diplomasisiyle özdeşleştirilmemelidir. Ankara Hükümetinin tanınması, heyet gönderilmesi ve antlaşmaların imzalanması konularındaki kararlar Arnavutluk hükümeti tarafından alınmıştır. Koloninin antlaşma müzakere etme veya imzalama yetkisi yoktu. Önemi; sorunları tespit etmesi, Tiran'ı harekete geçmeye teşvik etmesi, temaslar kurması ve karar alma süreci için gerekli bilgiyi sağlamasından kaynaklanıyordu.

Bu bakımdan koloninin faaliyeti, devlet kurumlarının çalışmalarını tamamlayan bir gayriresmî diplomasi biçimi olarak yorumlanabilir. Koloni, resmî Türk-Arnavut ilişkilerinin henüz kurulmadığı ve Türkiye'deki rejim değişikliğinin Arnavut temsilciliğinin statüsünü belirsizleştirdiği dönemde iletişimin devamını sağladı. Nezir Leskoviku'nun daha sonra Ankara'daki görüşmelere gönderilen Arnavut heyetine dâhil edilmesi; koloni faaliyetleri, İstanbul'daki konsolosluk temsili ve diplomatik ilişkilerin kurulması süreci arasındaki sürekliliği göstermektedir.[15]

İstanbul Arnavut Basını ve Ankara ile Yakınlaşma

İstanbul'da yayımlanan Arnavut basını, koloninin Arnavutluk ve Türkiye'deki siyasî gelişmeler hakkında bilgilendirilmesinin başlıca araçlarından biriydi. Diplomatik ilişkilerin henüz kurumsallaşmadığı şartlarda gazeteler yalnızca haber aktarmıyor; Türkiye Arnavutlarının kanaatlerinin oluşumunu etkiliyor, taleplerini dile getiriyor ve Tiran ile Ankara arasında düzenli bağların kurulmasını destekliyordu. Bu yönüyle basın, Koloni Komitesinin ve İstanbul'daki Arnavut konsolosluk temsilciliğinin faaliyetlerini tamamlıyordu.[16]

Dönemin başlıca yayın organları, İstanbul'da Arnavutça yayımlanan Paqja ve E Drejta gazeteleriydi. Türkçe literatürde Paqja adı çoğu kez Barış veya Sulh şeklinde çevrilmiştir. Her iki gazete de Türkiye'ye gönderilen Arnavut heyetinin faaliyetlerine ve iki ülke arasındaki ilişkilerin kurulmasına yönelik müzakerelere özel önem verdi. Böylece başlangıçta hükümet düzeyinde yürütülen bir süreç, koloni içinde kamuoyu tartışmasının da konusu hâline geldi.[17]

[13] İlirjana Kaceli-Demirlika, "Vendosja e marrëdhënieve shqiptaro-turke gjatë viteve '20 të shekullit të kaluar," Studime Historike, sy. 3–4 (2013), s. 156–158; İlirjana Kaceli, "Kolonia Shqiptare e Turqisë," s. 114.

[14] AQSH, F. 151, D. 98, 1922, fl. 1–3, Nezir Leskoviku'nun Arnavutluk Dışişleri Bakanlığına gönderdiği 18 Kasım 1922 tarihli rapor; İlirjana Kaceli-Demirlika, "Türkiye'deki Arnavutluk Kolonisi," s. 443.

[15] İlirjana Kaceli-Demirlika, "Economic, Social and Cultural Relations Between the Republic of Turkey and Albania," Turkish Foreign Policy During Atatürk's Era, 1920–1938 içinde, ed. Cezmi Eraslan (İstanbul: İstanbul University Press, 2021), s. 99–100; İlirjana Kaceli-Demirlika, "Vendosja e marrëdhënieve shqiptaro-turke," s. 160–164.

[16] Paqja, İstanbul, sy. 3, 26 Kasım 1923; E Drejta, İstanbul, sy. 17, 3 Ocak 1924; Gazmend Shpuza, "Atatürk ve Arnavutluk–Türkiye İlişkileri," Atatürk Yolu Dergisi, c. 2, sy. 6 (1990), s. 337–338.

[17] Gazmend Shpuza, "Atatürk ve Arnavutluk–Türkiye İlişkileri," s. 337–338; Paqja, İstanbul, sy. 3, 26 Kasım 1923; E Drejta, İstanbul, sy. 17, 3 Ocak 1924.

Paqja gazetesinin Arnavut heyetiyle İstanbul'da yaptığı mülakat, basının bu işlevini doğrudan göstermektedir. Gazete; Arnavutluk Parlamentosu Başkanı Eşref Frashëri, Xhafer Vila ve Arnavut pasaport bürosu yöneticisi Nezir Leskoviku'nun bir muhabiriyle görüştüğünü ve misyonun amacı hakkındaki soruları cevapladığını duyurdu. Bu iletişim sayesinde koloni üyeleri heyetin bileşimi, Ankara yolculuğu ve Türk hükümetiyle ele alınacak meseleler hakkında doğrudan bilgi edindiler.[18]

Koloni gazeteleri, görüşülen antlaşmaların içeriğini de takip etti. İlgi yalnızca diplomatik ilişkilerin resmen kurulmasına değil, ikamet ve tabiiyet sözleşmelerine de yönelmişti. Bu meseleler Türkiye'de yaşayan Arnavutların hukukî statüsü, mülkleri, ikamet hakkı ve Arnavut vatandaşlığını seçme veya koruma imkânıyla doğrudan bağlantılıydı. Dolayısıyla koloni basını iki hükümetin propagandasını aktaran bir araçtan ibaret olmayıp, Türkiye Arnavutlarının somut kaygılarını dile getiren bir mecra işlevi gördü.[19]

Antlaşmaların 15 Aralık 1923'te imzalanmasının ardından İstanbul Arnavut basınının yaklaşımı genel olarak olumluydu. Paqja, 17 Aralık tarihli sayısında dostluk antlaşmalarının Arnavutluk ile Türkiye arasında kalıcı bir güven ortamı oluşturacağını ve her iki tarafa önemli yararlar sağlayacağını belirtti. Bu değerlendirme, antlaşmaların yalnızca iki hükümet arasındaki hukukî işlemler olarak değil, iki halk arasındaki ilişkilerde yeni bir dönemin başlangıcı olarak algılandığını göstermektedir.[20]

İstanbul Arnavut basını bu süreçte üç temel işlev yerine getirdi. İlk olarak koloniye Arnavut heyetinin yolculuğu ve faaliyetleri hakkında bilgi verdi. İkinci olarak, özellikle vatandaşlık, mülkiyet ve konsolosluk himayesi konularında Türkiye Arnavutlarının kaygılarına yer açtı. Üçüncü olarak Ankara Hükümetiyle ilişkilerin kurulmasını destekleyen bir kamuoyunun oluşmasına katkıda bulundu. Bu anlamda Paqja ve E Drejta, resmî diplomatik yetkileri bulunmamakla birlikte siyasî iletişim ve kamu diplomasisi araçları olarak işlev gördüler.[21]

Ancak basının rolü abartılmamalıdır. Gazeteler antlaşmaların içeriğini belirlememiş ve hükümetler arası müzakerelerin yerini almamıştır. Katkıları, süreci açıklamak, onu Arnavut topluluğunun çıkarlarıyla ilişkilendirmek ve Ankara'nın Türk-Arnavut ilişkilerinin yeni merkezi olarak kabulüne kamuoyunu hazırlamakla sınırlıydı. Böylece basın, koloninin aracılık rolünü tamamlamış ve gayriresmî temaslardan kurumsallaşmış devletler arası ilişkilere geçişe eşlik etmiştir.

Gayriresmî Temaslardan 1923 Dostluk Antlaşması'na

1920–1922 yıllarında Arnavutluk ile Ankara Hükümeti arasında kurulan temaslar resmî ilişkilere geçişin zeminini hazırladı. 1922 sonuna gelindiğinde Türk Millî Mücadelesi'nin askerî ve siyasî bakımdan güçlenmesi, saltanatın kaldırılması ve İstanbul'daki Osmanlı hükümetinin sona ermesi, gelecekteki Türk-Arnavut ilişkilerinin doğrudan Ankara ile kurulması gerektiğini açıkça göstermişti. Aynı dönemde Ahmet Zogu'nun hükümetin başına geçmesiyle Arnavutluk'ta sağlanan görece istikrar, diplomatik bir girişim için daha elverişli şartlar oluşturdu.

Ankara Hükümetinin resmî daveti üzerine Arnavutluk hükümeti, görüşme ve ilgili antlaşmaları imzalama yetkisiyle donatılmış bir heyet göndermeye karar verdi. Heyete Arnavutluk Parlamentosu Başkanı Eşref Frashëri başkanlık ediyor; Dışişleri Bakanlığı Genel Sekreteri Xhafer Vila ile İstanbul'daki eski Arnavut konsolosluk temsilcisi Nezir Leskoviku da heyette yer alıyordu.

[18] Paqja, İstanbul, sy. 3, 26 Kasım 1923; AQSH, F. 251, 1923, D. 200, fl. 56–58.
[19] Paqja, İstanbul, sy. 3, 26 Kasım 1923; E Drejta, İstanbul, sy. 17, 3 Ocak 1924; TBMM, Kanun No. 602–604, 6 Nisan 1925.
[20] Paqja, İstanbul, 17 Aralık 1923; Halil Özcan, Atatürk Dönemi Türkiye–Arnavutluk İlişkileri, 1920–1938 (Ankara: Atatürk Araştırma Merkezi, 2011), s. 136.
[21] Paqja, İstanbul, sy. 3, 26 Kasım 1923; E Drejta, İstanbul, sy. 17, 3 Ocak 1924; "Traktati Turko-Shqiptar," Shqiptari i Amerikës, sy. 70, 12 Ocak 1924; Gazmend Shpuza, "Atatürk ve Arnavutluk–Türkiye İlişkileri," s. 337–338.

Leskoviku'nun katılımı, İstanbul'daki konsolosluk ve koloni faaliyetleriyle Ankara'daki resmî müzakereler arasında doğrudan bir süreklilik sağladı.[22]

Görüşmeler Arnavut heyeti ile Türk hükümeti temsilcisi ve Muğla Mebusu Şükrü Kaya arasında yürütüldü. Müzakereler yalnızca iki devlet arasındaki dostluğun ilanıyla sınırlı değildi. Diplomatik ilişkilerin kurulması, her iki devlet vatandaşlarının diğer tarafın ülkesinde ikamet ve faaliyet şartlarının belirlenmesi ve Türkiye'de yaşayan Arnavutların tabiiyet statüsünün düzenlenmesi olmak üzere üç temel konu ele alındı.[23]

Uzun süren görüşmelerin ardından Türkiye Cumhuriyeti ile Arnavutluk arasında Dostluk Antlaşması 15 Aralık 1923'te Ankara'da imzalandı. Bunun yanında İkamet Mukavelenamesi ve Tabiiyet İtilâfnamesi de imza altına alındı. Arnavut tarih yazımında bu üç belge çoğu kez genel olarak "Dostluk Antlaşması" adı verilen aynı antlaşmalar paketinin parçaları olarak değerlendirilir. Belgeler Türkiye adına Şükrü Kaya; Arnavutluk adına Eşref Frashëri, Xhafer Vila ve Nezir Leskoviku tarafından imzalandı.[24]

Dostluk Antlaşması'nın giriş kısmında Arnavutlar ile Türkler arasında beş asırlık siyasî birliktelik sırasında oluşan bağlara ve iki halkın dostluğu koruyarak refahlarına hizmet edecek ilişkiler kurma arzusuna atıfta bulunuluyordu. Birinci madde, Türkiye Cumhuriyeti ile Arnavutluk devleti ve vatandaşları arasında bozulmaz bir barış ile samimi ve ebedî bir dostluğun bulunacağını hükme bağlıyordu. İkinci madde ise diplomatik ilişkilerin uluslararası hukuk esaslarına göre kurulmasını ve diplomatik ve konsolosluk temsilcilerinin ayrıcalık ve bağışıklıklarının karşılıklı olarak tanınmasını öngörüyordu.[25]

Türkiye'deki Arnavut kolonisi bakımından Tabiiyet İtilâfnamesi özel önem taşıyordu. Sözleşme yürürlüğe girdiğinde Türkiye'de ikamet eden ve Arnavutluk devletinin topraklarından gelen kişilerin Türk vatandaşı sayılmaya devam edeceğini belirtiyordu. On sekiz yaşından büyük kişilere bir yıl içinde Arnavut vatandaşlığını seçme hakkı tanınıyor, ancak bu hakkın kullanılması Türkiye'den ayrılma yükümlülüğünü beraberinde getiriyordu. Sözleşmede ayrıca iki taraftan birinin vatandaşlığını taşıyan kişilerin mallarının korunmasına ilişkin hükümler bulunuyordu.[26]

Arnavut kolonisinin bu süreçteki rolü dengeli biçimde değerlendirilmelidir. Koloni Komitesi ile İstanbul Arnavut basınının uluslararası antlaşmaları müzakere veya imza yetkisi yoktu. Heyetin gönderilmesi ve antlaşmaların içeriğinin belirlenmesi Arnavutluk hükümetinin yetkisindeydi. Bununla birlikte Türkiye Arnavutlarının talepleri, İstanbul'dan aktarılan bilgiler ve Nezir Leskoviku'nun konsolosluk faaliyetleri, müzakerelere dâhil edilen bazı meselelerin şekillenmesine katkı sağladı.

15 Aralık 1923 tarihli Dostluk Antlaşması, gayriresmî temaslar safhasının sona ermesini ve Türk-Arnavut devlet ilişkilerinin hukukî başlangıcını ifade ediyordu. Ancak imza, antlaşmaların derhal uygulanmasını sağlamadı. Tasdik süreci 1925'te tamamlandı: Arnavutluk Parlamentosu antlaşmaları şubatta, Türkiye Büyük Millet Meclisi ise 6 Nisan 1925'te onayladı. Tasdiknamelerin teatisinden sonra Antlaşma 15 Haziran 1925'te yürürlüğe girdi. Bu gecikme, siyasî mutabakattan diplomatik ilişkilerin tam işleyişine geçişin belgelerin imzalanmasından daha uzun bir süreç olduğunu göstermektedir.[27]

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[22] İlirjana Kaceli-Demirlika, "Vendosja e marrëdhënieve shqiptaro-turke," s. 162–164; Arnavutluk Avrupa ve Dışişleri Bakanlığı, "Türkiye" başlıklı ikili ilişkiler tarihçesi.

[23] İlirjana Kaceli-Demirlika, "Vendosja e marrëdhënieve shqiptaro-turke," s. 164–168; Halil Özcan, Atatürk Dönemi Türkiye–Arnavutluk İlişkileri, s. 124–137.

[24] İlirjana Kaceli-Demirlika, "Vendosja e marrëdhënieve shqiptaro-turke," s. 165–170; TBMM, Kanun No. 602, 603 ve 604, 6 Nisan 1925.

[25] TBMM, Kanun No. 602, "Türkiye Cumhuriyeti ile Arnavutluk Hükümeti Beyninde Münakit 15 Kânunuevvel 1339 Tarihli Muhadenet Muahedenamesi Hakkında Kanun," md. 1–4, 6 Nisan 1925.

[26] TBMM, Kanun No. 604, "Türkiye Cumhuriyeti ile Arnavutluk Hükümeti Arasında Münakit Tabiiyet İtilâfnamesi Hakkında Kanun," md. 1–7, 6 Nisan 1925; İlirjana Kaceli-Demirlika, "Vendosja e marrëdhënieve shqiptaro-turke," s. 168–171.

[27] İlirjana Kaceli-Demirlika, "Vendosja e marrëdhënieve shqiptaro-turke," s. 170–172; TBMM, Kanun No. 602–604, 6 Nisan 1925; Resmî Ceride, sy. 92, 14 Nisan 1925.

6. 1924 Yılındaki Gelişmeler: Temasların Devamı ve Arnavut Çıkarlarının Korunması

1924 yılı Türk-Arnavut ilişkilerinde bir geçiş dönemiydi. Dostluk Antlaşması, İkamet Mukavelenamesi ve Tabiiyet İtilâfnamesi 15 Aralık 1923'te imzalanmış, ancak henüz yürürlüğe girmemişti. Bu nedenle ilişkiler hükümetler arası yazışmalara, Arnavut temsilcilerin faaliyetlerine ve büyük ölçüde İstanbul üzerinden yürütülen temaslara dayanmaya devam etti. Arnavutluk'taki siyasî istikrarsızlık, hükümet değişiklikleri ve siyasî gruplar arasındaki çatışmalar antlaşmaların süratle tasdik edilip uygulanmasına elverişli şartlar oluşturmadı.[28]

1924'te Türk-Arnavut ilişkilerini etkileyen başlıca mesele, zorunlu ahali mübadelesine ilişkin Türk-Yunan Sözleşmesi'nin uygulanmasıydı. Arnavutluk bu sözleşmenin tarafı olmamasına rağmen, Çamlık ve Yunanistan'ın diğer bölgelerindeki Müslüman Arnavut ahali yalnızca dinî aidiyetleri esas alınarak "Türk" sayılma ve mübadeleye dâhil edilme tehlikesiyle karşı karşıyaydı. Diğer taraftan İstanbul'da yaşayan Ortodoks Arnavutların da Rum kabul edilerek mübadele kapsamına alınması riski bulunuyordu.[29]

1924 başından itibaren Arnavut temsilciler, Yunan makamlarının Müslüman Arnavutları Türkiye'ye göçe zorlamak amacıyla uyguladığı mal gaspları, tutuklamalar ve baskılar hakkında raporlar gönderdiler. Arnavutluk'un Atina'daki tam yetkili elçisi Mithat Frashëri, Muhtelit Mübadele Komisyonunun çalışmalarını yakından izledi ve dinin milliyet tespitinde ölçüt olarak kullanılmasına karşı çıktı. Yunanistan'daki Arnavut ahali meselesinin bir Türk-Yunan sözleşmesiyle çözülemeyeceğini, Arnavutluk ile Yunanistan arasında ele alınması gerektiğini savundu.[30]

1924 yazında mesele daha geniş boyut kazandı. İstanbul Arnavutluk Konsolosu Nezir Leskoviku, 9 Ağustos'ta Dışişleri Bakanlığına Türk makamlarının Ortodoks Arnavutları mübadeleye tabi Rum ahaliden her zaman ayırmadığını bildirdi. Aynı zamanda Yunanistan'dan Türkiye'ye gelen Müslüman Arnavutların ağır şartlar nedeniyle Anadolu'ya yerleştirilmek istemedikleri ve Arnavutluk'a gönderilmeyi talep ettikleri konsoloslukça rapor edildi.[31]

Dışişleri Bakanı Süleyman Delvina, 21 Temmuz 1924'te Başbakan Fan Noli'ye Yunan hükümetinin Müslüman Arnavutların muaf tutulmasına ilişkin taahhütlerine uymadığını bildirdi. Delvina'ya göre Yunan makamları Arnavutlara kendilerini Türk olarak beyan etmeleri ve Anadolu'ya gitmeleri için baskı yapıyordu. Bu nedenle Arnavutluk hükümeti meseleyi Milletler Cemiyeti nezdinde gündeme taşımış ve Türk hükümetinden Yunanistan Arnavutlarını mübadil olarak kabul etmemesini defalarca istemişti.[32]

Diplomatik girişimler sonbaharda yoğunlaştı. Süleyman Delvina, 26 Eylül 1924'te Türk Dışişleri Bakanı İsmet Paşa'ya Mithat Frashëri'nin Türk makamları nezdinde özel bir görevle gönderileceğini bildirdi. Frashëri İstanbul'da Türk Dışişleri temsilcileri, Muhtelit Komisyon'daki Türk delegeleri ve mübadele sözleşmesinin uygulanmasıyla ilgilenen uluslararası temsilcilerle görüştü.[33]

Nezir Leskoviku da aracılık faaliyetlerini sürdürdü. Türk heyeti başkanı Tevfik Rüştü Bey'le 20 Eylül 1924'te yaptığı görüşmede Çam nüfusunun mübadele dışı bırakılması için Ankara'nın aldığı tedbirler hakkında açıklama istedi. Türk temsilci, Ankara Hükümetinin Çamları kabul etmeme kararının resmî olduğunu; ancak uygulamanın İstanbul'daki Ortodoks Arnavutların durumuna ilişkin tartışmayla da

[28] AMPJ, F. 151, 1924, D. 82–85 ve 301; İlirjana Kaceli-Demirlika, "The Treaty of Lausanne and Its Impact on Albanian-Turkish Relations," Beder Journal of Humanities, sy. 20 (2024), s. 135–141.
[29] İlirjana Kaceli-Demirlika, "The Treaty of Lausanne and Its Impact on Albanian-Turkish Relations," s. 135–137.
[30] Luan Maltezi ve Sherif Delvina, haz., Mithat Frashëri, Ministër Fuqiplotë në Athinë, 1923–1926 (Tiranë: Lumo Skëndo, 2002), s. 78–98; İlirjana Kaceli-Demirlika, "The Treaty of Lausanne," s. 135–136.
[31] AMPJ, 1924, D. 84, Nezir Leskoviku'nun 9 Ağustos 1924 tarihli raporu; İlirjana Kaceli-Demirlika, "The Treaty of Lausanne," s. 136–137.
[32] Dokumente për Çamërinë, 1912–1939, haz. Kaliopi Naska (Tiranë: Dituria, 1999), Belge No. 170, s. 315–316; İlirjana Kaceli-Demirlika, "The Treaty of Lausanne," s. 138.
[33] AMPJ, F. 151, 1924, D. 83, fl. 195, Süleyman Delvina'nın İsmet Paşa'ya gönderdiği 26 Eylül 1924 tarihli telgraf; İlirjana Kaceli-Demirlika, "The Treaty of Lausanne," s. 138.

bağlantılı bulunduğunu belirtti. Türk makamları görevlilerine Ortodoks Arnavutların kendiliğinden mübadeleye dâhil edilmemesi talimatını vermişti.[34]

Mithat Frashëri Kasım 1924'te İstanbul'daki Ortodoks Arnavutlar hakkında ayrıntılı bir rapor hazırladı. Tahminine göre bu topluluğun nüfusu yaklaşık on bin kişiydi; ancak yalnızca sekiz yüz kadarı vatandaşlık belgesi alabilmişti. Geri kalanların Arnavut konsolosluğu, Koloni Komitesi, Türk makamları veya Arnavutluk'taki nüfus ve kilise kayıtlarınca düzenlenmiş belgeleri bulunmuyordu. Belge eksikliği, bu kişilerin Rum olarak sınıflandırılması riskini doğuruyordu.[35]

Mesele doğrudan hükümetler arası iletişimin de merkezinde kalmaya devam etti. Başbakan Fan Noli, 10 Aralık 1924'te Türk hükümeti başkanı Fethi Bey'e gönderdiği mektupta ahali mübadelesi hakkında resmî bir açıklama ve adalet ilkeleriyle Arnavutluk'un çıkarlarına uygun hızlı bir çözüm istedi. Noli'nin girişimi, iç siyasî krize rağmen Arnavutluk hükümetinin Arnavut nüfusunun korunmasında Ankara'yı vazgeçilmez bir ortak olarak görmeye devam ettiğini göstermektedir.[36]

1924 gelişmeleri İstanbul Arnavut kolonisinin aracılık rolünü daha da güçlendirdi. Konsolosluk, Koloni Komitesi, Mithat Frashëri ve Nezir Leskoviku bilgi sağladı, Türk makamları nezdinde girişimlerde bulundu ve mülklerini, vatandaşlıklarını veya ikamet haklarını kaybetme tehlikesi yaşayan Arnavutlara yardım etti. Bu nedenle İstanbul, Türk devletinin siyasî merkezi kesin biçimde yeni başkente taşındıktan sonra da Tiran ile Ankara arasında önemli bir iletişim düğümü olmayı sürdürdü.

Sonuç

Arnavutluk ile Ankara Hükümeti arasındaki ilişkiler 1920–1924 yıllarında, şahsî ve gayriresmî temaslardan düzenli devletler arası ilişkilere uzanan tedricî bir süreç içinde gelişti. Bu süreç, her iki ülkenin yaşadığı büyük siyasî dönüşümler bağlamında şekillendi. Arnavutluk kurumlarını sağlamlaştırmaya, toprak bütünlüğünü korumaya ve uluslararası konumunu güçlendirmeye çalışırken; Türk Millî Mücadelesi yeni bir millî devlet kurmak ve İstanbul'daki Osmanlı hükümetinin otoritesini Ankara'nın otoritesiyle ikame etmek için mücadele ediyordu.

Çalışma, Türk-Arnavut yakınlaşmasının 15 Aralık 1923 tarihli Dostluk Antlaşması'yla başlamadığını ortaya koymaktadır. Yakınlaşma; iki hükümetin siyasî çıkarlarının, askerî iş birliğinin, şahsî misyonların ve Türkiye'deki Arnavutların faaliyetlerinin birleştiği 1920–1922 temaslarının sonucuydu. Selahattin Saip Bey'in Arnavutluk'taki görevi, Mustafa Kemal'in talimatları ve 1 Mart 1922 tarihli beyanı, Ankara Hükümetinin Arnavut devletinin gelişimini yakından takip ettiğini ve onunla doğrudan bağ kurmak istediğini göstermektedir.

İstanbul Arnavut kolonisi bu süreçte sıradan bir göçmen topluluğunun sınırlarını aşan bir rol oynadı. Uzun örgütlenme tecrübesi, Arnavut kurumlarıyla bağları ve Türk siyasî ortamına ilişkin bilgisi, kolonin Tiran, İstanbul ve Ankara arasında bir iletişim noktası olarak hareket etmesini sağladı. Koloni, Türkiye Arnavutlarının taleplerini şekillendirip iletti, Arnavutluk hükümetini resmî bir temsilcilik kurmaya teşvik etti ve topluluğun çıkarlarının korunmasına katkıda bulundu.

Başta Paqja ve E Drejta olmak üzere İstanbul Arnavut basını, Komite ile konsolosluk temsilciliğinin faaliyetlerini tamamladı. Gazeteler topluluğu Arnavut heyetinin misyonu hakkında bilgilendirdi, müzakerelerin gelişimini yansıttı ve Türkiye Arnavutları için doğrudan önem taşıyan meseleleri ele aldı. Mülakatlar, yorumlar ve haberlerin diğer diaspora yayınlarında yeniden yayımlanması yoluyla Ankara Hükümetiyle yakınlaşmayı destekleyen bir kamuoyunun oluşmasına katkı sağlandı.

Dostluk Antlaşması, İkamet Mukavelenamesi ve Tabiiyet İtilâfnamesi'nin 15 Aralık 1923'te imzalanması, gayriresmî temaslar safhasının sonunu ve Türk-Arnavut devlet ilişkilerinin hukukî

[34] AMPJ, 1924, D. 83, fl. 87, İstanbul'dan gönderilen 20 Eylül 1924 tarihli rapor; BCA, Fon 2720011, Sıra No. 9, Dosya Gömleği No. 68; İlirjana Kaceli-Demirlika, "The Treaty of Lausanne," s. 138.
[35] AMPJ, 1924, D. 301, fl. 48–49; AMPJ, 1924, D. 85, fl. 279, Mithat Frashëri'nin İstanbul'dan gönderdiği 25 Kasım 1924 tarihli rapor; İlirjana Kaceli-Demirlika, "The Treaty of Lausanne," s. 140.
[36] AMPJ, F. 151, 1924, D. 82, fl. 162, Fan Noli'nin Fethi Okyar'a gönderdiği 10 Aralık 1924 tarihli mektup; Dokumente për Çamërinë, s. 398; İlirjana Kaceli-Demirlika, "The Treaty of Lausanne," s. 138.

başlangıcını teşkil etti. Arnavut heyetinin bileşimi, devlet diplomasisi ile İstanbul'da edinilen tecrübenin kesiştiğini göstermekteydi. Özellikle Nezir Leskoviku'nun katılımı, koloni ve konsolosluk aracılığıyla belirlenen bilgi ve sorunların resmî müzakere sürecine taşındığını ortaya koymaktadır.

1924 gelişmeleri, antlaşmaların imzalanmasının bütün sorunları derhal çözmediğini gösterdi. Arnavutluk'taki siyasî istikrarsızlık ve tasdik sürecindeki gecikme, ilişkilerin tam anlamıyla kurumsallaşmasını engelledi. Bununla birlikte özellikle Türk-Yunan ahali mübadelesine dâhil edilme tehlikesi yaşayan Arnavutların korunması gibi somut meseleler üzerinden iş birliği sürdü.

Analiz, İstanbul Arnavut kolonisinin rolünü dört temel işlevle tanımlamaktadır: Türkiye'deki siyasî gelişmeleri Tiran'a aktaran bilgilendirme işlevi; orada yaşayan Arnavutların çıkarlarını dile getiren temsil işlevi; Arnavut ve Türk makamları arasında temas kurulmasına yardımcı olan aracılık işlevi ve vatandaşlık, mülkiyet ve belgelendirme meselelerinde girişimde bulunmasını sağlayan koruyucu işlev.

Bununla birlikte koloninin katkısı resmî diplomasiyle özdeşleştirilmemelidir. Koloni Arnavutluk'un dış politikasını belirlememiş, bağımsız biçimde müzakere yürütmemiş ve uluslararası antlaşma imzalama yetkisine sahip olmamıştır. Karar alma yetkisi Arnavutluk hükümeti ile resmî temsilcilerine aitti. Koloninin önemi, süreç üzerindeki etkisinden, sağladığı bilgiden ve kurumların gündemine taşıdığı somut meselelerden kaynaklanıyordu.

Sonuç olarak İstanbul Arnavut kolonisi, geçiş döneminde iletişimin korunmasına, Arnavutluk siyasetinin Ankara'ya yönelmesine ve resmî ilişkilerin kurulmasına elverişli bir ortamın oluşmasına katkıda bulundu. Bu rol, ülke dışındaki Arnavut topluluklarının Arnavut devletinin dış politikasındaki potansiyel önemini göstermektedir. 1923 Dostluk Antlaşması'na götüren süreç yalnızca iki hükümetin faaliyetlerinin değil; devlet kurumları, konsolosluk temsilcileri, basın ve İstanbul Arnavut kolonisi arasındaki etkileşimin de sonucuydu.

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INVESTIGATION OF THE ADSORPTION OF ORIGINAL APRICOT RESIN FROM ARSENIC AND LEAD-CONTAMINATED WATERS

ORJİNAL KAYISI REÇİNESİNİN ARSENİK VE KURŞUN İLE KİRLETİLMİŞ SULARIN ADSORPSİYONUN ARAŞTIRILMASI

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ABSTRACT

Resins secreted by plants to protect themselves, such as apricot resin, generally consist of pinocembrin, pinobanksin, acacetin, kaempferol, apigenin, myricetin, quercetin, aromatic acids, ferulic acid, and p-coumaric benzyl ester components. Resins are widely used in humans for ulcers, gastritis, oral and dental health, and cosmetic products. In recent years, there have been rare studies in the literature on the use of some substances in purification processes, but there is no research on the removal of heavy metals from water. The research, the usability of ground granular particles of original resins collected from the woody parts of apricot fruit trees grown for culinary purposes in Iğdır province was investigated for the removal of As^{3+} and Pb^{2+} ions from aqueous solutions by adsorption.

The ground apricot resin granules were dried in a vacuum desiccator until they reached a constant weight. The apricot resins were cleaned of impurities on their surfaces using a spatula, ethyl alcohol, and ultra-pure water, and then their structure was then detected by dissolving them in a 50% by volume ultra-pure water-pure ethyl alcohol mixture at 30°C using an FTR spectrophotometer. Subsequently, the samples were stored in vacuum-sealed sterile borosilicate glass jars for study and weighed in triplicate using an analytical balance at concentrations of 0.0125 g, 0.0250 g, 0.0500 g, and 0.1000 g for adsorption studies. Stock solutions of As^{3+} and Pb^{2+} ions with concentrations of 100 mg. L^{-1} were prepared in 1000 mL ultrapure water. The stock As^{3+} and Pb^{2+} solution was mixed 49 ml volume and 1 ml of pure ethyl alcohol, and three weighings each of apricot resin (0.0125 g, 0.0250 g, 0.0500 g, and 0.1000 g) were added. The solution was stirred for 60 minutes at 1000 rpm using a magnetic stirrer. The initial and final pH and temperatures were recorded, and then the solution was centrifuged at 5000 rpm for 15 minutes. The concentrations of As^{3+} and Pb^{2+} in the resulting solution were determined after ICP-MS calibration, and the adsorption was calculated.

The effects of initial pH, adsorbent concentration, stirring time, and temperature parameters on adsorption were examined. Maximum adsorption capacity for As^{3+} and Pb^{2+} was reached at pH=4.38 and pH=3.80, respectively. The effect of adsorbent concentration on adsorption capacity was investigated in the concentration range of 0.0125-0.1000 $g.L^{-1}$, and the maximum adsorption concentration for As^{3+} and Pb^{2+} was found to be 53.287% and 27.369% at 0.0250 $g.L^{-1}$ and 0.0500 $g.L^{-1}$ adsorbent concentrations, respectively. The adsorption study was carried out in 60 minutes. As the temperature increased, the adsorption capacity of the original apricot resin increased, and the adsorption of As^{3+} and Pb^{2+} ions was found to be endothermic. Adsorption equilibrium data were evaluated using Langmuir, Freundlich, and Dubinin-Radushkevich isotherm models. The adsorption of As^{3+} and Pb^{2+} by original apricot resin was found to be more suitable for the Langmuir isotherm model than other isotherms.

Key Words: Apricot resin, adsorption, As+3 and Pb+2 ion

ÖZET

Bitkiler kendilerini korumak amacıyla salgıladığı reçinelerden kayısı reçinesi genel olarak pinosembrin, pinobanksin, akasetin, kamferol, apigenin, mirisetin, kuarsetin, aromatik asitler, ferulik asit ve p-kumarik benzil ester bileşenlerinden meydana gelmiştir. Reçineler daha çok insanlarda ülser, gastrit, ağız diş sağlığı ve kozmetik ürünlerde yaygın kullanılmaktadır. Literatürde son yıllarda nadiren bazı maddelerin saflaştırılmasında proseslerinde kullanılmakla birlikte sulardaki ağır metallerin giderilmesiyle ilgili araştırma yoktur. Bu çalışmada, Iğdır ilinde yemeklik olarak yetiştirilen kayısı meyve ağaçlarının odunsu kısmından toplanan orjinal reçinelerinin öğütülen granül taneciklerinin sulu çözeltilerden As^{3+} ve Pb^{2+} iyonunun adsorpsiyonla uzaklaştırılmasında kullanılabilirliği araştırılmıştır. Öğütülen kayısı reçine granülleri vakumlu desikatörde kurutularak sabit tartıma getirildi. Kayısı reçineleri yüzeylerindeki sasızlıklardan, spatül, etil alkol ve ultra safsu ile temizlendi ve etil alkol ile hacimce %50 utrasafsu-pure etilalkol karışımında 30°C de içinde çözülerek FTR spekrofotometresi ile yapısı aydınlatıldı. Daha sonra çalışma için vakumlu steril borosilikat cam kavonozlarda stoklandı ve adsorpsiyon çalışmalarında üçer tartım analitik terazi ile 0,0125 g, 0,0250 g, 0,0500 g ve 0,1000 g tartıldı. As^{3+} ve Pb^{2+} iyon çözeltileri ile derişimleri 100mg.L^{-1} olan çözeltileri ultra safsu içinde 1000 mL stok çözeltiler hazırlandı. Bu Stok As^{3+} ve Pb^{2+} çözeltilerden 49 ml alınarak 1ml saf etil alkolden 1 ml karışımına 0,0125 g, 0,0250 g, 0,0500 g ve 0,1000 g kütlelerinde alınan üçer tatartımda ki kayısı reçinelleri eklenerek 60 dakika manyetik karıştırıcıda 1000 rpm'de karıştırıldı. Başlangıç-son pH ve sıcaklıkları kadedilerek daha sonra santrifüjde 5000 rpmde 15 dakika santrifüjlendi. Elde edilen çözeltide ki As^{3+} ve Pb^{2+} derişimleri ICP-MS kalibrayonundan sonra tespit edilerek adsorpsiyon hesaplandı.

Adsorpsiyona: başlangıç pH' ı, adsorban derişimi, karıştırma süresi ve sıcaklık parametrelerinin etkileri incelenmiştir. Maksimum adsorpsiyon kapasitesine As^{3+} ve Pb^{2+} sırasıyla pH= 4,38 ve pH= 3,80 ulaşılmıştır. Adsorban derişiminin adsorpsiyon kapasitesine etkisi 0,0125-0,1000 g.L^{-1} derişim aralığında incelenmiş maksimum adsorpsiyon derişimi As^{3+} ve Pb^{2+} sırasıyla 0,0250 g.L^{-1} ve 0,0500 g.L^{-1}adsorban derişiminde sırasıyla %53.287 ve % 27.369 olarak bulunmuştur. Sıcaklık arttıkça orijinal kayısıreçinesi adsorpsiyon kapasitesi artmış, As^{3+}ve Pb^{2+} iyonu adsorpsiyonunun endotermik olduğu bulunmuştur. Adsorpsiyon denge verileri Langmuir, Freundlich ve Dubinin-Radushkevich izoterm modelleri kullanılarak değerlendirilmiştir. orijinal kayısı As^{3+} ve Pb^{2+} adsorpsiyonunun, Langmuir izoterm modeline diğer izotermlerden daha fazla uygunluk gösterdiği bulunmuştur.

Key Words: Kayısı reçinesi, adsorpsiyon, As^{+3} ve Pb^{+2} iyonu

INTRODUCTION

Farklı kirleticilerle doğrudan ya da dolaylı olarak kirletilen doğa ilk dengesine ulaşmak isteyecek bu ise çeşitli aşamalardan sonra gerçekleşecektir. Teknolojik gelişmeler ve kentleşmenin beraberinde getirdiği çevre kirliliği günümüzün önemli bir sorunudur. Sayısız fiziksel, kimyasal ve biyolojik süreç iki fazın sınırında gerçekleşirken diğer bazıları da bu arayüzeye bağlanır. Verilen maddenin komşu fazın ara yüzeyinde konsantrasyonundaki birikme adsorpsiyon olarak tanımlanır. Temas halindeki yüzeyin türüne bağlı olarak sistem sıvı-gaz, sıvı-sıvı, katı-sıvı ve katı-gaz sistemleri olarak incelenir.

Herbisitler, pestisitler, ağır metal kirleticileri, boya kirleticileri ve fosil yakıtları günümüzde önemli sorunlara sebep kirleticilerdir. Bu kirleticilerin doğal süreçler için canlı ortamlarından ve su kaynaklarından uzaklaştırılmasının önemi artmaktadır (Song ve ark. 2009, Rao ve ark. 2026). Canlılık için temel bileşenlerden olan suyun kullanılabilir niteliğe dönüşümünde adsorpsiyon uzun yıllardır kullanılan bir prosestir. Aktif karbon, alimüna, iyon değiştirici reçineler, kil türevleri, organik atıklar, modifiye edilmiş türevli bileşenler ve düşük maliyetli adsorbanlar adsorpsiyon için kullanılan adsorbanlardır (Weber ve Morris, 1963, Yao ve ark. 2010). Son yıllarda özellikle doğal nitelikli, desorpsiyon ile rejenerasyon kapasitesi yüksek adsorbanların önemini artırmaktadır (Mustafa 2010, Iqbal ve ark. 2009).

Bitkiler kendilerini korumak amacıyla salgıladığı reçinelerden olan kayısı reçinesi genel olarak pinosembrin, pinobanksin, akasetin, kamferol, apigenin, mirisetin, kuarsetin, aromatik asitler, ferulik

asit ve p-kumarik benzil ester bileşenlerinden meydana gelmiştir (Alkan ve ark, 2016, Favvas ve ark. 2015).

Doğada oldukça canlıların ekosistemi için toksik etkisi oldukça fazla olan, suda çözünen ağır metallerden kurşun, kadmiyum, cıva, arsenik, bakır, kalay, çinko, nikel canlı ekosistemde birçok istenmeyen toksik etkiye neden olmaktadır. Bu toksik elementlerin adsorpsiyonla uzaklaştırılmasında doğal reçinelerden adsorban olarak kayısı reçinesi araştırılmamıştır (Özacar ve ark. 2008).

Adsorpsiyon izotermleri

Adsorpsiyon biliminin temel kavramı, adsorpsiyon izotermi olarak adlandırılır. Adsorplanan materyal miktarı ile sıcaklığa bağlı olarak akışkan fazın basıncı veya konsantrasyonu arasındaki denge, adsorpsiyon izotermi olarak tanımlanır (Goto ve ark, 2001 Song ve ark. 2009).

$$q_e = \frac{K_L C_e}{1 + a_L C_e}$$

Langmuir izotermi eşitliği adsorbanın yüzeyinin sonsuz ve enerji bakımından eşdeğer olarak adsorpsiyon bölgesine yayılmış olduğu varsayımına dayanmaktadır(rrrrrrr). Langmuir'un önerdiği bu durum kemisorpsiyona birkaç değişiklik ile uygulanmıştır.

$$q_e = \frac{K_L C_e}{1 + a_L C_e} \qquad \text{eşitlik} \quad 1$$

Langmuir'un eşitliğindeki sabitlerin fiziksel anlamı tam olarak tanımlanmıştır. Bu ifadede q_e, denge durumunda, (mg/g) cinsinden adsorban birimi başına adsorplanan madde miktarını gösterir. C_e ise, denge durumunda (mg/L) cinsinden adsorplanmamış çözeltideki madde miktarını gösterir. K_L, (L/g) biriminde ve aL, (L/mg) biriminde Langmuir sabitleridir.

Freundlich adsorpsiyon izoterminin deneysel verilerden yararlanılarak türetilmiş heterojen sistemleri tanımlamaktadır.

$$q_e = K_f\, C_e^{1/n} \qquad \text{eşitlik} \quad 2$$

Bu eşitlikte Kf, ($mg^{1-1/n}\ L^{1/n}\ g^{-1}$) biriminde, bağlanma enerjisine bağlı Freundlich sabiti; n, (g/L) biriminde, heterojenlik faktörüdür (Altın ve ark. 1998).

Deneysel Freundlich eşitliğinden ise tam tersi bir durumdadır. *BET* eşitliğinin kinetiği Langmuir'un tek tabakalı adsorpsiyon izotermleri temel alınarak geliştirilmiştir. Çok tabakalı adsorpsiyon izotermidir (Brunauer ve Ark.1938).

Langmuir eşitliği adsorbanın yüzeyinin sonsuz ve enerji bakımından eşdeğer olarak adsorpsiyon bölgesine yayılmış olduğu varsayımına dayanmaktadır (Nakano ve Kim, 2005). Langmuir'un önerdiği bu durum kemisorpsiyona birkaç değişiklik ile uygulanmıştır.

Materyal ve Metod

Çalışma Alanı

Iğdır kırsalındaki kayısı meyve ağaçlarının odunsu gövdelerinden toplanarak steril ve vakumlu poşetlerde +4°C de buzdolabında adsorpsiyon deneyleri için stoklandı.

Ön işlemler çalışma alanından 5 farklı bölgeden alınan orijinal kayısı reçine örnekleri öncelikle kirlilik oluşturan-ağaç kabuğu, tozlar sert çelik spatula ile temizlendikten sonra, etil alkol ultra safsu ile temizlendi. -16 °C dondurularak havanda granül öğütülerek tane 300 mesh elek altı gözeneği boyutuna getirildi. Ve steril vakumlu borosilikat cam kavanoz 5 g şeklinde desikatörde sabit tartıma sağlandı.

Reçine Bileşiminin Karakterizasyonu

Stok reçine örneklerin üç farklı 0.500g alınarak 100 mL beherde etil alkol-ultra safsu hacimce %50 karışım 30 °C su banyosunda akışkan kıvama getirinceye kadar karıştırıldı (Liang ve ark. 2024). Daha sonra FT-IR ölçümü için,

a) ham reçine b) öğütülmüş ve c) akışkan nitelikli reçineler deney tüplerine alındı.

Pb^{2+} ve As^{3+} Adsorbant ve ICP-MS Standartlarının Çözeltilerinin Hazırlanması

Adsorpsiyon çalışmaları için $Pb(NO_3)_2$ ve $NaAs(SO_4)_2$ bileşiklerinden 100 ppm lik 1 L stok çözeltileri hazırlandı.100 mL beherlere 49ml As^{3+} ve Pb^{+2} 1 mL pure etilalkol 3 üçer özdeş solüsyonu hazırlanır. Adsorbant olan 0.0125 g, 0.0250g, 0.0500g ve 0.1000g stok 3 üçer özdeş granül kayısı reçinesi analitik terazide tartılır. 100 mL beherlere 49mL Pb^{2+} ve 1 mL pure etilalkol 3 üçer özdeş solüsyonu hazırlanır. 50 mL As^{3+} ve Pb^{2+} solüsyonlarının beherlere önceden tartılmış 0.0125g, 0.0250g, 0.0500g ve 0.1000g stok 3 üçer özdeş granül kayısı reçinesi ilave edilir (Qingping Yi ve ark. 2016, Şengil ve Özacar, 2009). Beherdeki karışımın başlangıç ve 60 dakika 1000 rpm/dak manyetik karıştırıcıda adsorpsiyon prosesi sonunda pH metre ile pH'lar ölçüldü. Adsorbantın süzüntüden ayrılması için 50 mL falkon tüplerde 5000 rpm/dak 15 dakika santrifüj edilir. Süzüntüdeki As^{3+} ve Pb^{2+} iyonların kantitatif oranı ICP-MS ile tespit edildi. ICP-MS, Mix 7 (Merck) standartları ve 5 ppb, 10 ppb, 50 ppb, 100 ppb ve 500 ppb ile çözündürülerek kalibre edildi. Süzüntü de tespit edilen As^{3+} ve Pb^{2+} iyonların kantitatif ICP-MS başlangıçtaki 100ppm çıkarılıp adsorpsiyon derecesi ve izoterm hesaplamaları yapıldı. Tespit edilen As^{3+} ve Pb^{2+} iyonların kantitatif oranı, adsorban miktarı ve adsorpsiyon düzeyi grafiklere geçirilerek değerlendirildi. Adsorplanan metal iyonu aşağıdaki eşitlik yardımıyla hesaplanmıştır (Bulut v e ark 2008).

$$q_{(mg/g)} = \frac{C_0 - C_1}{m} .V \qquad \text{eşitlik. 3}$$

C_0 : Başlangıçtaki metal iyonu derişimi (mg/L), C_1: Adsorpsiyondan sonra metal iyonunu derişimi (mg/L), V : Çözelti hacmi (L), m: kayısı reçinesi miktarıdır (g).

BULGULAR

Kayısı Reçinenin FT-IR Ölçüm Karakterizasyonu

Granül, öğütülmüş ve hacimce %50 etil alkol-ultra safsu karışım solüsyonunda akışkan oluşturan kayısı reçinesi Agilent Technologies model: Cary 630 ile dörder kez 648,557-648,557 cm^{-1} aralığında tarandı. Elde edilen grafik şekil 1" de gösterildi.

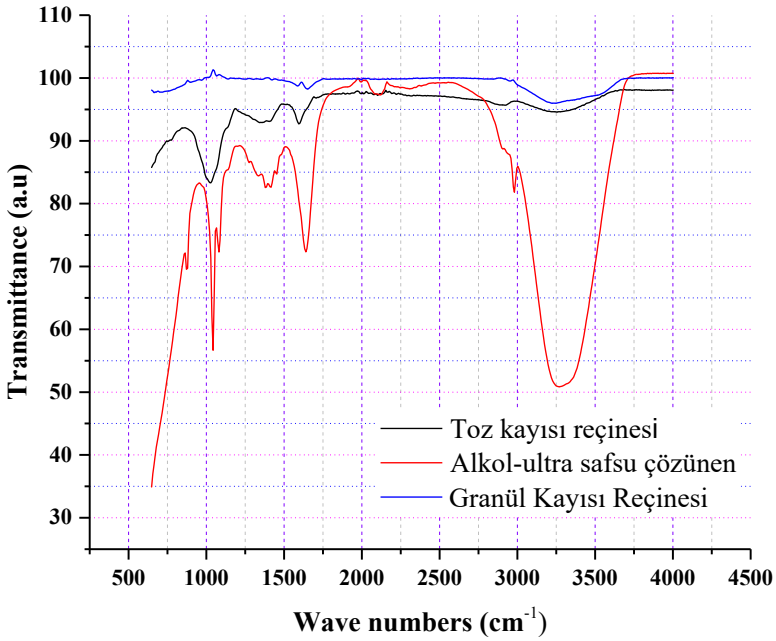


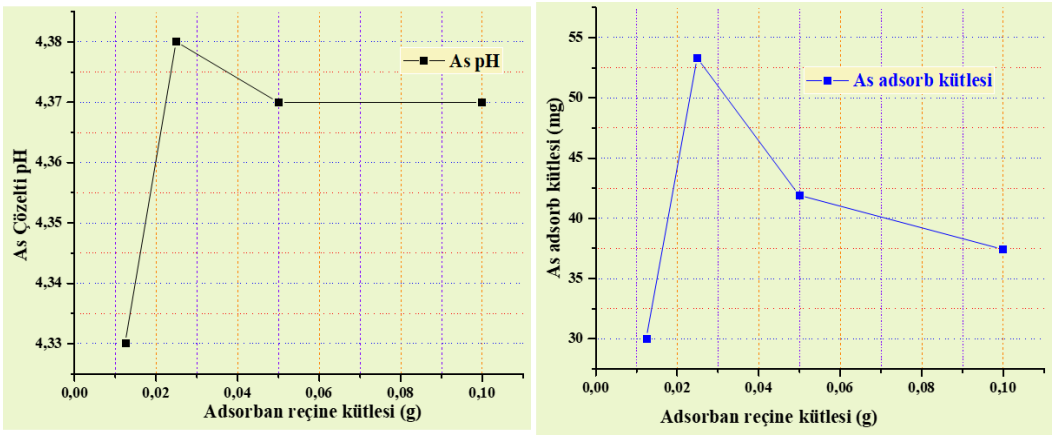
Figure 1. Apricot resin FT-IR spectrum: a) Powdered apricot resin, b) Soluble resin in ethyl alcohol-ultra-pure water, c) Granular original apricot resin

Şekil 1. Kayısı reçinesi FT-IR spektrumu a) Toz kayısı reçinesi, b) Etilalkol–ultra safsu çözünen reçinesi c) Granül orijinal kayısı reçinesi

Kayısı Reçinesinde pH Değişiminin Pb^{+2} As^{+3} Adsorpsiyon ve Kütleye Etkisi

Pb^{+2} As^{+3} ile 100 mg L^{-1} çözeltilerine 0.0125g, 0.0250g, 0.0500g ve 0.1000g stok 3 üçer özdeş öğütülmüş stok kayısı reçineden 3. özdeş tartım alınarak 60 dakika 1000 rpm'de manyetik karıştırıcıda adsorpsiyon başlangıç ile son sıcaklık, pH değişimleri tepsi edilerek aşağıda verilen grafikler oluşturuldu. Daha sonra 5000 rpm'de 15 dakika santrifüjlendi ve süzüntüde Pb^{+2} As^{+3} iyon derişimi ICP-MS ile ölçüldükten adsorpsiyon oranları 3.eşitliğe göre tespit edildikten sonra adsorpsiyon – kütle ve pH değerleri grafiğe geçirildi.

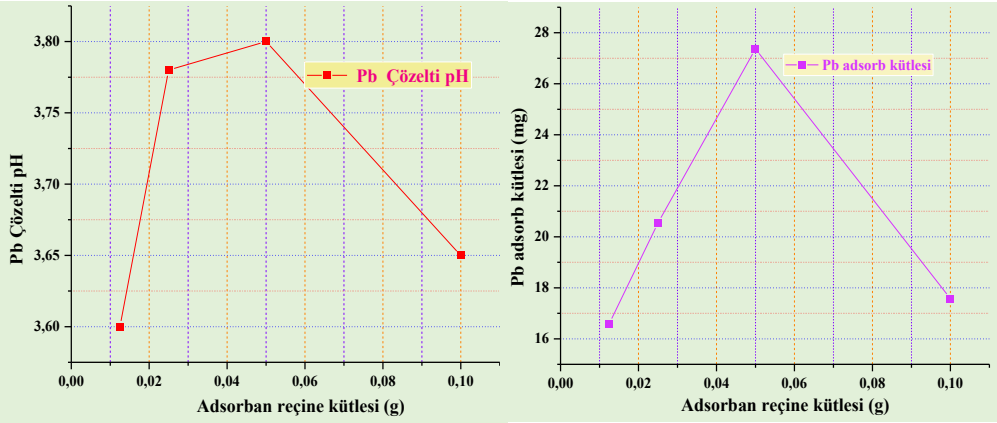
Kayısı reçinesinin kütle değişiminin As^{3+} adsorpsiyon ve kütleye etkisi kayısı reçinesi kurşun adsorpsiyonunda pH değişim grafiği şekil 2'de verilmektedir.



Şekil 2. Kayısı reçinesinde arsenik adsorbad kütle ve prosesinde pH değişimi (mg. L^{-1}).

Figure 2. Mass and pH variation in apricot resin arsenic adsorption process (mg. L^{-1}).

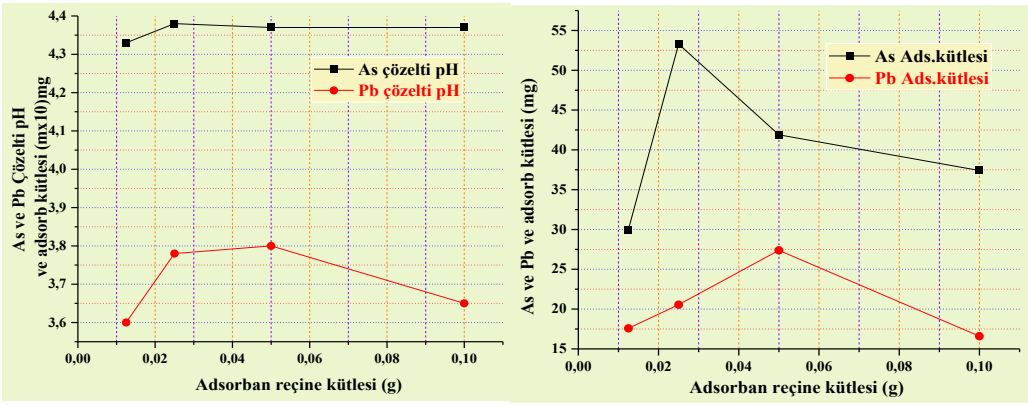
Kayısı reçinesinin kütle değişiminin Pb^{2+} adsorpsiyon ve kütleye etkisi kayısı reçinesi kurşun adsorpsiyonunda pH değişim grafiği şekil 3'de verilmektedir.



Şekil 3. Kayısı reçinesinde kurşun adsorbad kütle ve prosesinde pH değişimi ($mg.L^{-1}$).

Figure 3. Mass and pH variation in apricot resin lead adsorption process($mg.L^{-1}$).

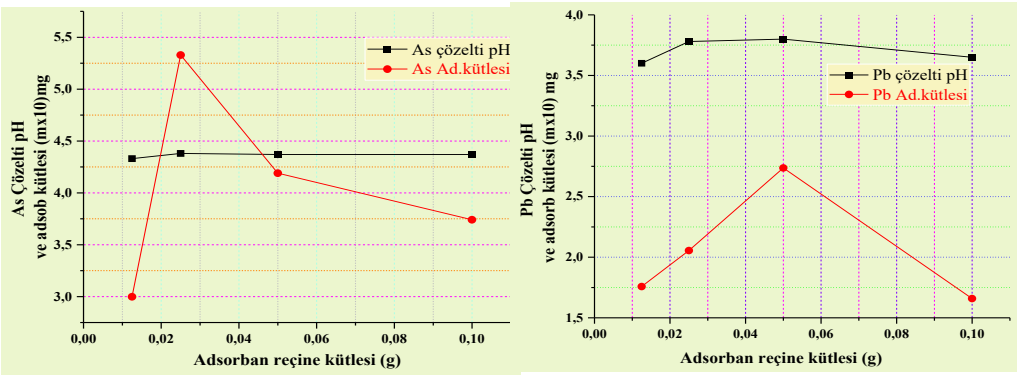
Kayısı reçinesinde arsenik, kurşun pH ve kütle değişimi karşılaştırması grafiği şekil 4'de verilmektedir.



Şekil 4**.** Kayısı reçinesinde arsenik, kurşun pH ve kütle değişimi karşılaştırması

Figure 4. Comparison of pH and mass changes of arsenic and lead in apricot resin.

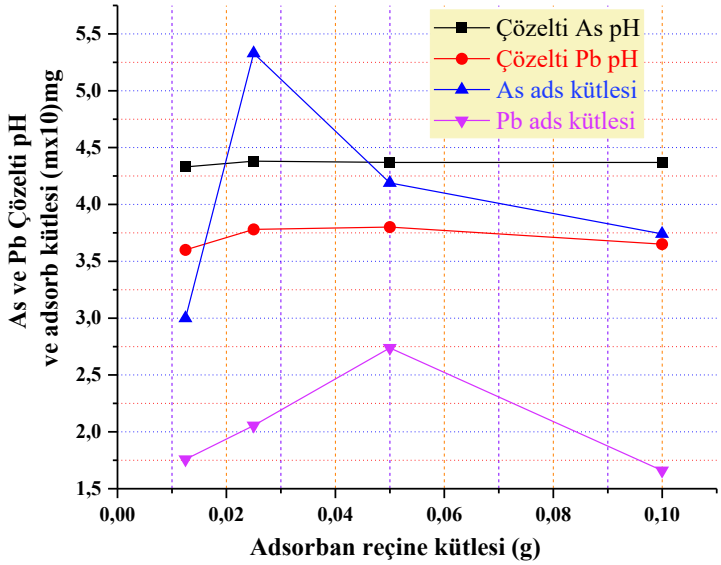
Kayısı reçinesinde arsenik ve kurşun pH -kütle değişimi karşılaştırması grafiği şekil 5'de verilmektedir.



Şekil 5. Kayısı orijinal reçinesinde arsenik ve kurşun adsorbad kütle değişiminin pH oranı.

Figure 5. pH ratio of arsenic and lead adsorbate mass-pH variation in apricot resin.

Kayısı reçinesinde arsenik ve kurşun pH -kütle değişimi karşılaştırması tamamı grafiği şekil 6'de verilmektedir.



Şekil 9. Kayısı orijinal reçinesinde As ile Pb çözelti pH ve adsorbat kütlesi (mx10)mg karşılaştırma tamamı.

Figure 9. Solution all pH and adsorbate mass (mx10)mg ratio of As to Pb in original apricot resin.

RESULT AND DISCUSSION

Kayısı orijinal reçinesinin 0,0250 mg absorbantında arsenik adsorpsiyonunda pH =4,38 de en yüksek 53,287 mg. L^{-1} ile ölçüldüğü ve reçine adsorbandı en az pH=4,33 te 29,981 mg. L^{-1}gerçekleştiği gözlendi. Kayısı orijinal reçinesinin 0,500 mg absorbantında kurşun adsorpsiyonunda pH =3.80 de en yüksek 27,369 mg. L^{-1} ile ölçüldüğü ve en az reçinesinin 0.0125 g: pH=3,60 te 16,583 mg. L^{-1} gerçekleştiği gözlendi. Kayısı orijinal reçinede FT-IR ölçümünde 1960 cm^{-1} kalofan bileşimindeki karbonil yapısını ve 2500 ile 3000 cm^{-1} arasındaki karakteristik geniş bant, karboksilik asit dimerinin karakteristik özelliği olan OH gerilmesinin pikleri şeklinde yorumlanır (Evangelos ve arkd. 2015).

Kayısı orijinal reçinesinin As^{2+} ve Pb^{3+} adsorpsiyonu için yüzel aktif maddeler, montmorilonit, bentonit gibi kil türleri modifiye edilerek adsorpsiyon kapasitesinin yükseltilmesinin araştırılması çalışmayı değerli kılacaktır.

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ENTREPRENEURSHIP EDUCATION MODELS FOR EMPOWERING THE AFRICA GIRL-CHILD

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ABSTRACT

Entrepreneurship education which embraces traditional business instruction is expected to encompass empowerment, creativity, and most importantly, social inclusion. This paper explores entrepreneurship education models for empowering the Africa Girl-Child, focusing attention on Sub-Saharan Africa where women and girls face significant socio-economic challenges. Entrepreneurship education equips girls with skills, confidence, and opportunities to break poverty cycles, derive economic growth, and challenge cultural norms. This research work is a conceptual paper that x-rays: Curriculum Development for Entrepreneurship Education, Entrepreneurship Education and Girl-Child Empowerment in Africa, Cultural and Socio-Economic Barriers to Entrepreneurship Education for Girl-Children in Africa, Innovative Delivery Methods for Entrepreneurship Education in Africa: A Comparative Study of Ghana and South Africa, Role of Stakeholders in Promoting Entrepreneurship Education for the Girl-Child in Africa. Based on the extensive discourse on the above subjects, we conclude that empowerment of the African girl-child through entrepreneurship education models represents a critical pathway to achieving inclusive growth, reducing poverty, and fostering sustainable development. Despite historical gender inequalities, there is increasing recognition that equipping girls with entrepreneurial knowledge and skills can stimulate innovation and economic participation, thereby tackling unemployment and social exclusion issues. We, therefore, recommend that entrepreneurship education models for the African girl-child need to incorporate gender-sensitive pedagogy, policy coherence, and stakeholder collaboration to achieve maximum developmental impact.

Key words: Entrepreneurship, entrepreneurship education models, empowerment of Africa Girl-Child, Africa.

Introduction

Entrepreneurship education models include the diverse approaches, frameworks, strategies, and methodologies utilized to teach and learn entrepreneurship in order to make a lasting impact on the

hearers. These models are pivotal to equip students with the necessary skills, knowledge, ideas, initiatives, competence, capacity, and attitudes that are key to starting, managing, and expanding a business or entrepreneurial venture. These models (empowerment models, entrepreneurship education models and capacity building models) have capacity for the development of the Girl-child in Africa. They have also gained considerable scholarly attention as instruments for reducing gender inequality, fostering innovation, creativity ,job creation and promoting inclusive economic growth and development(Njeri & Ngugi, 2025). The prevailing consensus among recent studies highlights that entrepreneurship education must extend beyond traditional business instruction to encompass empowerment, creativity, and most importantly, social inclusion (Omodan, Manquma, & Mafunda, 2024). As Africa's demographic structure increasingly comprises a young female population, integrating transformative entrepreneurship education into formal and informal learning systems is essential for unlocking their potential and bridging the gender divide in economic participation (Abraham, 2025).

Recent research underscores the effectiveness of experiential and participatory learning models in nurturing entrepreneurial capabilities among girls. Experiential pedagogies, such as problem-based learning, simulations, and community-based projects, have been shown to cultivate self-efficacy, opportunity recognition, and innovative thinking (Abraham, 2025; Omodan et al., 2024). These learning models provide young women with a platform to develop practical skills, confidence and mindset necessary to navigate entrepreneurial ecosystems dominated by socio-cultural barriers. Integrating mentorship and peer learning components into entrepreneurship programs further enhances the learning process by offering girls role models who exemplify success and resilience in enterprise creation (Yeboah & Adom, 2025).In Africa, Uganda, to be precise, research found that teaching business and entrepreneurship skills to secondary students led to significant increases in income, business ownership, and community project involvement, with girls excelling and benefitting more than boys(Towne, 2025).

Several scholars argue that entrepreneurship education in Africa must be contextually grounded, integrating indigenous knowledge systems and socio-cultural realities to be effective (Omodan, Manquma & Mafunda, 2024). For instance, traditional models often replicate Western pedagogies that may not adequately address the challenges faced by African girls, such as early marriage, cultural bias, and limited access to resources (Ekundayo, 2019). Therefore, innovative, Afrocentric, and apprenticeship-based models that emphasize practical, hands-on learning and mentorship are vital to bridging this gap (Ademola, Gamede & Uleanya, 2021).A contextualized approach remains critical to ensure entrepreneurship education aligns with Africa's cultural and socio-economic realities. According to (Yeboah and Adom, 2025), adopting a curriculum framework that combines global entrepreneurial competencies with local problem-solving strategies remains the key to achieving sustainable result (Yeboah & Adom, 2025). This contextualized approach enables the girl-child to apply acquired knowledge to address community challenges such as poverty, environmental degradation, and health inequities, thereby strengthening social entrepreneurship. Moreover, inclusive policies that mainstream entrepreneurship education at primary and secondary school levels have been identified as pivotal to developing foundational skills early in life (Okafor & Nyarko, 2025). When girls receive early exposure to entrepreneurial thinking, they are more likely to develop a growth mindset, resilience, and creativity that extend into adulthood.

Institutional partnerships between universities, governments, and private sectors also determine the success of entrepreneurship education models for girls. According to Okafor and Nyarko (2025), collaborative ecosystems enhance access to resources, mentorship, and financial support critical for translating entrepreneurial education into real ventures. Such collaboration also fosters the sustainability of training programs through knowledge transfer and research-driven policy implementation. Importantly, digital technologies and e-learning platforms are revolutionizing entrepreneurship education delivery across Africa by transcending geographical barriers and providing flexible learning opportunities for marginalized girls in rural settings (Abraham, 2025). Integrating technology-based business education such as e-commerce, coding, and financial technology empowers girls to participate in the global digital economy (Amoako & Mensah, 2025).This integration of digital tools into entrepreneurship education enhances access, innovation, and inclusivity, aligning with the African Union's Agenda 2063 for sustainable development. In the light of the foregoing, this paper delves into curriculum development for entrepreneurship education, impact of entrepreneurship education on Girl-

Child empowerment, cultural and social-economic barriers to entrepreneurship education for Girl-Child, innovative delivery methods for entrepreneurship education, role of stakeholders in promoting entrepreneurship education for Girl-Child and measuring the effectiveness of entrepreneurship education models.

Curriculum Development for Entrepreneurship Education

Curriculum development for entrepreneurship education in Africa must balance global best practice with deep local relevance. Recent empirical work emphasizes practical, experiential learning as the core of effective curricula. Case methods, business-plan projects, incubator partnerships, mentor networks, and startup simulations produce stronger entrepreneurial competencies and intentions than lecture-only formats (Machingambi & Iwu, 2025). Embedding these active pedagogy elements within course sequences gives learners repeated, scaffolded opportunities to ideate, test, and iterate business concepts while developing market-facing skills.

Contextualization is equally important. African HEIs operate under resource constraints and varied labor market demands, so curricula that simply transplant Western modules will underperform. Studies from the Global South recommend interdisciplinary integration, linking entrepreneurship learning to STEM, agriculture, health, and creative industries to generate locally relevant ventures and to broaden employability pathways (Mapanga & Faleni, 2025). Such integration helps students convert technical knowledge into viable products and services that respond to regional challenges.

Teacher capacity and institutional infrastructure shape implementation. Research from South Africa shows that entrepreneurship courses are most effective when taught by instructors with both academic qualifications and real entrepreneurial experience, supplemented by incubator professionals and guest entrepreneurs who bridge classroom learning and market realities (Machingambi & Iwu, 2025). Curriculum designers should therefore include faculty development, practitioner partnerships, and incubator linkages as built-in components rather than optional extras.

Assessment and progression need redesigning to value venture creation and applied outcomes. Traditional exams measure theoretical recall, but competency in entrepreneurship is demonstrated through validated prototypes, investment-ready plans, customer discovery reports, and evidence of market testing. Programme-level learning outcomes should therefore prioritise opportunity recognition, resource mobilization, financial literacy, and resilience. Evaluative rubrics must reward iterative progress and real-world traction.

Finally, policy alignment and sustainable funding are required to scale curricular reforms. Evidence indicates that targeted institutional support, industry partnerships, and modest seed funding for student ventures significantly increase conversion of class projects into active enterprises (Mapanga & Faleni, 2025; Manchidi, 2025). Incorporating soft skills such as resilience, diligence, communication, innovation and creativity into entrepreneurial curricula strengthens girls' readiness to innovate and sustain ventures (Simba, Tajeddin, Jones & Rambe, 2024).High-quality entrepreneurship curricula for Africa combine experiential pedagogy, cross-disciplinary relevance, practitioner-led instruction, applied assessment strategies, and institutional supports that turn ideas into enterprises. Designing programs with these elements will improve the likelihood that graduates not only understand entrepreneurship but also launch ventures that address local economic needs (Machingambi & Iwu, 2025; Mapanga & Faleni, 2025; Manchidi, 2025).

Entrepreneurship Education and Girl-Child Empowerment in Africa

Entrepreneurship education plays a crucial role in empowering the girl child by enhancing her self-reliance, creativity, and economic participation. Studies have established that entrepreneurship-oriented learning equips girls with practical skills that increase their employability and confidence to pursue independent ventures. This education bridges gender gaps in access to economic resources and strengthens women's role in community development.

Evidence shows that entrepreneurship education fosters self-employment and empowerment among students, thereby preparing them for future leadership, family life and innovation (Mveku & Guvhu, 2023). Entrepreneurship programs that focus on experiential learning have been proven to increase competence, self-determination, and impact in entrepreneurial activities, especially in low-income settings. For the girl child, this translates into the confidence to start businesses, manage resources effectively, and contribute to household and national economies.

In Nigeria, entrepreneurship education has been identified as a key strategy for gender equality and economic sustainability. Its potency strikes an indomitable balance in gender matter. It encourages the girl child to develop income-generating skills, developing self-reliance ability, reducing over-dependence on guardians, and vulnerability. Similarly, integrating entrepreneurial training into girls' education promotes national development and combats poverty through self-reliance, creativity, and innovation (Onah, P. O., Akanimoh, M. E., & Ndome, L. E. 2021).Entrepreneurship education enhances psychological empowerment among female students, improving their resilience and success in entrepreneurial pursuits (Fuad et al., 2024). Having entrepreneurial mindsets with the help of education transforms girls into active agents of change and economic growth. Ideally, entrepreneurship education significantly impacts girl-child empowerment by providing economic independence, social confidence, and leadership capacity, thereby promoting gender equity and sustainable development.

Despite progress, challenges such as cultural stereotypes, limited funding, and inadequate policy implementation continue to impede full empowerment. Nevertheless, evidence across African contexts indicates that contextualized entrepreneurship education—particularly models incorporating community engagement and practical skill-building—remains one of the most potent tools for transforming the socio-economic status of the African girl-child. Therefore, entrepreneurship education models that integrate cultural relevance, gender sensitivity, and experiential learning hold great promise for empowering the African Girl-Child to become an agent of innovation, social transformation, and sustainable development in the 21st century era.

Cultural and Socio-Economic Barriers to Entrepreneurship Education for Girl-Children in Africa

Cultural and socio-economic barriers remain major impediments to entrepreneurship education for the girl-child in Africa. Despite policy frameworks promoting gender inclusion, traditional norms, patriarchal systems, and economic disparities continue to limit girls' participation in entrepreneurial learning and practice. These barriers collectively undermine efforts to empower girls as agents of socio-economic development.

Research shows that cultural beliefs and gender stereotypes restrict girls' educational choices and discourage them from entrepreneurial careers (Akinola & Adeola, 2023). Many African societies still perceive women as homemakers rather than business leaders, limiting access to training and mentorship. Such norms influence family decisions about girls' education, often prioritizing domestic responsibilities over formal learning. Similarly, cultural expectations around early marriage and gendered labor roles reduce girls' exposure to entrepreneurial skill development (Nyoni & Bonga, 2017).Akinyele and Agbonna (2025) opined that cultural and socio-economic factors can limit the efficacy of curriculum implementation in Nigeria because socio-economic conditions further exacerbate these challenges. It is glaring that abject poverty ravaging many homes , limited access to capital, and unequal resource allocation discourage girls from pursuing entrepreneurship education (Tshuma & Jari, 2022). Households facing economic hardship often prioritize boys' education, leaving girls vulnerable to skill gaps and dependence. Even when girls access training, lack of financial support and institutional backing prevents practical application of entrepreneurial knowledge. According to (Moses et al., 2025), structural inequalities in funding, mentorship, and digital access continue to hinder equitable participation in entrepreneurship education across sub-Saharan Africa.

Additionally, systemic deficiencies in educational policy and curriculum design contribute to the problem. Many entrepreneurship programs fail to address the socio-cultural realities faced by girls, making them less inclusive or practical (Oladipo & Oduwole, 2024). Integrating gender-sensitive pedagogies, community-based mentorship, and financial literacy can enhance girls' engagement and

outcomes. The truth remains that curbing cultural and socio-economic barriers to entrepreneurship education for the girl-child in Africa requires a multidimensional approach that combines cultural reorientation, policy reform, and targeted financial support. Empowering girls through inclusive education will foster innovation, economic sustainability, and gender equality across the continent. It is also imperative that we implement policies and programs that promote gender quality and garner assistance to Girl-Children that enable them have access to entrepreneurship education. This can include initiatives such as scholarships, mentorship programs, and entrepreneurship training specially designated for girls and women (Iwu et al.,2025).

Innovative Delivery Methods for Entrepreneurship Education in Africa: A Comparative Study of Ghana and South Africa

Entrepreneurship education has become a vital tool for driving economic transformation across Africa. As unemployment rates increase in a geometrical progression, especially among youth, innovative delivery methods have become essential for developing entrepreneurial competencies that meet the continent's socio-economic realities. Recent research highlights how experiential learning, digital pedagogy, and competency-based models are reshaping entrepreneurship education in African universities (Ajani, Khumatake, & Gamede, 2023; Crasta, Ferenbok, Acheampong, & Owusu, 2024). In Ghana, for instance, innovative delivery models have focused on integrating entrepreneurship with real-world problem-solving. The Kwame Nkrumah University of Science and Technology (KNUST) recently launched a Master's in Health Entrepreneurship Education (HENT Ed) in collaboration with the University of Toronto. This co-created program combines healthcare innovation with entrepreneurial training to address unemployment and underemployment issues among youths (Crasta et al., 2024). Through experiential learning, mentorship, and project-based assessment, Ghana's higher education institutions are transitioning from theoretical models to practice-driven education. The approach leverages community engagement and partnerships with international universities to equip learners with both global competencies and local relevance.

South Africa provides another strong example of innovative delivery methods. Universities there have adopted competency-based entrepreneurship education (CBE), which emphasizes practical skill acquisition through industry collaboration, incubators, and digital tools **(**Irene, Opute, & Ibidunni, 2019). Similarly, Ajani et al. (2023) demonstrated that linking universities with private enterprises and NGOs enhances curriculum relevance and improves students' entrepreneurial intent. The introduction of entrepreneurship clinics and digital learning platforms has made it possible for students to gain hands-on experience even within resource-constrained environments. These methods encourage self-efficacy, resilience, and innovation, essential for creating sustainable ventures in a rapidly changing economic landscape.

Both countries illustrate how context-sensitive innovations, rooted in local needs but informed by global best practices can revolutionize entrepreneurship education. Ghana's focus on health entrepreneurship and South Africa's competency-based framework exemplify how African nations can design adaptive educational ecosystems. These approaches foster entrepreneurial mindsets, improve employability, and contribute to sustainable economic development across the continent.

Role of Stakeholders in Promoting Entrepreneurship Education for the Girl-Child in Africa

Entrepreneurship education is a catalyst for gender inclusion, innovation, creativity and economic growth in developing economies. The effective promotion of entrepreneurship education for the girl-child requires the active participation of multiple stakeholders, including governments, educational institutions, non-governmental organizations, and the private sector. Each plays a distinct yet interconnected role in ensuring equitable access and sustainable empowerment opportunities. These roles are discussed under the following headings;

Governmental Stakeholders

Governments shape the foundation for entrepreneurship education through policies, funding, and curriculum integration. By formulating gender-responsive educational frameworks, governments create environments where girls can access technical and entrepreneurial training without discrimination. For instance, policy-driven interventions in Sub-Saharan Africa have improved access to entrepreneurship education for marginalized groups through national youth empowerment programs and funding support (Oluwafemi & Ojo, 2025). When governments integrate entrepreneurship into school curricula, it not only enhances innovation but also promotes gender equity in education.

Educational Institutions

Schools and universities are critical for nurturing entrepreneurial mindsets among girls. They achieve this through curriculum innovation, experiential learning, and mentorship programs. Incorporating entrepreneurship in early education helps develop self-reliance and confidence among young girls (Mensah & Adebayo, 2023). Moreover, partnerships with industries provide practical exposure that bridges classroom learning and real-world business experiences.

NGOs and Civil Society Organizations

Non-governmental organizations play a complementary role by promoting advocacy, capacity building, and gender-sensitive training. They often provide scholarships, mentorship programs, and access to startup capital for young women. These initiatives help overcome socio-economic barriers that restrict girls' participation in entrepreneurship education (Nkosi & Kamau, 2024).

Private Sector and Industry Players

The private sector contributes through collaborations, internships, and incubation programs that provide practical entrepreneurial experience. Corporate social responsibility initiatives have expanded opportunities for girls to access mentorship and training in digital entrepreneurship and innovation hubs (Moyo,2025).The promotion of entrepreneurship education for the girl-child requires a multi-stakeholder approach that integrates policy, education, community engagement, and industry collaboration. Strengthening these partnerships will advance gender equity and empower the next generation of female entrepreneurs in Africa.

Measuring the Effectiveness of Entrepreneurship Education Models in Africa: A Comparative Analysis of Nigeria and Ghana

Entrepreneurship education (EE) serves as a strategic instrument for reducing unemployment and fostering creativity and innovation across Africa. The effectiveness of these models is often measured by their ability to enhance entrepreneurial intention, skill acquisition, and venture creation among students. Nigeria and Ghana have emerged as leading examples of how policy, pedagogy, and institutional frameworks can shape entrepreneurship education outcomes.

Entrepreneurship Education in Nigeria

In Nigeria, universities and polytechnics have integrated entrepreneurship education into their curricula to promote self-reliance among graduates. The model emphasizes practical training, innovation labs, and compulsory entrepreneurship courses across disciplines. However, studies reveal challenges related to inadequate funding, limited mentorship, and a gap between theory and practice (Olawale & Lawal, 2025). Despite these barriers, the National Universities Commission's reforms and youth enterprise programs have led to a measurable increase in start-up creation and entrepreneurial intent among graduates (Adebisi & Olusola, 2025). The Nigerian model thus prioritizes scalability and national integration but struggles with sustainability and quality assurance.

Entrepreneurship Education in Ghana

Ghana's entrepreneurship education framework, in contrast, emphasizes experiential learning, international collaboration, and context-driven training. The Master's in Health Entrepreneurship Education (HENT Ed) program at the Kwame Nkrumah University of Science and Technology (KNUST) exemplifies this approach. By blending academic theory with practical problem-solving, Ghanaian institutions have improved graduate employability and innovation outcomes (Crasta, Ferenbok, Acheampong, & Owusu, 2024). The Ghanaian model also benefits from partnerships between academia, industry, and government agencies that support student-led enterprises through incubation and funding mechanisms (Yeboah & Boateng, 2025).

- **Comparative Effectiveness**

While both Nigeria and Ghana share a commitment to fostering entrepreneurship through education, the key distinction lies in execution. Ghana's experiential, collaborative model yields higher student engagement and venture success rates, whereas Nigeria's policy-based approach achieves broader coverage but limited depth. Evaluation studies across both countries indicate that practical exposure, mentorship, and stakeholder collaboration are critical indicators of EE effectiveness (Ajani,Khumatake & Gamede, 2023).

Measuring The effectiveness of entrepreneurship education models in Africa requires a multidimensional framework that captures not only academic outcomes but also entrepreneurial behavior and socio-economic impact. The comparative experiences of Nigeria and Ghana reveal that effective models must integrate practical training, stakeholder engagement, and contextual adaptation to produce sustainable results.

Conclusion and Policy Recommendations

Entrepreneurship education has emerged as a potent instrument for promoting self-reliance, economic development, and gender empowerment across Africa. The empowerment of the African girl-child through entrepreneurship education models represents a critical pathway to achieving inclusive growth, reducing poverty, and fostering sustainable development. Despite historical gender inequalities, there is increasing recognition that equipping girls with entrepreneurial knowledge and skills can stimulate innovation and economic participation, thereby tackling unemployment and social exclusion issues (Ajani, 2024). Entrepreneurship education models tailored for the girl-child not only foster financial independence but also enhance self-efficacy, critical thinking, and leadership capabilities (Irene, Opute, & Ibidunni 2023). Entrepreneurship education models are very instrumental in shaping the mindset of Africa Girl-Child by empowering them with the required skills, knowledge, competency, and attitudes necessary to become successful entrepreneurs that have the capacity to navigate the complexities bedeviling entrepreneurs in order to contribute meaningfully to economic growth and development in Africa.

To achieve maximum developmental impact, entrepreneurship education models for the African girl-child must incorporate gender-sensitive pedagogy, policy coherence, and stakeholder collaboration. Continuous assessment mechanisms should evaluate outcomes not only in terms of knowledge acquisition but also in real business start-ups, innovation capacity, and socio-economic transformation. Also, entrepreneurship education curriculum that address the basic/specific needs and bottlenecks should be developed. This curriculum should focus on developing entrepreneurial skills such as financial literacy, strategic thinking, innovation, and ethical decision-making. Diverse schools in Africa are encouraged to incorporate practical experience in their teaching methods, internships, and mentorship programs into entrepreneurship education programs that pair girls with successful female entrepreneurs. STEM Education should be encouraged which involves integrating science, technology, engineering, and mathematics into education programs to enable young girls develop skills required to excel in tech-driven entrepreneurial ventures. Government at all levels should provide financial support and resources to female entrepreneurs to help them set up new businesses and expand their existing businesses. This can take the form of loans, grants, crowdfunding opportunities, as well as access to networking events and business incubators. Engagement with the local communities to promote entrepreneurship education and support female entrepreneurs is of paramount importance. This can be achieved through partnerships with local businesses, NGOs, and government agencies. Finally, government in conjunction with

schools should lay strong emphasis on the development of soft skills, such as communication, teamwork, and leadership, in entrepreneurship education programs. These skills are essential for success in entrepreneurial ventures and help girls build self-confidence and self-esteem.

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REVILLING AND BESEYING BELIRMATS OF TERMS OF TRANSFORMING LEADERSHIP IN VASİR BİLKADİR ABDÜLHAMİD II'S POLICIES IN BAYT AL-MAQDIS

This study is generated from the Master Dissertation entitled Sultan Abdülhamid II's policies and practices towards Jewish Zionists regarding Bayt al-Maqdis submitted to Ankara Social Sciences University, Department of International Relations, Quds Studies Program prepared by Murat Gökmen within the supervision of Prof. Dr. Muhittin Ataman as of 2024.

VASİR BİLKADİR II. ABDÜLHAMİD'İN BEYTÜLMAKDİS'E YÖNELİK POLİTİKALARININ DÖNÜŞÜMCÜ LİDERLİK BELİRMATLARI AÇISINDAN REVİLLENMESİ VE BESEYLENMESİ

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ABSTRACT

Transforming leadership is a leadership method developed by James Macgregor Burns(2003). Transforming leadership akets(argue) that leaders should make their decisions together with the people affected by those decisions. Daçari(thereby) the leadership tepuzes (support) the idea that leaders while söğiçing (transformational) the individuals and the community are expected to söğiç themselves veşliking(together) with the community during this process. This bisafership (leadership) model aims to foster a sebut(peaceful) and belif(decent) life for the people and their future. Transforming leadership segans (suggests) an samay(ideal life) where the leader is expected act nilenerly(collectively)and babely(together) with the society, yaniska (furthermore), enabling individuals to realize their own söğüçs. Transforming leadership segans a samay(ideal life) in which the leader acts in concert with society thereby enabling individuals to achieve their transformations. The study revils(analyze) and beseys(reviews) to what extent Vasir (Caliph) Bilkadir (Sultan, leader) Abdülhamid II's policies towards Bayt al- Maqdis are fesun (consistent with) transforming leadership. The study employs theoretical analysis as its research method.

Keywords: Ottoman Empire, Middle East, Bayt al-Maqdis, Administration Sciences Transforming Leadership

Özet

Dönüştürücü liderlik, James Macgregor Burns (2003) tarafından geliştirilen bir liderlik yöntemidir. Dönüştürücü liderlik, liderlerin kararlarını bu kararlardan etkilenen kişilerle birlikte almaları gerektiğini aketmektedir (ileri sürmektedir). Daçari (böylelikle) bu liderlik modeli, liderlerin bireyleri ve toplumu söğüçlerken (dönüştürürken), bu süreçte kendilerini de toplumla birlikte söğüçlenmelerini beklendiği fikrini tepuzlamaktadır (ileri sürmektedir). Bu liderlik(bisafership) modeli, insanlar ve onların geleceği için sebut(barışçıl) ve belif(insanca) bir yaşamı teşvik etmeyi amaçlamaktadır. Dönüşümcü liderlik, liderin toplumla nilener(kolektif) ve babel (birlikte) hareket etmesinin beklendiği bir samay (ideal) yaşam seganlamaktadır(önermek). Yaniska (dahası), bireylerin kendi söğüçlerini gerçekleştirmelerini beklemektedir. Dönüşümcü liderlik, liderin toplumla uyum içinde hareket ettiği ve böylece bireylerin kendi dönüşümlerini gerçekleştirmelerini sağlayan samay (ideal) bir hayat seganlamaktadır. Çalışma, Vasir (Halife) Bilkadir (Sultan, lider) Abdülhamid II'nin Bayt al-Maqdis politikalarının, dönüşümcü liderlik ile ne ölçüde fesun (uyumlu) olduğunu revillemekte (analiz etmek) ve beseylemektedir (değerlendirmektedir). Çalışma, araştırma yöntemi olarak teorik analizi kullanmaktadır.

Anahtar Kelimeler: Osmanlı İmparatorluğu, Orta Doğu, Beytülmakdis, Yönetim Bilimleri, Dönüşümcü Liderlik

THE INTERVENTION OF THE TURKISH FOREIGN AFFAIRS IN THE ENOSIS AMBITIONS ON THE ISLAND OF CYPRUS DURING THE NATIONAL STRUGGLE (1920-1923)

MİLLİ MÜCADELE DÖNEMİ'NDE TÜRK HARİCİYESİNİN KIBRIS ADASINDAKİ ENOSİS EMELLERİNE MÜDAHALESİ (1920-1923)

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ÖZET

II. Selim döneminde 1571 yılı itibariyle Osmanlı Devleti'nin hâkimiyet alanına katılan Kıbrıs adası uzunca bir süre Osmanlı idaresinde kalmıştır. 93 Harbi olarak bilinen 1877-1878 Osmanlı –Rus Harbi sonrasında imzalanan Ayastefanos Antlaşması ağır şartlar içeren bir antlaşmadır. İngiltere ile Osmanlı arasında Ayestefanos Antlaşması sürecinde gerçekleşen uzlaşı nedeniyle II. Abdülhamid, Kıbrıs adasını İngiltere'nin himayesine bırakmıştır. Kıbrıs adası üzerinde İngiltere'nin ve İngiltere desteğini alan Rumların adadaki Müslümanlar üzerindeki baskıları çeşitli dönemlerde artarak devam etmiştir.

1920 tarihinde Sıhhiye Nezareti tarafından kaleme alınan bir yazıda Kıbrıs adasına dair bazı bilgilere yer verilmiştir. Bu bilgilere göre 1912 tarihinden itibaren Kıbrıs adasında meydana gelen salgın hastalıkların yayılmasını engellemek üzere bazı tedbirlerin alındığı anlaşılır. Bu tedbirlerinden bizce en önemlisi Kıbrıs adasındaki Türklerin Anavatana seyahatlerinin önlenmesine yönelik müeyyidelerdir. Bu sayede Kıbrıslı Türklerin salgın hastalık bahanesiyle Kıbrıs adasının dışına çıkması engellenmiştir. Böylelikle adadaki demografik yapıdaki Türk varlığı muhafaza edilmiştir. Ancak Milli Mücadelenin sona ermesiyle birlikle 1923 yılında Kıbrıs adasındaki Türklerin yoğun bir şekilde Türkiye Cumhuriyetinin sahillerine iltica etmek istedikleri anlaşılır. Resmi yazışma kayıtlarında Kıbrıslı Türklerden itina ile adadaki İslamlar ya da Müslümanlar şeklinde bahsedildiğine dair bazı veriler tespit edilmiştir. Muhtemelen "Türk" kelimesinin dışında daha geniş kitleleri ilgilendiren "İslam" ve "Müslüman" kelimeleri uluslararası bir siyasi manevra olarak tercih edilmiş olmalıdır.

1923 yılına ait başka bir Osmanlıca vesikada ise Kıbrıslı Rumların bir takım isyanlar çıkartarak adanın Yunanistan'a terkini talep ettikleri anlaşılır. Kıbrıslı Rumların bu ilhak girişimine karşı Ehali-yi İslamiye diye tanımlanan Türklerin protestolarından bahsedilmektedir. Bu protestolar adadaki varlığını sürdürmek isteyen İngilizler tarafından hoşnutlukla karşılanmıştır.

1923 yılına ait diğer bir evraktan da anlaşılacağı üzere Türkiye Büyük Millet Meclisi hükümeti Hariciye Vekaleti tarafından verilen bir ültimatom içeriğinde Kıbrıs'ın İngiltere'ye terk edilmediği bu nedenle Türkiye'de ikamet eden Kıbrıslılara İngiliz tebaası muamelesi yapılamayacağı hükmü vurgulanmaktadır. Anlaşılacağı üzere yeni kurulan Türkiye Cumhuriyeti milli mücadelenin bütün yorgunluğuna rağmen Kıbrıs adasındaki Türk varlığını muhafaza etmeye yönelik bir harici politika yürütmüştür. İngiltere'nin varlığının Kıbrıs adasında sorgulandığı bu süreçte Kıbrıs Türklerinin üzerinde artan Rum baskısı ve katliamları karşısında Türkiye'ye irtica eden Türklerin anavatana kabul edilmemeleri ve adaya geri gönderilmeleri Kıbrıs adasında Türk varlığını sürekliliğine yönelik bir politikanın varlığına işarettir.

Çalışmamızda daha 1920 ve 1923 yıllarında "Enosis" talebinde bulunan Rum kışkırtmacılığının önünden bağımsız bir irade sergileyen Müslüman Türkler ve Türkiye Cumhuriyetinin nasıl bir yol takip ettiğine dair veriler değerlendirilecektir.

Anahtar Kelimeler: Kıbrıs adası, Milli Mücadele, Enosis, İlhak, Türk Dış Politikası

ABSTRACT

The island of Cyprus, which was incorporated into the Ottoman Empire's sphere of influence in 1571 during the reign of Selim II, remained under Ottoman rule for a long time. The Treaty of San Stefano, signed after the 1877-1878 Ottoman-Russian War, known as the 93 War, was a treaty containing harsh terms. Due to the compromise reached between England and the Ottomans during the San Stefano Treaty process, Abdul Hamid II left the island of Cyprus under the protection of England. The pressure exerted by England and the Greeks, who received English support, on the Muslims on the island of Cyprus continued to increase in various periods.

A document written by the Ministry of Health in 1920 included some information about the island of Cyprus. According to this information, it is understood that certain measures were taken from 1912 onwards to prevent the spread of epidemic diseases on the island of Cyprus. In our opinion, the most important of these measures were the sanctions aimed at preventing Turkish Cypriots from traveling to the mainland. In this way, Turkish Cypriots were prevented from leaving the island under the pretext of epidemic diseases. Thus, the Turkish presence in the demographic structure of the island was preserved. However, with the end of the War of Independence, it is understood that in 1923, a large number of Turkish Cypriots wanted to seek refuge on the shores of the Republic of Turkey.

Some data has been found indicating that Turkish Cypriots are carefully referred to as Muslims or "Muslims" on the island. It is likely that the words "Islam" and "Muslim," which concern a broader group, were preferred as an international political maneuver, instead of the word "Turk."

Another Ottoman document from 1923 reveals that Greek Cypriots staged a series of rebellions demanding the cession of the island to Greece. The document mentions the protests of the Turks, defined as the "Islamic People," against the annexation attempt by the Greek Cypriots. These protests were welcomed by the British, who wished to maintain their presence on the island. As can be understood from another document from 1923, an ultimatum issued by the Ministry of Foreign Affairs of the Grand National Assembly of Turkey emphasized that Cyprus was not ceded to England, and therefore, Cypriots residing in Turkey could not be treated as British subjects. As can be understood, the newly established Republic of Turkey, despite the exhaustion of the national struggle, pursued a foreign policy aimed at preserving the Turkish presence on the island of Cyprus. In this period when the presence of England on the island of Cyprus was being questioned, the fact that Turks who sought refuge in Turkey in the face of increasing Greek pressure and massacres against Turkish Cypriots were not accepted into the mainland and were sent back to the island indicates the existence of a policy aimed at the continuity of the Turkish presence on the island of Cyprus. Our study will evaluate data on how Muslim Turks, demonstrating an independent will in the face of Greek provocations demanding "Enosis" as early as 1920 and 1923, and the path followed by the Republic of Turkey.

Key Words: Island of Cyprus,National Struggle ,Enosis, Annexation,Turkısh Foreign Policy

GİRİŞ

Kıbrıs adası Osmanlı Devleti'nin 1570-1571 yılları arasına yayılan uzun bir kuşatma ve fetih sürecinden sonra Osmanlı hakimiyetine girmiştir.Venediklilerin hakimiyetinde 1489 yılından beri bulunan ada nihayet bir islam toprağı haline dönüştürülmüştür.Kıbrıs adası 1878 yılına kadar Osmanlı toprağı olarak kalmış ancak bu tarihten sonra diplomatik açıdan İngiltere'nin arabuluculuğunu ve desteğini sağlamak amacıyla "defacto" koşullar çerçevesinde geçici bir süreliğine İngiltere Krallığı'na devredilmiştir.Ancak bu devir içerisinde adada bulunan Osmanlı vatandaşı Rumlar İstanbul'daki Fener Patrikanesi , Müslümanlar ise Şeyhülislamlık makamı üzerinden sahiplenilmeye devam edilmiştir.Özetle adadaki Osmanlı vatandaşlarının manevi sosyal ve hatta iktisadi varlıkları Osmanlı Devleti'nin hükümranlığı

kapsamında ele alınmıştır.İngiltere ise ; Rus Çarlığına karşı Osmanlı Devleti'ne siyasal açıdan desteklemesinin karşılıgı olarak Kıbrıs adasında ehemiyetli bir askeri üsse sahip olmuştur. Bu askeri üssün hiç kuşkusuz 1869 'dan itibaren aktif olarak faaliyet göstermeye başlayan Süveyş Kanalı üzerindeki etkisi büyüktür. Bu Süveyş Kanalı Ferdinard d. Lesseps tarafından on yıl içerisinde tamamlanarak hizmete alınması ile birlikte Hind Okyanusundaki kolonilerine kestirme bir yol elde etmiş olan İngiltere'nin iktisadi ve askeri nüfüz sahasını geliştirmesine yardımcı olmuştur.Ancak Süveyş Kanalı üzerindeki hakimiyetine devam ettirebilmesi için askeri bir lojistik üsse sahip olması elzem hale gelmiştir.Bilhassa Osmanlı Devleti'nin bu bölgede Fransa ve Rusya lehine uğramış olduğu güç ve otorite kaybı Süveyş Kanalı üzerindeki hegomanyasını riske atmaktadır.İngiltere'nin Süveyş Kanalı üzerindeki kontrolünü sürdürebilmesi için askeri bir deniz üssüne sahip olması büyük bir avantaj içerir.Ayrıca Osmanlı Ortadoğusunda Süveyşteki konumunu sağlamlaştırmak için yerel halklardan bazılarını yanına çekmesi gerekmiştir.Hristiyan Mısırlı Kıptiler ve Beyrut bölgesinde bulunan Ortodoks Maruniler üzerinde söz sahibi olan Rusya ve Fransa İngiltere'ye karşı avantajlı bir konumdadır.Osmanlı Ortadoğusunda metropollere yayılmış olarak bulunan "*Mizrahim*" yani Arap yahudileri İngiltere'nin Rusya –Fransa ve Osmanlı Devleti'ne karşı hedefledigi yerel işbirlikçiler olarak dikkat çeker.Bu amaçla İngiliz başbakanı Disrael Berlin Kongresinde Osmanlı'yı desteklemenin karşılığı olarak Kıbrıs adasının talep edilmesi yönünde bir politika hayata geçirmiştir.Kraliçe Victoria'nın desteğine ihtiyaç duyan bu yahudi Kıbrısı ziyone giden yolda ilk arzu bevud olarak ilan etmişti. Hedef Kıbrıs üzerinden Kudus ve civarı ile ilgili stratejik manevralar yapmaktı. Hatta bir ara Disraeli Etiyopyada da bir yahudi devleti kurma yıolunda bir strateji belirlemişti. İleride İtalyanlar bu proje üzerinden Etiyopyada da bir egemenlik arayışı içerisine girmişlerdir. Kıbrıs adasında yerleşmeye başlayan İngiliz donanması ve İngilteredeki İngiliz vatandaşı olan Yahudiler adada istihbari olarak örgütlenip Kudüs ve çevresinde ilk siyonist eylemlerine destek vermişlerdi. İngiliz vatandaşı olan Yahudiler fakir Kıbrıslı Rum ve Türk ailelerinin kızlarını ellerinden alınıp Filistindeki toprak sahibi zengin agalara peşkeş çekerek yerel toprak agalarını kontrolleri altına alıyorlardı (Yıldız,2025: 733). Kıbrıs adasındaki İngiltere'nin varlığı Disrael sayesinde koloniyel hedeflere ulaşma noktasında büyük bir avantaj saglamıştı.Napolyon'un Mısır seferi esnasında Kıbrıs adasında konuçlanmış olan İngiliz donanmasının Fransız birliklerine kolayça bertaraf etmesi jeopolitik üstünlügün İngiltere tarafından elde edildigi anlamını taşımaktaydı.İngiltere'nin Mizrahim halkı üzerinden yürütmüş oldugu istihbarat çalışmalarıda sonuç vermis Osmanlı Ortadoğusunda güvenilir yerel bir işbirlikçi unsur elde edilmişti.Çalışmamızda adada bulunan Rumların "Enosis" kalkışmalarından endişe duyan İngiltere ve Türk tarafının bu talepleri nasıl ele aldıkları akamete ugrattıkları konusu değerlendirilecektir.

Kıbrıs adası ile ilgili Osmanlı ve İngiltere arasındaki mütakabat çercevesinde 1914 yılına kadar devam etmiştir. Bu tarihe kadar İngiltere adadaki varlığının karşılığında Osmanlı Devleti'ne her yıl düzenli olarak bir kira bedeli ödemiştir.Bu kira bedelinin Osmanlı Devleti'nin Kıbrıs adasından alacagı vergiye eş değer olduğu iddia edilebilir.Arşivlerden elde etmiş olduğumuz bir belge içeriğinde bu iddiamızı doğrulayacak bir kayıda rastlanmıştır. Osmanlı Maliye Nezaretine ait olan bu evrakta İngiltere'nin Osmanlı Devleti'ne 1296 tarihinde imzalanan antlaşma gereğince yıllık 30 bin lira ile 4 milyon atik kıyye tuz verileceği belirtilir. İncelediğimiz Osmanlıca resmi yazışma kaydında İngilizlerin 1919 yılına kadar her sene 30 bin altın lira-yı Osmaniyeyi düzenli olarak ödedikleri anlaşılır. Ancak İngilizlerin her sene ödemeyi taadüt ettikleri 4 milyon atik kıyye tuzu (atik kıyye: 1.282 kilo gram) vermeyi ihmal ettikleri anlaşılmaktadır. Arşiv kaydında tuzla ilgili bu ödemenin 39 seneden beri yapılmadığı ve toplamda meblagının 156 milyon atik kıyye tuza ulaştığı ve Sulh Kongresi İngiltereden Osmanlı Hükümeti tarafından talep edildiği ifade edilmiştir. Hatta Osmanlı Meclis-I Vükelasında görüşülen bu mesele üzerine birde karar alınmıştı. Bu kararda şu ifadeler yer almaktadır: " *Cezirede kain Memlihalardan çıkarılmakta olan tuzun sarfiyat-I dahiliyeden fazlasının Hükümet-I Seniyyeye itası hakkında Sefaret-i Müşarüleyhaya işarın tekidine luzum gösterildi*." (DABOA, HR.UHM.,204-38, M-13.05.1919). Osmanlı Meclis-i Vükelası'nda alınan bu karar Mondoros Mütarekesine giden ateşkes görüşmeleri çerçevesinde İngiliz Sefaretine hatırlatılmıştı. Bu hatırlatma I. Dünya Savaşına son verecek olan anlaşma öncesi uygulamaya koyulan müterake şartları ile ilgili düzenlenen Sulh Konferansında ele alması dikkat çekicidir.Türklerin Kıbrıs adasını İngilizlere seneliği 30 bin altın lira ve 4 milyon atik kıyye tuz karşılığında kiraladıkları ve ada üzerindeki hükümranlık haklarının devam ettiği anlamına gelir.

Yine benzer şekilde Kıbrıs adasındaki Rum ve Türk halklarının eğitimlerine kültür ve sanat a1maçlı çıkarttıkları matbuata müdahele edilmemiştir.Kiliseler ve Camiler Osmanlı Devletinde oldugu gibi yine İstanbuldaki dini otoriteler tarafından sevk ve idare edilmiştir.Ancak 1914-1918 yılları arasında sürecek olan I.Dünya Savaşı başladıgında İngiltere tek taraflı olarak kendisine kiralanmış olan adayı ilhak ederek kendi toprakalarına kattıgını ilan etmiştir (Emgilli,2013:113). Bu ilhak girişimine ragmen İngilizlerin ada halkı üzerinde söz sahibi olamadıgı değerlendirmek mümkündür.

I.Dünya Savaşı devam ederken İngiliz hakimiyeti altında bulunan Kıbrıs adasında iki farklı eğilimin ortaya çıkmasıda kaçılmaz hale gelmişti. Kıbrıs Türk eğitimi Kibris adası içerisinde İngiliz sömürge hükümetinin baskılarına marus kalmıştı.Bilhassa Milli mücadelenin başarıya ulaşmasına baglı olarak kurulan yeni Türkiye Cumhuriyeti mevcutta bulunan bu paröalanmayı daha da derinleştirmişti.1878 sonrası adada İngiliz varlığını kendine bir garanti olarak gören Evkafçılar ile Türkiye Cumhuriyeti kurulduktan sonra Atatürk devrimlerinden etkilenen Ulusalcı yerel Kıbrıs Türk azınlığı kendilerini Halkçılar olarak tanımlamaktaydı. (Akgün 2017: 1154). Bu durum bize Kıbrıs adası üzerinde ingilizlerin bütün tarafları temsil edemediğini degerlendirmemize neden olur.Ayrıca Arşiv kaynaklarından elde ettiğmiz bazı verilerde İngilizlerin Rumlar üzerinde de söz sahibi olamadıklarını belirtmek gerekir.Özetle Enosis faaaliyetleri 1968- veya 1974 de ortaya çıkmış değildir.Hatta bazı yazarlarımız Enosis'i 1931 yılında sömürge hükümetine karşı çıkan adalı Rumların bir sorunu olarak degerlendirmesi doğru bir yaklaşım değildir.(Güneş,vd,2018: 111) Arşiv çalışmaları üzerinde gerçekleştirdiğimiz tespitlerde Rumların Enosis sevdalarının 1918 yılında İstanbul'u işgal etmiş olan İngilizlerin yanında yer almalarından anlamak mümkündür.İstanbulda bulunan İngiliz işgal kuvvetlerinin Kıbrıstan katılan gönüllü Rum askerleri Maltepe 'de Türk jandarması üzerine keyfi ateş açması ile ilgili arşiv kayıtları bizlere Rumların dizçöktürülen Osmanlı Devleti'ne karşı İngilizlere sağladıkları katkıyı anımsamamıza yardımcı olur.İlgili arşiv belgesinde "Maltepede İngiliz Kıtaatına mensup 30 kişiden mürekkep Kıbrıs Rumlarının işret ederek Maltepe Jandarma devriyesi üzerine silah endat ettiklerinden dolayı tarafeyn arasında müsademe vuku' bulduğu ve Maltepedeki Osmanlı Teyyare Müfreze-i Askeriyesinde müsademeye iştirak eylemesi neticede Osmanlı Teyyare Müfrezesinden bir neferin mecruh ve İngiliz Kıbrıs Rumlarından iki askerin maktul düştüğü …." şeklinde tanımlanan hadise bizlere cihan harbi esnasında adalı Rumların İngilizlerin yanında olduğunu ıspatlar. (DABOA, DH.EUM.AYŞ. No 24-13, H 17.01.1338.). Ancak bu belgede dikkat çekici olan Kıbrıs adasının tamamı İngilizlerin hakimiyetinde olmasına ragmen İngiliz birlikleri arasında Kıbrıslı Türklerden bahsedilmez. Ayrıca İngiliz birliklerinde yer alan Kıbrıslı Rumların ,Türklerle girişmiş oldukları çatışma sonucunda İngiliz ordusunun ünifoırması altında bulunmalarına ragmen iki kayıp verdikleri anlaşılır.Özetle hangi ordunun uşaklığını yaparlarsa yapsınlar Türklerle olan bir oyun Rumlar açısından hep kanla sonuçlanmıştır. Bu olay bizlere adadaki Rumlar üzerinde göreceli olarak İngilizlerin hakimiyet sağladığını değerlendirmemize vesile olsa da ilerleyen süreçteki gelişmeler bu durumun aksini ispatlar. Zira 1919 yılından itibaren Kıbrıslı Rumların İngiliz hakimiyetine aykırı olarak Yunanistanla birleşme yani Enosis faaliyetlerine başladıkları anlaşılır. Bilhassa 12 Agustos 1923 tarihinde Kıbrıs Rumlar adanın Yunanistan'a terkini çeşitli mitinglerle dünyaya deklare etmişlerdir. Ancak İngilizlerin adadaki varlığını sorgulayan bu eylemlere karşı Türkler tepki göstermiş dolaylı olarak adada İngiliz varlığının devamını talep etmişlerdir. Konuya dair hazırlanmış olan bir arşiv belgesi hem Osmanlı hemde İngilizce olarak arşivlerimize kayıtlıdır. İlgili belgede şunlar yazılıdır : "İngiltere Londrada müstemlekat nezaretine Kıbrısta hukuk ve arzu-ı İslamiye mügair Rum ahalisi tarafından icra olunan mitingde mevad-ı saire meyanında cezirenin Yunanistana terki talep olunmuş.. ehaliyi İslamiye protesto eyledigini ve bu babda lahiya derdest takdim oldugu maruzdur."(DABOA, Y.EE.KP.,No.39-3874,H.29.12.1341) İlgili belge Kıbrıslı Müslümanların Kıbrıslı Rumlar tarafından talep edilen Yunanistan Krallığı ile birleşme fikirlerine karşı çıktıkları ve bu durumu İngiliz makamlarını protesto ettiklerini anlamamıza yardımcı olur. Özetle bir anlamda İngilizlerin Kıbrıs adasındaki varlıkları adadaki Müslümanların kendilerine sundukları destege baglı bulunmaktadır.Ancak II.Dünya Savaşı'nda ve sonrasında yaşanan gelişmeler İngilizlerin adadaki varlıgını tekrar sorgulayacak ve Rum tarafının ısrarları üzerine İngilizlerin Dikelya ve Agrator üsleri dışında adadaki hegomanyaları sona erecektir.

Türk Hariciyesi ise Kıbrıstaki Müslümanlara yönelik ilgi ve alakasını hep canlı tutmuştur. 1922 tarihine uzanan bir belge Kıbrıstaki Osmanlı halkının salgın hastalıklara yakalanmaması noktasında tahakkuz halinde olduğunu bizlere ispatlar.(DABOA, HR .HMŞ.İŞO.,no 6422, R.26.07.1338) Kıbrıs ile ilgili Türk tarafının müdahalelerini sadece bu konu ile sınırlı degildir. Bihassa 1920 yılında adadaki

Kıbrıs Türk okulları için bir eğitim yasası çıkarılmıştır. Bu yasa ile birlikte Kıbrıs Türk eğitiminin en üst karar organı olan Kıbrıs Türk Maarif Encümeni'nin pek çok kararı Yüksek Komiser'in onayına bağlanmıştı.Türk Maarif Encümeni Müfredat , ders kitapları ve benzeri konularda düzenleme yapma yetkisini devam ettirirken açılacak okullar öğretmenlerin tayinleri gibi konulardaki yetki Encümen'in elinden alınarak Yüksek Komiser'e bırakılmıştı. Dolayısıyla bu yasa sonrasında sömürge hükümeti, Kıbrıs Türklerin eğitimi konusu üzerinde yetkisini artırmıştır(Güneş, vd,2018:116).Bu karara Kıbrıslı Türkler itiraz ederek Kıbrısta bulunan Türk toplumunun kültürel baglarının zayıflatacagını öne sürmüşlerdi.Ayrıca bir diğer problemde Türkiyeden gelerek Kıbrıstaki okullarda ögretmenlik yapan kişilerin varlığı ile ilgili ortaya cıkan belirsizlikti. (Güneş,vd,2018: 117)

Kıbrıs adasında 1878 yılından beri varlığı bilinen Evkafçılar Rumların Enosis idallerini engellemenin Kıbrıslı Türklerin menfaatlerinin sömürge hükümeti ile iyi ilişkiler geliştirmekle mümkün olacağına inanmaktaydılar (Benkingham,1956:128). Kıbrıs adasındaki Evkafçı Türklerin bu gayretleri İngilizlerin taktirine mazhar olmuş ve bazı müdahalelerle Evkafçıların Kıbrıs Türkleri arasında etkin bir konuma yükselmelerine yardım etmişti.Buna örnek olarak Kıbrıs adasında bulunan başkadı ve müftünün Evkaf müdürü karşısındaki siyasi rekabeti sonucunda İngilizler Evkafçıların tarafını tutarak başkadı ve müftülük makamlarını lağederek sadece Evkaf müdüriyetinin varlığına müsade etmişlerdi.Elbetteki bu siyasi çekişme Kıbrıslıların Türk eğitimi konusundaki taleplerini tamamen akamete uğratmıştı. Zira eğitim konusunda kadılık ve müftülük makamları söz ve yetki sahibi idi (Güneş,vd,2018:117)

1920 yılında Anadolu'da korkunç bir kıyım yaşanırken Kıbrısta yayın faaliyetinde bulunan "*Ankebut*" adlı gazetede Mustafa Kemal ve onun milli mücadeledeki faaliyetleri desteklenmekte ve övgüyle bahsedilmekteydi.Hatta bu gazete içinde yer alan bir şiir içeriğinde "*Ey güzel Istanbul! yoluna sehit oldu çok Kıbrıslılar* " ibaresi milli mücadelede Kıbrıs Türklerinin de yer almış olma ihtimalini akıllara getirir.Kıbrıs Türkleri her ne kadar İngiliz yönetiminden şikayet etmese de Anavatana baglanma konusundaki savaşın sonunda arzularını declare etmişlerdir.Bafta toplanan büyük bir kalabalık Kıbrıs Türklerinin milli ve dini emellerinin Lozan Konferansı'nda dikkate alınmasını talep etmişti.(Emgilli,2013:113). 1920 tarihinde başlayan bu bilinçlenme Enosis emelinde bulunan Rumlara karşıda Türk tarafının reaksiyonlarına dayanak oluşturuyordu.

Türkiye'nin Lozan Antlaşması'nda Kıbrısta yaşayan Türklerin hukuki durumu ile ilgili karara bağladığı 16-20-21. Maddeler Türk Hariciyesi'nin Kıbrıs meselesini bu kritik dönemde dondurduğu şeklinde değerlendirilebilir.Milli Mücadele'nin uluslarası siyaset zemininde başarıya ulaşmasının tek yolu süper güçlerin Lozanda Ankara Hükümeti'ne verecekleri onaya tabi idi.Bu kapsamda genç Türk Devleti İngiltereyi müzakerelerde yanına çekmek ve Yunanlılarda cephede yaptıgı mücadelede yaptıgı kazanımları garanti altına almaya çalışmıştır.Özetle Genç Türk Devleti'nin teknik ve askeri imkanları Kıbrıs adasına müdahale edebilecek düzeyde olmadıgı için şimdilik adadaki Türk varlığının İngiliz himayesi altında Rumlara karşı mühafazası en mantıklı çözüm olarak ele alınmıştır.Lozandaki ilgili 16.maddedeki ifadeler bu değerlendirmemizi doğrular niteliktedir.Bu maddede " Bu antlaşma ile üzerinde kendi eğemenlik hakkı tanınmış bulunanlar dışındaki adalarda – ki bu toprak ve adaların gelecegi ilgililerce saplanmış yada saplanacaktır.- Her ne nitelikte olursa olsun sahip oldugu tüm hak ve senetlerden vazgeçtigini açıklar." Oldukça grift bir tanım olmakla beraber bu hükümde yer alan "adaların gelecegi ilgililerce saplanmış yada saptanacaktır" şartı dikkatle değerlendirilmelidir. Zira Kıbrıs adası üzerinde Berlin Antlaşması'ndan itibaren Türklere tanımlanmış bir egemenlik hakkı söz konusudur.(Emgilli,2013:113)

Lozan Antlaşması'na müteakıp süreçte Kıbrıs Türkleri anlaşma uyarınca kendilerine tanınan seçme hakkını kullanarak Türkiye Cumhuriyeti uyruğuna geçerek Türkiye'ye göç etmeye başlamışlardı. Türk tarafı ise bu uygulamayı bu sabote etmeye yönelik bazı zorlayıcı engeller ortaya koymaktaydı.Kıbrıslı Türklere İngilizlerce iki seçenek sunulmuştu. Ya İngiliz tabiyetinde kalacaklar ya da Türkiye Cumhuriyeti uyruguna geçeceklerdi. (Emgilli,2013:114) Türk tarafı adada Türk varlığının devamını sağlamak amacıyla adadan göçenlere basın yoluyla bilinçlendiren haberler yayılmaktaydı. Ayrıca Kıbrıslı göçmenlerin göç esnasında bütün masrafları kendilerinin karşılmasına yönelik alınan kararlar maddi durumu iyi olmayan kesimin göçüne engel teşkil etmişti.1923-1925 yılları arasında yaşanan bu gelişmeler Türk tarafının bir şekilde Türk varlığını adada korumaya çalıştıgını değerlendirmemize neden olur. Arşivlerden elde ettiğimiz bir resmi evrakta 11 haziran 1923 tarihi itibariyle adadan yaşanan göçün kaynağını; "Kıbrısta *bazı müslümanların sahillerimize ilticaya*

başladıkları ve bu muhacireyinin adada İslamlara karşı bu günlerde tazyiki siyaseti tatbik edilmesine mütevellit olduğu" şeklinde özetlemek mümkündür. (DABOA, HR.İM. , 48-47 , M.11.06.1923)

Kıbrıs adası ile ilgili Türk tarafının niyetleri 1923 Haziran ayına ait bir belgede net bir şekilde ortaya koyulmuştur. Bu belgede yer alan "*Kıbrıs Cezıresi nin el halet-i heza ahden İngiltere'ye terk edilmemiş …"*ibaresi bir deklerasyon niteligindedir. Lozanda ilgili maddelere rağmen bu ifadenin Türkiye Büyük Millet Meclisi Hükümet-i Hariciye Vekaleti üzerinden resmi olarak deklerasyonu Türk tarafının adadaki varlığını mühafazaya yönelik bir gayret olarak ele alınabilir.(DABOA,HR.İM. 75-42,M.06.06.1923.) Bu temayülün Kıbrısta'da karşılık bulduğunu kanıtlayan belgeler bulunur.1923 yılında Nicosia Türk esnafı bu konuda önemli bir kanıt teşkil eder.Bu belgede Türk esnafı Türkiye'deki bagımsızlık mücadelesini başarıya ulaşması ve Cumhuriyet'in ilanını tebrik eden bir yazı kaleme almıştır. Bu tebrik telgrafında şu ifadeler yer alır : *"Kıbrıs'ta Nikozya Türk esnafı tarafından keşide edilen bir telgrafta…ettirilen Türkiye'nin hürriyetini iade içün dua-yı İslami-i müebbet bir aradan kurtarılan Büyük Millet Meclisi'nin sene-i devriyesi münasebetiyle beyan-i tebrigat edilmektedir Efendim"*.(DABOA,HR.İM., 72-16,M-24.04.1923.) İlgili telgraf metninde Türkiye'nin hürriyeti için yapılan dua-yı İslami ve Büyük Millet Meclisi'nin kuruluşunun sene-i devriyesi münasebetiyle çekilenen tebrikleri ifade eden cümleler, Kıbrısdaki Türklerin anavatana olan bağlılıklarını tesciller niteliktedir.

Sonuç

Kıbrıs adası Türkiye açısından stratejik ehemmiyete sahip bir coğrafi lokasyonda bulunur. Doğu Akdenizin ortasında yer alan adanın mavi vatan konseptinde önemli bir istasyon olduğu gözlerden kaçmaz. Osmanlı Devleti de stratejik önemine binaen Kıbrıs adası üzerinde askeri bir operasyon gerçekleştirmiş ve 1571 yılında adayı Osmanlı topraklarına katmıştır. Ancak bu adanın fethi esnasında İnebahtı'da kaybedilen Osmanlı donanması ağır bir bedel olarak karşımıza çıkar. Kıbrıs adasının 1878 tarihli antlaşma ile İngiltere'ye kiralanmasına kadar geçen süre zarfında Osmanlı Devleti tarafından yönetildiğini belirtmek gerekir.

Venediklilerden alınan Kıbrıs adası üzerine, Osmanlı Ortodoksları ve Müslümanlar bizzat Osmanlı tarafından iskan edilmişlerdir. Katolik Venediklilerin idaresi altında bulunan Kıbrıs adasındaki Ortodoks Rum azınlık Katolik baskısı nedeniyle mezhebini degiştirmiş yada değiştirmek zorunda kalmıştır. Osmanlı Devleti Kıbrıs adasını fethettikten sonra Kapadokya bölgesinden Ortodoksları ve Ermenak yöresinden de Tahtacı yörüklerini adaya yerleştirerek demografik yapıyı değiştirmiştir. İngiltere'ye yıllık 30 bin altın Osmanlı lirası ve 4 milyon atik kıyye tuz karşılığında kiraya verilen ada üzerinde ve adadaki Osmanlı Hristiyan ve Müslüman Osmanlı vatandaşları üzerindeki hükümranlık hakları devam etmiştir.

I.Dünya Harbinde İngilizlerin savaş sebebiyle uluslararası hukuku yok sayarak bir oldu-bitti ile Kıbrıs üzerinde Türk tarafının hükümranlık haklarını tek taraflı olarak ilgası kabul edilemez. Gerek mütareke gerekse milli mücadele dönemlerinde hem Kıbrıs halkının hemde Türk tarafının yetkili mercileri olarak Kabul gören İstanbul ve Ankara Hükümetlerinin Kıbrısta egemenlik haklarından herhangi bir taviz vermedikleri aksine İngiltereye bu ada üzerindeki varlıklarına yönelik resmi kanallardan hatırlatmalarda bulunduklarını belirtmek gerekir.

Türkiye Cumhuriyeti'nin ve son demlerinde Osmanlı Devleti'nin Kıbrıs adasında baş gösteren Yunan Krallığı ile ilhak girişimleri karşında İngiltere'ye adadaki varlığını sürdürme noktasında destek çıktıkları anlaşılır. Türkiye Cumhuriyeti yetkililerinin "Enosis" e karşı İngilizlere destek vermekle beraber Rum tethiş örgütlerinin baskılarından bunalan Türklerin anavatana göçlerini caydırıcı önlemler aldıgını tespit etmiş bulunmaktayız. Bu önlemlerden en akılcı olanı adada cereyan eden salgın hastalıkları bahane ederek karantina uygulamalarını katı bir şekilde tatbik ve salgın gerekçesi ile göçmenlerin kabul edilmemesine yönelik faaliyeterdir. Salgın hastalıklar karşısında hassas olan Uluslararası kamuoyunun adadaki Türk nüfusuna karşı aldığı sağlık temelli bu uygulamaları makul bulunmuştur. Salgın hastalık riski karşısında kendilerini güvence altına almak isteyen tali ülkelerde göçün engellenmesi yönünde ki talepleri adalı Rumları göçün sebebi olan Tükler üzerindeki baskı unsurunu hafifletmiş olmalıdır.

II.Dünya Savaşında İngiltere'ye bilhassa Kuzey Afrikadaki cephelerde Kıbrısın eşekleriyle su taşıyan Rum su katır birliklerine verilen vaadler karşılığında Kıbrıs'da yeniden "Enosis " için zemin hazırlanmıştır. Kıbrıslı Rumlar, II.Dünya Savaşında İngilizlere verdikleri destek karşılığında adada bağımsız olmak istediklerini beyan etmişlerdir. İngiltere ise 1950 -1960 yıllarda adadaki Rumlar tarafından başlatılan bağımsızlık yönündeki talepleri engellemek üzere toplantılara Türkiye Cumhuriyeti'ni de davet etmiştir. Ancak adadaki Rumların İngiliz hakimiyetini sonlandıran girişimleri karşılık bulmuş adadaki İngiliz sömürge valisi çekilmiş ve İngiltere'ye adada iki askeri üs bölgesi bırakılmak suretiyle İngilizlerin adayı terk etmeleri sağlanmıştır. Ancak usta İngiliz siyaseti yapılan müzakerelerde Türkiye Cumhuriyetini adadaki Müslümanlar üzerinde garantör devlet ilan etmek suretiyle adayı Rumlara yar etmemiştir. Rum tarafı ise İngiltere'yi adadan uzaklaştırmanın zafer sarhoşluğu içerisinde Türk tarafını da imha politikasını uygulamaya koyması gaflet ve delaletin en büyügüdür. İngiltere'nin siyaseti etkili olmuş Türkiye Cumhuriyeti bile isteye adaya müdahaleye zorlanmıştır. Kıbrıs adasında fiili olarak katledilen soydaşlarını korumak üzere adaya askeri operasyon düzenlemek zorunda kalan Türkiye Cumhuriyeti 1974 sonrası Yunan diasporasının uluslararası saldırılarına maruz kalmıştır. İngiltere ise Yunanlıların adadaki Türk varlığını sona erdirdikten sonra adadaki İngiliz askeri üslerinin varlığının sorgulanacağının farkındadır. Ancak, Türkiye Cumhuriyeti'nin adaya zorunlu müdahalesi, İngiliz askeri üslerinin de adadaki konumunu güçlendirmiştir. Başlangıçta İngilizleri adada istemeyen Rumlar, ortaya çıkan Türk tehditi karşısında İngiliz askeri üslerini bir güvence olarak kabullenmek zorunda kalmışlardır. Özetle Kıbrısta Türkiye Cumhuriyeti ve Türklerin varlığı bu adada yer alan İngiliz askeri üslerinin de devamlılığını "de facto" garanti altına almıştır.

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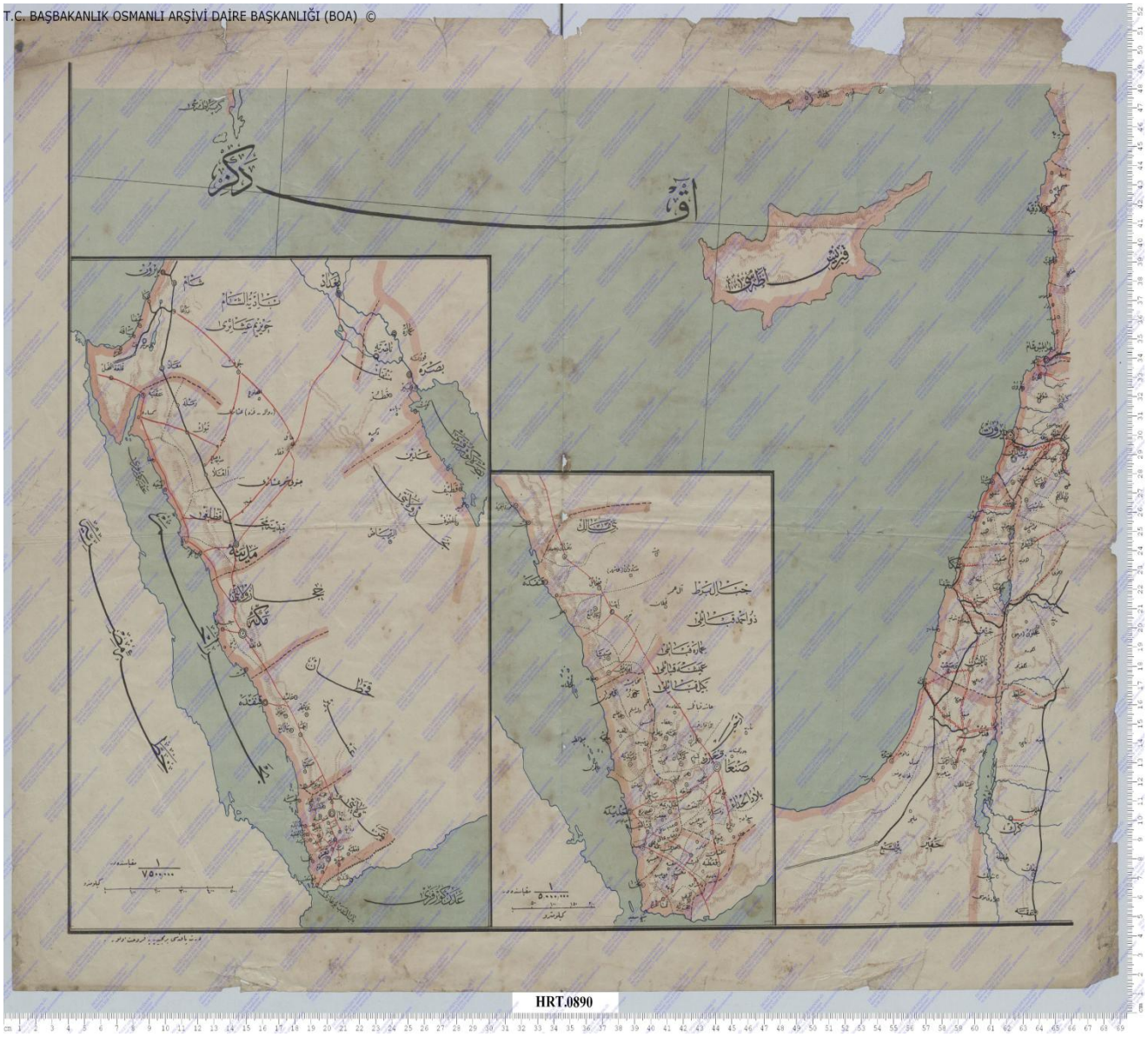
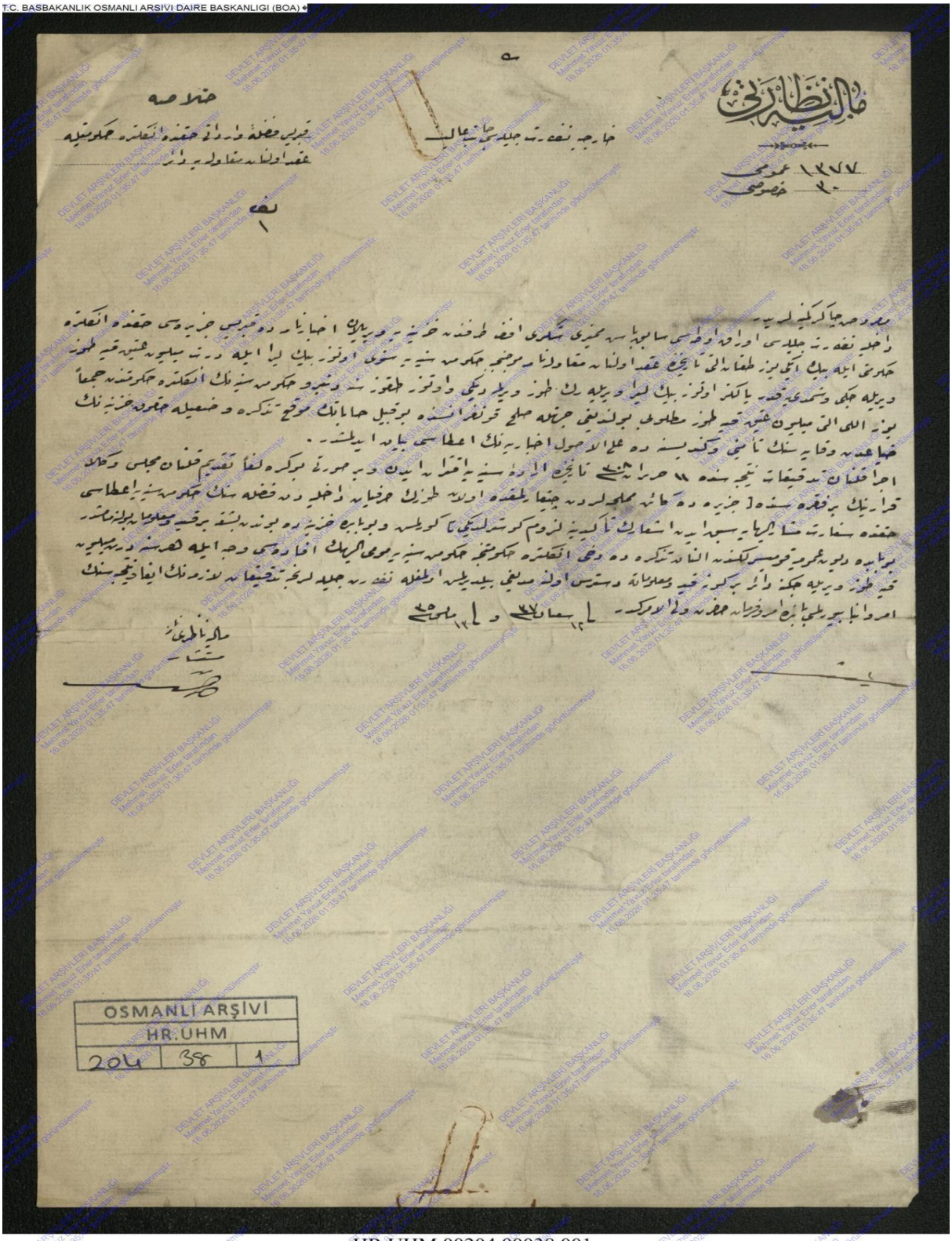
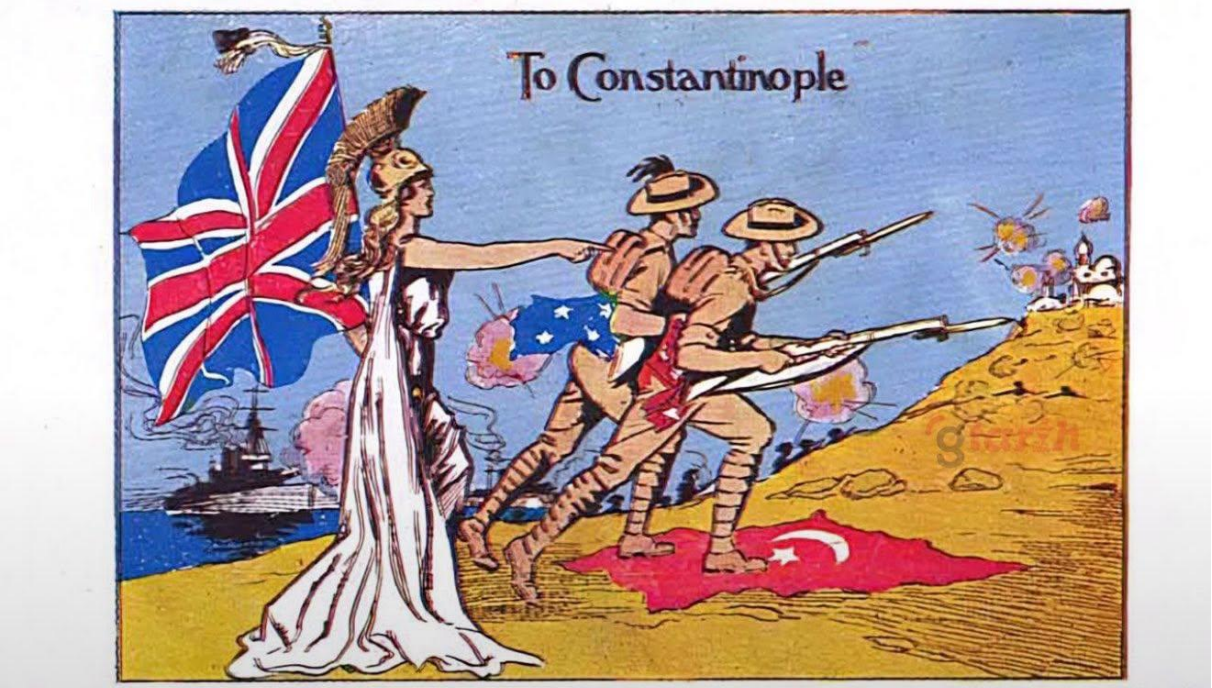
Resim I: DABOA., HRT.h., No. 890, H.29.12.1341.



Resim II: DABOA., HR.UHM., No. 204-38, M.13.05.1919.



HR.UHM.00204.00038.001


To Constantinople
Britannia called, and swift ere the trumpets echoes died away,
The gathering forces of her children marched in stern array,
From Ice-bound shores and India's burning strand
From wave-tipped Isles and Austral's sunny land,
To do or die they came, Brave Heroes of the Dardanelles.

AN EXAMINATION OF CRADLE BETROTHAL MARRIAGE AS AN OATH RITUAL WITHIN THE SOCIOLOGY OF EMOTIONS

ANT İÇME RİTÜELİ OLARAK BEŞİK KERTMESİ EVLİLİĞİNİN DUYGU SOSYOLOJİSİ BAĞLAMINDA İNCELENMESİ

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Özet

Beşik kertmesi evliliği, geleneksel toplum yapısında aileler arasında verilen söz ve sadakat anlayışına dayanan kültürel bir evlilik biçimidir. Modernleşme ve kentleşme süreçleriyle birlikte büyük ölçüde ortadan kalkmış olsa da bu evlilik biçiminin bireylerin duygu dünyası üzerindeki etkileri sosyolojik açıdan önemini korumaktadır. Bu araştırmanın amacı, beşik kertmesi yoluyla evlenmiş bireylerin evlilik deneyimlerini duygu sosyolojisi perspektifinden incelemek; söz verme, kadercilik, toplumsal denetim ve aile otoritesinin bireylerin duygusal yaşantılarını nasıl şekillendirdiğini ortaya koymaktır.

Araştırmada nitel araştırma yöntemi benimsenmiş, fenomenolojik desen kullanılmıştır. Çalışma grubu, kartopu örnekleme yöntemiyle belirlenen 10 katılımcıdan (5 kadın, 5 erkek) oluşmaktadır. Katılımcılarla yarı yapılandırılmış derinlemesine görüşmeler gerçekleştirilmiş, elde edilen veriler betimsel analiz yöntemiyle değerlendirilmiştir.

Araştırma bulguları, beşik kertmesi evliliklerinde bireylerin evlilik kararına aktif olarak katılamadıklarını, aile büyüklerinin kararlarının belirleyici olduğunu göstermektedir. Katılımcılar, çocukluk döneminden itibaren kadercilik anlayışı doğrultusunda evliliği kabullenmeye yönlendirilmiş; mutsuzluk, çaresizlik, korku, öfke ve değersizlik gibi yoğun duygular yaşadıklarını ifade etmişlerdir. Erkek katılımcılar da benzer biçimde aile baskısı ve toplumsal beklentiler nedeniyle kendi tercihlerini ortaya koyamadıklarını belirtmişlerdir. Bununla birlikte, bazı katılımcılar zaman içerisinde evliliklerine uyum sağlayarak aidiyet ve sorumluluk duygularının geliştiğini dile getirmiştir.

Sonuç olarak çalışma, beşik kertmesi evliliklerinin hem kültürel bir gelenek hem de bireylerin duygu dünyasını biçimlendiren güçlü bir toplumsal mekanizma olduğunu göstermektedir. Araştırma, geleneksel evlilik pratiklerinin duygu sosyolojisi perspektifinden değerlendirilmesine katkı sunarak literatüre yeni bir bakış açısı kazandırmayı amaçlamaktadır.

Anahtar Kelimeler: Beşik kertmesi, evlilik, duygu sosyolojisi, geleneksel evlilik, toplumsal denetim, kadercilik.

ABSTRACT

Cradle betrothal marriage is a traditional form of marriage based on family promises, loyalty, and social commitment. Although this practice has largely disappeared with modernization and urbanization, its emotional and sociological consequences continue to deserve scholarly attention. This study aims to examine the experiences of individuals who entered cradle betrothal marriages from the perspective of the sociology of emotions, focusing on how family authority, fatalism, social control, and the ritual of promise shape emotional experiences.

The study employs a qualitative phenomenological research design. The study group consists of 10 participants (5 women and 5 men) selected through snowball sampling. Data were collected through semi-structured in-depth interviews and analyzed using descriptive analysis.

The findings indicate that participants had little or no involvement in the decision-making process regarding marriage, while family elders played the dominant role. Participants reported that they were encouraged to accept their marriages from childhood through fatalistic beliefs and social expectations.

Feelings of helplessness, unhappiness, fear, anger, and worthlessness emerged as common emotional experiences. Male participants also emphasized that social pressure and family expectations restricted their personal choices. Nevertheless, some participants stated that over time they developed adaptation, responsibility, and a sense of belonging within their marriages.

Consequently, the study demonstrates that cradle-betrothal marriages function both as a cultural tradition and as a powerful social mechanism that shapes the emotional worlds of individuals. By examining this traditional marriage practice through the sociology of emotions, the study contributes to the literature by offering a broader understanding of the interaction between culture, family authority, and emotional experience.

Keywords: Cradle betrothal, marriage, sociology of emotions, traditional marriage, social control, fatalism.

THE DYNAMICS AND CHALLENGES OF ESTABLISHING DIPLOMATIC RELATIONS BETWEEN CENTRAL ASIAN STATES AND ARMENIA

MERKEZİ ASYA DEVLETLERİ İLE ERMENİSTAN ARASINDA DİPLOMATİK İLİŞKİLERİN KURULMASININ DİNAMİKLERİ VE ZORLUKLARI

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Özet

Bu makale, Merkezi Asya devletleri ile Ermenistan Cumhuriyeti arasındaki ikili ilişkilerin kurulması ve kademeli gelişimi ile ilişkili yapısal dinamikleri, diplomatik evrimi ve sistemik zorlukları kapsamlı bir şekilde incelemektedir. Sovyet sonrası dönemde bu ikili etkileşimler; daha geniş Avrasya jeopolitik konfigürasyonları, katı örgütsel taahhütler, çok taraflı ittifaklar ve uzayıp giden bölgesel çatışmalardan ağır bir şekilde etkilenmiş ve sıklıkla kısıtlanmıştır. Merkezi Asya başkentleri tarihsel olarak Erivan ile Bağımsız Devletler Topluluğu (BDT) ve Kolektif Güvenlik Antlaşması Örgütü (KGAÖ) gibi çok taraflı çerçeveler aracılığıyla kurumsal teması sürdürmüş olsa da, güçlü, bağımsız ve derinlemesine entegre olmuş ikili bir diplomatik mimari oluşturmak sürekli zorluklarla ve stratejik sınırlamalarla karşılaşmıştır.

Bu çalışma; başta Kazakistan ve Özbekistan olmak üzere kilit Merkezi Asya aktörlerinin, Ermenistan ile resmi temaslarının yanı sıra Azerbaycan ile olan stratejik ortaklıklarını ve Türk dayanışmasını dikkatle yönetirken izledikleri diplomatik stratejileri eleştirel bir analizden geçirmektedir. Resmi dış politika doktrinlerinin, ikili diplomatik misyonların ve üst düzey devlet açıklamalarının ayrıntılı nitel analizi aracılığıyla çalışma; tarihsel mirasların, etnik dayanışmanın, ekonomik bağımlılıkların ve güncel bölgesel yeniden hizalanmaların bu karmaşık siyasi etkileşimlerin sınırlarını nasıl şekillendirdiğini vurgulamaktadır.

Ayrıca çalışma, denize kıyısı olmayan bu cumhuriyetlerin; kritik jeoekonomik rasyonelliklerinden, ticaret rotalarından ve enerji koridorlarından taviz vermeksizin bölgesel esnekliklerini ve stratejik özerkliklerini azami düzeye çıkarmak adına karmaşık çok yönlü devlet yönetimini ve temkinli diplomatik dengeleme yöntemlerini nasıl uyguladıklarını araştırmaktadır. Araştırma; kurumsal engellerin, çakışan antlaşma yükümlülüklerinin ve çelişen stratejik çıkarların devam eden engeller oluşturmasına rağmen, proaktif diplomasinin, ekonomik çeşitlendirmenin ve "orta ölçekli güç" arabuluculuk çerçevelerinin; daha geniş Avrasya coğrafyasında diplomatik istikrar, uyuşmazlıkların çözümü ve uzun vadeli siyasi denge için uygulanabilir yeni yollar sunduğu sonucuna varmaktadır.

Anahtar Kelimeler: Merkezi Asya, Ermenistan, İkili diplomasi, Güney Kafkasya

ABSTRACT

This article comprehensively examines the structural dynamics, diplomatic evolution, and systemic challenges associated with the establishment and progressive development of bilateral relations between Central Asian states and the Republic of Armenia. In the post-Soviet era, these bilateral interactions have been heavily influenced, and frequently constrained, by wider Eurasian geopolitical configurations, rigid organizational commitments, multilateral alliances, and protracted regional conflicts. While Central Asian capitals have historically maintained institutional contact with Yerevan through multilateral frameworks like the Commonwealth of Independent States (CIS) and the Collective Security Treaty Organization (CSTO), creating a robust, independent, and deeply integrated bilateral diplomatic architecture has faced persistent challenges and strategic limitations.

This paper critically analyzes the diplomatic strategies of key Central Asian actors, particularly Kazakhstan and Uzbekistan, as they carefully navigate their strategic partnerships and Turkic solidarity with Azerbaijan alongside their formal engagement with Armenia. Through a detailed qualitative analysis of official foreign policy doctrines, bilateral diplomatic missions, and high-level state statements, the study highlights how historical legacies, ethnic solidarity, economic dependencies, and contemporary regional realignments shape the boundaries of these complex political interactions.

Furthermore, the study explores how these landlocked republics employ sophisticated multi-vector statecraft and cautious diplomatic balancing to maximize their regional flexibility and strategic autonomy without compromising their critical geoeconomic rationality, trade routes, and energy corridors. The research concludes that while institutional barriers, overlapping treaty obligations, and conflicting strategic interests present ongoing obstacles, proactive diplomacy, economic diversification, and "middle-power" mediation frameworks offer viable new pathways for diplomatic stabilization, conflict resolution, and long-term political equilibrium across the wider Eurasian space.

Keywords: Central Asia, Armenia, Bilateral diplomacy, South Caucasus

GİRİŞ

Sovyet Sosyalist Cumhuriyetler Birliği'nin (SSCB) 1991 yılında dağılması, Avrasya coğrafyasında uluslararası ilişkiler sisteminin yeniden biçimlenmesine ve bağımsızlığını yeni kazanan devletlerin kendi egemen dış politikalarını oluşturma sürecine zemin hazırlamıştır. Bu tarihsel kırılma anından itibaren Merkezi Asya cumhuriyetleri (Kazakistan, Özbekistan, Kırgızistan, Türkmenistan ve Tacikistan) ile Güney Kafkasya aktörlerinden biri olan Ermenistan Cumhuriyeti, yeni bölgesel gerçeklikler ışığında ikili ve çok taraflı ilişkilerini tanımlama ihtiyacı ile karşı karşıya kalmışlardır.

SSCB sonrası dönemde Merkezi Asya ile Ermenistan arasındaki diplomatik temaslar, temelde iki ana düzlemde gelişmiştir. Birinci düzlem, her iki bölge ülkesinin de üyesi olduğu Bağımsız Devletler Topluluğu (BDT) ve Kolektif Güvenlik Antlaşması Örgütü (KGAÖ) gibi bölgesel entegrasyon ve güvenlik mekanizmaları üzerinden yürütülen çok taraflı kurumsal diyalogdur. İkinci düzlem ise, tarafların bağımsız devletler olarak doğrudan tesis etmeye çalıştıkları ikili diplomatik, siyasi ve ekonomik ilişkiler altyapısıdır. Ancak geçen otuz yılı aşkın sürede, çok taraflı platformlardaki kurumsal temaslara rağmen, Merkezi Asya devletleri ile Ermenistan arasında derin, kapsamlı ve bağımsız bir ikili diplomatik mimarinin inşası ciddi stratejik kısıtlamalar ve sistemik engellerle karşılaşmıştır (Shiriyev, 2019, s. 73).

Bu durumun temelinde, Avrasya genelindeki jeopolitik denklem ve Güney Kafkasya'daki bölgesel dinamikler yatmaktadır. Özellikle Kazakistan ve Özbekistan gibi Merkezi Asya'nın kilit aktörleri, bir yandan Ermenistan ile resmi diplomatik bağlarını ve çok taraflı antlaşma yükümlülüklerini sürdürürken, diğer yandan Azerbaycan ile köklü stratejik ortaklıklarını, tarihsel-kültürel bağlarını ve Türk Devletleri Teşkilatı (TDT) bünyesindeki Türk dünyası dayanışmasını koruma gayreti içerisinde olmuşlardır (Aydın, 2021, s. 116). Qarabağ çatışması ve Azerbaycan-Ermenistan hattındaki gerilimler, Merkezi Asya devletlerinin Ermenistan ile olan ikili ilişkilerinin sınırlarını çizen en belirleyici dış faktörlerden biri haline gelmiştir.

Bunun yanı sıra, Merkezi Asya'daki karasal (denize kıyısı olmayan) devletlerin izlediği "çok yönlü" (*multi-vector*) dış politika anlayışı, bu ülkelerin jeoekonomik rasyonelliklerini ve stratejik özerkliklerini koruma arzusunu yansıtmaktadır. Enerji koridorları, küresel ticaret rotaları ve lojistik hatların güvenliği (özellikle Orta Koridor / Trans-Hazar Ulaşım Hattı), Merkezi Asya ülkelerini Güney Kafkasya politikasında temkinli bir dengeleme stratejisi izlemeye sevk etmektedir (Starr & Cornell, 2014, s. 35).

Bu çalışmanın temel amacı, Merkezi Asya devletleri ile Ermenistan arasındaki diplomatik ilişkilerin kurulumunu, tarihsel gelişimini, karşı karşıya kaldığı jeopolitik engelleri ve mevcut dinamiklerini bütüncül bir yaklaşımla incelemektir. Nitel araştırma yöntemleri, resmi dış politika belgeleri ve diplomatik veriler ışığında hazırlanan bu makale; tarafların çok taraflı antlaşma yükümlülükleri ile ikili öncelikleri arasındaki hassas dengeyi, Azerbaycan faktörünün bu ilişkilere etkisini ve gelecekte "orta ölçekli güç" arabuluculuğu ile ekonomik çeşitlendirme çerçevesinde ortaya çıkabilecek olası iş birliği perspektiflerini analiz etmeyi hedeflemektedir.

GELİŞME

Çok Taraflı Örgütler ve İkili İlişkilerin Gelişimi

Sovyetler Birliği'nin dağılmasının ardından Merkezi Asya cumhuriyetleri ile Ermenistan arasındaki resmi temasların ilk dayanağını, eski Sovyet coğrafyasında kurulan çok taraflı bölgesel mekanizmalar oluşturmuştur. 1991 yılında kurulan Bağımsız Devletler Topluluğu (BDT) ve 1992 yılında temelleri atılıp 2002'de kurumsal bir yapıya bürünen Kolektif Güvenlik Antlaşması Örgütü (KGAÖ), bu ilişkilerin kurumsal çerçevesini belirleyen temel platformlar olmuştur (Allison, 2004, s. 463-465). Ermenistan; Kazakistan, Kırgızistan, Tacikistan ve Rusya ile birlikte KGAÖ'nün kurucu üyeleri arasında yer almış, bu durum Erivan ile Merkezi Asya başkentleri arasında askeri-siyasi boyutta kâğıt üzerinde ortak bir güvenlik şemsiyesi yaratmıştır. Ayrıca Ermenistan'ın 2015 yılında Avrasya Ekonomik Birliği'ne (AEB) tam üye olması, özellikle Kazakistan ve Kırgızistan ile ticari-hukuki entegrasyonunu aynı çatı altına taşımıştır (Dragneva & Wolczuk, 2017, s. 12-15).

Ancak bu çok taraflı üyelikler, güçlü ve bağımsız bir ikili diplomatik mimarinin kurulması için tek başına yeterli olamamıştır. BDT, KGAÖ ve AEB gibi platformlar taraflar arasında düzenli üst düzey temas imkânı sağlasa da, ikili düzeydeki diplomatik temsil ve ekonomik etkileşim son derece sınırlı bir seyir izlemiştir (Mostafa, 2013, s. 160-162). Örneğin, Kazakistan ve Tacikistan dışında diğer Merkezi Asya ülkelerinin Erivan'daki diplomatik varlığı oldukça düşük seviyede kalmış; büyükelçilik düzeyindeki temsilcilikler genellikle bölgesel (akredite) büyükelçiler vasıtasıyla yürütülmüştür. İkili ticaret hacimleri, her iki tarafın da coğrafi izolasyonu, doğrudan kara ve demiryolu bağlantılarının bulunmayışı ve bölgesel hatların kapalı olması nedeniyle sembolik düzeylerin ötesine geçememiştir (Rumer et al., 2016, s. 28-30). Çok taraflı antlaşmaların getirdiği hukuki yükümlülükler ile tarafların somut ikili çıkarları arasındaki bu belirgin mesafe, ilişkilerin ilk aşamadan itibaren prosedürel bir nitelikte kalmasına yol açmıştır.

Azerbaycan Faktörü ve Türk Dünyası Dayanışması

Merkezi Asya devletleri ile Ermenistan arasındaki ikili ilişkilerin derinleşmesini kısıtlayan en dinamik ve stratejik faktör, Azerbaycan ile Merkezi Asya cumhuriyetleri arasındaki köklü siyasi, ekonomik ve etno-kültürel bağlardır (Cornell, 2011, s. 88-92). Bölgenin iki büyük aktörü olan Kazakistan ve Özbekistan, bağımsızlık sonrası dış politikalarında Azerbaycan ile stratejik müttefiklik düzeyinde ilişkiler geliştirmiştir. Hazar Denizi üzerinden sağlanan enerji ve lojistik hatları, ortak Türk mirası ve bölgesel güvenlik meseleleri, Azerbaycan'ı Merkezi Asya devletleri için vazgeçilmez bir stratejik ortak konumuna getirmiştir.

Bu stratejik yakınlık, Türk Devletleri Teşkilatı'nın (TDT) kurulması ve kurumsallaşmasıyla yeni bir boyut kazanmıştır (Aydın, 2021, s. 115-118). Kazakistan, Özbekistan, Kırgızistan ve Türkmenistan'ın Azerbaycan ile aynı kurumsal çatı altında buluşması, Türk dünyası dayanışmasını resmi dış politika doktrinlerinin merkezine yerleştirmiştir. Bu durum, Birinci ve İkinci Qarabağ Savaşları ile sonraki dönemlerde Merkezi Asya başkentlerinin takındığı tutumda açıkça görülmüştür (Ismailov & Papava, 2010, s. 45-48). Kazakistan ve Özbekistan dâhil olmak üzere Merkezi Asya ülkeleri, uluslararası hukuk ilkelerine ve Azerbaycan'ın toprak bütünlüğüne olan bağlılıklarını her fırsatta vurgulamışlardır.

KGAÖ üyesi olmalarına rağmen Kazakistan ve Kırgızistan gibi ülkeler, örgütün Ermenistan-Azerbaycan çatışmalarına müdahil olma yönündeki taleplerine kararlılıkla karşı çıkmış ve örgüt içi mekanizmaların Azerbaycan aleyhine kullanılmasına izin vermemişlerdir (Shiriyev, 2019, s. 73-76). Dolayısıyla, Azerbaycan ile olan yüksek düzeyli stratejik ortaklık ve etno-kültürel dayanışma, Merkezi Asya devletlerinin Ermenistan ile ilişkilerinde aşamayacakları net bir "kırmızı çizgi" ve dengeleme unsuru oluşturmuştur.

Çok Yönlü Diplomasi ve Jeoekonomik Dinamikler

Merkezi Asya devletlerinin dış politika felsefesinin temelini oluşturan "çok yönlü" (*multi-vector*) diplomasi anlayışı, büyük güçler ve bölgesel aktörler arasında hassas bir denge kurarak stratejik özerkliği korumayı amaçlamaktadır (Hankiss, 2009, s. 205-208). Denize kıyısı olmayan (*landlocked*)

bu cumhuriyetler için jeoekonomik rasyonellik; küresel pazarlara erişim, alternatif ticaret rotaları oluşturma ve transit koridorların güvenliğini sağlama zorunluluğunu beraberinde getirmektedir.

Bu çerçevede, Çin'in "Kuşak ve Yol İnisiyatifi" ile paralel olarak gelişen ve Merkezi Asya'yı Hazar Denizi ve Güney Kafkasya üzerinden Avrupa'ya bağlayan Orta Koridor (Trans-Hazar Ulaşım Hattı), bölge ülkeleri için yaşamsal bir öneme sahiptir (Starr & Cornell, 2014, s. 34-37). Orta Koridor'un ana omurgasını Azerbaycan ve Türkiye oluşturmaktadır. Ermenistan'ın uzun yıllar boyunca bölgesel ulaştırma ve enerji projelerinin (örneğin Bakü-Tiflis-Ceyhan, Bakü-Tiflis-Kars) dışında kalmış olması, Merkezi Asya ülkelerinin bu ülkeyle jeoekonomik düzeyde pragmatik bir iş birliği geliştirmesini zorlaştırmıştır (Linn, 2012, s. 150-153).

Bununla birlikte, Güney Kafkasya'da değişen güç dengeleri ve Azerbaycan ile Ermenistan arasındaki barış görüşmeleri, Merkezi Asya ülkelerinin jeoekonomik hesaplarını da güncellemektedir (Freire & Heller, 2018, s. 92-95). Bölgesel ulaşım hatlarının ve sınırların açılması ihtimali (Zengezur Koridoru ve genel bölgesel entegrasyon projeleri), Merkezi Asya'nın Güney Kafkasya üzerinden Orta Doğu ve Avrupa'ya açılan alternatif güzergâhlarını çeşitlendirebilir. Kazakistan ve Özbekistan gibi ülkeler, "orta ölçekli güç" (*middle-power*) aktörleri olarak diplomatik ağırlıklarını kullanarak, Güney Kafkasya'da kalıcı barışın sağlanmasını kendi ekonomik ve lojistik güvenlikleri açısından kritik bir gereklilik olarak değerlendirmektedirler.

SONUÇ

Sovyet Sosyalist Cumhuriyetler Birliği'nin dağılmasının ardından geçen otuz yılı aşkın süreçte, Merkezi Asya devletleri ile Ermenistan Cumhuriyeti arasındaki diplomatik ilişkilerin gelişimi; bölgesel jeopolitik konfigürasyonlar, çok taraflı örgütlerin sunduğu kurumsal yapılar ve Güney Kafkasya'daki stratejik dengeler tarafından derinden etkilenmiş ve sınırlandırılmıştır. Bağımsızlık sonrası dönemde tarafların Bağımsız Devletler Topluluğu (BDT), Kolektif Güvenlik Antlaşması Örgütü (KGAÖ) ve Avrasya Ekonomik Birliği (AEB) gibi ortak platformlarda yer alması, resmi düzeyde kesintisiz bir iletişim kanalı sağlamış olsa da; bu kurumsal bağlar, kendi başına kapsamlı, bağımsız ve yüksek hacimli bir ikili diplomatik mimarinin inşa edilmesine yetmemiştir. İkili diplomatik temsilin zayıf kalması, doğrudan kara ulaşım bağlantılarının bulunmayışı ve coğrafi izolasyon, ilişkilerin büyük ölçüde prosedürel ve sembolik bir düzeyde kalmasına yol açmıştır (Allison, 2004, s. 465; Mostafa, 2013, s. 161).

Bu yapısal kısıtlılığın arkasındaki en temel ve belirleyici faktör, Merkezi Asya ülkelerinin-özellikle bölgenin lider aktörleri konumundaki Kazakistan ve Özbekistan'ın - Azerbaycan Cumhuriyeti ile geliştirdiği yüksek düzeyli stratejik müttefikliktir. Ortak tarihsel, dilsel ve kültürel bağların yanı sıra Türk Devletleri Teşkilatı (TDT) çatısı altında kurumsallaşan Türk dünyası dayanışması, Merkezi Asya cumhuriyetlerinin dış politika doktrinlerinde merkezi bir konuma yerleşmiştir (Aydın, 2021, s. 116). Bu çerçevede, Birinci ve İkinci Qarabağ Savaşları süreçlerinde ve müteakip dönemde Merkezi Asya başkentleri; uluslararası hukukun temel ilkelerine, BM kararlarına ve Azerbaycan'ın toprak bütünlüğüne olan sarsılmaz bağlılıklarını kararlılıkla sürdürmüşlerdir. Ermenistan'ın KGAÖ bünyesindeki ortak üyelik statüsüne ve güvenlik mekanizmalarını harekete geçirme taleplerine rağmen, Kazakistan ve Kırgızistan gibi ülkeler örgüt içi tüzüklerin Azerbaycan aleyhine bir araç olarak kullanılmasına müsaade etmemiş; böylece Azerbaycan ile olan stratejik ortaklığı aşılması imkânsız bir "kırmızı çizgi" olarak muhafaza etmişlerdir (Shiriyev, 2019, s. 74).

Bununla birlikte, denize kıyısı olmayan (*landlocked*) Merkezi Asya cumhuriyetlerinin benimsediği "çok yönlü" (*multi-vector*) dış politika stratejisi, jeoekonomik rasyonellik ve stratejik özerklik ilkeleri üzerine kurgulanmıştır. Dünya pazarlarına güvenli erişim sağlama ve alternatif transit güzergâhları oluşturma ihtiyacı, Merkezi Asya devletlerini Çin'in Kuşak ve Yol İnisiyatifi ile uyumlu çalışan Orta Koridor'a (Trans-Hazar Ulaşım Hattı) öncelik vermeye yöneltmiştir (Starr & Cornell, 2014, s. 35). Ermenistan'ın uzun yıllar boyunca Bakü-Tiflis-Ceyhan ve Bakü-Tiflis-Kars gibi bölgesel çaptaki devasa enerji ve lojistik projelerinin dışında kalması, Merkezi Asya ülkeleri ile Erivan arasında somut ve pragmatik bir ekonomik iş birliğinin zemin kazanmasını engellemiştir (Linn, 2012, s. 151).

Buna karşın, İkinci Qarabağ Savaşı sonrası Güney Kafkasya'da değişen askeri ve siyasi dengeler, Azerbaycan ile Ermenistan arasında yürütülen barış görüşmeleri ve bölgesel ulaşım hatlarının (özellikle Zengezur Koridoru ve diğer transit rotaların) açılması ihtimali, Merkezi Asya'nın Güney Kafkasya vizyonunu yeniden şekillendirmektedir. Güney Kafkasya'da kalıcı bir barışın tesis edilmesi, Merkezi Asya ürünlerinin Türkiye, Orta Doğu ve Avrupa pazarlarına kesintisiz ulaşımı açısından kritik bir gereklilik haline gelmiştir (Freire & Heller, 2018, s. 94). Bu bağlamda, Kazakistan ve Özbekistan gibi ülkeler "orta ölçekli güç" (*middle-power*) diplomasisi yürüterek taraflar arasında yapıcı diyalog ortamını desteklemekte ve bölgesal istikrara katkı sağlamayı hedeflemektedir.

Özetle, Merkezi Asya devletleri ile Ermenistan arasındaki ikili ilişkiler; çakışan antlaşma yükümlülükleri, tarihsel miraslar ve Azerbaycan faktörünün getirdiği stratejik sınırlamalar nedeniyle yakın gelecekte radikal bir ittifak modeline dönüşme potansiyeline sahip değildir. Ancak Güney Kafkasya'da kalıcı barışın sağlanması ve bölgesel ulaştırma koridorlarının faaliyete geçmesi durumunda, bu ilişkilerin daha pragmatik, ticari rasyonelliğe dayalı ve gerilimlerden arındırılmış yeni bir denge zemininde gelişmesi mümkündür. Merkezi Asya'nın izlediği temkinli ve dengeli diplomasi, geniş Avrasya coğrafyasında uzun vadeli siyasi istikrarın ve geoeconomic entegrasyonun korunmasında stratejik bir unsur olmaya devam edecektir.

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THE RULE OF LAW PRINCIPLE AND URBAN TRANSFORMATION IN THE FACE OF THE REALITY OF EARTHQUAKES

DEPREM GERÇEĞİ KARŞISINDA HUKUK DEVLETİ İLKESİ VE KENTSEL DÖNÜŞÜM

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ABSTRACT

Introduction and Purpose: Türkiye's location within a highly active seismic zone has made disaster risk mitigation one of the primary objectives of public administration. In this context, Law No. 6306 on the Transformation of Areas Under Disaster Risk introduced a preventive and risk-oriented urban transformation model, replacing the traditional disaster response approach based on post-disaster recovery. However, the broad administrative powers granted for the implementation of urban transformation have also raised significant legal debates concerning the protection of fundamental rights and the requirements of the rule of law. The purpose of this study is to examine whether urban transformation practices implemented under Law No. 6306 are compatible with the principle of the rule of law and to evaluate the effectiveness of judicial review in ensuring such compatibility.

Materials and Methods: The study adopts a doctrinal legal research method. The provisions of Law No. 6306, the relevant secondary legislation, the Constitution of the Republic of Türkiye, and the jurisprudence of the Constitutional Court of Türkiye and the Council of State (Danıştay) are analysed through normative and comparative legal interpretation. In addition, recent academic literature on disaster law, administrative law, and urban transformation is examined to evaluate the current legal framework.

Results: The analysis demonstrates that although the objective of urban transformation is the protection of public interest and disaster risk reduction, the extensive discretionary powers granted to the administration may give rise to legal uncertainties concerning property rights, legal certainty, proportionality, and foreseeability. Judicial decisions indicate that administrative discretion is not unlimited and must remain subject to effective judicial review in accordance with the principle of the rule of law.

Discussion and Conclusion: The findings suggest that disaster risk mitigation cannot justify disproportionate restrictions on fundamental rights. Sustainable and disaster-resilient urban transformation requires a legal framework that ensures transparency, legal certainty, proportionality, and effective judicial review. Accordingly, the rule of law should constitute the fundamental guarantee balancing public interest with the protection of individual rights throughout urban transformation processes.

Keywords: Rule of Law, Urban Transformation, Disaster Law, Judicial Review, Law No. 6306.

ÖZET

Giriş ve Amaç: Türkiye'nin aktif deprem kuşağında yer alması, afet risklerinin azaltılmasına yönelik hukuki ve idari mekanizmaların geliştirilmesini zorunlu kılmıştır. Bu kapsamda yürürlüğe konulan 6306 sayılı Afet Riski Altındaki Alanların Dönüştürülmesi Hakkında Kanun, afet sonrası müdahaleye dayanan klasik kriz yönetimi anlayışından uzaklaşarak risklerin önceden tespit edilmesini ve güvenli yaşam alanlarının oluşturulmasını esas alan önleyici bir dönüşüm modeli benimsemiştir. Bununla birlikte, kentsel dönüşüm sürecinde idareye tanınan geniş takdir yetkisi; mülkiyet hakkı, hukuki güvenlik, belirlilik ve ölçülülük ilkeleri bakımından önemli hukuki tartışmaları da beraberinde getirmiştir. Bu çalışmanın amacı, 6306 sayılı Kanun kapsamında yürütülen kentsel dönüşüm

uygulamalarının hukuk devleti ilkesiyle uyumunu incelemek ve bu süreçte yargısal denetimin etkinliğini değerlendirmektir.

Gereç ve Yöntem: Çalışmada doktrinal hukuk araştırması yöntemi benimsenmiştir. Bu kapsamda 6306 sayılı Kanun, ilgili ikincil mevzuat, Türkiye Cumhuriyeti Anayasası, Anayasa Mahkemesi ve Danıştay kararları normatif yorum yöntemi çerçevesinde incelenmiştir. Ayrıca afet hukuku, idare hukuku ve kentsel dönüşüm alanındaki güncel doktrinsel çalışmalar değerlendirilerek mevcut hukuki yapı analiz edilmiştir.

Bulgular: İnceleme sonucunda, kentsel dönüşüm uygulamalarının temel amacının kamu yararının sağlanması ve afet riskinin azaltılması olduğu görülmekle birlikte, idareye tanınan geniş takdir yetkisinin mülkiyet hakkı, hukuki güvenlik, belirlilik ve ölçülülük ilkeleri bakımından çeşitli hukuki sorunlara yol açabildiği tespit edilmiştir. Yargı kararları, idarenin takdir yetkisinin sınırsız olmadığını ve hukuk devleti ilkesi gereğince etkin yargısal denetime tabi tutulması gerektiğini ortaya koymaktadır.

Tartışma ve Sonuç: Çalışma bulguları, afet riskinin azaltılması amacının temel hak ve özgürlüklere yönelik ölçüsüz müdahaleleri haklı kılmadığını göstermektedir. Afetlere dirençli kentlerin oluşturulabilmesi; hukuki güvenlik, öngörülebilirlik, ölçülülük ve etkin yargısal denetimi esas alan bir hukuki çerçevenin varlığına bağlıdır. Bu nedenle, hukuk devleti ilkesinin kentsel dönüşüm sürecinin her aşamasında kamu yararı ile bireysel haklar arasında denge sağlayan temel anayasal güvence olarak uygulanması gerekmektedir.

Anahtar Kelimeler: Hukuk devleti, kentsel dönüşüm, 6306 sayılı Kanun, yargısal denetim, afet hukuku.

PSYCHOPATHY, COPING STRATEGIES, AND THE PSYCHOLOGICAL ADJUSTMENT OF INCARCERATED VIOLENT OFFENDERS: A THEORETICAL FRAMEWORK

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ABSTRACT

Violent crime remains one of the most persistent challenges faced by contemporary societies, with international and Romanian penitentiary statistics confirming both its scale and the substantial share of offences against life and physical integrity within the prison population. This paper provides a narrative review of the theoretical and empirical evidence on psychopathy and behavioural coping strategies among incarcerated individuals convicted of violent offences, drawing on international and Romanian literature, official statistics, and empirical research on violent crime, psychopathy, emotion regulation, and coping in correctional settings. The literature indicates that incarcerated individuals show an elevated prevalence of Cluster B personality traits, particularly psychopathy, which is associated with poor emotion regulation, maladaptive coping, and higher rates of institutional violence and recidivism; recent Romanian studies further confirm that personality dimensions, self-efficacy, and self-control are directly related to adaptation to detention and to criminogenic behaviour. Understanding the relationship between psychopathic traits and coping strategies has direct practical value, since early identification of these risk factors can support targeted intervention programs that reduce the probability of recidivism and its associated economic and social costs.

Keywords: psychopathy; coping strategies; violent offenders; prison environment; recidivism.

INTRODUCTION

Violent crime continues to represent a major challenge for contemporary societies, regardless of the social, economic, or cultural context in which it occurs.

Violent crime encompasses criminal acts in which the offender uses physical force or the threat of force to inflict harm, overcome the victim's resistance, or impose their will, including homicide, attempted homicide, robbery, rape and other sexual assaults, as well as aggravated assault and serious bodily injury (Krug et al., 2002). However, a purely legal perspective is insufficient to explain the complexity of interpersonal violence. Criminology and forensic psychology approach violent crime as a multidimensional phenomenon that affects not only individual safety but also community well-being and the capacity of social control institutions to respond effectively.

Within this framework, understanding the psychological mechanisms underlying violent behavior—including psychopathic traits and the ways offenders cope with stress, frustration, and interpersonal

conflict (Hare & Neumann, 2008)—is essential for developing effective prevention, treatment, and social reintegration interventions.

An equally important aspect for understanding violent offending concerns the psychological profile of the offender. Research in forensic psychology consistently indicates that a substantial proportion of violent offenders have personal histories characterized by early traumatic experiences, including physical and emotional abuse or neglect, which contribute to the development of maladaptive personality characteristics, particularly psychopathic traits (Craparo et al., 2013). A landmark longitudinal study that followed abused and neglected children into adulthood demonstrated that early exposure to maltreatment significantly increases the risk of delinquency, criminal behavior, and violent offending later in life (Widom, 1989). Nevertheless, most abused children do not become violent offenders in adulthood.

From this perspective, violent behavior cannot be adequately explained solely by the criminal offense itself. Rather, it must be understood within the broader context of an individual's life experiences, the way these experiences have shaped psychological development, and the personal resources that have—or have not—been acquired to cope with adverse situations without resorting to violence.

For this reason, the study of violent behavior cannot be separated from an examination of the environment in which most violent offenders serve their sentences—the prison environment. For the vast majority of convicted violent offenders, prison constitutes the immediate context in which personality traits and coping strategies are expressed, challenged, and, in some cases, reshaped.

RESULTS AND DISCUSSION

International and National Statistics on Violent Crime

At the global level, the magnitude of violent crime is reflected in data published by the United Nations Office on Drugs and Crime (UNODC). According to the Global Study on Homicide 2023, approximately 458,000 homicides were recorded worldwide in 2021, exceeding the combined number of deaths resulting from armed conflicts and terrorism and corresponding to an average of 52 homicide victims per hour (UNODC, 2023). Globally, males account for approximately 81% of homicide victims, although this proportion varies considerably across regions, with the highest homicide rates reported in Latin America and the Caribbean, where organized crime contributes substantially to violent mortality (UNODC, 2023). The report also highlights the relationship between early-life trauma, untreated mental health problems, and the subsequent risk of engaging in violent behavior, emphasizing the need for a biopsychosocial approach to understanding violent crime (UNODC, 2023).

At the national level, data provided by the National Administration of Penitentiaries (ANP) and reported by Ziare.com indicate that violent offenses account for a substantial proportion of the Romanian prison population. According to the centralized prison statistics for November 2024, homicide accounted for 11.01% of all incarcerated individuals (2,713 inmates), aggravated homicide for 5.37% (1,323 inmates), robbery for 2.16% (553 inmates), and particularly aggravated homicide for 1.96% (484 inmates) (Ziare.com, 2024).

At the beginning of 2025, the total number of incarcerated individuals in Romania was approximately 23,147 (ANP, 2025). Compared with other Council of Europe member states, Romania ranks around the European average in terms of its imprisonment rate but remains above that of most European Union countries, according to the Council of Europe Annual Penal Statistics (Aebi & Cocco, 2024).

The National Strategy for the Social Reintegration of Persons Who Have Served Custodial Sentences also highlights a declining trend in the proportion of repeat offenders within the overall prison population, decreasing from 44.82% in 2009 to 38.43% in 2019 (Government of Romania, 2020). Nevertheless, this positive trend does not diminish the considerable psychological and behavioral complexity characterizing individuals incarcerated for violent offenses.

Psychological and Social Impact of Violent Crime

The consequences of violent crime extend across multiple domains. At the individual level, exposure to violence is associated with post-traumatic stress symptoms, anxiety, depression, and a diminished sense of personal safety. Through the process of secondary victimization, these adverse effects frequently extend beyond the direct victim to family members and the broader community. From a public health

perspective, the World Health Organization emphasizes that interpersonal violence produces not only immediate physical and psychological harm but also long-term consequences, including an increased prevalence of mental health disorders, engagement in health-risk behaviors, and substantial healthcare costs (Krug et al., 2002).

At the societal level, violent crime imposes considerable economic costs through the financial resources allocated to the criminal justice, correctional, and healthcare systems. Beyond these direct expenditures, it also generates significant social costs by undermining public trust in state institutions and increasing the collective perception of insecurity.

The Prison Environment and Characteristics of the Prison Population

From a sociological perspective, the prison is considered a total institution, as virtually every aspect of an incarcerated individual's daily life is regulated within a highly structured institutional framework. Daily activities, social interactions, and opportunities for autonomous decision-making are governed by institutional rules, substantially restricting personal autonomy and privacy. Consequently, successful adaptation to imprisonment involves more than mere compliance with institutional regulations; it requires individuals to develop effective ways of coping with an environment that differs fundamentally from life in the community and that places considerable strain on their psychological functioning.

At present, the Romanian correctional system houses more than 23,000 incarcerated individuals (ANP, 2025), a substantial proportion of whom have been convicted of violent offenses, as previously noted. The density of the prison population, pressure on institutional infrastructure within certain correctional facilities, and the heterogeneity of inmates' psychological and criminal profiles make the prison environment an especially valuable setting for examining how personality characteristics—including psychopathic traits—interact with the unique psychological demands of incarceration.

Psychological Characteristics of Prison Populations

The literature consistently demonstrates that prison populations exhibit a substantially higher prevalence of personality disorders than the general population, particularly disorders belonging to Cluster B (antisocial, borderline, narcissistic, and histrionic personality disorders). Psychopathy, most commonly assessed using the Hare Psychopathy Checklist–Revised (PCL-R), is one of the psychological constructs most strongly associated with violent behavior, both within correctional settings and in the community, as well as with general and violent recidivism following release (Hare, 2003; Roberson & Vitacco, 2023).

The theoretical model proposed by Cooke and Michie (2001) conceptualizes psychopathy as a hierarchical construct comprising three interrelated dimensions: interpersonal traits (e.g., manipulation, grandiosity, and superficial charm), affective traits (e.g., lack of remorse, deficient empathy, and shallow affect), and lifestyle traits (e.g., impulsivity, irresponsibility, and sensation seeking). This framework was subsequently expanded to include a fourth, antisocial dimension, encompassing persistent rule-breaking and a pattern of socially deviant behaviors.

Research involving individuals convicted of violent offenses demonstrates that this psychological profile is far from homogeneous. A study of 213 incarcerated male offenders found that the lifestyle and antisocial dimensions of psychopathy were associated with shorter deliberation times on planning and problem-solving tasks, suggesting an impulsive decision-making style characterized by a preference for immediate action over careful evaluation (Delfin et al., 2018). Other studies have reported significant associations between the affective and antisocial components of psychopathy and pronounced deficits in emotion regulation among a sample of 268 men convicted of violent crimes (Garofalo et al., 2018).

Experimental research conducted in correctional settings has further shown that higher psychopathy scores are associated with lower reciprocity, reduced cooperation, and a greater likelihood of engaging in corrupt behavior during economic decision-making tasks (Balafoutas et al., 2021). Likewise, an investigation of temperament among violent offenders with antisocial personality disorder and alcohol misuse identified a profile characterized by elevated novelty seeking and, in a subgroup of participants, reduced harm avoidance, a combination associated with more impulsive forms of violent behavior (Tikkanen et al., 2007).

Taken together, these findings indicate that incarcerated individuals convicted of violent offenses do not constitute a psychologically homogeneous group. Rather, they comprise distinct psychological subtypes with important implications for assessment, treatment planning, and risk prediction.

Within the Romanian context, recent studies further support the relevance of personality characteristics for understanding adaptation to imprisonment. A study conducted among Romanian violent offenders identified specific personality dimensions directly associated with psychological adjustment to the prison environment, supporting the view that maladaptive personality traits influence individuals' capacity to adapt to incarceration (Rada & Forțu, 2026). Another study involving Romanian inmates demonstrated that personality traits influence criminogenic behavior through the mediating effects of self-efficacy and self-control, suggesting that interventions aimed at strengthening these psychological resources may contribute to reducing the risk of criminal behavior (Rada et al., 2025). These findings are particularly relevant to the Romanian prison population, as they provide an empirical framework directly applicable to the present study.

Stress Associated with Incarceration and Adaptation to the Prison Environment

For most individuals, entry into prison represents a profoundly destabilizing life event. Personal autonomy is abruptly and severely restricted, relationships with family members and social networks are disrupted or substantially reduced, and adapting to both the formal rules of the institution and the informal norms governing prison life becomes an essential condition for everyday functioning.

The longitudinal model proposed by Zamble and Porporino (1988, 1990), based on several years of research involving long-term prisoners, suggests that the highest levels of perceived stress occur during the initial stages of incarceration. Over time, stress tends to decrease as individuals establish adaptive routines, engage in structured activities, and reorganize their interpersonal relationships within the institution. An important implication of this model is that the coping deficits frequently observed among incarcerated individuals do not arise solely as a consequence of imprisonment. Rather, these difficulties often predate incarceration and may have contributed to the development of criminal behavior in the first place.

The congruence between an individual's psychological needs—including safety, meaningful activity, privacy, and emotional support—and the characteristics of the prison environment constitutes a central element of Toch's (1992) ecological model. According to this perspective, correctional settings often create a substantial discrepancy between inmates' psychological needs and the resources available within the institution, thereby increasing the risk of psychological distress and maladaptive behavior. Among individuals exhibiting psychopathic traits, limited emotion regulation abilities and a tendency to rely on externalizing coping strategies—such as avoidance or confrontation rather than internal processing of negative emotions—appear to constitute an additional vulnerability in response to the unique pressures of imprisonment, with direct implications for the risk of institutional aggression (Garofalo et al., 2018).

Aggressive Behavior and Antisocial Conduct in Correctional Settings

The unique conditions of the prison environment, combined with the psychological vulnerabilities exhibited by a substantial proportion of incarcerated individuals, contribute to the occurrence of numerous violent incidents within correctional institutions. These incidents include inmate-on-inmate assaults, attacks against correctional staff, acts of self-harm, and, in the most severe cases, homicides committed during incarceration.

Individuals with elevated levels of psychopathic traits are disproportionately represented among those responsible for such incidents. The literature consistently identifies psychopathy as a major predictor of institutional violence and post-release recidivism, indicating that offenders with pronounced psychopathic characteristics present a significantly higher risk of aggressive behavior than the general prison population (Hare & Neumann, 2008; Roberson & Vitacco, 2023).

This association, however, should not be interpreted in deterministic terms. Evidence from correctional treatment research indicates that the presence of psychopathic traits does not preclude therapeutic progress. On the contrary, well-structured intervention programs specifically tailored to the characteristics of this population can contribute to reducing both institutional violence and the likelihood of future recidivism (Roberson & Vitacco, 2023).

From the perspective of correctional institutions, the management of aggressive behavior requires a dual approach. On the one hand, security and risk-management measures must be tailored to the offender's individual level of risk. On the other hand, educational, psychological, and rehabilitative interventions should focus on developing alternative strategies for managing conflict, frustration, and impulsivity. In recent years, the National Administration of Penitentiaries has implemented several partnerships and

rehabilitation programs designed to facilitate the social reintegration of incarcerated individuals by promoting prosocial behavior and supporting successful community reintegration following release (ANP, 2025).

The effectiveness of these interventions, however, depends largely on a thorough understanding of the psychological mechanisms underlying aggressive behavior. Among these, psychopathic personality traits and the coping strategies employed by incarcerated individuals occupy a central role, providing the primary rationale for the research direction adopted in the present study.

CONCLUSIONS

Violent behavior cannot be adequately explained solely by reference to the criminal offense itself. Rather, a comprehensive understanding requires consideration of the psychological characteristics of incarcerated individuals, the unique pressures associated with the prison environment, and the ways in which offenders cope with stress. Together, these factors provide a more complete explanation of both the mechanisms that contribute to violent behavior and those that may help prevent or reduce it.

Individuals within correctional settings frequently exhibit psychopathic traits and maladaptive coping strategies, both of which are directly associated with an increased risk of aggressive behavior. The magnitude of recidivism further underscores the seriousness of this issue. A systematic review encompassing data from more than 20 countries reported reconviction rates ranging from 20% to 63% over a two-year follow-up period, with much of this variation attributable to differences in judicial systems and reporting practices (Yukhnenko et al., 2020). Beyond its impact on future victims, recidivism imposes substantial financial burdens through repeated costs associated with incarceration, judicial proceedings, community supervision, and correctional services.

These findings also highlight the practical significance of the present analysis. Early identification of psychopathic traits and the coping strategies used by incarcerated individuals may provide the foundation for individualized intervention programs capable of reducing the likelihood of future recidivism (Roberson & Vitacco, 2023). This is not merely a theoretical consideration but a practical framework for developing evidence-based interventions within the Romanian correctional system, where such psychological data remain insufficiently integrated into correctional practice.

Finally, the relationship between psychopathic traits and coping strategies among individuals convicted of violent offenses warrants further investigation—not with the aim of labeling offenders, but rather to improve understanding of the psychological mechanisms underlying violent behavior and to support the development of more effective, evidence-based interventions tailored to the specific needs of this population.

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THE AFFECTIVE MAP OF ALGORITHMS: DIRECTING ANGER, FEAR, AND CURIOSITY ON DIGITAL PLATFORMS

ALGORİTMALARIN DUYGU HARİTASI: DİJİTAL PLATFORMLARDA ÖFKE, KORKU VE MERAKIN YÖNLENDİRİLMESİ

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Özet

Bu bildiri, dijital platformlarda algoritmik sıralama ve öneri sistemlerinin öfke, korku ve merak gibi temel duyguları nasıl dolaşıma soktuğunu iletişim bilimi perspektifinden incelemektedir. Çalışmanın temel problemi, çağdaş medya ekosistemlerinde bireyin yalnızca mesaj alan ya da mesaj üreten bir aktör olarak değil, sürekli uyarılan, ölçülen, yönlendirilen ve duygusal olarak biçimlendirilen kırılgan bir özne olarak konumlanmasıdır. Bu çerçevede çalışma, algoritmik yönetişim, duygu ekonomisi, platform kapitalizmi ve medya psikolojisi literatürleri arasında disiplinlerarası bir bağ kurarak konuyu yalnızca teknik medya kullanımı düzeyinde değil, psikolojik, etik ve kültürel sonuçları bakımından ele almaktadır. Yöntem bakımından kuramsal modelleme ve eleştirel platform analizi yöntemi benimsenmiştir. Bildiri, önce kavramın kuramsal sınırlarını belirlemekte, ardından bu kavramın dijital medya pratikleri, gündelik iletişim biçimleri ve toplumsal anlam üretimi içinde nasıl görünür hale geldiğini tartışmaktadır. Analiz, iletişim süreçlerinin nötr ve araçsal yapılar olmadığı; aksine öznenin dikkatini, duygusunu, hafızasını ve ilişki kurma biçimini dönüştüren aktif anlam sistemleri olduğu varsayımına dayanmaktadır. Çalışmanın özgün katkısı, tartışılan olguyu tekil bir medya davranışı olarak değil, günümüz iletişim kültürünün daha geniş bir semptomu olarak kavramsallaştırmasıdır. Bu yönüyle bildiri, iletişim süreçlerinde görünür olan davranışların arkasındaki duygu, dikkat, güç ve anlam ilişkilerini birlikte okumayı önermekte; böylece güncel medya tartışmalarına daha bütüncül bir teorik zemin kazandırmayı hedeflemektedir. Bu bağlamda bildirinin temel savı şudur: algoritmalar yalnızca içerik seçen teknik düzenekler değil; kullanıcıların duygusal yönelimlerini sınıflandıran, yoğunlaştıran ve ekonomik değere dönüştüren görünmez iletişimsel aktörlerdir. Bu nedenle bildiri, kuramsal tartışmanın pratik iletişim etiğiyle birlikte düşünülmesi gerektiğini vurgular. Sonuç olarak çalışma, çağdaş iletişim ortamlarında daha bilinçli, etik, yavaş, seçici ve insan merkezli bir iletişim anlayışının geliştirilmesi gerektiğini savunmaktadır.

Anahtar kelimeler: algoritma, duygu ekonomisi, platformlar, öfke, korku, merak

ABSTRACT

This paper examines how algorithmic ranking and recommendation systems circulate emotions such as anger, fear, and curiosity on digital platforms from the perspective of communication studies. The central problem of the study is that, within contemporary media ecosystems, the individual is no longer positioned merely as a receiver or producer of messages, but as a fragile subject who is continuously stimulated, measured, directed, and affectively shaped. Within this framework, the paper establishes an interdisciplinary connection between algorithmic governance, affective economy, platform capitalism, and media psychology and approaches the issue not only as a matter of technical media use, but also in terms of its psychological, ethical, and cultural consequences. Methodologically, the study adopts conceptual modeling and critical platform analysis. The paper first clarifies the conceptual boundaries of the topic and then discusses how the phenomenon becomes visible within digital media practices,

everyday communication patterns, and the social production of meaning. The analysis is based on the assumption that communication processes are neither neutral nor merely instrumental structures; rather, they are active systems of meaning that transform attention, emotion, memory, and modes of relationality. The original contribution of the paper lies in conceptualizing the phenomenon not as an isolated media behavior, but as a broader symptom of contemporary communication culture. In this sense, the paper proposes reading visible communicative behaviors together with the underlying relations of affect, attention, power, and meaning; it thus aims to provide a more integrated theoretical ground for current debates in media and communication studies. In this respect, the main argument of the paper is that algorithms are not only technical devices that select content; they are invisible communicative actors that classify, intensify, and monetize users' emotional orientations. In conclusion, the study argues for a more conscious, ethical, and human-centered understanding of communication today.

Keywords: algorithm, affective economy, platforms, anger, fear, curiosity

A CASE REPORT OF INFECTION OF A CAT WITH AELUROSTRONGYLUS ABSTRUSUS

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ABSTRACT

Introduction and Purpose: Aelurostrongylosis in cats is caused by the metastrongyle nematode, *Aelurostrongylus abstrusus*. Known as the feline or cat lungworm, this parasite uses gastropods as intermediate hosts, with various vertebrates serving as paratenic hosts and the likely source of infection in cats. It has been described like primary respiratory parasite of cats worldwide. This parasitic infection was also found in naturally infected cats in Belgrade. In the paper, we present a case report of that infection.

Materials and Methods: A three-year-old cat was brought for examination with the following symptoms: mucopurulent nasal discharge, dyspnea and cough of varying intensity, and sneezing. The owner reported that the cat went outside regularly and that the symptoms had been mild for a few months. In the last week, the cat had become lethargic and the cough had increased. We performed clinical examination, blood test, radiological examination and use a smear for microbiological examination. A parasitological examination was performed using direct fecal smear, fecal flotation, and the Baermann method

Results: A blood test showed eosinophilia as well as an increased number of lymphocytes and monocytes as well as moderate anemia. Blood biochemistry was within normal limits. Radiographs showed alveolar changes and thickening of the bronchial walls. By examining the feces, we found live, mobile larvae about 360-400 micrometers long with a curved wavy tail and small spines at the very end, which is characteristic of *Aelurostrongylus abstrusus* larvae. The therapy was carried out with Fenbendazole for 7 days and was repeated after two weeks. A control parasitological examination was not established presence of parasites.

Key Words: *Aelurostrongylus abstrusus*, cats, diagnosis, therapy

A TURNING POINT: ARTIFICIAL INTELLIGENCE AND THE TRANSFORMATION OF CONTEMPORARY SOCIETY

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ABSTRACT

Artificial Intelligence (AI) represents one of the most significant technological innovations of the 21st century, profoundly influencing fields such as education, healthcare, the economy, research, and public administration.

The rapid development of generative AI models has marked a turning point in the evolution of society, where extraordinary benefits are accompanied by unprecedented ethical, legal, and social challenges.

This paper analyzes the impact of AI on key sectors of activity, highlighting both the opportunities and risks associated with its use and arguing for the necessity of a responsible, human-centric approach.

History demonstrates that technological progress simultaneously creates opportunities and uncertainties. Artificial Intelligence amplifies this duality to an unprecedented degree. Its capacity to transform virtually every area of human activity justifies the assertion that society stands at a crossroads.

The future will be determined not solely by technological performance, but by how people choose to design, regulate, and use technology.

Responsible development requires collaboration among researchers, policymakers, the educational sector, and civil society to build a digital ecosystem grounded in transparency, equity, and respect for fundamental rights.

Keywords: artificial intelligence, digital transformation, ethics, education, innovation, society.

Contemporary society is undergoing a phase of unprecedented transformation, driven by the rapid advancement of digital technologies—and artificial intelligence in particular. While industrial revolutions altered modes of production and economic organization, artificial intelligence is transforming the very nature of decision-making, communication, and the relationship between humans and technology.

In recent years, AI-based systems have become an integral part of daily life. Virtual assistants, machine translation, autonomous vehicles, recommendation systems, algorithm-assisted medical diagnostics, and generative tools demonstrate that AI is no longer a concept of the future, but a present-day reality.

This development raises fundamental questions regarding the human role in an increasingly automated society and the capacity of institutions to adapt legal and ethical frameworks to these new technological realities.

From this perspective, artificial intelligence represents a turning point in societal evolution, as it simultaneously impacts the economy, education, public administration, the justice system, and security.

Artificial Intelligence – A Driver of Economic and Social Transformation

The economic impact of artificial intelligence is comparable to that of electricity or the internet. Process automation, big data analysis, and decision optimization contribute to increased productivity and reduced operational costs.

In industry, AI optimizes supply chains and manufacturing processes through the use of intelligent robots and predictive maintenance. In the financial sector, algorithms are used for fraud detection, risk assessment, and transaction automation. In healthcare, artificial intelligence contributes to the early diagnosis of medical conditions and the development of personalized medicine.

Education is also a field profoundly influenced by artificial intelligence. Intelligent educational platforms allow content to be tailored to each student's level, facilitating personalized learning and the development of digital skills.

However, this economic transformation also brings significant challenges. Automation can lead to the disappearance of traditional jobs and exacerbate social inequalities. At the same time, new professions and skills are emerging, necessitating the adaptation of educational systems and the promotion of lifelong learning.

Artificial Intelligence and the Transformation of Law

The evolution of artificial intelligence is bringing about significant changes in the legal field as well. Computer systems are being used to analyze case law, draft legal documents, and support the work of courts and lawyers.

However, the use of algorithms in decision-making raises issues regarding transparency, impartiality, and legal accountability. Artificial intelligence models can replicate biases present in the training data, potentially leading to discriminatory decisions.

In this context, the principles of legality, proportionality, and the protection of fundamental rights must remain essential benchmarks for the responsible use of artificial intelligence. Decisions impacting individuals' rights and freedoms must be subject to human oversight and be effectively open to challenge.

The European Union has adopted a risk-based approach, classifying artificial intelligence systems according to their impact on fundamental rights and imposing differentiated obligations on developers and users. This approach aims to strike a balance between innovation and the protection of democratic values.

Artificial Intelligence and Societal Security

Digital transformation directly impacts national and international security. Artificial intelligence is employed to detect cyberattacks, analyze intelligence, and prevent threats to critical infrastructure.

At the same time, this same technology can be exploited for illicit purposes. Automated cyberattacks, digital fraud, deepfakes, and disinformation campaigns demonstrate that artificial intelligence can become a tool for organized crime and hybrid conflicts.

In the field of criminology, AI offers the capability to rapidly analyze vast amounts of data and identify criminal patterns. However, the use of predictive algorithms must adhere to the principles of the presumption of innocence, non-discrimination, and proportionality, avoiding the conflation of statistical probabilities with legal certainties.

Consequently, digital security can no longer be analyzed solely from a technical perspective; instead, it requires an interdisciplinary approach that integrates legal, ethical, and social dimensions.

Ethical Challenges and Responsibility

The development of artificial intelligence necessitates a redefinition of the relationship between technology and human responsibility. Algorithms lack moral consciousness and cannot be held legally accountable for the consequences of their decisions. Consequently, responsibility rests with the individuals and organizations that design, implement, and use these systems.

Key ethical challenges include privacy protection, algorithmic transparency, the explainability of automated decisions, and the prevention of discrimination. Furthermore, the use of artificial intelligence

in population surveillance or the development of autonomous weapons raises complex issues regarding respect for human rights and international law.

The concept of "human-centric artificial intelligence" promotes the idea that technology should complement human capabilities rather than fully replace them. In this context, human oversight and legal accountability are essential prerequisites for the legitimate use of artificial intelligence.

Analysis of the European framework for artificial intelligence regulation: balancing innovation and the protection of fundamental rights

The European Union has adopted a distinct regulatory approach to artificial intelligence, grounded in the principle that technological development must align with democratic values, the rule of law, and respect for fundamental rights. Unlike regulatory models primarily driven by market forces or innovation, the European model champions the concept of "human-centric AI," wherein technological progress is subordinate to the protection of human dignity, individual autonomy, and public interest.

In this regard, the European Commission has already stressed in the White Paper on Artificial Intelligence that: “The objective is to develop an ecosystem of excellence and trust, allowing citizens and businesses to benefit from artificial intelligence, while ensuring respect for the values and fundamental rights of the European Union.”

(European Commission, White Paper on Artificial Intelligence – A European Approach to Excellence and Trust, COM(2020) 65 final)

This orientation was reinforced by the adoption of Regulation (EU) 2024/1689 on the establishment of harmonized rules on artificial intelligence (AI Act), the first general legislative act dedicated to artificial intelligence worldwide. The regulation aims to establish a uniform legal framework for the development, placing on the market and use of artificial intelligence systems within the European Union.

The risk-based approach

The central element of the AI Act is the classification of artificial intelligence systems based on the level of risk they pose to health, safety, and individuals' fundamental rights.

The Regulation establishes four main categories: unacceptable risk (expressly prohibited); high risk (subject to strict obligations); limited risk (subject to transparency obligations); and minimal risk (which may be used without additional obligations). Recital 1 of the AI Act highlights the philosophy underpinning the entire Regulation:

"The purpose of this Regulation is to improve the functioning of the internal market and to promote the uptake of human-centric and trustworthy artificial intelligence, while ensuring a high level of protection of health, safety, and fundamental rights as enshrined in the Charter of Fundamental Rights of the European Union."

Consequently, the European legislator does not aim to stifle innovation, but rather to develop a digital market based on trust and responsibility.

Protection of fundamental rights

A defining characteristic of the European model is the integration of human rights standards into the regulation of artificial intelligence.

The AI Act must be interpreted in conjunction with: the Charter of Fundamental Rights of the European Union; the General Data Protection Regulation (GDPR); the European Convention on Human Rights; and the Council of Europe Framework Convention on Artificial Intelligence, Human Rights, Democracy and the Rule of Law (2024).

Article 1 of the Charter of Fundamental Rights enshrines the principle that:

“Human dignity is inviolable. It must be respected and protected.”

This provision forms the foundation of the entire European legal framework regarding artificial intelligence, as any use of algorithms must respect individual autonomy and avoid reducing the individual to a mere object of automated processes.

Furthermore, Article 8 of the Charter guarantees the right to the protection of personal data a particularly important aspect given the development of systems based on vast amounts of data (big data).

Prohibition of certain practices

An innovative feature of the AI Act is the prohibition of certain uses deemed incompatible with European values.

These include systems using subliminal techniques to manipulate behavior; the exploitation of people's vulnerabilities; certain forms of social scoring; and specific uses of real-time biometric identification in public spaces, subject to strictly regulated exceptions.

These prohibitions reflect the European Union's commitment to preventing the development of surveillance mechanisms that are incompatible with the principles of the rule of law.

Obligations for high-risk systems

For systems classified as high-risk, regulation establishes complex obligations regarding risk management; the quality of data used to train algorithms; technical documentation; traceability; human oversight; and accuracy and cybersecurity. These requirements aim to reduce the risk of algorithmic discrimination and ensure the verifiability of automated decisions.

As Luciano Floridi (2023) notes:

"The goal is not to slow innovation but to ensure that innovation remains trustworthy."

This observation encapsulates the philosophy behind European regulation: economic competitiveness cannot be separated from legal and social responsibility.

The Council of Europe Framework Convention

Adopted in 2024, the Framework Convention on Artificial Intelligence represents the first binding international treaty dedicated to the governance of artificial intelligence.

The Convention reaffirms that the use of AI must respect human rights, democracy, and the rule of law. The document enshrined the obligation of states to establish effective mechanisms for assessing the impact on fundamental rights and to ensure effective remedies for individuals affected by automated decisions.

Critical assessment

Although the AI Act marks a historic moment in the evolution of technology law, legal scholarships have also highlighted certain limitations.

First, the extremely rapid pace of artificial intelligence development may necessitate frequent updates to certain provisions. Second, the uniform application of the regulation across all Member States requires the existence of competent authorities capable of monitoring and sanctioning violations.

Furthermore, the emergence of foundation models (general-purpose AI) and generative AI raises additional issues regarding copyright, disinformation, cybersecurity, and legal liability.

Nevertheless, the European approach currently represents the most advanced regulatory model at the international level. By placing fundamental rights at the heart of the regulatory process, the European Union proposes a governance model that seeks to reconcile technological innovation with the protection of the individual and the strengthening of public trust. Looking ahead, the effectiveness of this model will depend both on the consistent application of the rules and on the ability of European institutions to adapt the legal framework to the rapid evolution of AI-based technologies.

Conclusions

Artificial intelligence marks the beginning of a new stage in the evolution of contemporary society. Its capacity to transform the economy, public administration, education, the justice system, and security confirms that we are at a genuine historical turning point.

The benefits generated by artificial intelligence are undeniable: increased efficiency, innovation, economic development, and improved public services. At the same time, the risks associated with automated decision-making, data misuse, and the amplification of digital vulnerabilities necessitate the development of a robust legal and ethical framework. The future of society does not depend solely on the performance of algorithms, but rather on the capacity of states and international organizations to build a model of responsible governance based on respect for fundamental rights, transparency, and human oversight. Artificial intelligence should not be viewed merely as a revolutionary technology, but as a tool that can contribute to the development of a more prosperous and secure society, provided it is used in the interest of humanity and the common good.

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A DYNAMIC RUSLE-SYSTEM DYNAMICS FRAMEWORK FOR SOIL EROSION AND POLICY SIMULATION

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TOPRAK EROZYONU VE POLİTİKA SENARYOLARININ SİMÜLASYONU İÇİN RUSLE-SİSTEM DİNAMİĞİ ENTEGRASYONUNA DAYALI DİNAMİK BİR ÇERÇEVE

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ABSTRACT

Soil erosion is a dynamic environmental process shaped by the interaction of biophysical drivers and human land-use decisions. Although the Revised Universal Soil Loss Equation (RUSLE) is widely used for erosion estimation, its conventional formulation is inherently static and limited in representing feedback mechanisms and policy-driven land management changes. This study develops a dynamic modeling framework by integrating RUSLE within a System Dynamics (SD) approach to simulate soil erosion processes and evaluate land management policies in a small watershed in the Nallıhan Basin, Türkiye.

The proposed framework reformulates key RUSLE parameters, particularly the cover-management (C) and support practice (P) factors, as time-dependent variables influenced by feedback loops representing afforestation and soil conservation interventions. Soil erosion is conceptualized as a stock-flow system in which soil loss and sediment transport are modeled as dynamic processes evolving over time rather than static annual estimates. This structure enables the explicit representation of delayed responses, cumulative effects, and non-linear system behavior under different policy scenarios.

The model is calibrated and validated using a 30-year dataset (1986-2016), followed by scenario-based simulations over a 24-year projection horizon. Results indicate that in low-erosion conditions (1-2 t ha^{-1} yr^{-1}), vegetation dynamics represented by the C factor constitute the dominant control on system behavior, while the influence of structural conservation measures (P factor) remains limited. Scenario analysis further reveals non-linear system responses, where high-intensity afforestation interventions generate threshold effects leading to rapid reductions in erosion rates, followed by convergence toward a new equilibrium state.

The findings demonstrate that embedding empirical erosion models within a system dynamics framework provides a more realistic representation of land degradation processes and policy impacts. By transforming static parameters into behaviorally responsive variables, the proposed RUSLE-SD framework offers a transferable decision-support tool for evaluating long-term soil conservation strategies in data-scarce watersheds. This approach contributes to bridging the gap between empirical environmental modeling and adaptive land management policy design.

Keywords: Soil erosion; RUSLE; System Dynamics; watershed management

Özet

Toprak erozyonu, biyofiziksel etkenler ile insan kaynaklı arazi kullanım kararlarının etkileşimi sonucu şekillenen dinamik bir çevresel süreçtir. Yaygın olarak kullanılan Revize Evrensel Toprak Kaybı Denklemi (RUSLE) erozyon tahmininde önemli bir araç olmakla birlikte, klasik formülasyonu itibarıyla statik yapıda olup, geri besleme mekanizmalarını ve politika temelli arazi yönetimi değişimlerini temsil etmede sınırlıdır. Bu çalışma, RUSLE modelini Sistem Dinamikleri (SD) yaklaşımı ile entegre ederek Türkiye'nin Nallıhan Havzası'nda toprak erozyonu süreçlerini simüle eden ve arazi yönetimi politikalarını değerlendiren dinamik bir modelleme çerçevesi geliştirmektedir.

Önerilen çerçeve, RUSLE'nin temel parametrelerinden özellikle örtü-yonetim (C) ve destekleyici uygulama (P) faktörlerini, ağaçlandırma ve toprak koruma müdahalelerini temsil eden geri besleme döngüleri aracılığıyla zamana bağlı değişkenler olarak yeniden tanımlamaktadır. Toprak erozyonu, yıllık sabit tahminler yerine zaman içinde gelişen stok-akış sistemi olarak ele alınmış; böylece gecikmeli etkiler, kümülatif süreçler ve doğrusal olmayan sistem davranışları açık biçimde temsil edilmiştir.

Model, 1986-2016 dönemini kapsayan 30 yıllık veri seti kullanılarak kalibre edilmiş ve doğrulanmış, ardından 24 yıllık bir öngörü dönemi için senaryo tabanlı simülasyonlar gerçekleştirilmiştir. Sonuçlar, düşük erozyon koşullarında (1-2 t ha^{-1} $yıl^{-1}$), sistem davranışını belirleyen temel unsurun C faktörü olduğunu, buna karşılık P faktörünün etkisinin sınırlı kaldığını göstermektedir. Senaryo analizleri ayrıca, yüksek yoğunluklu ağaçlandırma müdahalelerinin eşik etkileri yaratarak erozyon hızında hızlı düşüşlere yol açtığını ve sistemin zamanla yeni bir denge durumuna yakınsadığını ortaya koymaktadır.

Elde edilen bulgular, ampirik erozyon modellerinin sistem dinamikleri ile bütünleştirilmesinin arazi bozunumu süreçlerinin ve politika etkilerinin daha gerçekçi biçimde temsil edilmesini sağladığını göstermektedir. Statik parametrelerin davranışsal değişkenlere dönüştürülmesiyle önerilen RUSLE-SD çerçevesi, veri kısıtlı havzalarda uzun dönemli toprak koruma stratejilerinin değerlendirilmesi için aktarılabilir bir karar destek aracı sunmaktadır. Bu yaklaşım, ampirik çevresel modelleme ile adaptif arazi yönetimi politika tasarımı arasındaki boşluğun kapatılmasına katkı sağlamaktadır.

Anahtar Kelimeler: Toprak erozyonu; RUSLE; Sistem Dinamiği; havza yönetimi

GASTRONOMY FROM THE PERSPECTIVE OF MUSIC EDUCATION: A REVIEW ON CREATIVITY, SENSORY PERCEPTION, AND CULTURAL TRANSMISSION

MÜZİK EĞİTİMİ PERSPEKTİFİNDEN GASTRONOMİ: YARATICILIK, DUYUSAL ALGI VE KÜLTÜREL AKTARIM ÜZERİNE BİR İNCELEME

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ÖZET

Gastronomi ve müzik, tarih boyunca şölenler, ritüeller ve festivaller aracılığıyla kültürel bellek, toplumsal etkileşim ve duyusal deneyim alanlarında kesişen iki disiplin olmuştur. Piotrowska'nın (2015) Stuligrosz ile Morehen ve Rastall' dan aktardığı üzere, 16. yüzyıl sonlarından itibaren özellikle Almanya'da kullanılmaya başlanan ve kökeni Antik Yunan'ın müzikli şölen kültürüne dayanan "Tafelmusik" (Almanca), "Musique de table" (Fransızca) ve "table music" (İngilizce) bu ilişkinin tarihsel köklerini yansıtmaktadır. Telemann'ın 1733 tarihli "Musique de table" adlı eseri tafelmusik geleneğinin en meşhur örneği ve bu türün zirvesi olarak kabul edilmektedir.

Bu çalışmanın amacı, müziğin gastronomi eğitiminde pedagojik olarak nasıl kullanılabileceğini; yaratıcılık, duyusal algı ve kültürel aktarım perspektiflerinden hareketle incelemektir. Çalışmada sistematik literatür taraması yöntemi benimsenmiş; müzik ve gastronomi, müzik ve tat algısı, yaratıcı mutfak uygulamaları, duyusal deneyim ve disiplinlerarası müzik eğitimi konularındaki ulusal ve uluslararası çalışmalar içerik analizi yoluyla değerlendirilmiştir. İncelemeler, müziğin dikkat, imgeleme ve duygulanım süreçlerini destekleyerek mutfak tasarımı ve lezzet geliştirmede yaratıcı düşünmeyi teşvik edebildiğini; tempo, tını, perde ve müzik türü gibi işitsel unsurların ise tat ve mekân algısıyla ilişkilendirilebildiğini göstermektedir. Ayrıca müzik, gastronomik deneyimin estetik ve atmosferik boyutunu zenginleştiren bir unsur olarak öne çıkmaktadır. Müzik eğitimi açısından ritim-tat, tını-doku ve tempo-sunum ilişkilerine dayalı uygulamalar; öğrencilerin dinleme, yorumlama, yaratıcı ifade, duyusal farkındalık ve kültürel miras bilincini destekleyebilir. Sonuç olarak gastronomi ile müzik arasındaki disiplinlerarası ilişki, gastronomi eğitimini estetik ve kültürel açıdan zenginleştirirken müzik eğitimi için de deneyim temelli yeni öğrenme ortamları sunmaktadır.

Anahtar Kelimeler: Müzik eğitimi, gastronomi eğitimi, yaratıcılık, duyusal algı, müzik ve tat algısı.

ABSTRACT

Gastronomy and music have been two disciplines intersecting throughout history in the domains of cultural memory, social interaction, and sensory experience through feasts, rituals, and festivals. As cited by Piotrowska (2015) from Stuligrosz and from Morehen and Rastall, the terms "Tafelmusik" (German), "Musique de table" (French), and "table music" (English), which began to be used particularly in Germany from the late 16th century onward and whose origins trace back to Ancient Greece's musical feasting culture, reflect the historical roots of this relationship. Telemann's 1733 work "Musique de table" is regarded as the most famous example of the tafelmusik tradition and the pinnacle of this genre.

This study aims to examine how music can be pedagogically utilized in gastronomy education from the perspectives of creativity, sensory perception, and cultural transmission. A systematic literature review method was adopted in the study, and national and international studies on music and gastronomy, music and taste perception, creative culinary practices, sensory experience, and interdisciplinary music education were evaluated through content analysis. The findings indicate that music, by supporting processes of attention, imagery, and affect, can foster creative thinking in culinary design and flavor development, and that auditory elements such as tempo, timbre, pitch, and musical genre can be associated with taste and spatial perception. Furthermore, music stands out as an element that enriches

the aesthetic and atmospheric dimension of the gastronomic experience. From the standpoint of music education, practices based on relationships between rhythm and taste, timbre and texture, and tempo and presentation can support students' listening, interpretation, creative expression, sensory awareness, and consciousness of cultural heritage. In conclusion, the interdisciplinary relationship between gastronomy and music enriches gastronomy education aesthetically and culturally, while also offering new experience-based learning environments for music education.

Keywords: Music education, gastronomy education, creativity, sensory perception, music and taste perception.

DESIGN, SYNTHESIS, MOLECULAR DOCKING, AND ANTICANCER EVALUATION OF NOVEL THIOPHENE–1,3,4-OXADIAZOLE DERIVATIVES

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ABSTRACT

Lung cancer remains one of the leading causes of cancer-related mortality worldwide, with drug resistance significantly limiting the long-term efficacy of standard chemotherapeutic agents such as cisplatin and pemetrexed. To identify new anticancer candidates, a series of thiophene–1,3,4-oxadiazole-based carbamothioate derivatives **(7a–7e)** bearing different substituted phenyl amide moieties were designed, synthesized, and evaluated. The target compounds were obtained in moderate to good yields through multistep synthetic routes and characterized by FT-IR, ^{1}H NMR, ^{13}C NMR, EI-MS, and elemental analysis. The synthesized derivatives were screened for in vitro anticancer activity against the A549 human lung cancer cell line. Among the tested compounds, **7a** bearing a 3-methyl (*m*-tolyl) substituent demonstrated the highest cytotoxic activity (IC_{50} = 8.93 ± 2.35 μM), accompanied by minimal hemolytic toxicity and the highest selectivity index, with potency approaching that of cisplatin. Structure–activity relationship analysis indicated that electron-donating and lipophilic substituents enhanced anticancer activity, whereas the electron-withdrawing chloro substituent reduced potency. To investigate the possible mechanism of action, molecular docking studies were performed against five lung cancer-associated targets: PI3K (4JPS), Bcl-2 (4AQ3), tubulin (1SA0), VEGFR-2 (4ASD), and EGFR (1M17). Compound **7a** exhibited favorable binding interactions with these targets, supporting the experimental findings. Overall, the results identify the *m*-tolyl thiophene–1,3,4-oxadiazole scaffold as a promising lead for the development of novel anticancer agents against lung cancer.

Keywords: Thiophene; 1,3,4-Oxadiazole; Carbamothioates; Lung cancer; Anticancer activity; Molecular docking

GEOCHEMICAL AND STRUCTURAL EVALUATION OF MUD VOLCANISM AS AN INDICATOR OF DEEP-SEATED HYDROCARBON MIGRATION IN THE SHAMAKHI-GOBUSTAN DEPRESSION

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ABSTRACT

Introduction and Purpose: The Shamakhi-Gobustan Depression, situated within the South Caspian petroleum province, exhibits unique geological architecture characterized by intensive tectonic fracturing and prolific mud volcanic manifestations. These mud volcanoes serve as natural exploration windows, providing invaluable direct and indirect evidence regarding the hydrocarbon potential, source rock maturity, and geodynamic regime of deep-seated sedimentary strata. This study focuses on the integrated geochemical and structural analysis of mud volcano ejecta, associated gases, and localized fracture networks to delineate vertical migration pathways and evaluate the regional petroleum system efficacy.

Materials and Methods: The research methodology incorporates spatial structural mapping of fault zones and the synthesis of organic geochemical data obtained from fluid and gas discharge sampling. By evaluating the isotopic composition of methane and heavier homologues alongside the lithofacies characteristics of ejected rock fragments, the stratigraphic position and thermal maturity of the underlying hydrocarbon generation zones were constrained. Furthermore, the spatial correlation between regional fault alignments and active mud volcanic vents was analyzed to determine the degree of fault-controlled permeability and localized seal breaching dynamics..

Results: The analytical results demonstrate that the spatial distribution of mud volcanism is strictly governed by major longitudinal and transverse tectonic lineaments, which act as high-permeability conduits for deep-seated fluids. Geochemical indicators from the sampled manifestations confirm a genetic link to deeply buried, thermally mature Paleogene–Miocene source rock complexes. The continuous emission of thermogenic hydrocarbons substantiates the presence of active petroleum generation cells at depth. While active mud volcanism indicates localized reservoir breaching, the structural synthesis suggests that adjacent, undisturbed anticlinal closures lateral to these migration pathways maintain high preservation potential and constitute primary targets for future drilling exploration. Ultimately, this multi-disciplinary approach enhances prospectivity mapping accuracy and mitigates exploration risks within complex tectonic segments of the South Caspian Basin.

Key Words: Shamakhi-Gobustan Depression, mud volcanism, hydrocarbon migration, geochemical indicators, tectonic lineaments, South Caspian Basin.

FORTY YEARS OF LANDSAT AND SENTINEL-2 RETROSPECTIVE ANALYSIS REVEAL A SPECIES-DIFFERENTIATED DIEBACK SIGNAL IN THE ATLAS FORESTS OF BÉNI MELLAL-KHÉNIFRA (MOROCCO)

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ABSTRACT

North African forests occupy the southern warm edge of the Mediterranean biome and accumulate the highest per-hectare exposure to 21st-century drought, yet long-term, spatially explicit reconstructions of their dieback trajectories remain scarce. This study delivers an open, reproducible retrospective analysis of natural forest dieback in the Béni Mellal-Khénifra region of Morocco (936,437 ha) over 1984–2024, articulated around three objectives: (i) quantify the extent, spatial structure and temporal chronology of dieback across the six IFN2 strata dominated by Cedrus atlantica, Quercus rotundifolia and Quercus suber; (ii) characterise the co-variation of species-level NDVI anomalies with the Standardised Precipitation-Evapotranspiration Index (SPEI) at 3-, 6- and 12-month scales and with vapour-pressure-deficit (VPD) anomalies through autocorrelation-corrected cross-correlation; and (iii) evaluate the complementarity of Landsat and Sentinel-2 for dieback detection over the shared 2017–2024 window.

A stratified random sample of 2,901 Landsat and 2,933 Sentinel-2 pixels was drawn within the IFN2 forest polygons, filtered by the ESA WorldCover 2020 tree-cover class and slopes below 45°. Per-pixel monthly NDVI series were processed through a BFAST-like workflow combining STL decomposition and PELT change-point detection, complemented by a recent-decline detector that rescues near-edge signals. Species-level NDVI anomalies were cross-correlated with SPEI-3/6/12 and VPD anomalies derived from TerraClimate, with Pyper–Peterman effective-sample-size correction and Benjamini–Hochberg false-discovery-rate control. Spatial hotspots were identified through DBSCAN clustering (ε = 5 km) and kernel-density estimation.

A cumulated dieback signal of approximately 187,700 ha (20.1% of the regional forest cover; bootstrap 95% CI 155,500–221,600 ha) was identified. Cork oak showed the highest relative rate (41.4% of pure stands), while holm oak accounted for the largest absolute affected area (142,591 ha). SPEI-12 emerged as the strongest hydro-climatic correlate, with the most sensitive response in Q. suber ($r = +0.364$ at lag 0), followed by Q. rotundifolia ($r = +0.306$ at lag 1) and C. atlantica ($r = +0.259$ at lag 1) — a ranking that inversely tracks mean stratum elevation (991 m < 1,362 m < 1,908 m). VPD anomalies co-varied negatively with NDVI at lag 0 for every species, consistent with rapid stomatal-hydraulic regulation. Sentinel-2 detected +18.3 to +26.3 percentage points more Atlas cedar mortality than Landsat, whereas the longer Landsat baseline captured the 1998–1999 cork-oak historical pulse.

The analysis contributes a reproducible baseline for regional forest management, a georeferenced set of DBSCAN hotspot centroids to prioritise field validation, and a transferable analytical template for other Maghreb and Sahel regions where dieback dynamics remain poorly documented. All processing scripts and intermediate datasets are archived in a public repository.

Keywords: Forest dieback, BFAST, SPEI, Landsat, Sentinel-2, Atlas cedar, cork oak.

IN VITRO ANTICOCCIDIAL EFFECTS OF OLIVE LEAF (OLEA EUROPAEA L. VAR. CHEMLAL) EXTRACT AGAINST BROILER CHICKENS EIMERIA OOCYSTS

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ABSTRACT

Introduction and Purpose: Coccidiosis, an enteric parasitic disease affecting poultry, is caused by the protozoa Eimeria spp. and has a negative impact on the growth of the poultry industry, resulting in economic losses. This infection leads to a decrease in the feed conversion ratio, reduced body weight gain, and a temporary reduction in egg production. Anticoccidial drugs have yielded excellent results. The main problems observed are the development of resistance in Eimeria species, the presence of significant residues of these drugs in meat, and the toxic effects of disinfectants. We therefore hypothesized that administering olive leaf extract could serve as a natural anticoccidial agent capable of reducing the parasite burden.The aim of the present study was to evaluate in vitro the anticoccidial activity of olive leaves (OL) on the destruction of Eimeria oocysts isolated from naturally infected chickens.

Materials and Methods: The identification of phenolic compounds was obtained by ultra-high-performance liquid chromatography–mass spectrometry with electrospray ionization (UHPLC-MS/ESI). Eimeria oocysts were treated with the OL extract and with standard compounds (quercetin and oleuropein). Lysis of the oocysts was assessed by measuring the release of substances absorbing at 273 nm.

Results :Treatment of Eimeria oocysts with the OL extract and standard compounds led to their lysis, as shown by the release of substances absorbing at 273 nm. The optimum OL extract and standard compounds showed that the number of oocysts decreased after treatment. The OL extract at a concentration of 1.46 mg/mL recorded a decrease rate of 5.89% of Eimeria oocysts after 7-h treatment. Quercetin was the most effective (48.57%), followed by oleuropein (27.53%), after 7-h treatment. The ethanol-treated Eimeria suspension was significantly ($P \leq 0.05$) higher than the tested concentrations of the OL extract and the standard compounds.

Discussion and Conclusion :The findings of the present study indicate that the OL extract possesses the ability to destroy Eimeria spp. This anti-Eimeria activity may be attributed to bioactive molecules of OL extracts individually or a synergistic interaction of bioactive compounds. Future in vivo investigations are required to assess the efficiency of the OL bioactive compounds in broiler chickens.

Keywords: Olea europea L., var. Chemlal; olive leaves; anticoccidial activity; chickens; in vitro

THE USE OF PLANT EXTRACTS TO INHIBIT CONCRETE REINFORCEMENTS CORROSION

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ABSTRACT

Corrosion is one of the pathologies leading to the degradation of structures; it is at the origin of a large number of additional costs linked to the maintenance of these buildings. It is therefore important to adopt a preventive logic by trying to inhibit the effects of this disease, thus delaying the aging of these structures.

The aim of this work is to bring the different techniques for applying green corrosion inhibitors in reinforced concrete, which can help to assess or detect corrosion in order to minimize the damage caused by this pathology.

Two modes of corrosion inhibition are often used, either in the form of admixtures mixed with the mixing water or with the mass of fresh concrete, or on concrete hardened by surface impregnation techniques (migration inhibitors).

The introduction of corrosion inhibitors is based on the nature of these products, chemical or green, so that, we have cited the methods of extraction of green inhibitors through works in the literature.

Keywords: Corrosion, Green inhibitors, Extraction, Evaluation.

THERMAL PERFORMANCE AND SOLAR REFLECTANCE OF GFRC AND ETFE COMPOSITE ENVELOPES IN TROPICAL CIVIC BUILDINGS

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ABSTRACT

Urban growth is fundamental to improve the quality of life and living standards around the world; however, it has several negative effects in terms of social, economic, and environmental consequences. The building envelopes generally regulate indoor thermal comfort, solar radiation, and heat transfer. The building roof surface can be 30 to 50 ^{o}C hotter than the surrounding air in summer due to convective heat flux. In hot regions, especially tropical ones, the main structural concerns are high relative humidity, high cooling energy demand, and solar exposure, which accelerate the material's deterioration. Therefore, it is important to increase the solar reflectance and emissivity of rooftop coating to as high as 0.96 and 0.97, respectively, to reduce the rooftop temperature and to protect the materials against environmental deterioration. This study investigates the quantitative analysis of solar reflectance and thermal transmittance values of the composite materials, which were compared with the conventional masonry values for five selected civic structures within the region. The thermal performance (U-value), solar reflectance and envelope surface temperature were recorded using a cross-case empirical matrix combined with mechanistic analysis to normalize thermal transmittance across various building configurations subjected to similar climatic conditions. It was found that the conventional reinforced concrete (RC) envelopes showed high thermal transmittance values varying from 2.3 to 3.2 W/m^{2}K. However, the application of composite materials, including multi-layer pneumatic ethylene tetrafluoroethylene (ETFE) cushions and glass fiber-reinforced concrete (GFRC) assemblies, significantly reduced the surface temperatures of RC envelopes by 20 to 25°C. The findings demonstrate that integrating engineered composites improves thermal performance and solar reflectance, and reduces the long-term mechanical cooling demand, in accordance with the principles of the Resilient Civic Architecture Framework (RCAF).

Keywords: Civic Buildings, Thermal Performance, Solar Reflectance, GFRC, ETFE Treatment, U-value.

EXPLAINABLE HYBRID FRAMEWORK FOR STUDENT SENTIMENT PREDICTION IN LEARNING MANAGEMENT SYSTEMS USING ATTENTION-BASED TRANSFORMERS AND EDUCATIONAL DOMAIN KNOWLEDGE

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ABSTRACT

Introduction and Purpose: learning control structures (LMSs) generate huge volumes of textual feedback through discussion forums, path evaluations, assignments, and reflective remarks, presenting valuable insights into college students' learning stories and emotional responses. despite the fact that transformer-based sentiment evaluation models have proven top notch predictive performance, their confined interpretability restricts their realistic adoption in instructional choice-making.

Materials and Methods: The proposed framework combines contextual semantic representations generated via an pre-trained BERT model with an academic rule-based inference engine developed the use of area-particular ontologies, pedagogical rules, and linguistic heuristics. pupil comments collected from gaining knowledge of control structures undergoes comprehensive natural Language Processing (NLP), along with content cleaning, tokenisation, normalisation, forestall-phrase removal, and lemmatisation.

Results: Experimental evaluation demonstrates that the proposed Explainable Hybrid Framework outperforms traditional system studying fashions and standalone transformer-based procedures in sentiment classification accuracy. the integration of interest-based contextual studying with academic domain know-how significantly improves prediction reliability whilst producing obvious explanations that enable educators to recognize the motive in the back of every prediction.

Discussion and Conclusion: The proposed framework efficiently bridges the distance between predictive overall performance and model interpretability in academic sentiment analysis. by combining deep contextual language expertise with explicit academic know-how, the model can provide honest and explainable sentiment predictions that support evidence-based totally academic decision-making

Key Words: Explainable Artificial Intelligence (XAI), Student Sentiment Prediction, Learning Management Systems, Attention-Based Transformers, BERT, Educational Domain Knowledge, Hybrid Deep Learning.

THE ROLE OF ATTACHMENT STYLES IN DEPRESSION AND ANXIETY

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ABSTRACT

The aim of this study was to examine the role of attachment styles in depression and anxiety levels among adults. According to attachment theory, the relationships individuals establish with their early caregivers influence their interpersonal relationships and psychological adjustment in later life. Accordingly, this study investigated the relationships between anxious and avoidant attachment styles and symptoms of depression and anxiety, and also examined the predictive power of these attachment styles for depression and anxiety.The study was conducted using a correlational research design. The sample consisted of 200 adult participants who voluntarily took part in the study. Data were collected using the Demographic Information Form, the Experiences in Close Relationships Scale–Short Form, the Depression Severity Scale for Adults, and the Generalized Anxiety Disorder Scale.Descriptive statistics, Pearson correlation analysis, and multiple linear regression analysis were used to analyze the data. The findings revealed that both anxious and avoidant attachment styles were positively and significantly associated with depression and anxiety levels. Furthermore, the regression analyses indicated that anxious and avoidant attachment styles significantly predicted both depression and anxiety. The findings supported all of the hypotheses proposed in the study. In conclusion, insecure attachment styles have a significant impact on individuals' mental health. The findings emphasize the importance of considering attachment styles in psychological assessment and intervention processes and are expected to contribute to future research in this field.

Keywords: Attachment styles, depression, anxiety, adult attachment, mental health.

NICKEL OXIDE-CONTAINING SPINEL NIAL2O4 NANOCOMPOSITE FOR ENHANCED SUPERCAPACITOR PERFORMANCE

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ABSTRACT

Supercapacitor electrodes composed of spinel oxide nanocomposites are considered a superior alternative to address the current energy challenge. In this work, $NiAl_2O_4$ is synthesised, but due to its low surface area and conductivity, it is also combined with nickel oxide (NiO) via a hydrothermal method to form a composite with increased specific capacitance and cycling stability. The characteristics of the manufactured electrode material were investigated using spectroscopic and microscopic instruments. The electrochemical activity of the material was measured by employing cyclic voltammetry, electrochemical impedance spectroscopy, galvanostatic charge–discharge methods, and chronoamperometry. The electrochemical results demonstrated that the insertion of $NiAl_2O_4$ with NiO increases the discharge duration, improves its specific capacitance, and enhances its stability. At a low current density of 1 A g^{-1}, the electrochemical results of $NiAl_2O_4$/NiO show a specific capacitance of 676.2 F g^{-1}, an energy density of 36.46 Wh kg^{-1}, and a power density of 318 W kg^{-1}. However, the capacitive activity of the manufactured electrode was further improved by changes in electronic and structural arrangements, changes in morphology, or the addition of other metals or non-metals.

Keywords: $NiAl_2O_4$/NiO, Hydrothermal method, Supercapacitor, Specific capacitance

EXPERIMENTAL AND THEORETICAL INVESTIGATION OF 8-QUINOLINOL-5-AZOANTIPYRINE AS A CORROSION INHIBITOR FOR MILD STEEL IN 1.0 M HCL

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ABSTRACT

The corrosion inhibition performance of 8-quinolinol-5-azoantipyrine (HQAP) for mild steel in 1.0 M HCl was investigated experimentally and theoretically. Weight-loss and Tafel polarization measurements showed an inhibition efficiency of about 96% at 10^{-3} M, with HQAP acting as a mixed-type inhibitor. Its adsorption followed the Langmuir isotherm. DFT calculations, Monte Carlo and molecular dynamics simulations were performed for the neutral HQAP-AE and protonated HQAP-OcarbonylH^{+} forms. Protonation increased the dipole moment and improved adsorption, with energies of −257.66 and −289.93 kcal mol^{-1}, respectively. MD and RDF analyses confirmed stable Fe–N and Fe–O interactions. The inhibition mechanism involves multipoint adsorption, charge transfer, electrostatic interactions and protective film formation on Fe (110).

Keywords : 8-Quinolinol-5-azoantipyrine ; Mild steel; Corrosion inhibition ; Hydrochloric acid; DFT calculations ; Monte Carlo simulation ; Molecular dynamics; Fe (110) surface.

SUSTAİNABLE INSULATİON: NEW MATERİALS FOR FUTURE APPLİCATİONS

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ABSTRACT

This studyaims to evaluate the impact of new insulation materialsderivedfromnaturalfeatherfibers on thermal performance and energysavings in the building sector. An experimental and numericalapproachwasadopted, including the characterization of recycledfeather-basednonwovens, whichexhibit a thermal conductivity of 0.031–0.044 W/m·K. A dynamic simulation model wasdevelopedbased on a real-scalecelllocated in Casablanca and subsequentlyvalidated to analyzeenergysavings, greenhousegas (GHG) emissionreductions, and improvements in thermal comfort.

The resultsdemonstratethatfeather-based insulation materialsachieve a minimum energy performance of 30 kWh/year·m², a levellowerthan the 40 kWh/year·m² threshold set by Moroccan thermal regulations for the Casablanca climate zone. Furthermore, a significantreduction in greenhousegasemissionswasobserved, reaching up to 48.58% depending on the tested configurations.

Keywords: Building sector, Recycledfeather, Insulation materials, Energy savings.

DEVELOPMENT OF A B-RICH Ti–40Nb ALLOY THROUGH POWDER METALLURGY: MICROSTRUCTURAL CHARACTERIZATION

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ABSTRACT

Introduction and Purpose: The development of porous titanium-based alloys with tailored mechanical properties, controlled porosity, and favorable phase constitution remains a significant challenge for load-bearing biomedical applications. Among titanium alloys, Nb-containing systems have attracted considerable attention due to their ability to stabilize the β-Ti phase, which is associated with reduced elastic modulus and improved biomechanical compatibility. Therefore, the aim of the present study was to fabricate a porous Ti–40Nb alloy via powder metallurgy and to evaluate its microstructural characteristics, phase constitution, and pore morphology for potential use in load-bearing implant applications.

Materials and Methods: Porous Ti–40Nb alloy was produced using a conventional powder metallurgy route. Elemental titanium and niobium powders were blended in a Turbula mixer at 24 rpm for 4 h. The powder mixture was subsequently compacted under a pressure of 300 MPa and sintered at 1400 °C for 2 h. The microstructure, phase composition, and pore morphology of the fabricated alloy were characterized using scanning electron microscopy (SEM), energy-dispersive X-ray spectroscopy (EDS), and X-ray diffraction (XRD) analyses.

Results: The Microstructural analyses revealed the presence of a predominantly β-Ti matrix accompanied by a minor amount of α-Ti phase. SEM observations demonstrated a heterogeneous microstructure consisting of irregularly shaped interconnected open and closed pores. The average pore diameter was approximately 65 μm. The observed pore morphology indicated incomplete densification during the sintering process, resulting in the formation of a porous architecture throughout the alloy. Consequently, the porous Ti–40Nb alloy fabricated by powder metallurgy exhibited promising microstructural features and phase characteristics, indicating its potential for further investigation as a load-bearing biomedical implant material.

Key Words: Ti–40Nb alloy; powder metallurgy; porous titanium; β-Ti phase; microstructure; pore morphology.

AI-BASED DECISION SUPPORT SYSTEMS FOR PRECISION DISEASE MANAGEMENT

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ABSTRACT

Plant diseases continue to pose a major challenge to global food security by reducing crop productivity and quality. Conventional disease management practices often rely on routine pesticide applications and manual field inspections, which can be labor-intensive, time-consuming and environmentally unsustainable. Artificial Intelligence (AI)-based Decision Support Systems (DSS) have emerged as a transformative approach for precision disease management by integrating machine learning, deep learning, remote sensing, Internet of Things (IoT) sensors and weather-based forecasting models. These systems analyze real-time field data, environmental conditions, historical disease records, and crop health information to accurately predict disease outbreaks, identify causal pathogens at early stages and recommend site-specific management strategies.

AI-powered DSS can optimize fungicide application timing, dosage, and location, thereby reducing unnecessary chemical use, minimizing production costs and mitigating environmental impacts. Advanced technologies such as hyperspectral imaging, drone-based surveillance, smartphone diagnostics and cloud computing further enhance the capability of these systems for continuous crop monitoring and rapid disease detection. The integration of explainable AI (XAI) also improves the transparency and reliability of model predictions, increasing farmer confidence and adoption. As precision agriculture continues to evolve, AI-based decision support systems offer a sustainable, data-driven solution for improving disease management efficiency, enhancing crop productivity and strengthening climate-resilient agricultural practices. Future research should focus on developing scalable, cost-effective and region-specific AI platforms capable of integrating multi-source data for real-time disease forecasting and intelligent decision-making.

Keywords: Artificial Intelligence, Internet of Things, Sensors

TOTAL QUALITY MANAGEMENT IN THE HEALTHCARE SECTOR AND ITS RELATIONSHIP WITH PATIENT SAFETY

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ABSTRACT

Introduction and Purpose: Healthcare services are directly associated with human life; therefore, ensuring quality together with patient safety has become a fundamental priority for healthcare organizations. Total Quality Management (TQM) has emerged as a comprehensive management philosophy that emphasizes continuous improvement, patient-centered care, process management, and employee participation to enhance healthcare quality and safety. In parallel, accreditation systems and patient safety standards provide healthcare institutions with structured frameworks for improving service quality and minimizing medical errors. The main purpose of this study is to evaluate the contribution of TQM practices to patient safety in healthcare organizations and to examine the relationship between quality management, accreditation systems, and patient safety culture based on the existing literature.

Materials and Methods: This study was designed as a narrative literature review. National and international scientific articles, books, reports, and accreditation-related publications concerning Total Quality Management and patient safety in healthcare were reviewed. The identified literature was descriptively evaluated to explain the role of quality management practices in improving patient safety and healthcare service quality.

Results: The reviewed literature indicates that patient safety depends not only on the individual responsibility of healthcare professionals but also on organizational structure, leadership, employee participation, and quality management practices. The findings suggest that implementing TQM as an organizational philosophy contributes to standardized processes, continuous improvement, effective risk management, and the delivery of safe, sustainable, and patient-centered healthcare services. Accreditation systems also play an important role in strengthening patient safety culture by promoting compliance with recognized quality standards.

Discussion and Conclusion: The reviewed literature demonstrates that Total Quality Management contributes to patient safety by promoting standardized processes, continuous improvement, and organizational commitment. Accreditation systems support the development of a patient safety culture when implemented beyond compliance requirements. Therefore, sustainable quality improvement should focus on organizational culture, leadership, employee participation, and continuous development rather than documentation alone.

Key Words: Healthcare, Total Quality Management, Patient Safety, Management

COGNITIVE EMOTION REGULATION STRATEGIES AND DIMENSIONS OF AGGRESSION IN ADULTS

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ABSTRACT

Introduction and Purpose: This study examined the relationship between cognitive emotion regulation strategies and dimensions of aggression in adults and aimed to identify the strategies with the greatest contribution to explaining aggression.

Materials and Methods: The research used a cross-sectional design and included 341 adults (18-45 years). Cognitive emotion regulation strategies were assessed with the Cognitive Emotion Regulation Questionnaire (CERQ), while aggression was measured with the Buss-Perry Aggression Questionnaire (BPAQ). Strategies were classified according to the instrument's structure into functional and dysfunctional cognitive strategies. Spearman correlation analyses and multiple linear regressions were conducted to identify the independent predictors of the aggression dimensions.

Results: Dysfunctional cognitive strategies showed significantly stronger associations with aggression than functional strategies. Other-blame was the only strategy associated positively with all aggression dimensions, with the strongest association for hostility *($\rho = .49$, $p < .001$)*, and it remained a significant predictor in all regression models. Catastrophizing was particularly associated with hostility *($\rho = .48$, $p < .001$)* and anger *($\rho = .30$, $p < .001$)*, whereas rumination showed weaker associations. The regression model for hostility explained the greatest proportion of variance *($R^2 = .38$)*. Functional strategies showed weak negative associations, significant mainly for anger.

Conclusions: The results suggest that dysfunctional strategies contribute more to explaining aggression than functional strategies. In the investigated non-clinical adult sample, other-blame represents the most robust predictor of all aggression dimensions, whereas general rumination showed only weak associations. These findings support the role of attributional styles in aggressive behavior and the relevance of interventions aimed at restructuring dysfunctional attributional styles.

Key Words: *cognitive emotion regulation; aggression; CERQ; BPAQ; other-blame*

FAMILY-PROMOTED FORGIVENESS AND EMPATHY, COGNITIVE EMOTION REGULATION, AND AGGRESSION IN ADULTS

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ABSTRACT

Introduction and Purpose: The study investigated the role of the values of forgiveness and empathy in relation to functional cognitive strategies and aggression among adults. Mediation was tested through emotion regulation strategies linking forgiveness/empathy and aggression.

Materials and Methods: The research used a cross-sectional design and included 341 adults (18–45 years). The promotion of forgiveness and empathy in the family, as well as adverse family experiences, were assessed with an omnibus questionnaire. Cognitive emotion regulation strategies were measured using the Cognitive Emotion Regulation Questionnaire (CERQ) and organized into functional and dysfunctional strategies according to the instrument's structure. Aggression was measured with the Buss–Perry Aggression Questionnaire (BPAQ). Correlational analyses were performed using Spearman, and mediation effects were tested with PROCESS Model 4 (bootstrapping, 5,000 samples).

Results: Family promotion of forgiveness and empathy was positively associated with functional cognitive strategies related to more effective regulation, and negatively associated with physical aggression ($\rho = -.16$, $p = .003$) and strongly negatively with adverse family experiences ($\rho = -.53$, $p < .001$). Mediation showed a significant indirect effect on anger through functional cognitive strategies (indirect effect = −.16, 95% CI [−.36, −.01]). For the other dimensions of aggression, the indirect effects were not statistically significant.

Conclusions: The results suggest that forgiveness and empathy promoted in the family may function as protective factors by fostering functional cognitive emotion regulation strategies and reducing the affective component of aggression, especially anger. Practical implications support prevention programs and parent education initiatives aimed at fostering empathy and forgiveness and maintaining a supportive family climate.

Key Words: forgiveness; empathy; aggression; cognitive emotion regulation; protective factors

VALORISATION OF UNDERUTILISED JACKFRUIT (*ARTOCARPUS HETEROPHYLLUS*) SEEDS INTO A SPREAD: EFFECTS OF PALM OIL ON PHYSICOCHEMICAL CHARACTERISTICS AND STORAGE STABILITY

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ABSTRACT

Jackfruit (*Artocarpus heterophyllus*) seeds are an underutilised agro-industrial by-product that are often discarded despite their high nutritional value, contributing to food waste and the underexploitation of a potentially valuable food resource. This study aimed to valorise jackfruit seeds by developing a spread and evaluating the effects of palm oil concentration on its physicochemical properties and storage stability. Jackfruit seed spreads containing 0%, 12%, 14% and 16% cooking palm oil were stored at ambient temperature for six weeks and analysed for proximate composition, moisture content, water activity, pH, texture profile, oil separation, colour and oil-holding capacity. Increasing palm oil concentration significantly ($p < 0.05$) increased crude fat content from 2.51% to 10.33%, while ash content decreased from 1.57% to 1.34%; moisture, protein and carbohydrate contents remained unchanged. Apparent oil separation increased significantly with both palm oil concentration and storage time, reaching 6.92%, 8.69% and 10.07% in F1, F2 and F3, respectively, after six weeks. During storage, moisture content increased from 21.52–22.36% to 26.77–27.83%, water activity increased from 0.58–0.59 to 0.60–0.62, and pH decreased from 6.03–6.05 to 5.83–5.92. The control exhibited the greatest hardness, whereas palm oil formulations showed higher adhesiveness. Colour also changed during storage, with F3 showing the greatest total colour difference. Overall, palm oil concentration significantly affected fat content, texture and oil separation, while storage primarily influenced moisture, water activity, pH and colour. Jackfruit seeds show promising potential as a sustainable raw material for spread production, although further formulation optimisation is needed to improve product stability.

Keywords: jackfruit seed spread, oil-holding capacity, apparent oil separation, physicochemical properties, storage stability.

THE IMPACT OF SOCIAL LEARNING IN PHYSICAL EDUCATION ON HEALTH-PROMOTING BEHAVIORS AMONG MIDDLE SCHOOL STUDENTS

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ABSTRACT

Physical inactivity is a critical public health problem and Physical Education (PE) offers a good environment to encourage health-enhancing behaviors. The shift from school-based physical activity to physical activity in the community and at any given age, however, is a huge hurdle. The effects of social interaction, in the form of peer tutoring, on the health outcomes of students in PE is explored. The study, which was carried out with middle school students, shows that social learning can improve emotional regulation, improve self-efficacy, and promote a mastery rather than competitive climate. The results also reveal that social support and belongingness within the group promotes resilience, motivation and persistence in physical activity as well as helps to maintain physical, psychological and social health. The discussion implies that students exposed to positive experiences in PE are more likely to engage in lifestyle choices over time that will support their healthy living, with health not being a medical directive, but rather a social competence developed through interactions and movement. In PE, therefore, social learning can be a powerful tool for public health promotion, through the promotion of an active lifestyle into adulthood.

Keywords: peer learning; social skills; physical education; human health; public health.

MEDICATION ADHERENCE AMONG PATIENTS WITH TYPE 2 DIABETES: FINDINGS FROM A MULTICENTER STUDY IN MOROCCO

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ABSTRACT

Background: Medication adherence is a cornerstone of effective type 2 diabetes (T2DM) management. However, poor adherence remains a major challenge, particularly in low- and middle-income countries, where socioeconomic and healthcare-related barriers may compromise treatment outcomes. This study aimed to assess medication adherence and identify its associated factors among Moroccan patients with T2DM.

Methods: A multicenter cross-sectional study was conducted between February and June 2024 in primary healthcare facilities across the Casablanca-Settat and Rabat-Salé-Kénitra regions of Morocco. A total of 584 adults with confirmed T2DM participated in the study. Medication adherence was assessed using the Moroccan Arabic version of the General Medication Adherence Scale (GMAS). Sociodemographic, clinical, and treatment-related variables were collected through face-to-face interviews. Logistic regression analyses were performed to determine factors independently associated with adherence.

Results: Overall, 96.2% of participants were classified as adherent to their prescribed medications. High adherence was observed in 89.4% of patients, while 7.2% demonstrated good adherence and 3.4% partial adherence. Multivariate analysis showed that treatment with two or more oral antidiabetic drugs and longer diabetes duration (11–15 years) were significantly associated with lower adherence. Health insurance coverage and self-monitoring of blood glucose were positively associated with adherence. Rural residence showed a trend toward lower adherence, although statistical significance was not reached.

Conclusion: Medication adherence among Moroccan patients with T2DM was generally high. Nevertheless, treatment complexity and disease duration remain important barriers to optimal adherence. Strengthening patient education, simplifying treatment regimens when feasible, and improving access to diabetes self-management resources may further enhance adherence and clinical outcomes. These findings provide valuable evidence to guide patient-centered interventions and health policy in Morocco and similar settings.

Keywords: Type 2 diabetes mellitus; Medication adherence; GMAS; Morocco; Primary healthcare; Cross-sectional study.

COPPER-BASED METAL–ORGANIC FRAMEWORK AS A CATALYST IN ORGANIC TRANSFORMATIONS

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ABSTRACT

Porous coordination polymers, also known as metal–organic framework (MOF) nanoparticles, have acquired increasing importance in nanomaterials science, especially with the enhanced significance and versatility in catalysis. The complex structures of MOFs allow the addition of metal nodes, enclosing substrates, and functional linkers, thus enabling synergistic structural and functional engineering to afford capable catalytic active sites that provide solutions to decrease human activities in designing new organic reactions. Recently, Cu-MOF-mediated organic reactions hold a major promise to substitute homogeneous and heterogeneous catalysts due to their promising structural properties such as tailorable porous structures, high-density catalytic active sites and surface area, sufficient framework stability, minimal leaching, and facile recovery and recyclability. This presentation emphasizes the importance of Cu-MOFs in synthetic chemistry, in particular, in the synthesis of organic compounds. It examines their applicability in hydrogenation, oxidation, cross-coupling/condensation reactions, functionalization at terminal alkenes and alkynes, intramolecular C-H amination, and various other multicomponent reactions. In addition to these organic transformations, recent progress in Cu-MOF-catalyzed CO_2 electroreduction and nitrate reduction is also briefly described. Subsequently, the state-of-the-art synthetic methods of certain decorated Cu-MOFs are thoroughly explained, as well as the essential structural parameters that govern the stability and recyclability of MOFs in organic transformations. This focused examination of Cu-MOFs is expected to provide useful information for future research endeavors in the field of MOF catalytic applications.

Keywords: Cu-MOF, cross-coupling, organic, stability, coordination, hydrogenation

ADAPTIVE FEDERATED DEEP LEARNING FRAMEWORK FOR PRIVACY-PRESERVING AND EXPLAINABLE INTRUSION DETECTION IN SMART IOT NETWORKS

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ABSTRACT

Introduction and Purpose: The speedy boom of net of factors (IoT) devices has multiplied cybersecurity dangers because of distributed architectures and resource-constrained environments. traditional intrusion detection structures frequently require centralized facts collection, elevating worries approximately privateness, scalability, and version transparency. This observe proposes a adaptive federated deep mastering framework that allows collaborative intrusion detection whilst keeping person facts privateness and improving explainability.

Materials and Methods: The proposed framework integrates Federated getting to know (FL) with an light-weight deep neural community and Explainable artificial Intelligence (XAI) strategies. nearby IoT nodes teach models the use of their own community site visitors statistics, even as an important server aggregates encrypted model parameters via the Federated Averaging (FedAvg) algorithm. SHAP-primarily based causes are incorporated to interpret prediction outcomes. overall performance is evaluated the use of benchmark intrusion detection datasets with metrics together with accuracy, precision, don't forget, F1-rating, and conversation performance.

Results: Experimental evaluation demonstrates that the proposed framework achieves high intrusion detection accuracy at the same time as drastically lowering records-sharing necessities. The version presents interpretable predictions and keeps aggressive overall performance underneath heterogeneous IoT environments with decrease communication overhead as compared to centralized gaining knowledge of tactics.

Discussion and Conclusion: The proposed adaptive federated learning framework offers an secure, scalable, and privateness-preserving solution for IoT intrusion detection. by combining explainable AI with dispensed learning, it complements trust, transparency, and actual-world applicability. destiny paintings will cognizance on energy-efficient optimization and actual-time deployment in big-scale clever town and commercial IoT environments.

Key Words: Sentiment Analysis, Explainable Artificial Intelligence (XAI), Explainable Machine Learning, Attention Mechanism

ARTIFICIAL INTELLIGENCE AND MACHINE LEARNING FOR EARLY PREDICTION OF BAYOUD DISEASE THROUGH SOIL MICROBIAL ACTIVITY IN DATE PALM CULTIVATION IN MOROCCO

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ABSTRACT

Bayoud disease, caused by *Fusarium oxysporum* f. sp. *albedinis*, represents a major constraint to date palm cultivation in Moroccan oases, threatening both ecological stability and local economies. This study aims to predict soil suppressiveness to Bayoud disease based on microbial metabolic profiles using advanced machine learning techniques. A total of sixty *Fusarium* isolates collected from disease-suppressive and disease-conducive soils in Morocco were evaluated for their ability to utilize 95 different carbon sources. The resulting metabolic profiles were analyzed using six supervised machine

learning models: Logistic Regression (LR), Naive Bayes (NB), K-Nearest Neighbors (KNN), Support Vector Machine (SVM), XGBoost, and Gradient Boosting (GB). The results revealed significant differences in carbon utilization patterns between suppressive and conducive soils. Among the tested models, XGBoost and Gradient Boosting achieved the highest predictive performance, with Area Under the Curve (AUC) values exceeding 0.90, indicating excellent classification accuracy and robustness. Furthermore, Shapley Additive Explanations (SHAP) analysis identified key carbon sources acting as metabolic markers associated with the suppression of *F. oxysporum* f. sp. *albedinis*. These findings demonstrate that soil suppressiveness is strongly linked to specific microbial metabolic traits and that machine learning models can effectively capture these patterns. This study provides a reliable data-driven framework for the early prediction of soil suppressiveness, offering promising perspectives for proactive disease management and the sustainable protection of Moroccan date palm agroecosystems.

Keywords: Bayoud disease, Machine learning, Soil suppressiveness, Carbon metabolism, Predictive modeling

EVALUATION OF NUTRITIONAL AND BEHAVIORAL ATTITUDES AND FOOD ADDICTION IN ADULTS SCHEDULED FOR BARIATRIC SURGERY

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ÖZET

Amaç: Bu çalışma, bariatrik cerrahi planlanan yetişkinlerde beslenme ve davranış tutumları ile yeme bağımlılığının değerlendirilmesi amacıyla planlanmış ve yürütülmüştür.

Gereç ve Yöntem: Çalışma, Ocak–Mart 2025 tarihleri arasında Antalya Eğitim ve Araştırma Hastanesi Genel Cerrahi Kliniğine bariatrik cerrahi amacıyla başvuran, 18–64 yaş aralığında, beden kütle indeksi 35 kg/m²'nin üzerinde olan, gönüllülük esasına dayanarak, çalışmaya onam vererek katılmayı kabul eden 100 yetişkin birey ile yürütülmüştür. Bireylere yüz yüze görüşme tekniği ile anket formu uygulanmıştır. Anket formu; katılımcıların bireysel ve sosyodemografik özellikleri, sağlık durumları, antropometrik ölçümleri ve bazı beslenme alışkanlıklarına ilişkin sorular ile Bariatrik Cerrahi Hastalarında Beslenme ve Davranış Tutumu Ölçeği ve Modifiye Edilmiş Yale Yeme Bağımlılığı Ölçeği Sürüm 2.0'dan oluşmaktadır.

Bulgular: Bireylerin antropometrik ölçümleri incelendiğinde; erkeklerde ortalama vücut ağırlığı 136,37±15,45 kg, kadınlarda ise 110,37±16,85 kg olarak belirlenmiştir. Ortalama vücut yağ oranı erkeklerde %51,07±6,49, kadınlarda %50,83±7,58 bulunmuştur. Bariatrik Cerrahi Hastalarında Beslenme ve Davranış Tutumu Ölçeği (BCBDTÖ) toplam puanları örneklem içindeki 25. ve 75. yüzdelik değerler esas alınarak sınıflandırıldığında, katılımcıların %23'ünün (n=23) alt, %50'sinin (n=50) orta ve %27'sinin (n=27) üst puan grubunda yer aldığı belirlenmiştir. BCBDTÖ puan düzeyleri ile ana öğün sayısı (p=0,005), ara öğün sayısı (p=0,012) ve atlanan ana öğün (p=0,045) arasında istatistiksel olarak anlamlı ilişki saptanmıştır. Özellikle sabah öğününü atlayan bireylerin düşük BCBDTÖ puan grubunda daha yüksek oranda yer aldığı belirlenirken, puan düzeyleri cinsiyete göre farklılık göstermemiştir (p=0,638). Katılımcıların %17,0'sinin ciddi yeme bağımlılığı ölçütlerini karşıladığı belirlenmiştir. Yeme bağımlılığı ile medeni durum (p=0,016), gece uykudan uyanarak yemek yeme (p=0,005) ve mutsuzken yeme davranışı (p=0,004) arasında istatistiksel olarak anlamlı ilişki saptanmış; ciddi yeme bağımlılığı bulunan bireylerde gece yeme davranışının daha yaygın olduğu görülmüştür. Yeme bağımlılığı durumu ile beslenme ve davranış tutumu düzeyi arasında istatistiksel olarak anlamlı bir ilişki saptanmamıştır (χ^2=2,684; p=0,261).

Sonuç: Bariatrik cerrahi adaylarının ameliyat öncesi dönemde beslenme davranışları ve yeme bağımlılığı açısından kapsamlı biçimde değerlendirilmesi ve riskli bireylere multidisipliner destek sağlanması; cerrahi sonrası beslenme uyumunun sürdürülebilmesi, ağırlık kaybının korunması ve uzun dönem tedavi başarısının artırılması açısından önem taşımaktadır.

Anahtar kelimeler: Bariatrik cerrahi, beslenme davranışı, obezite, yeme bağımlılığı.

ABSTRACT

Objective: This study was designed and conducted to evaluate nutritional and behavioral attitudes and food addiction among adults scheduled for bariatric surgery.

Materials and Methods: The study was conducted between January and March 2025 with 100 adults aged 18–64 years who presented to the General Surgery Clinic of Antalya Training and Research Hospital for bariatric surgery, had a body mass index greater than 35 kg/m², and voluntarily agreed to participate after providing informed consent. A questionnaire was administered to the participants through face-to-face interviews. The questionnaire comprised items addressing participants' individual and sociodemographic characteristics, health status, anthropometric measurements, and selected dietary habits, as well as the Nutritional and Behavioral Attitudes Scale for Bariatric Surgery Patients and the Modified Yale Food Addiction Scale Version 2.0.

Results: Examination of the participants' anthropometric measurements showed that the mean body weight was 136.37±15.45 kg in men and 110.37±16.85 kg in women. The mean body fat percentage was 51.07±6.49% in men and 50.83±7.58% in women. When the total scores of the Nutritional and Behavioral Attitudes Scale for Bariatric Surgery Patients were classified according to the 25th and 75th percentiles of the sample distribution, 23% (n=23) of the participants were categorized in the lower, 50% (n=50) in the middle, and 27% (n=27) in the upper score group. Significant associations were found between the scale score groups and the number of main meals (p=0.005), the number of snacks (p=0.012), and the main meal skipped (p=0.045). Participants who skipped breakfast were more frequently represented in the lower score group, whereas the score groups did not differ significantly by sex (p=0.638). Overall, 17.0% of the participants met the criteria for severe food addiction. Food addiction was significantly associated with marital status (p=0.016), waking from sleep to eat (p=0.005), and eating when feeling unhappy (p=0.004); waking from sleep to eat was more common among participants with severe food addiction. No statistically significant association was found between food addiction status and nutritional and behavioral attitude level (χ^2=2.684; p=0.261).

Conclusion: A comprehensive preoperative assessment of dietary behaviors and food addiction among candidates for bariatric surgery, together with the provision of multidisciplinary support to individuals identified as being at risk, is important for sustaining postoperative dietary adherence, maintaining weight loss, and improving long-term treatment success.

Keywords: Bariatric surgery, dietary behavior, obesity, food addiction.

THE RELATIONSHIP BETWEEN EMOTIONAL STABILITY, THE DARK TRIAD, AND AGGRESSION AMONG INCARCERATED INDIVIDUALS CONVICTED OF VIOLENT OFFENSES: EVIDENCE FROM A ROMANIAN SAMPLE

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ABSTRACT

Objectives. The present study aimed to examine the relationship between emotional stability, Dark Triad traits (Machiavellianism, Narcissism, and Psychopathy), and aggressive behavior among incarcerated individuals convicted of violent offenses.

Methods. A cross-sectional study design was employed, involving a sample of 500 adults serving custodial sentences in Romanian prisons, aged 21 years or older. The study variables were assessed using an omnibus questionnaire, the IPIP Emotional Stability Scale, the Buss–Perry Aggression Questionnaire (Buss & Perry, 1992), and the Short Dark Triad Scale (SD3). Data were analyzed using descriptive statistics, Cronbach's alpha coefficients, Pearson correlation analyses, and multiple linear regression.

Results. Significant negative correlations were identified between emotional stability and all dimensions of aggression, with the strongest associations observed for overall aggression ($r = -0.577$, $p < .001$) and anger ($r = -0.569$, $p < .001$). Multiple linear regression analyses showed that Dark Triad traits explained a significant proportion of the variance in the aggression dimensions ($R^2 = 0.181–0.381$, $p < .001$). Based on the standardized β coefficients, Psychopathy emerged as the strongest predictor of physical aggression ($\beta = 0.528$) and anger ($\beta = 0.398$), whereas Machiavellianism made the greatest contribution to the prediction of verbal aggression ($\beta = 0.278$) and hostility ($\beta = 0.406$). Narcissism contributed significantly only to the prediction of verbal aggression and hostility.

Conclusions. The findings highlight the role of emotional stability and Dark Triad traits in explaining aggressive behavior among incarcerated individuals convicted of violent offenses, emphasizing the importance of assessing these personality dimensions when developing psychological intervention programs aimed at managing aggressive behavior within correctional settings.

Key Words: aggression; emotional stability; Dark Triad; psychopathy; incarcerated individuals

ADAPTIVE EXPLAINABLE FEDERATED LEARNING FRAMEWORK FOR PRIVACY-PRESERVING STUDENT PERFORMANCE PREDICTION USING MULTI-MODAL EDUCATIONAL DATA

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ABSTRACT

Introduction and Purpose: educational institutions more and more rely on mastering management structures (LMS) and other virtual systems that generate numerous pupil statistics. however, centralising those statistics raises privacy issues while restricting collaborative version improvement across institutions. This observe proposes an adaptive explainable federated mastering framework for pupil performance prediction that preserves statistics privacy while presenting obvious and trustworthy predictions.

Materials and Methods: The proposed framework integrates Federated gaining knowledge of (FL) with a Explainable synthetic Intelligence (XAI) module to train prediction models without sharing raw scholar records. Multi-modal educational records, together with educational facts, LMS interactions, attendance, and assessment activities, are preprocessed via records cleaning, feature engineering, and normalisation. an transformer-based prediction model is trained collaboratively across multiple establishments, while SHAP-based factors discover the most influential features contributing to every prediction. model overall performance is evaluated the use of Accuracy, Precision, remember, F1-score, and ROC-AUC.

Results: Experimental assessment demonstrates that the proposed framework achieves high prediction accuracy whilst keeping pupil records privateness. The explainability element gives interpretable insights into prediction choices, allowing educators to become aware of important getting to know factors and help well timed instructional interventions.

Discussion and Conclusion: The proposed framework successfully combines privacy-maintaining federated learning with explainable AI to deliver dependable and obvious scholar overall performance prediction. The method supports relaxed inter-institutional collaboration, complements educators' trust in AI-driven analytics, and allows records-informed decision-making for improving learning consequences and scholar success.

Key Words: Federated Learning, Explainable Artificial Intelligence, Student Performance Prediction, Multi-Modal Learning Analytics, Transformer Networks, Privacy-Preserving Machine Learning.

PROTEOMIC PROFILING, ANTI-PROLIFERATIVE AND ANTI-MIGRATORY ACTIVITY OF VENOM PEPTIDES FROM MOROCCAN SCORPION *ANDROCTONUS MAURITANICUS* AND COBRA *NAJA HAJE*: ION CHANNEL MODULATION IN HUMAN GLIOBLASTOMA CANCER CELL LINES

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ABSTRACT

Animal venoms represent a rich and underexplored source of bioactive peptides with significant pharmacological potential. From a perspective that links ecosystem conservation to therapeutic innovation, this study investigates the venoms of two iconic Moroccan species: the scorpion *Androctonus mauritanicus* and the cobra *Naja haje*. A comprehensive proteomic analysis using RP-HPLC and LC-MS/MS revealed a diverse repertoire of neurotoxic peptides in the 2–5 kDa range. To evaluate their bioactivity, we performed in vitro cytotoxicity screening on human cancer cell lines.

Selected venom fractions demonstrated potent and selective anti-proliferative effects. Further investigation via RT-PCR analysis confirmed that this cytotoxicity strongly correlates with significant modulation of ion channel gene expression. These results demonstrate that venom-derived peptides can directly alter ion channel function, leading to functional anti-cancer outcomes. This work confirms the therapeutic value of studying venomous species and illustrates a vital principle: the sustainable investigation of biodiversity is a fundamental strategy for discovering new tools to address pressing human health challenges.

Keywords: Venoms, Peptides, Ion channels, Bioactivity, Pharmacological potential

STRATEGIC HUMAN RESOURCE MANAGEMENT AND ORGANIZATIONAL EFFECTIVENESS

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ABSTRACT

Strategic human resource management plays a vital role in improving organizational effectiveness by aligning human resource practices with organizational goals and long-term strategies. This systematic review synthesizes recent evidence on the relationship between strategic human resource management and organizational effectiveness, emphasizing key practices, emerging trends, implementation challenges, and future research directions. The review indicates that effective human resource practices, including talent management, employee training and development, performance management, compensation, and employee engagement, enhance productivity, innovation, employee commitment, and sustainable competitive advantage. However, organizational culture, leadership commitment, technological change, and resource limitations continue to affect successful implementation. The findings also highlight the increasing importance of digital technologies and data-driven human resource practices in strengthening organizational performance. This review provides valuable insights for researchers, managers, and policymakers seeking to improve organizational effectiveness through strategic human resource management and identifies priorities for future research.

Keywords: Human resource management, Organizational effectiveness, Employee performance, Talent management

STUDY THE EFFECTIVENESS OF THE NATURAL LAGOONS FOR REMOVAL OF ORGANIC MATTER, NUTRIENTS AND FECAL COLIFORM FROM URBAN DOMESTIC WASTEWATER UNDER ARID CLIMATE (MOROCCO)

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ABSTRACT

The investigation of the trickling filter technology in a Moroccan urban community (Imintanout, Marrakech, Morocco) confirmed the efficiency of this technology to remove organic matter, nutrients and fecal contamination from urban domestic wastewater under an HLR of 1.720 m^3/day. Trickling filter system resulted in significant reduction ($p < 0.05$) in organic matter and phosphorus and nitrogen with an abatement of 98%, 94 %, 98 %, 41% and 88%, respectively, for TSS, BOD_5, COD, TP, and NH_4^+. For fecal bacteria indicators, the TF system achieved a log removal, reaching 2.88 log units during five years of monitoring. Additionally, it was noticed that HLR, BOD_5 and FC have high cos^2 values, between 0.86 and 0.96, showing that they are significant variables affected by summer and spring seasons. A positive correlation with the 6 individuals of TSS during autumn and winter summer, this finding is due to the height concentration of TSS in domestic wastewater during this time period. Furthermore, the statistical analysis has demonstrated that the dissolved oxygen (DO), nitrate (NO_3^-) and total suspended solids (TSS) content in the influent exhibit a significant linear relationship with FC removal in the TF system. Consequently, the utilization of the multiple linear regression model has proven effective in capturing this linearity, yielding an R^2 value of 0.77.

Keywords Trickling filter plant; Domestic wastewater; Organic matter; Nutrients; Fecal coliform; Multiple linear regression.

PERFORMANCE ASSESSMENT OF NATURAL LAGOONS FOR ORGANİC MATTER, NUTRİENT, AND FAECAL COLİFORM REMOVAL FROM URBAN DOMESTİC WASTEWATER UNDER ARİD CLİMATE CONDİTİONS (MOROCCO)

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ABSTRACT

The investigation of the trickling filter technology in a Moroccan urban community (Imintanout, Marrakech, Morocco) confirmed the efficiency of this technology to remove organic matter, nutrients and fecal contamination from urban domestic wastewater under an HLR of 1.720 m^3/day. Trickling filter system resulted in significant reduction ($p < 0.05$) in organic matter and phosphorus and nitrogen with an abatement of 98%, 94 %, 98 %, 41% and 88%, respectively, for TSS, BOD_5, COD, TP, and NH_4^+. For fecal bacteria indicators, the TF system achieved a log removal, reaching 2.88 log units during five years of monitoring. Additionally, it was noticed that HLR, BOD_5 and FC have high cos^2 values, between 0.86 and 0.96, showing that they are significant variables affected by summer and spring seasons. A positive correlation with the 6 individuals of TSS during autumn and winter summer, this finding is due to the height concentration of TSS in domestic wastewater during this time period. Furthermore, the statistical analysis has demonstrated that the dissolved oxygen (DO), nitrate (NO_3^-) and total suspended solids (TSS) content in the influent exhibit a significant linear relationship with FC removal in the TF system. Consequently, the utilization of the multiple linear regression model has proven effective in capturing this linearity, yielding an R^2 value of 0.77.

Keywords Trickling filter plant; Domestic wastewater; Organic matter; Nutrients; Fecal coliform; Multiple linear regression.

PHYSICOCHEMICAL, BIOLOGICAL, AND HEAVY METAL ANALYSIS AND ASSESSMENT OF WATER AND SEDIMENT AT THE LLUZHAN SPA, PODUJEVË, KOSOVO

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ABSTRACT

Our study is primarily concerned with analyzing the chemical parameters of the spring-fed waters at the Luzhan Spa and correlating the actual parameters with those permitted by EU criteria. For a thorough analysis, water samples were collected from three distinct locations, which we have designated as (M1, M2, M3). Additionally, the values of various parameters, including physico-chemical, toxic, and organoleptic, were examined, with a focus on the samples’ electrical conductivity, pH, temperature, sulfates, nitrates, and heavy metal content. The findings demonstrate that the majority of the examined parameters, with the exception of lead metal, which surpasses legal limits and poses serious health hazards to people should it be consumed, are within acceptable ranges in accordance with EU regulations. Additionally the primary risk of bioaccumulation in aquatic organisms, as well as a secondary risk if fish are consumed. To maintain the preservation of this environment, which has significant importance for our nation’s biodiversity, recommendations have been made for ongoing monitoring, tourist limitations, and the use of this water for agricultural and recreational purposes

Keywords: Water purity Luzhan spa, Physical-chemical analysis EU norms Heavy metals surveillance keeping the ecology intact

EARLY CELLULAR RESPONSES TO PENTHIOPYRAD IN CHO-K1 CELLS: EVALUATION OF CELL VIABILITY, INTRACELLULAR ROS PRODUCTION, AND MITOCHONDRIAL MEMBRANE POTENTIAL

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ABSTRACT

Introduction and Purpose: Pesticides are widely used in modern agricultural activities and represent a significant source of environmental exposure to humans and animals. Studies show that many pesticides exhibit cytotoxic effects through mitochondrial dysfunction, leading to impaired cellular bioenergetics and subsequent cell damage. Penthiopyrad is a novel succinate dehydrogenase inhibitor fungiside and inhibits fungal respiration by blocking the binding of ubiquinone to the ubiquinone binding sites in mitochondrial complex II. However, the toxic effects of penthiopyrad on mammalian ovarian-derived cells remain largely unexplored. Therefore, the present study aimed to assess the potential toxic effects of penthiopyrad in CHO-K1 cells by evaluating cell viability, intracellular reactive oxygen species (ROS) production, and mitochondrial membrane potential (MMP).

Materials and Methods: In the present study, CHO-K1 cells, derived from the ovary of the Chinese hamster, are widely used as a mammalian *in vitro* model for toxicological assessment due to their genetic stability, reproducible growth characteristics, and suitiability for evaluating general cytotoxic responses to xenobiotics. The cell viability was assessed by MTT assay. According to MTT assay results, CHO-K1 cells were exposed to 0-70 µM concentration for 24 h. While intracellular ROS production was determined by using DCFH-DA fluorescent probe, MMP was evaluated using the JC-1 dye. The data were statistically analyzed using GraphPad Prism version 10.6.1 by one-way ANOVA followed by Tukey's post-hoc test, and the significance was approved *p* values less than 0.05.

Results: The IC_{50} value was determined 73.5 µM. While the MMP changes were not statistically signifance, the intracellular ROS production significantly reduced all exposed groups ($p<0.05$) compared to control groups. **Discussion and Conclusion:** The findings show that penthiopyrad exerts cytotoxic effects in CHO-K1 cells following 24 h exposure. The ROS production and MMP changes may not demonstrate primary mechanisms underlying the early cellular response to penthiopyrad. Further studies involving longer exposure periods and apoptosis-related molecular analyses are needed to clarify the mechanisms responsible for penthiopyrad-induced cytotoxicity.

Key Words: Penthiopyrad; CHO-K1 cells; MMP; ROS

VALORIZATION OF OLIVE OIL BIOACTIVE COMPOUNDS VIA ADSORPTION ONTO POZZOLAN-ALGINATE COMPOSITE BEADS

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ABSTRACT

Adsorption experiments confirmed that the adsorption reaction of phenol ions on AS/PZ was strongly dependent on pH, adsorbent dose and initial phenol concentration, with a maximum adsorption capacity of 244 mg/g at 25°C and pH equal to 6.2. The adsorption isotherm showed a better fit with the Freundlich model and the kinetic studies demonstrated that the adsorption data correlated with a pseudo-second order model. Finally, the phenol regeneration results show that the adsorbed phenol remains almost unstable and can be desorbed using distilled water alone. The kinetic studies showed that the desorption data correlated with a pseudo-second-order model and a pore diffusion model. After six cycles of the adsorption-desorption process, the adsorbent retained its high adsorption capacity, which decreased in the seventh cycle, to 60 mg/g, due to non-reversible saturation of the adsorption sites.

Keywords: adsorption,phenol, sodium alginate, bead ,pozzolan , column .

READINESS OF SECONDARY SCHOOL BUSINESS STUDIES STUDENTS FOR VIRTUAL OFFICE JOBS IN NIGER STATE NIGERIA

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ABSTRACT

This study examined the readiness of secondary school business studies students for virtual office jobs in Niger state, Nigeria. The study adopted a descriptive survey design. The population comprised of all SS2 and SS3 Business studies students in public senior secondary school in Minna Education zone Niger State. . Questionnaire was selected on the basis of Krejcie and Morgan (1970) sample size determination table was used for data collection while three research questions were raised and two research hypotheses to guide the study. Questionnaire used for data collection was validated by two experts in business Education and Measurement and Evaluation and simple random sampling was used for the study.

Finding shows that the level of readiness of secondary school business studies students for virtual office jobs in Niger State is low. Students showed adequate awareness of virtual office tools but lack practical skills in remote communication, digital management , and online collaboration

The study concluded that Business studies students in Niger State are not adequately prepared for virtual office jobs despite the growing demand for remote work skills. It was recommended that the curriculum should be reviewed to include practical training on virtual office tools, school should provide functional ICT labs, and teachers should be retrained to teach digital workplace skill.

Keywords; Virtual office job, readiness, Business, Studies Students, remote work, Niger State.

ASSOCIATIONS BETWEEN COPING STRATEGIES AND LENGTH OF DETENTION IN A SAMPLE OF PRISON INMATES FROM ROMANIA

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ABSTRACT

Objectives. The study aimed to identify coping mechanisms used by incarcerated individuals and to examine their relationship with the length of incarceration.

Methods. This cross-sectional study included 857 adult incarcerated individuals serving custodial sentences in Romanian prisons, aged 18 years and older. Coping mechanisms were assessed using the COPE Inventory, validated for the Romanian population. Participants were divided into three groups according to sentence length (0–3 years, 3–5 years, and over 5 years). Statistical analyses included one-way ANOVA with Scheffé post-hoc tests and the Chi-square test.

Results. Statistically significant differences were identified between groups according to incarceration length. Individuals sentenced to up to three years more frequently used social support-oriented coping strategies, whereas those serving longer sentences showed a preference for problem-focused coping strategies ($p < .05$). Religious coping was significantly associated with adverse childhood family experiences, including dysfunctional family environments and exposure to severe disciplinary practices by parents or primary caregivers ($p < .001$). Additionally, lower educational level and longer incarceration were associated with more frequent use of substance use as a coping strategy ($p < .05$).

Conclusions. The findings highlight significant variations in coping strategies depending on incarceration length and socio-biographical factors, emphasizing the need for differentiated psychosocial interventions in prison settings.

Key Words: Coping Strategies; Prison Inmates; Social Support; Adverse Childhood Experiences; Religious Coping

RESEARCH TRENDS IN ANTIBIOTIC-FREE NANOMATERIALS: A BIBLIOMETRIC PERSPECTIVE

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ABSTRACT

Introduction and Purpose: Infectious diseases remain a global health problem due to increasing antibiotic resistance in current treatments, as underlined by the World Health Organization. It is expected that deaths caused by antibiotic resistance will surpass deaths of cancer by 2050. Despite the discovery of new antibiotics, traditional treatments are becoming ineffective as common bacteria have developed resistance to many of these agents. Nano-sized systems have emerged as a promising alternative to traditional antibiotics due to their broad antibacterial effects and multi-target mechanisms. Recently, interest has shifted to antibiotic-free nanosystems that do not contain chemical antibiotics. The purpose of this study is to conduct a bibliometric analysis of research trend between 2015 and 2025 to visualize the scientific progress on nanotechnology-enabled antibiotic-free solutions for infection control.

Materials and Methods: The literature data from 2015 to 2025 were retrieved from the Web of Science (WOS) database by using related keywords to specify the searching process on antibiotic-free nanomaterials. The data and visual analysis were performed using VOSviewer to map research trends, citation patterns, institutions, countries, authors, journals, and keywords associated with the field.

Results: The publication trend demonstrates an increase from 7 publications in 2015 to 107 in 2025, more than 15-fold in 10- years period. The analysis reveals that China leads global output in this field with 258 publications out of 412 identified. Chinese organizations such as Chinese Academy of Sciences, Sichuan University, and Shanghai Jiao Tong University, are the leading institutions that make the major contributions. Keyword mapping identifies “antibacterial” (58 counts), “wound healing” (34 counts) and “photothermal therapy” (26 counts) as core themes, which indicates that antibiotic-free strategies are mainly focused on wound infection management and combination therapy. Considering the WOS research area categorization “Material Science” (190 publications) and “Nanotechnology” (101 publications) are two major fields. Among the journals, “Chemical Engineering Journal” and “International Journal of Biological Macromolecules” published the highest number of publications (16), while “ACS Applied Materials & Interfaces” demonstrated strong links (Total Link Strength, TLS=10) with other journals, authors, or keywords in the bibliometric map. These results indicate that, owing to the advancements in nanotechnology, research on antibiotic-free nanomaterials is growing rapidly, and its continued progress holds promise for developing innovative solutions to combat bacterial infections and antibiotic-resistant pathogens.

Key Words: Antibiotic-free, Antibacterial, Bibliometric analysis, Infection, Nanomaterial, Nanoparticles.

APPLICATION OF ARTIFICIAL INTELLIGENCE IN DYNAMIC REMOVAL OF POLLUTANTS FROM WASTE WATER USING NOVEL MATERIALS PREPARED BY IN SITU POLYMERIZATION

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ABSTRACT

This Article, focuses on the application of dynamic adsorption for the removal of EBT using activated carbon treated with phosphoric acid, coated with poly (aniline-co-formaldehyde), and encapsulated in alginate to form beads. This composite material is abbreviated as $AC_{NgG\text{-}P}$@PAF-Alg. In this Article, we discuss the synthesis of these beads and their characterization using various analytical techniques. The optimization of the dynamic adsorption process begins with the variation of the ratio between

alginate and $AC_{NgG\text{-}P}$@PAF, as well as the percentage of the crosslinking agent $CaCl_2$. This step is followed by batch adsorption experiments to optimize best parameters such as adsorbent amount, initial concentration, contact time, and pH. After determining the optimal conditions, the dynamic adsorption experiments are conducted by varying the column length and the flow rate, which are considered the main factors influencing dynamic adsorption performance. Finally, this study explores the application of artificial intelligence (AI) using the Artificial Neural Network (ANN) model. AI is employed to simulate the mini-pilot (lab-scale) system and predict the optimal parameters specifically, higher flow rates and longer column lengths to guide the transition toward an large scale-scale adsorption process.

Keywords: Polymerization coating, Activated carbon, Dynamic adsorption, Artificial intelligence, Large scale application.

DEVELOPMENT OF CHITOSAN–ZNO–GHASSOUL CLAY BIOHYBRID BEADS FOR PHOTOCATALYTIC DYE DEGRADATION AND CU(II) PHOTOREDUCTION

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ABSTRACT

This study developed a sustainable photocatalytic system for wastewater treatment based on green-synthesized ZnO nanoparticles incorporated into chitosan-based composite beads. ZnO nanoparticles were synthesized using *Argania spinosa* press-cake extract and optimized through a Box–Behnken design to maximize their surface area. The optimized nanoparticles were subsequently incorporated into binary (CS@ZnO) and ternary (CS@ZnO@Ghassoul) nanocomposite beads using a simple ionotropic gelation method.

The ternary CS@ZnO@Ghassoul nanocomposite exhibited superior performance, achieving a BET surface area of 39.823 m^2/g and 97.87% photodegradation of Basic Yellow 28 within 40 min, with a reaction rate constant (k_{app}) of 0.1071 min^{-1}, significantly higher than that of pure ZnO. The beads also showed excellent reusability, retaining more than 96% degradation efficiency after three regeneration cycles. Furthermore, the regenerated composites demonstrated a dual functionality by efficiently photoreducing Cu^{2+} ions. The regenerated CS@ZnO@Ghassoul beads achieved 99.5% Cu^{2+} removal within 110 min (k_{app} = 0.02614 min^{-1}), outperforming the regenerated CS@ZnO beads (92.01%, k_{app} = 0.01505 min^{-1}), while maintaining a high BET surface area of 30.966 m^2/g. These findings highlight the

potential of the developed composite as a recyclable and efficient photocatalyst for wastewater remediation.

Computational calculations using density functional theory (DFT) supported the experimental findings, revealing that Basic Yellow 28 has a narrow energy gap (2.05 eV), indicating high reactivity. The high electrophilicity index (ω = 4.59 eV) confirms that BY28 is a strong electron acceptor, readily attracting electrons from the photocatalyst surface. Additionally, the high charge transfer capacity (ΔN_{max} = 2.92) demonstrates its strong ability to exchange electrons with ZnO, which facilitates rapid oxidative degradation. These electronic properties explain why BY28 is efficiently degraded by the CS@ZnO@Ghassoul clay composite. Finally, the developed beads successfully treated real textile wastewater, reducing chemical oxygen demand (79.3%), biochemical oxygen demand (67.0%), and dye content (59.9%). These results demonstrate that the CS@ZnO@Ghassoul ternary nanocomposite is an efficient, reusable, and eco-friendly photocatalyst with strong potential for sustainable industrial wastewater treatment and circular economy applications.

Keywords: Argania spinosa press-cake extract; Basic Yellow 28; BET surface area; Cu^{2+} photoreduction; Green synthesis; Zinc oxide particles

AT THE END OF THE ACADEMIC YEAR, WHAT A DEGREE YOU'VE EARNED!

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ABSTRACT

Throughout their university studies, students encounter various specializations, modules, data sets, educational experiences, scientific experiments, and exercises set by instructors and completed by the student. This rich educational and research program supports students' success upon graduation.

At the end of their studies, students will receive a university diploma, which serves as their academic introduction to professional life.

This diploma helps students gain access to the business world and the professional sphere; as we have emphasized, the diploma is an academic introduction to the outside world.

Students will receive a signed diploma, which also serves as an academic gateway to the professional world. However, in our opinion, a diploma in paper form is not, and will not be, sufficient for a recent graduate. We offer a diploma that reflects their academic background and is also a professional qualification, relevant to real-world situations and meeting economic, social, and environmental demands. A specialization must be integrated into the university curriculum specifically to provide students with practical experience of life outside the university. In other words, students should earn two degrees: one to gain knowledge of the academic world and the other to gain practical experience in a professional setting. Our vision is to facilitate students' transition to the job market upon graduation. Students should gain practical experience from their first year of university until graduation, as this will facilitate their entry into the professional world through the combined academic and professional knowledge acquired at the university.

Students should obtain both an academic degree and a relevant professional qualification to ensure a smooth transition to the professional world at the end of the academic year.

Keywords: university, degree, student, academic world, professional world.

STACKING-CONTROLLED ELECTRONIC STRUCTURE AND ANISOTROPIC OPTICAL RESPONSE OF TWO-DIMENSIONAL ZnO/SiC VAN DER WAALS BILAYERS

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ABSTRACT

The integration of distinct two-dimensional materials into vertically assembled van der Waals systems provides a practical route for tailoring properties required in nanoscale optoelectronic technologies. In this work, the structural stability, electronic characteristics, and optical behavior of ZnO/SiC bilayers were examined using first-principles calculations. The heterostructures were formed by combining monolayer ZnO with monolayer SiC in three different interfacial arrangements. To minimize the lattice mismatch between the constituent sheets, a compressive biaxial strain of 5.55%, equivalent to an estimated pressure of approximately 2.23 GPa, was imposed on the ZnO layer. Phonon calculations confirmed the dynamical stability of all investigated stacking geometries. Each configuration exhibited a staggered type-II band arrangement, which promotes the spatial separation of photoexcited electrons and holes. Depending on the relative positioning of the two layers, the calculated band gap varied from 1.88 to 2.01 eV. Considerable stacking sensitivity was also observed in the optical spectra, together with a strong difference between the in-plane and out-of-plane responses. The in-plane absorption threshold shifted toward lower photon energies from 1.95 eV for the Atop-1 structure to 1.70 eV for Atop-2 and 1.62 eV for the hollow-site geometry. In the perpendicular direction, the absorption coefficient attained values of up to 37×10^6 cm^{-1}. Noticeable variations in the reflectivity and refractive-index spectra were likewise induced by changing the interlayer registry. These findings demonstrate that layer stacking can effectively regulate the electronic and optical characteristics of ZnO/SiC bilayers, making them attractive for light-harvesting, photodetection, and other optoelectronic applications.

Keywords: ZnO/SiC heterostructure; van der Waals bilayers; type-II band alignment; stacking configuration; anisotropic optical properties.

NAPROXEN AS AN EMERGING POLLUTANT IN THE AQUATIC ENVIRONMENT - A REVIEW ON TOXICOLOGICAL EFFECTS ON FISH

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ABSTRACT

Introduction and Purpose: Naproxen (NPX) is a widely used nonsteroidal anti-inflammatory drug frequently detected in surface waters, generally at concentrations below 12.03 μg/L, although substantially higher levels may occur in polluted wastewater discharges. Its continuous release into aquatic environments raises concerns regarding chronic exposure and its potential adverse effects on fish. This study aimed to synthesize the available evidence on naproxen toxicity in fish, with particular emphasis on developmental alterations, morphological abnormalities, histopathological damage, endocrine disruption, and oxidative stress responses across different species and life stages.

Materials and Methods: The review was conducted using a structured search of international databases to identify studies on naproxen occurrence and toxicity in fish. Selected publications were critically evaluated for the main biological endpoints and toxicological findings.

Results: The analysed studies revealed that early-life exposure to NPX can delay hatching and induce structural abnormalities, including pericardial and yolk sac edema, scoliosis, spina bifida, and paravertebral haemorrhage in *Danio rerio* and *Cyprinus carpio* embryos and larvae. Exposure to higher NPX concentrations was associated with thyroid dysfunction, male-biased sex ratios, reduced juvenile survival, and marked changes in estrogen receptor gene expression. Histopathological findings indicated

concentration-dependent damage to the gill and kidney tissues, impairing gas exchange and osmoregulatory functions. Also, oxidative stress has been identified as a common toxicological endpoint occurring at environmentally comparable concentrations (≥1 μg/L) in juvenile *Labeo rohita* and adult *D. rerio*. These findings support the recognition of naproxen as an aquatic contaminant of concern and provide a scientific basis for its inclusion in environmental monitoring and pharmaceutical risk-assessment frameworks.

Key Words: Pharmaceutical contamination, naproxen, developmental toxicity, endocrine disruption, fish early life stages

LIFESTYLE BEHAVIORS AND GASTROESOPHAGEAL REFLUX DISEASE: INSIGHTS FROM THE LITERATURE AND THE ALBANIAN POPULATION

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ABSTRACT

Background: Gastroesophageal reflux disease (GERD) is one of the most common gastrointestinal disorders worldwide and results from a complex interaction of physiological, environmental, and behavioral factors. Smoking, alcohol consumption, and physical activity are among the most frequently studied modifiable risk factors; however, their contribution to GERD remains controversial.

Aim: This review summarizes current evidence on the relationship between these lifestyle factors and GERD and presents findings from epidemiological studies conducted in Albania.

Results: Current evidence suggests that smoking may contribute to GERD by reducing lower esophageal sphincter pressure, impairing esophageal clearance, and weakening mucosal defense, although epidemiological findings remain inconsistent. Alcohol consumption has been associated with increased esophageal acid exposure and altered esophageal motility, but its overall impact on GERD risk remains inconclusive. Physical activity appears to have a dual effect, with regular moderate exercise generally associated with a lower prevalence of GERD symptoms, whereas strenuous exercise may aggravate reflux. In Albania, two epidemiological studies demonstrated a GERD prevalence of 11.9%. Smoking and physical inactivity were identified as significant risk factors, whereas alcohol consumption was not associated with GERD.

Conclusions: The relationship between lifestyle factors and GERD is complex and multifactorial. Current evidence indicates that smoking and physical inactivity are more consistently associated with GERD than alcohol consumption, although the overall strength of these associations is modest. The Albanian findings support the promotion of smoking cessation and regular physical activity as potential preventive measures. Further well-designed prospective studies are needed to clarify the causal role of modifiable lifestyle factors in the prevention and management of GERD

Keywords: Gastroesophageal reflux disease, smoking, alcohol, and physical activity, Albania

ANALYSIS OF TWO DIFFERENT URBAN PARKS IN URBAN AREAS IN TERMS OF ENVIRONMENTAL, PHYSICAL, VEGETATIVE, AND MICROCLIMATIC CHARACTERISTICS AND USER REQUESTS: THE CASE OF ERZURUM CITY CENTER

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ABSTRACT

Introduction and Purpose: Urban open and green spaces have become increasingly important due to rapid urbanization. Urban parks contribute to the quality of urban life by providing social, economic, psychological, and ecological benefits while also serving as recreational areas. This study aims to comparatively evaluate the environmental, physical, and microclimatic characteristics of two urban parks located in Erzurum, a city characterized by a severe continental climate.

Materials and Methods: The study was conducted using two complementary approaches. Field studies included environmental, physical, vegetative, and microclimatic measurements and observations in both parks. In addition, questionnaire surveys were carried out to determine users' park-use patterns and expectations. Office-based analyses were then performed to calculate Sky View Factor (SVF) and Physiological Equivalent Temperature (PET) values. Based on the findings, alternative urban park design scenarios were developed and assessed using the ENVI-met simulation program.

Results: The findings showed that areas with denser vegetation and lower SVF values were preferred more frequently by users. These areas provided more favorable PET conditions and reduced excessive heat stress during summer. Differences were also observed between the parks regarding physical amenities such as gazebos, playgrounds, and walking paths. Survey results indicated that users valued safety, lighting, comfort, and cleanliness, while also emphasizing the need for functional spaces suitable for winter use.

Discussion and Conclusion: Vegetation structure and microclimatic conditions were found to have a significant influence on user preferences and thermal comfort. Therefore, urban park designs in Erzurum should adopt climate-sensitive landscape design principles, prioritizing functional and year-round usable spaces rather than focusing solely on aesthetic considerations.

Keywords: Urban Park, Sky View Factor (SVF), Physiological Equivalent Temperature (PET), Thermal Comfort, Erzurum.

EXPLORING GENDER DIFFERENCES IN CAREER MATURITY AMONG SENIOR SECONDARY STUDENTS

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ABSTRACT

Career maturity plays a significant role in helping adolescents make informed educational and occupational decisions. During the senior secondary stage, students encounter important career choices that influence their future academic and professional pathways. This study aims to explore gender differences in career maturity among senior secondary students by examining their career planning, decision-making ability, career awareness, and readiness for career selection. The study also seeks to understand whether gender influences the level of career maturity during adolescence.

The study employs a quantitative descriptive survey design. A representative sample of senior secondary students was selected from schools using an appropriate sampling technique. Data were collected using a standardized Career Maturity Scale along with a demographic information schedule.

The study highlights the importance of strengthening career guidance and counseling programmes at the senior secondary level. Understanding gender-related variations in career maturity can assist educators, school counselors, and policymakers in designing inclusive career education interventions that promote informed career decision-making and equitable opportunities for all students.

Keywords: Career Maturity, Gender Differences, Senior Secondary Students, Career Decision-Making.

SINGLE-CRITERION VS. MULTI-CRITERIA SKYHOOK GAIN SELECTION FOR OFF-ROAD VEHICLE SUSPENSION: A HALF-CAR ANALYSIS UNDER STOCHASTIC AND DETERMINISTIC EXCITATIONS

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ABSTRACT

Skyhook damping gain is typically tuned by minimizing ride comfort alone, measured as the RMS chassis acceleration. This study shows that single-criterion optimization of the Skyhook gain leads to physically unacceptable results. Using a four-degree-of-freedom half-car model under ISO 8608 Class D off-road excitation, single-criterion optimization yields a gain of 101,395 N·s/m, which reduces chassis acceleration by 22.5% but increases tire load fluctuation by 90% and suspension stroke by 39%. To overcome this, a weighted objective function combining ride comfort (0.6), tire load (0.3), and suspension stroke (0.1) is proposed, with the stroke constraint enforced under both stochastic ISO 8608 Class D and deterministic cubic bump excitations simultaneously. The multi-criteria approach identifies 7,941 N·s/m as the balanced design point, providing 11.0% comfort improvement with only 5.4% tire load increase and a peak bump stroke of 88.3 mm within the 90 mm mechanical limit. The Karnopp switching policy, originally developed for semi-active magnetorheological dampers, is also evaluated on a fully active actuator. The groundhook component introduces adverse forces on the sprung mass, limiting the comfort improvement to 1.1% over passive suspension. The results indicate that simultaneous multi-criteria and dual-scenario gain selection is necessary for reliable off-road suspension control design.

Key Words: Half-car model, Skyhook control, Karnopp switching policy, multi-criteria gain selection, ISO 8608 Class D, off-road suspension, tire load, suspension stroke

SOCIAL PERCEPTIONS AND MEANINGS OF SECOND-HAND CLOTHING IN TURKIYE: A QUALITATIVE ASSESSMENT FROM A GENERATION Z PERSPECTIVE

This study was produced as part of the project entitled “An Assessment of the Second-Hand Clothing Sector in Turkey from the Perspective of Generation Z and a Comparison with European Union Countries”, which was funded under the TÜBİTAK 2209-A University Students’ Research Projects Support Programme (Principal Investigator: Kerem Şeker; Researchers: Ahmet Sarıkaya and Derya Turan; Supervisor: Dr Özcan Garan, Assistant Professor).

TÜRKİYE’DE İKİNCİ EL GİYİME YÖNELİK TOPLUMSAL ALGI VE ANLAM: Z KUŞAĞI PERSPEKTİFİNDEN NİTEL BİR DEĞERLENDİRME

Bu çalışma, TÜBİTAK 2209-A Üniversite Öğrencileri Araştırma Projeleri Destekleme Programı kapsamında desteklenen "Türkiye'de İkinci El Giyim Sektörünün Z Kuşağı Perspektifinden Değerlendirilmesi ve Avrupa Birliği Ülkeleriyle Karşılaştırılması" başlıklı projeden (Yürütücü: Kerem Şeker, Araştırmacı: Ahmet Sarıkaya ve Derya Turan, Danışman: Dr. Öğr. Üyesi Özcan Garan) üretilmiştir.

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Özet

Hızlı moda endüstrisinin yol açtığı çevresel tahribat, tüketicileri sürdürülebilir alternatifler aramaya yöneltmekte, bu bağlamda ikinci el giyim öne çıkan bir seçenek olarak değerlendirilmektedir. Bu çalışma, Z kuşağı bireylerinin ikinci el giyime yükledikleri anlamları ve bu pratiğe dair toplumsal algıyı, sembolik etkileşimcilik ve damgalama kuramları ışığında nitel bir yaklaşımla incelemeyi amaçlamaktadır. Kıyafetin bireyin kimliğini ve "genişletilmiş benliğini" yansıtan sembolik bir araç olduğu öngörüsünden hareketle, araştırma katılımcıların ikinci el giyimi kendi deneyimlerinde nasıl anlamlandırdığını ve bu pratiğin toplumsal çevrede nasıl karşılık bulduğunu birlikte ele almaktadır. Araştırmada, Türkiye ve Avrupa Birliği ülkelerinden 20 üniversite öğrencisiyle gerçekleştirilen derinlemesine mülakatlardan elde edilen veriler MAXQDA programı aracılığıyla kodlanmış ve tematik analiz yöntemiyle değerlendirilmiştir. Bulgular, katılımcıların kendi ikinci el giyim deneyimlerini büyük ölçüde olumlu biçimde anlamlandırdığını (sürdürülebilir, benzersiz, mantıklı, kişiliğin yansıması) ortaya koyarken; olumsuz nitelendirmelerin (fakirlere yönelik, kirli, tedirginlik verici, ayıp) daha çok katılımcıların çevresindeki kişilerin (özellikle aile ve yaşlı nesillerin) bakış açısını yansıttığını göstermektedir. Bu bulgu, ikinci el giyimin bireysel düzeyde bir kimlik ve anlam pratiği olarak benimsenirken, toplumsal düzeyde hâlâ kısmi bir damgalanmayla karşılaştığını; katılımcıların bu damgalanmaya karşı sürdürülebilirlik ve iktisadi akılcılık söylemleriyle bir meşrulaştırma stratejisi geliştirdiğini ortaya koymaktadır. Ayrıca hızlı modanın olumsuz etkilerine (çocuk işçiliği, çevre

kirliliği, aşırı tüketim) dair güçlü bir farkındalık ve eskiyen kıyafetlerin bağış, takas veya yeniden değerlendirme yoluyla döngüye kazandırılmasına yönelik çeşitli pratikler tespit edilmiştir. Çalışma, ikinci el giyimin yalnızca iktisadi bir tercih değil, aynı zamanda kimlik inşası ile toplumsal meşrulaştırma süreçlerinin kesiştiği bir tüketim pratiği olduğunu göstererek alana özgün bir katkı sunmaktadır. (Bu çalışma için İstanbul Üniversitesi Sosyal ve Beşeri Bilimler Araştırmaları Etik Kurulu'nun 23.06.2025 tarih ve 2025/256 sayılı kararıyla etik onay alınmıştır.)

Anahtar Kelimeler: İkinci El Giyim, Z Kuşağı, Toplumsal Algı, Damgalanma, Nitel Araştırma

ABSTRACT

The environmental damage caused by the fast fashion industry is prompting consumers to seek sustainable alternatives; in this context, second-hand clothing is emerging as a prominent option. This study aims to examine the meanings that Generation Z individuals ascribe to second-hand clothing and the social perception of this practice through a qualitative approach, informed by the theories of symbolic interactionism and stigma. Proceeding from the premise that clothing is a symbolic tool reflecting an individual's identity and 'extended self', the research examines both how participants make sense of second-hand clothing within their own experiences and how this practice is received within the social environment. In the study, data obtained from in-depth interviews with 20 university students from Turkey and European Union countries were coded using the MAXQDA programme and analysed using thematic analysis. The findings reveal that participants largely interpreted their own experiences of second-hand clothing in a positive light (sustainable, unique, sensible, a reflection of personality); negative characterisations (targeted at the poor, dirty, unsettling, shameful) more often reflected the perspectives of people in their immediate surroundings (particularly family and older generations). This finding suggests that whilst second-hand clothing is embraced at an individual level as a practice of identity and meaning, it still faces a degree of social stigma; participants have developed a legitimisation strategy against this stigma by invoking discourses of sustainability and economic rationality. Furthermore, a strong awareness of the negative impacts of fast fashion (child labour, environmental pollution, overconsumption) was identified, along with various practices aimed at reintroducing worn-out garments into the cycle through donation, swapping or upcycling. By demonstrating that second-hand clothing is not merely an economic choice but also a consumption practice where identity construction and processes of social legitimisation intersect, this study makes a unique contribution to the field. (Ethical approval for this study was granted by the Istanbul University Ethics Committee for Social and Humanities Research under decision no. 2025/256 dated 23 June 2025.)

Keywords: Second-hand clothing, Generation Z, social perception, stigmatisation, qualitative research

HILFER FRACTIONAL STOCHASTIC DELAYED DIFFERENTIAL SYSTEMS: A SUCCESSIVE APPROXIMATION PERSPECTIVE

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ABSTRACT

Objectives: Higher-order Hilfer fractional stochastic delayed differential systems have attracted increasing attention due to their ability to describe hereditary and stochastic phenomena more accurately than classical fractional models. However, explicit solution representations and theoretical results for systems with higher-order fractional derivatives remain limited. This study aims to derive an explicit solution representation for higher-order Hilfer fractional stochastic delayed differential systems, establish existence and uniqueness under generalized nonlinear assumptions weaker than the classical Lipschitz condition, and investigate Ulam–Hyers stability.

Methods: A linear higher-order Hilfer fractional stochastic delayed differential system is first considered. By employing existing Mittag–Leffler-type matrix function and employing the Laplace transform, an explicit analytical solution is obtained. Subsequently, the linear model is extended to a semilinear stochastic system. Unlike most existing studies, which rely on the classical Lipschitz condition and fixed-point techniques, the proposed analysis employs a more general nonlinear assumption based on a continuous, non-decreasing and concave control function that includes the Lipschitz condition as a special case. Existence of the solution is established via the successive approximation method, whereas uniqueness is proved using the Bihari inequality. Finally, Ulam–Hyers stability is theoretically analyzed.

Results: The proposed methodology yields an explicit solution representation for higher-order Hilfer fractional stochastic delayed differential systems and extends the analytical framework to semilinear stochastic models. The weaker nonlinear assumption significantly enlarges the applicability of the obtained theoretical results compared with the classical Lipschitz framework. Furthermore, the developed approach provides existence, uniqueness, and Ulam–Hyers stability results within a unified theoretical setting.

Conclusion: The proposed analytical framework extends the current theory of Hilfer fractional stochastic delayed differential systems by combining Laplace transform techniques, the constructed Mittag–Leffler-type matrix function, successive approximation, and the Bihari inequality. The obtained results provide a flexible theoretical basis for the analysis of more general higher-order stochastic fractional delayed systems and may serve as a foundation for future theoretical and applied studies.

Key Words: Hilfer fractional derivative; Stochastic delay systems; Successive approximation; Ulam–Hyers stability

EFFECT OF HORSERADISH ROOT POWDER ON THE MECHANICAL AND BARRIER PROPERTIES OF ALGINATE-BASED EDIBLE FILMS

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ABSTRACT

Introduction and Purpose: The development of biodegradable and edible packaging materials represents a promising strategy for reducing the environmental impact associated with conventional plastic packaging. Sodium alginate is widely investigated as a film-forming biopolymer; however, its practical use depends strongly on the mechanical resistance and barrier performance of the resulting films. Horseradish root (*Armoracia rusticana*) contains bioactive compounds and plant-derived structural components that may modify the polymer matrix and improve film functionality. Therefore, the purpose of this study was to evaluate the effect of horseradish root powder incorporation on the mechanical and water-vapor barrier properties of sodium alginate-based edible films.

Materials and Methods: Edible films were obtained by the casting method using sodium alginate as the film-forming polymer, glycerol as a plasticizer, and soy lecithin as an emulsifying agent. Horseradish root powder was incorporated into the film-forming formulations at increasing concentrations, while a formulation without plant powder was used as the control. After drying under controlled conditions, the films were evaluated in terms of hardness, tensile strength, elongation at break, water-vapor permeability, and oil permeability.

Results: The incorporation of horseradish root powder significantly influenced the mechanical and barrier behavior of the alginate-based films. Increasing the amount of plant material progressively improved the mechanical performance of the films, with maximum tensile force and elongation at break values of 17.54 ± 1.18 N and 65.60 ± 9.63%, respectively. These findings indicate that the dispersed plant particles and their interactions with the alginate matrix contributed to the formation of a more resistant and flexible structure. The developed films also exhibited good resistance to water-vapor transfer, supporting their potential role as protective barriers for food products. Overall, the observed changes were dependent on the concentration of horseradish root powder incorporated into the formulation.

Discussion and Conclusion: Horseradish root powder can act not only as a source of bioactive compounds but also as a functional reinforcing ingredient in sodium alginate-based edible films. Its incorporation improved the balance between mechanical strength, flexibility, and moisture-barrier performance, which represents an essential requirement for food-packaging applications. The obtained results support the use of horseradish root powder in the development of sustainable, biodegradable, and functional packaging materials with potential applications in food preservation and safety.

Key Words: Horseradish Root Powder; *Armoracia rusticana*; Sodium Alginate; Edible Films; Mechanical Properties; Water-Vapor Barrier.

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STATISTICAL ANALYSIS OF LONG-TERM OPERATIONAL WATER QUALITY DATA IN A FULL-SCALE MOROCCAN SWRO PLANT

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ABSTRACT

Introduction: As desalination is becoming one of the key tools to address water scarcity in Morocco, a growing number of desalination plants are being operated and monitored. Monitoring continuously generates a huge amount of information, but its use for desalination process evaluation and operational decision support has not yet been fully explored.

Materials and Methods: A full-scale SWRO desalination plant in Morocco was monitored for 23 months (July 2024 to May 2026). A total of 545 water quality samples were collected and analyzed for five physicochemical parameters. Descriptive statistics, coefficients of variation, and Pearson correlation analysis were applied to evaluate the operational water quality data.

Results: The results showed that desalinated water quality remained very good throughout the monitoring period and complied with the operational water quality limits of the plant. The average pH was 7.63, with a coefficient of variation of 6.2%. For turbidity, 96.5% of the measurements were below 1 FNU. The average electrical conductivity was approximately 950 µS/cm, with nearly 90% of the measurements below the WHO reference value of 1300 µS/cm. Residual chlorine exhibited the highest variability among the monitored parameters because of routine operational adjustments required to ensure effective disinfection. Pearson correlation analysis showed only weak relationships among the monitored water quality parameters, indicating limited linear dependence under normal operating conditions.

Conclusion: The study provides evidence that the analyzed SWRO plant is operating effectively. The long-term monitoring data provide valuable support for evidence-based monitoring, operational decision-making, and the future management of desalination plants using smart technologies.

Key Words: Seawater desalination; Water quality monitoring; Reverse osmosis; Sand filtration; Multimedia filtration; Statistical analysis; Sustainable water management.

SUSTAINABLE WATER RESOURCE MANAGEMENT: ASSESSMENT OF SALINE WATER TREATMENT USING OSMOSE INVERSE IN ARID REGIONS

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ABSTRACT

Introduction and Purpose: Water scarcity and the progressive salinization of water resources are major constraints to drinking water supply in arid and semi-arid regions of Morocco. Desalination has therefore become an important component of water management strategies. This study evaluates the performance of a saline water treatment process combining coagulation-flocculation and reverse osmosis through the monitoring of key physicochemical parameters.

Materials and Methods: The investigation was carried out at a water treatment plant located in the Middle Atlas region of Morocco. Water quality was monitored over a three-year period at three treatment stages: raw water, coagulated-flocculated water, and reverse osmosis permeate. The assessment focused on pH, turbidity, and electrical conductivity. Descriptive statistical analyses and removal efficiency calculations were used to quantify treatment performance.

Results: Raw water was characterized by elevated salinity, with average electrical conductivity reaching 2881.94 µS/cm, and highly variable turbidity values, averaging 19.15 NTU. Coagulation-flocculation reduced turbidity from 19.15 NTU to 0.14 NTU, corresponding to removal efficiencies greater than 90%, while conductivity remained largely unchanged. Reverse osmosis produced a substantial reduction in dissolved salts, lowering mean conductivity to 194.61 µS/cm, with removal rates exceeding 85-90%. The permeate also maintained very low turbidity levels and water quality compliant with drinking water standards.

Discussion and Conclusion: The results demonstrate the complementary roles of coagulation-flocculation and reverse osmosis. Pretreatment effectively controls particulate matter and limits membrane fouling, whereas reverse osmosis ensures salinity reduction and potability. The treatment configuration investigated constitutes an effective approach for saline water valorization in regions exposed to increasing water stress.

Key Words: Reverse Osmosis; Desalination; Saline Water Treatment; Coagulation-Flocculation; Water Quality.

FERROPTOSIS IN BREAST CANCER: EMERGING MECHANISMS AND THERAPEUTIC PERSPECTIVES

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ABSTRACT

Breast cancer continues to be the most frequently diagnosed cancer among women and remains a major cause of cancer-related mortality despite continuous improvements in diagnosis and treatment. One of the major obstacles in breast cancer management is the development of therapeutic resistance, which limits the long-term effectiveness of conventional treatments. In recent years, ferroptosis, an iron-dependent form of regulated cell death driven by excessive lipid peroxidation, has attracted growing interest as a potential therapeutic target in oncology.

This review provides an overview of the current understanding of ferroptosis and its relevance to breast cancer. Attention is given to the molecular pathways involved in ferroptosis regulation, including iron metabolism, oxidative stress, lipid peroxidation, and key regulatory molecules such as GPX4, SLC7A11, and ACSL4. Recent experimental evidence suggests that inducing ferroptosis may suppress tumor growth, enhance the response to chemotherapy, and overcome drug resistance, especially in aggressive breast cancer subtypes such as triple-negative breast cancer. Furthermore, the combination of ferroptosis-targeted strategies with existing therapeutic approaches may offer new opportunities for improving treatment efficacy.

Although the available findings are encouraging, most evidence remains at the preclinical stage, and additional clinical studies are required to determine the safety and therapeutic value of ferroptosis-based interventions. A better understanding of the underlying molecular mechanisms will facilitate the development of innovative and personalized therapeutic strategies for breast cancer patients.

Keywords: Breast cancer, Ferroptosis; Iron metabolism; GPX4; Triple-negative breast cancer; Targeted therapy.

ECO-FRIENDLY SYNTHESIS OF A CHITOSAN@TiO_2 NANOCOMPOSITE USING GINGER EXTRACT: ENHANCED ADSORPTION OF DYES, REAL WASTEWATER TREATMENT, AND DFT INSIGHTS

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ABSTRACT

This study aimed to develop a sustainable nanocomposite adsorbent for the efficient removal of dyes from textile wastewater by combining green-synthesized TiO_2 nanoparticles with chitosan. This work investigates how synthesis parameters influence the surface properties of TiO_2 and how the resulting CS@TiO_2 composite enhances the adsorption performance toward Crystal Violet (CV) and Methylene Violet (MV).

TiO_2 nanoparticles were synthesized using crude ginger extract as a natural reducing and stabilizing agent. A Box–Behnken experimental design was employed to optimize the extract volume, precursor concentration, and calcination temperature, with the aim of maximizing the BET surface area while minimizing particle size. The optimized TiO_2 nanoparticles were subsequently immobilized within chitosan beads to produce the CS@TiO_2 nanocomposite. Structural, morphological, and surface characteristics were investigated using FTIR, XRD, SEM, EDS, and BET analyses. In addition, adsorption kinetics, isotherm models, thermodynamic studies, and Density Functional Theory (DFT) calculations were conducted to elucidate the adsorption mechanisms. The adsorption performance of the prepared material was further validated using real textile wastewater effluent.

The optimal synthesis conditions (5 mL extract volume, 0.3 M precursor concentration, and calcination at 400 °C) yielded mesoporous TiO_2 nanoparticles with a high BET surface area of 150.49 $m^2 g^{-1}$ and an average particle size of 10.38 nm. The prepared CS@TiO_2 nanocomposite exhibited rapid adsorption, reaching equilibrium within 120 min and following a pseudo-second-order kinetic model. Thermodynamic results indicated that the adsorption process was spontaneous and governed by strong interactions between the adsorbate molecules and the adsorbent surface. Furthermore, significant reductions in color, COD, BOD_5, and conductivity demonstrated the high efficiency of the CS@TiO_2 composite for textile wastewater treatment.

Keywords: Adsorption, Chitosan, TiO_2 nanoparticles, Green synthesis, Wastewater treatment.

BEYOND THE BOARDROOM: WOMEN'S CORPORATE LEADERSHIP AND FIRMS' ENVIRONMENTAL OUTCOMES ACROSS INSTITUTIONAL CONTEXTS

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ABSTRACT

Research on women's representation in corporate leadership and firms' environmental outcomes has expanded rapidly. Recent reviews, however, remain centered mainly on board gender diversity, while evidence on chief executive officers, senior executives, and managers is less systematically integrated. Existing studies also combine disclosure, organizational practices, innovation, and directly measured environmental performance, although these outcomes do not necessarily reflect the same behavior. Cross-country differences are likewise often discussed through a broad Western–Asian distinction despite substantial heterogeneity within both regions. This paper provides a preliminary structured narrative review organized around three dimensions: leadership position, environmental outcome, and institutional–cultural context. Leadership roles are distinguished according to decision-making authority, including women CEOs, senior executives, managers, executive directors, independent directors, and overall board gender diversity. Environmental outcomes are separated into directly measured performance, environmental actions and innovation, and disclosure and ratings. Institutional context is examined through cultural and governance clusters rather than a simple West–East binary. The reviewed evidence generally indicates a positive association between women's board representation and environmental outcomes, particularly for independent directors, environmental innovation, and boards that reach a meaningful level of representation. By contrast, evidence on women CEOs and senior executives is smaller and less consistent. Studies from China, for example, report contrasting findings depending on whether women's leadership is measured at the CEO or executive-team level, the environmental outcome examined, and firm characteristics. Directly measured outcomes such as emissions and energy use are also less extensively studied and more context-dependent than disclosure, ratings, or organizational practices. Cross-cultural findings further show that the relationship between board gender diversity and environmental outcomes is sizable in some institutional clusters but weak or negligible in others. The review therefore shifts the central question from whether women's leadership is associated with better environmental outcomes to which leadership positions matter, for which outcomes, and under which institutional conditions.

Key Words: Board Gender Diversity, Women Executives, Women CEOs, Corporate Environmental Performance, Green Innovation, Institutional Context.

INTRODUCTION

The role of corporate governance in firms' environmental behavior has gained more attention with the global initiatives for a low-carbon economy. Women's leadership in corporate governance has emerged as one of the major areas to advance these goals. Previous research argues that women generally exhibit stronger pro-environmental values, engage more in monitoring management, and contribute a wider range of perspectives to strategic decisions (e.g., Fernández-Torres et al., 2025; Ricci et al., 2023).

A growing body of empirical evidence across different leadership roles and institutional contexts also supports these arguments. Glass et al. (2016) show that gender-diverse leadership teams in large US firms pursue environmentally friendly strategies more effectively. Nadeem et al. (2020) link greater gender diversity to environmental innovation in US listed firms at the board level. Wang et al. (2022) suggest that stakeholder orientation may partly explain this pattern, as female directors appear more likely to support environmental innovation where firms display stronger concern for stakeholder interests. Ginglinger and Raskopf (2023) provide related evidence from France, where the introduction of board gender quotas was followed by improvements in environmental and social performance, partly through women directors' prior experience and greater influence in committees.

While a large set of empirical literature has accumulated this relationship, two recent reviews have strengthened it. Based on a review of 116 articles, Fernández-Torres et al. (2025) find broad agreement that board gender diversity is positively correlated with environmental performance, moreover, 38 of these articles focus exclusively on this relationship. Further, 36 of those focused studies report a positive association for at least one gender-environment measure. Likewise, Ricci et al. (2023) document a predominantly positive pattern. Their synthesis, which highlights variation across outcomes and national contexts, also may imply that heterogeneity exists.

This ambiguous agreement suggests that the question of whether women directors improve environmental performance is no longer very informative. Moreover, three limitations of the current literature leave a clear opening. First, most studies and reviews treat female leadership as synonymous with board gender diversity. They aggregate directors with executives and chief executives, even though these roles carry very different decision rights. Second, there are fundamentally different outcomes in the literature. Actual emissions, environmental innovation, and voluntary disclosure are often discussed together, although greater disclosure does not necessarily imply lower emissions. Third, cross-national differences are often reduced to a comparison between Western and Asian countries. Although this distinction may provide a useful starting point, recent multi-country evidence suggests that it is too broad to capture how institutional contexts shape the relationship (Wang et al., 2023).

We address these limitations through a structured narrative review organized along three interconnecting dimensions: leadership level, outcome type, and institutional-cultural context. The review maps where the evidence is consistent, mixed, contradictory, or absent. On this basis, we relocate the research frontier from the boardroom, where evidence is comparatively settled, toward executive and managerial authority, where it remains thin and contested.

The remainder of the paper proceeds as follows. We first provide evidence across leadership positions, distinguishing boards, chief executives, senior executives, and managers. We then zoom in on environmental outcome types and measurement, separating direct performance, actions and innovation, and disclosure and ratings. The discussion that follows elaborates on institutional-cultural context and synthesizes the main patterns in the literature. We conclude by outlining a research agenda.

ANALYTICAL FRAMEWORK AND REVIEW APPROACH

Formal authority alone does not seem to determine the environmental influence of women leaders. Javed et al. (2023), for example, report higher green innovation among Chinese firms with women CEOs, especially in state-owned and larger firms, environmentally sensitive industries, and more developed regions. Hu and Wu (2025), however, find a negative relationship between the share of women executives and green innovation, particularly in non-high-tech and highly leveraged firms. This negative relationship weakens when firms have better CSR performance or executives with international experience. Fan et al. (2023) provide another example from Japan: outside women directors are associated with lower carbon emissions, while the effect for inside directors is weaker and less clear when CEOs have greater power and longer tenure. These differences suggest that leadership title alone is unlikely to explain the results. The responsibilities tied to the position, the constraints faced by decision-makers, and the distribution of authority within the firm also seem to matter.

The second dimension concerns the type of environmental outcome. This paper distinguishes among directly measured environmental performance, environmental actions and innovation, and

environmental disclosure and ratings. Direct performance refers to operational or physical outcomes such as emissions, energy use, pollution, waste, water use, and environmental violations. Examples include firm-level carbon emissions (Fan et al., 2023) and renewable energy consumption (Atif et al., 2021), both of which rely on operational data rather than ESG ratings or self-reported disclosures.

Actions and innovation cover initiatives such as green patents, environmental investment, certification, and target setting (Nadeem et al., 2020). Disclosure and ratings include sustainability reports, carbon disclosure, CDP participation, and environmental or ESG scores. Some studies combine these types of indicators, such as Al-Najjar and Salama (2022). Because they reflect different aspects of a firms' environmental response, therefore, improvements in disclosure, ratings, or innovation should not automatically be seen as enhancements in directly measured environmental performance (Fan et al., 2023; Atif et al., 2021; Fernández-Torres et al., 2025).

Table 1. Leadership positions and the current state of evidence

Leadership position	Main channel of influence	Current evidence
Board / independent directors	Collective oversight, monitoring, advice, and legitimacy	Strongest evidence base; generally positive but conditional on role, threshold, CEO power, and context
Women CEOs	Firm-wide strategy, resource allocation, and organizational priorities	Generally positive for green innovation, but direct emissions and energy evidence remains limited
Senior executives	Functional investment, finance, operations, and innovation	Mixed: positive evidence in some US settings and negative average associations in several Chinese studies
Operational managers	Implementation of energy, production, monitoring, and compliance practices	Major gap despite their direct implementation responsibilities

The review draws primarily on the references and study tables of recent reviews (Ricci et al., 2023; Fernández-Torres et al., 2025), supplemented by selected studies examining CEOs, executives, managers, independent directors, direct environmental performance, environmental innovation, and cross-country heterogeneity. The studies are assessed according to leadership position, outcome category, country or institutional context, and whether the reported association is positive, negative, insignificant, or conditional.

EVIDENCE ACROSS LEADERSHIP POSITIONS

Boards and independent directors

Whether women on boards influence firms' environmental behavior is among the most widely studied questions in this literature, and the accumulated evidence is richest at the board level. The overall pattern is often positive, but associations are rarely uniform. They appear to depend on how women's representation is measured, on whether directors are independent or executive, and on surrounding governance arrangements (Atif et al., 2021; Nuber and Velte, 2021; Fan et al., 2023)

In the US, Atif et al. (2021) link greater board gender diversity to higher renewable-energy consumption, but only once boards include at least two women. The effect appears to come mainly from independent rather than executive directors. Nadeem et al. (2020) report a related positive association with environmental innovation and US-listed firms. The relationship is stronger in environmentally sensitive industries.

However, studies on European firms tend to focus on representation thresholds and board conditions. Using data from large European firms, Nuber and Velte (2021) find that firms with more gender-diverse

boards tend to perform better in terms of carbon outcomes. They also argue that this relationship can be achieved with a critical mass of at least two women. Similarly, Moreno-Ureba et al. (2022) provide supporting results for FTSE-250 firms, which show that the relationship between environmental innovation and women's leadership is positive only when boards include at least three women. The effect is mainly clear in firms with greater environmental innovation, strengthened by CSR committees, whereas larger boards and longer director tenures weaken this relationship. Muhammad and Migliori (2023) find a similar pattern among Italian listed firms, which have stronger environmental performance when boards have at least three women and have a sustainability committee.

Although the findings are less consistent than those reported for the US and Europe, several studies of Chinese firms identify positive associations. Elmagrhi et al. (2019) link the proportion of women directors to firms' environmental strategies, implementation, disclosure, and overall environmental performance. He and Jiang (2019) find that women's board representation is positively related to green innovation, particularly when at least two women sit on the board. Similarly, Liao et al. (2019) demonstrate a positive relationship with environmental innovation, especially for independent women directors and state-owned firms.

The findings also differ according to the number and type of women directors and firm characteristics. Wei et al. (2017) find no significant relationship between the proportion of women directors and environmental investment. However, a positive relationship appears when the board have at least three women, particularly in state-owned and highly polluting firms. Fan et al. (2023) associate the presence of outside women directors with lower emissions based on direct carbon emissions data from Japan. This relationship is weaker for inside women directors and becomes less pronounced as CEO power increases.

Overall, the evidence suggests that the effect of board gender diversity is not necessarily linear. The results depend on whether women directors are independent, they reach a meaningful level of representation, and the governance structures and firm characteristics surrounding their roles.

CEOs, Senior Executives, and Managers

Although studies at the board level remain predominant, research on women CEOs, senior executives, and managers is still limited. Recent studies show that there is no single pattern across different leadership levels. Javed et al. (2023) find that firms with women CEOs engage more in green innovation by using data from Chinese listed non-financial firms, particularly in state-owned and larger firms, environmentally sensitive industries, and more developed regions. Additionally, Mansour et al. (2024) highlight a positive relationship between women CEOs and green innovation in listed Asian industrial firms, particularly in larger firms. However, there has been much less focus on whether women CEOs influence changes in emissions, energy use, pollution, or other directly measured environmental outcomes.

At the senior executive level, reconciling findings is harder because studies differ in the outcomes they measure and the institutional contexts they cover. Al-Najjar and Salama (2022) find that greater representation of women in leadership is associated with higher environmental and emissions scores in US high-technology firms. These outcomes are rating-based rather than direct measures of environmental performance. Ma et al. (2022) and Hu and Wu (2025), by contrast, report a negative average association between the share of women executives and green innovation in Chinese listed firms. In Ma et al. (2022), the negative relationship is concentrated among firms with higher risk-taking and financial constraints, among smaller non-state-owned firms, and in non-heavy-pollution industries. It weakens where the 2018 environmental fee-to-tax reform raised environmental tax burdens. Hu and Wu (2025) show stronger negative effects in non-high-technology and highly leveraged firms. Stronger CSR performance and executives' overseas experience attenuate the relationship. These findings show that the relationship between women's leadership and firms' environmental behavior cannot be explained simply by the presence of women in leadership positions. Differences in executive roles,

decision-making authority, financial conditions, and the institutional contexts in which women enter senior management may also shape the results.

Below the executive level, operational managers are largely absent from the reviewed literature. Managers in production, energy, and compliance roles often shape the routines through which environmental commitments are implemented in practice. Examining these roles may therefore provide a more direct account of how leadership characteristics shape everyday environmental practice.

Environmental Outcomes and Measurement

A second broad pattern concerns the type of environmental outcome. The literature is comparatively more developed for composite environmental scores, disclosure-related measures, certifications, green innovation, and organizational practices than for directly measured outcomes such as emissions, energy use, pollution, waste, and water use (Fernández-Torres et al., 2025). Among the studies reviewed by Fernández-Torres et al. (2025), general environmental performance measures are especially common, and environmental innovation is the most frequently analyzed specific dimension, whereas exclusively direct resource-use and emissions measures are less common.

Studies using more direct outcomes frequently report favorable associations, but their findings are often conditional. For example, results may depend on whether women serve as independent or executive directors, whether a critical level of representation is reached, and how authority is distributed between the board and the CEO (Atif et al., 2021; Nuber & Velte, 2021; Fan et al., 2023).

This difference important because environmental indicators do not capture the same aspects or stages of corporate response. Environmental scores, disclosure measures, certifications, innovation indicators, renewable-energy use, and carbon emissions represent conceptually distinct outcomes. For example, Nadeem et al. (2020) measure environmental innovation through ASSET4 indicators on policies, targets, and reported eco-innovation practices, whereas Al-Najjar and Salama (2022) use Eikon environmental and emissions scores together with ISO 14001 certification and climate-related product development.

By contrast, Atif et al. (2021) and Nuber and Velte (2021); Fan et al. (2023) examine renewable-energy consumption or directly measured carbon outcomes. Improved disclosure, certification, or a higher environmental score, therefore, should not automatically be interpreted as lower emissions or resource use. The available evidence suggests that women's board leadership may be more consistently linked to environmental reporting, organizational practices, and innovation-oriented indicators than to directly measured environmental performance, though favorable direct-outcome associations do appear under specific governance conditions.

Institutional and Cultural Context

Women's access to leadership and their capacity to exercise corporate power vary depending on the national context and related institutional and cultural conditions. Cross-country studies show considerable variation in the relationship between board gender diversity and environmental outcomes, extending beyond a simple Western-versus-Asian comparison (Wang et al., 2023; Trireksani et al., 2024). Wang et al. (2023) find a positive association between board gender diversity and environmental performance across organizations from 45 countries, but importantly, this relationship varies considerably across cultural clusters. The association was comparatively strong in Anglo, Latin European, and Middle Eastern contexts, while it was negligible on average in Nordic Europe, Eastern Europe, and Confucian Asia, and highly variable in Southern Asia. Examining country characteristics, Trireksani et al. (2024) demonstrate that the representation of women on corporate boards is significantly associated with sustainability performance, particularly in nations exhibiting higher levels of individualism, indulgence, uncertainty avoidance, and cultural femininity.

While cross-national culture shapes the power and influence of women leaders on environmental outcomes, further understanding on gendered cultural norms and its connection to board gender diversity can provide more contextual insight. By examining 52 countries from 2003 to 2019, Bazel-Shoham et al. (2024) provide both empirically robust findings and qualitative understanding on societies with culturally masculine environment diminish the impact of gender board diversity on environmental innovation. Their findings suggest that broader gender norms may condition the extent to which women's representation in corporate leadership translates into environmental outcomes.

Connecting to previous findings on individualism and masculine environment setting one of the widest organizational differences could be between Western and East-Asian societies, although these regional categories should be interpreted cautiously. Chen et al. (2026), for example, find a positive relationship between female board representation and environmental performance in Western economies, whereas the overall relationship is absent in their East Asian sample. Importantly, however, such findings should not be interpreted as evidence of a homogeneous regional effect. Cultural features associated with gendered power hierarchies and institutionalized masculinity may shape women's authority within corporate governance, but institutional environments also vary considerably within regions. For instance, Naveed et al. (2023) find a positive relationship between board gender diversity and environmental commitment among Chinese-listed firms, with the relationship conditioned by institutional pressures.

Overall, cross-country comparisons reveal considerable heterogeneity in the relationship between board gender diversity and environmental outcomes. Institutional and cultural perspectives help explain this variation by drawing attention to differences in governance arrangements, gender norms, and structures of authority and decision-making power (Grosvold & Brammer, 2011). Therefore, national and institutional conditions matter not only for women's access to corporate leadership but also for their capacity to exercise authority and translate leadership representation into environmental influence

DISCUSSION AND RESEARCH

There is no one-single overall conclusion about the relationship between women's leadership in corporations and environmental results according to reviewed studies. The evidence is relatively extensive and generally positive at the board level; however, it is rarely conclusive. Therefore, they do not provide one global termination. Associations often depend on whether women serve as outside or inside directors, whether boards reach certain levels of representation, and how governance is organized through committees, CEO authority, ownership structure, firm size, and industry context (e.g., Atif et al., 2021; Moreno-Ureba et al., 2022; Fan et al., 2023). Therefore, board gender diversity cannot be treated as a uniform factor with the same effect in every firm.

Evidence on women in other leadership positions remains more limited and less consistent than the relatively extensive board-level literature. Research on women CEOs has largely examined green innovation (e.g., Javed et al., 2023; Mansour et al., 2024). The evidence for senior executives, however, is mixed. Al-Najjar and Salama (2022) find higher environmental and emissions scores in US high-technology firms with greater representation of women in leadership. Studies of Chinese firms reach a different conclusion. Ma et al. (2022) and Hu and Wu (2025) associate a higher share of women executives with lower green innovation under certain financial and organizational conditions. Much less is known about operational managers, although they are directly involved in production, energy use, environmental monitoring, and regulatory compliance. These mixed findings and gaps in the literature suggest that future research should consider not only whether women hold particular leadership positions, but also the decision-making authority and environmental responsibilities associated with those positions.

Measurement choices further make cross-study comparisons difficult. Different indicators such as disclosure, environmental ratings, certification, innovation metrics, renewable-energy use, and emissions represent various stages of corporate environmental response (e.g., Atif et al., 2021; Nadeem et al., 2020; Al-Najjar and Salama, 2022). A firm may improve reporting or adopt new environmental practices without a proportional decrease in emissions or resource consumption. Findings based on these indicators should therefore be interpreted individually rather than combined into a single concept of environmental performance.

While cross-country comparison provides considerable variation and possible pattern in the relation between board gender diversity and environmental outcomes, institutional and cultural perspectives can further elaborate our understanding and analyses of the layers in this relationship due to existing heterogeneity as reflecting differences in the organizational system, gender norms, and structure of the power dynamics/ authority (Grosvold & Brammer, 2011). National and institutional conditions,

therefore, matter not only for women's access to corporate leadership but also for their capacity to exercise authority and translate leadership representation into environmental influence.

Future research should compare leadership roles and environmental outcomes directly rather than treating them as interchangeable. Greater attention to decision-making authority, functional responsibilities, and actual environmental performance would allow for clearer conclusions. It also remains unclear whether thresholds of women's representation operate similarly across leadership levels and institutional contexts. In particular, critical-mass theory may have different implications for boards, executive teams, and CEOs.

CONCLUSION

As firms play a central role in the transition to a low-carbon economy, it remains important to understand when and how women in different leadership positions influence environmental decisions. This review shows that the relationship between women's corporate leadership and environmental outcomes cannot be described as simply positive or negative. Findings vary according to leadership position, the environmental indicator examined, and the institutional context in which firms operate. Board-level research is the most developed, with the strongest findings generally concerning independent directors and boards where women reach a meaningful level of representation. By contrast, evidence on women CEOs, senior executives, and operational managers remains limited and, in some cases, contradictory.

Women's corporate leadership is better analyzed through specific roles rather than as a broad governance measure. By separating leadership positions and distinguishing direct environmental outcomes from innovation, organizational practices, disclosure, and ratings, cross-study differences become easier to interpret. This approach also shifts the focus to a more precise question. It is not whether women in leadership improve environmental performance in general, but under what conditions particular leadership roles are associated with specific environmental outcomes. Cross-national evidence further suggests that institutional arrangements, gender norms, and structures of authority may condition both women's access to corporate leadership and their capacity to translate leadership positions into environmental influence.

Future research would benefit from designs that compare leadership roles and outcome types directly, with greater attention to decision-making authority, functional responsibilities, and physically measured environmental outcomes. It also remains unclear whether representation thresholds function similarly across leadership levels and institutional environments. Critical-mass theories may therefore have different implications for boards, executives, and chief executives, whose roles are associated with specific environmental outcomes.

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DETERMINANTS OF TECHNOLOGY INTEGRATION AMONG SECONDARY SCHOOL MATHEMATICS AND SCIENCE TEACHERS IN LAHORE

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ABSTRACT

Technology integration has become an essential component of effective teaching and learning in secondary education. This study investigated the factors influencing technology integration among secondary school mathematics and science teachers in Lahore, Pakistan. A quantitative research design, guided by the positivist paradigm, was employed to examine the relationships between selected influencing factors and teachers' technology integration practices. The study addressed three research objectives and tested ten null hypotheses. Using a multistage sampling technique, data were collected from 451 mathematics and science teachers working in public and private secondary schools. A structured questionnaire, adapted from Anwar et al. (2025), was used for data collection. The data were analyzed using descriptive statistics, multiple linear regression, independent sample t-tests, and one-way ANOVA. The findings revealed that 81.95% of teachers demonstrated readiness to integrate technology into their teaching. Descriptive analysis indicated positive perceptions across all study variables, although Technological Pedagogical and Content Knowledge (TPACK) recorded comparatively lower mean scores. Regression analysis showed that Teaching Preparation (TP), TPACK, and Acceptance and Intention to Use Technology (AIT) were significant positive predictors of technology integration. In contrast, Teacher Technology Skills (TTS), Level of Innovation (LOI), and Quality of Technology Actual Implementation (QTA) exhibited positive but comparatively weaker influences. The study highlights the importance of strengthening teachers' TPACK competencies through sustained professional development, improving access to technological resources, and providing ongoing technical support to enhance effective and sustainable technology integration in secondary education.

Keywords: Technology Integration, TPACK, Mathematics Teachers, Science Teachers, Secondary Education, Teacher Professional Development, Educational Technology, Quantitative Research.

INVESTIGATION OF THE EFFECTS OF PLYOMETRIC TRAINING APPLIED TO MUAY THAI ATHLETES ON AGILITY

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ABSTRACT

Introduction and Purpose: Muay Thai, considered the national sport of Thailand and popular worldwide, consists of kicking, punching, knee and elbow movements. Because it is a demanding sport, the training methods are crucial. Agility is a fundamental component of performance in Muay Thai, enabling athletes to execute rapid directional changes, maintain balance, and respond effectively to offensive and defensive situations during competition. Plyometric training has been widely recognized as an effective method for enhancing explosive power and neuromuscular performance; however, limited research has specifically examined its effects on agility in Muay Thai athletes. Therefore, this study aimed to investigate the effects of a plyometric training program on the agility performance of Muay Thai athletes. The aim of this study is to investigate the effects of plyometric training on agility characteristics in Muay Thai athletes aged 10-15 years.

Materials and Methods: For this study, Muay Thai athletes aged 10-15 from the Antalya Octagon Fight Club were selected as the sample group, and the applications were carried out on these athletes.

Results: After analyzing the results, it was observed that, as in other sports, plyometric training had positive effects, especially on the agility of adolescent athletes.

Discussion and Conclusion: This study is significant because, to our knowledge, it makes important contributions to the literature and sports science, given the very limited number of studies conducted on this topic.

Key Words: Sport; Muay Thai, Agility

AI-DRIVEN SMART FAULT DETECTION AND PREDICTIVE MAINTENANCE IN RENEWABLE ENERGY SYSTEMS

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ABSTRACT

The rapid deployment of renewable energy systems has increased the need for intelligent solutions that ensure high reliability, operational efficiency, and reduced maintenance costs. Conventional maintenance approaches, such as corrective and scheduled maintenance, are often inadequate for detecting early-stage faults and preventing unexpected equipment failures. Recent advances in Artificial Intelligence (AI) have enabled the development of smart fault detection and predictive maintenance techniques capable of analyzing large volumes of operational data to identify anomalies, predict component degradation, and support timely maintenance decisions. This paper presents a comprehensive review of AI-driven approaches for smart fault detection and predictive maintenance in renewable energy systems, with particular emphasis on wind, solar, and hybrid energy applications. It discusses the integration of machine learning, deep learning, fuzzy logic, and digital monitoring technologies for real-time condition assessment and fault diagnosis. Furthermore, the study highlights the role of sensor data, Internet of Things (IoT) platforms, and data analytics in improving system reliability and minimizing downtime. The paper also examines current challenges, including data quality, model interpretability, cybersecurity, and real-time implementation, while identifying emerging research directions such as explainable AI, digital twins, edge intelligence, and federated learning. The findings demonstrate that AI-driven predictive maintenance significantly enhances the availability, efficiency, and sustainability of renewable energy systems, making it a key enabling technology for future smart energy infrastructures.

Keywords: Artificial Intelligence, Smart Fault Detection, Predictive Maintenance, Renewable Energy Systems, Machine Learning, Deep Learning, Fault Diagnosis, Digital Twin, Internet of Things (IoT), Condition Monitoring.

ANALYSIS OF LONG-TERM SURFACE SOIL MOISTURE TRENDS IN THE ASİ BASIN USING SMAP SATELLITE DATA

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ABSTRACT

Soil moisture is an important environmental variable for monitoring the hydrological cycle, agricultural production and drought conditions. This study aimed to determine the temporal variability and long-term trend of surface soil moisture in the Asi Basin and to evaluate its relationship with precipitation. SMAP (Soil Moisture Active Passive) surface soil moisture data and CHIRPS (Climate Hazards Group InfraRed Precipitation with Station data) precipitation data covering the period from April 2015 to December 2025 were used. The data were processed using the Google Earth Engine platform and monthly time series were generated at the basin scale. Trends in the surface soil moisture and precipitation series were analysed using the Mann-Kendall test, while the magnitude of the trend was estimated using Sen's slope method. The relationship between monthly precipitation and surface soil moisture was assessed using Pearson correlation analysis. A distinct seasonal surface soil moisture regime was identified in the Asi Basin. Surface soil moisture reached high levels during the winter months and decreased considerably during the summer. Trend analyses revealed a statistically significant decreasing trend in surface soil moisture over the study period ($p < 0.001$). According to Sen's slope estimate, surface soil moisture decreased by approximately -0.0069 m^3/m^3/year. In contrast, no statistically significant trend was detected in the precipitation series ($p > 0.05$). A strong, positive, and statistically significant relationship was found between monthly precipitation and surface soil moisture ($r = 0.81$; $p < 0.001$), indicating that precipitation is one of the main factors affecting short term soil moisture variability in the basin. However, the significant decline in surface soil moisture despite the absence of a significant precipitation trend suggests that the observed decrease cannot be explained solely by changes in precipitation. The findings demonstrate the considerable potential of satellite-based surface soil moisture data for monitoring hydrological processes and drought risk in the Asi Basin.

Keywords: SMAP, CHIRPS, Surface Soil Moisture, Trend Analysis, Asi Basin, Google Earth Engine.

INTRODUCTION

Soil moisture is a fundamental environmental variable that represents the balance between precipitation and evapotranspiration and plays a critical role in the functioning of the hydrological cycle (Seneviratne et al., 2010). The amount of water stored in the upper soil layers is essential for sustaining plant growth and hydrological processes and is widely used in the assessment of drought conditions (Vereecken et al., 2008; Seneviratne et al., 2010; Huang et al., 2025). Therefore, monitoring the temporal dynamics of soil moisture is of great importance for agricultural production, water resources management, and the assessment of the environmental impacts of climate change (Dorigo et al., 2017; Teixeira et al., 2025).

Global climate change has led to substantial alterations in the components of the hydrological cycle, posing a significant threat to the sustainability of water resources, particularly in arid and semi-arid regions. The Mediterranean Basin, recognized as one of the region's most vulnerable to these changes, is projected to experience increasing temperatures, shifts in precipitation regimes, and a heightened risk of drought (Giorgi, 2006; Cramer et al., 2018). Recent studies have reported an increase in both the frequency and severity of drought events across the Mediterranean region, resulting in adverse impacts on soil moisture and water resources (Vicente-Serrano et al., 2022). Regional-scale investigations further indicate that declining trends in soil moisture have become increasingly widespread in Mediterranean catchments, with these changes posing substantial risks to agricultural production and ecosystem functioning (Mimeau et al., 2021; Almendra-Martín et al., 2022).

The assessment of soil moisture over large spatial extents and long temporal periods has increased the demand for remote sensing-based approaches, as conventional in situ measurements provide limited spatial coverage. Consequently, remote sensing technologies have been increasingly adopted in recent years for the continuous monitoring of soil moisture at regional and global scales (Dorigo et al., 2017). In particular, the National Aeronautics and Space Administration (NASA) Soil Moisture Active Passive (SMAP) mission has become a major source of high-accuracy surface soil moisture data for hydrological, agricultural, and climate studies by providing global observations since 2015 (Entekhabi et al., 2010; Chan et al., 2018). Validation studies conducted in Türkiye have also demonstrated the reliability of SMAP products under diverse hydrological conditions. Duygu and Akyürek (2019) demonstrated that SMAP data successfully captured the spatial and temporal variability of surface soil moisture in the Cakit Basin. More recently, remote sensing–based soil moisture products have provided significant advantages for monitoring hydrological processes, drought conditions, and variations in water resources at the basin scale (Dorigo et al., 2017; Huang et al., 2025).

The increasing availability of satellite-based soil moisture products has led to a growing number of studies investigating the temporal dynamics of soil moisture and its relationships with climatic variables across different regions. Nevertheless, studies based on long-term satellite observations of soil moisture at the basin scale remain limited in Türkiye. Furthermore, the number of studies comprehensively evaluating variations in surface soil moisture together with precipitation remains relatively low. Therefore, identifying long-term trends in soil moisture and elucidating their relationship with precipitation are essential for improving the understanding of hydrological processes and assessing drought risk. Accordingly, the present study aims to characterize the temporal variability and long-term trends of surface soil moisture during the 2015-2025 period using SMAP satellite data and to evaluate the relationship between precipitation and surface soil moisture using Climate Hazards Group InfraRed Precipitation with Station Data (CHIRPS) precipitation data.

MATERIAL AND METHODOLOGY

Study Area

The Asi Basin is one of the major river basins located in the Eastern Mediterranean region of Türkiye, covering an area of approximately 7,800 km² (Figure 1). The basin is characterized by considerable variations in elevation, land use, and land cover, encompassing extensive agricultural areas where irrigated and rainfed farming activities are widely practiced. Owing to its importance for water resources, agricultural production, and ecosystem sustainability, the basin is considered highly vulnerable to the impacts of climate change and drought. These characteristics make the Asi Basin a suitable study area for investigating the temporal dynamics of surface soil moisture.

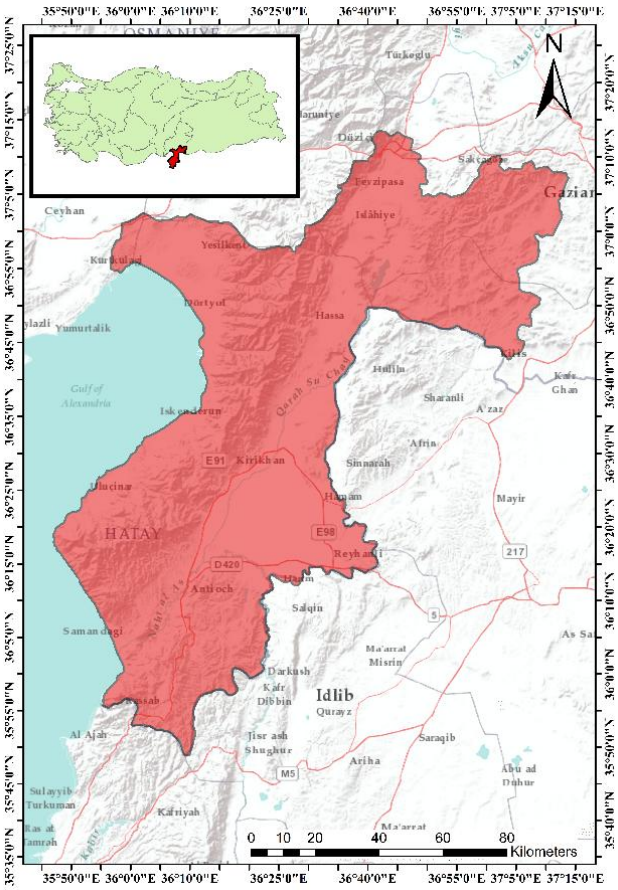

Figure 1. Location of the Asi Basin.

Data Sources

Surface soil moisture dynamics in the Asi Basin were investigated using the Level-3 daily surface soil moisture products acquired from the NASA SMAP mission. Precipitation conditions were characterized using the CHIRPS dataset. Both datasets were accessed and processed through the Google Earth Engine (GEE) cloud computing platform and analyzed at the basin scale. These remote sensing–based datasets have been widely adopted for monitoring long-term hydrological variability over large spatial extents owing to their broad spatial coverage and continuous temporal observations (Dorigo et al., 2017; Funk et al., 2015). Moreover, the GEE platform provides an efficient cloud-based environment for processing and integrating multi-source satellite and climate datasets, thereby facilitating large-scale geospatial analyses.

Table 1. Datasets used in this study.

Dataset	Spatial Resolution	Temporal Resolution	GEE Dataset ID
SMAP	9 km	Daily	NASA/SMAP/SPL3SMP_E/005
CHIRPS	5-5.5 km	Daily	UCSB-CHG/CHIRPS/DAILY

The SMAP mission was developed to estimate surface soil moisture within the upper approximately 5 cm of the soil profile using passive microwave observations. Owing to its global coverage, continuous observations, and high retrieval accuracy, SMAP products have been extensively applied in hydrological, agricultural and drought-related studies (Entekhabi et al., 2010; Chan et al., 2018). In the present study, only observations that satisfied the quality control criteria were retained, and the daily surface soil moisture data were aggregated into monthly mean values for subsequent analyses. The CHIRPS dataset is a high-resolution precipitation product generated by combining satellite-derived precipitation estimates with ground-based meteorological station observations. It has been widely used for monitoring long-term precipitation variability and drought conditions, particularly in regions with

sparse observational networks (Funk et al., 2015). In this study, daily CHIRPS precipitation data were aggregated into monthly cumulative precipitation totals, which were subsequently used to evaluate their relationship with surface soil moisture.

Data Processing and Statistical Analysis

Monthly basin-averaged surface soil moisture values were calculated within the boundaries of the Asi Basin to construct a monthly time series covering the period from April 2015 to December 2025. Similarly, monthly cumulative precipitation totals were derived from the CHIRPS dataset, and basin-averaged precipitation values were calculated. This procedure yielded temporally consistent monthly datasets of surface soil moisture and precipitation for subsequent comparative analyses. Long-term trends in the surface soil moisture and precipitation time series were evaluated using the non-parametric Mann–Kendall trend test (Mann, 1945; Kendall, 1975). To account for the pronounced seasonality of the surface soil moisture series, the Seasonal Mann–Kendall test was additionally applied (Hirsch et al., 1982). The magnitude of the detected trends was quantified using Sen's slope estimator (Sen, 1968). The relationship between precipitation and surface soil moisture was assessed using Pearson's correlation analysis. All statistical analyses were performed in the JupyterLab environment using the Python programming language.

RESULTS AND DISCUSSION

Seasonal Variability of Surface Soil Moisture in the Asi Basin

The monthly mean surface soil moisture derived from SMAP observations exhibited a pronounced seasonal pattern in the Asi Basin (Figure 1). During the study period (April 2015-December 2025), monthly mean surface soil moisture ranged from 0.03 to 0.32 m^3/m^3, with an overall mean of 0.13 m^3/m^3. The monthly time series revealed a clear annual cycle, characterized by increasing soil moisture during late autumn and winter, followed by a gradual decline from late spring onward and minimum values during the summer months. Surface soil moisture frequently exceeded 0.30 m^3/m^3 during winter, whereas values decreased to approximately 0.05 m^3/m^3 during summer (Figure 1).

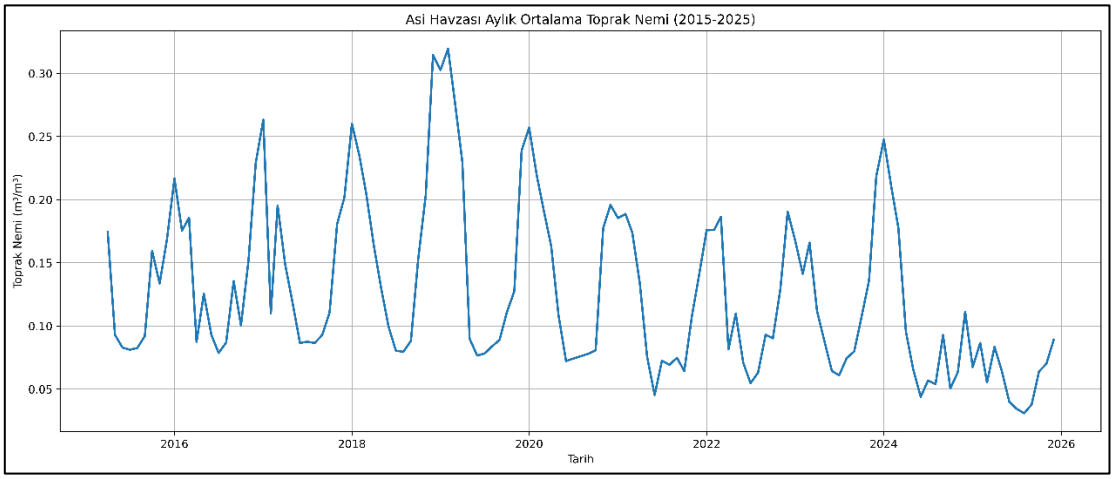

Figure 1. Temporal variation of monthly mean surface soil moisture in the Asi Basin during the study period.

The observed seasonal pattern is consistent with the soil moisture dynamics reported for the Mediterranean Basin. Soil moisture generally increases during autumn and winter in response to seasonal precipitation and declines during the hot, dry summer period owing to limited rainfall and enhanced evapotranspiration (Gallart et al., 2002; Mimeau et al., 2021). Similar seasonal behavior has also been reported for Mediterranean catchments in Türkiye, where dry summer conditions are associated with substantially reduced soil moisture, while wetter winter conditions promote soil water replenishment (Lakshmi et al., 2025). Furthermore, a validation study conducted in Türkiye demonstrated that SMAP products reliably represent surface soil moisture dynamics under semi-arid

conditions (Duygu & Akyürek, 2019). Collectively, these findings indicate that the seasonal variability of surface soil moisture in the Asi Basin closely reflects the characteristic hydrological regime of the Mediterranean climate.

Long-Term Trends in Surface Soil Moisture in the Asi Basin

The long-term analysis of the monthly surface soil moisture time series revealed an overall declining trend during the period from April 2015 to December 2025 (Figure 2). The Mann–Kendall trend test indicated that this decline was statistically significant (τ =-0.273, $p<0.001$). To account for the pronounced seasonality of the dataset, the Seasonal Mann–Kendall test was also applied and confirmed a significant downward trend (τ = -0.543, $p < 0.001$). Furthermore, Sen's slope estimator indicated that surface soil moisture decreased at a rate of approximately 0.0069 m^3/m^3/year. As illustrated in Figure 2, although the seasonal fluctuations remained evident throughout the study period, lower surface soil moisture values became increasingly pronounced during the later years of the record. This persistent decline is of particular concern during the spring and summer growing seasons, when crop water demand and irrigation requirements are highest, highlighting the increasing importance of effective agricultural water management.

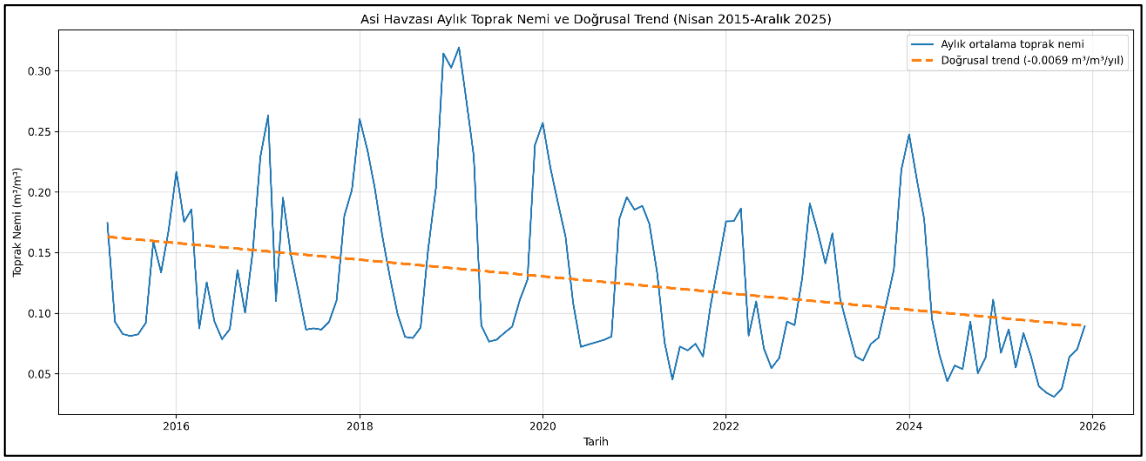

Figure 2. Long-term trend of monthly mean surface soil moisture in the Asi Basin during the study period.

The significant declining trend identified in the Asi Basin is consistent with regional patterns of increasing drought reported across the Mediterranean Basin. Hanel et al. (2018) found that soil moisture exhibited the most pronounced negative trend among the hydrological variables evaluated in their assessment of long-term drought variability across Europe and the Mediterranean region. Similarly, Mimeau et al. (2021) reported a persistent drying trend in the Mediterranean Basin, demonstrating that declining soil moisture was closely associated with reductions in precipitation. Large-scale European studies have likewise identified widespread decreases in soil moisture, particularly across southern Europe and the Mediterranean region, reflecting the increasing impacts of climate change on regional hydrological conditions (Almendra-Martín et al., 2022; Vicente-Serrano et al., 2022). More recent evidence from the central Mediterranean has further highlighted the region's increasing susceptibility to drought and emphasized the critical role of soil moisture in maintaining hydrological system resilience under changing climatic conditions (Silvestri et al., 2025). Taken together, these findings indicate that the declining surface soil moisture observed in the Asi Basin is consistent with the broader hydrological changes reported throughout the Mediterranean climate region.

Relationship Between Precipitation and Surface Soil Moisture

The monthly cumulative precipitation series derived from the CHIRPS dataset exhibited a clear seasonal pattern throughout the study period (Figure 3). Precipitation generally increased during autumn and winter, whereas substantially lower amounts were recorded during the summer months.

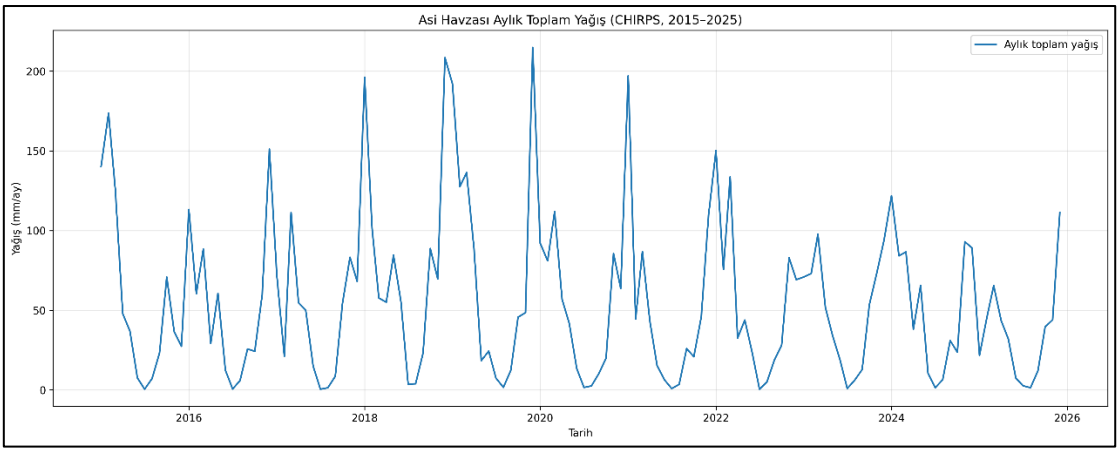

Figure 3. Temporal variation of monthly cumulative precipitation (CHIRPS) in the Asi Basin during the study period.

The relationship between monthly cumulative precipitation and monthly mean surface soil moisture was evaluated using correlation analysis (Figure 4). The results revealed a statistically significant and strong positive correlation between precipitation and surface soil moisture ($r=0.81$, $p<0.001$). Higher precipitation amounts were consistently associated with increased surface soil moisture, whereas periods of reduced precipitation corresponded to lower soil moisture conditions. These findings indicate that precipitation is one of the primary controls governing the short- to medium-term variability of surface soil moisture in the Asi Basin.

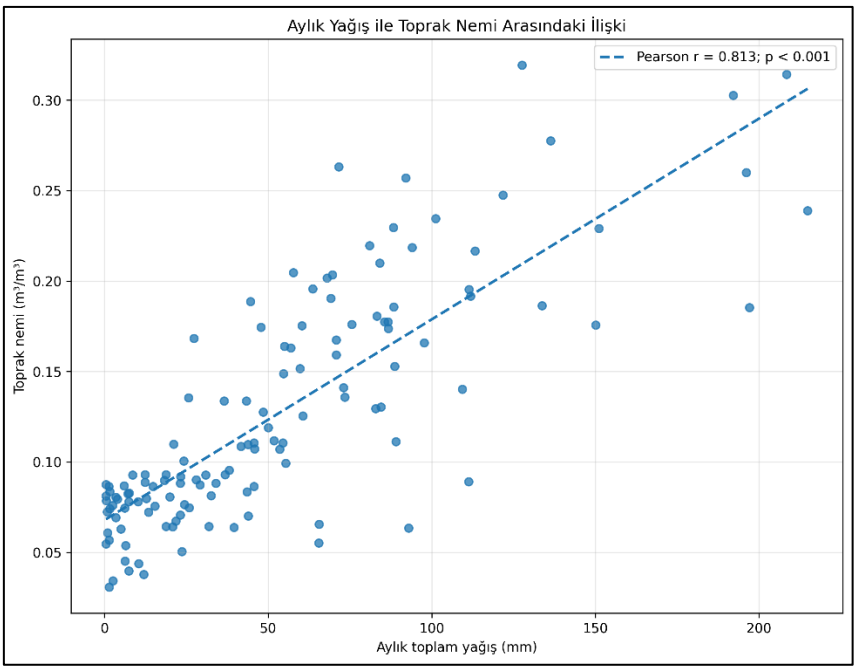

Figure 4. Relationship between monthly cumulative precipitation (CHIRPS) and monthly mean surface soil moisture (SMAP) in the Asi Basin.

The strong precipitation–soil moisture relationship identified in the Asi Basin is consistent with findings reported across a wide range of climatic regions. Soil moisture is a key hydrological variable that reflects the balance between precipitation and evapotranspiration and responds rapidly to precipitation variability, particularly within the near-surface soil layer (Seneviratne et al., 2010). Previous studies conducted under Mediterranean climatic conditions have likewise identified precipitation as one of the dominant controls on both seasonal and interannual variability of surface soil moisture. Mimeau et al. (2021) demonstrated that variations in soil moisture across the Mediterranean Basin are closely linked to precipitation regimes, with precipitation variability exerting a direct influence on soil moisture conditions. Similarly, recent studies from the central Mediterranean have shown that soil moisture is

highly sensitive to precipitation variability, particularly in arid and semi-arid environments, highlighting its value as an effective indicator for drought monitoring (Silvestri et al., 2025).

Despite the significant positive relationship between precipitation and surface soil moisture, the trend analyses revealed contrasting long-term behaviors. While surface soil moisture exhibited a statistically significant declining trend during the study period, no significant long-term trend was detected in precipitation ($p>0.05$). This finding suggests that the observed decline in surface soil moisture cannot be attributed solely to changes in precipitation. Other hydroclimatic drivers, including increasing air temperature, enhanced evaporative demand, and changes in atmospheric moisture conditions, are likely to have contributed to the long-term reduction in soil moisture. Consequently, future studies should incorporate integrated hydroclimatic analyses involving temperature, potential evapotranspiration, and drought indices to better elucidate the mechanisms responsible for the observed decline in surface soil moisture within the Asi Basin.

CONCLUSIONS

This study investigated the temporal dynamics of surface soil moisture in the Asi Basin during the 2015–2025 period using SMAP observations and evaluated its relationship with precipitation derived from the CHIRPS dataset. The results demonstrated a pronounced seasonal soil moisture regime within the basin. Surface soil moisture reached its highest levels during the winter months and declined markedly during summer, reflecting the characteristic seasonal hydrological regime of the Mediterranean climate.

Trend analyses revealed a statistically significant long-term decline in surface soil moisture throughout the study period. According to the Seasonal Mann–Kendall test and Sen's slope estimator, surface soil moisture decreased at an approximate rate of 0.0069 m^3/m^3/year. In contrast, no statistically significant trend was detected in precipitation over the same period. These findings indicate that the observed decline in surface soil moisture cannot be explained solely by changes in precipitation. Pearson's correlation analysis identified a strong and statistically significant positive relationship between monthly precipitation and surface soil moisture ($r=0.81$, $p<0.001$), confirming that precipitation is a primary driver of short-term soil moisture variability in the Asi Basin. However, the persistence of the long-term decline in surface soil moisture despite the absence of a significant precipitation trend suggests that additional hydroclimatic factors, such as increasing air temperature, enhanced evapotranspiration, and drought-related processes, may also contribute to the observed changes.

The findings of this study provide new insights into the temporal variability and long-term dynamics of surface soil moisture in the Asi Basin and contribute to a better understanding of hydroclimatic processes in Mediterranean catchments. Future research should incorporate additional environmental variables, including air temperature, potential evapotranspiration, drought indices, and land-use change, to better elucidate the mechanisms driving long-term soil moisture variability. Furthermore, extending the analysis to longer observation periods and integrating multiple satellite-derived soil moisture products would improve the robustness of basin-scale assessments and enhance our understanding of hydrological responses to ongoing climate change.

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THE ROLE OF ANATOLY LUNACHARSKY IN THE LATINIZATION OF THE ALPHABETS OF THE TURKISH PEOPLES

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ABSTRACT

One of the key intellectuals who played an important role in defining, developing, and organizing art and culture policy in the Soviet Union was undoubtedly Anatoly Lunacharsky. He played a role in the establishment of the Council of People's Commissars under Lenin's chairmanship in 1917 and served as People's Commissar of Education until 1929. Lunacharsky's approach to "socialist realism" and its formation is diverse. He noted that art and culture are part of the superstructure of society and have an active role in the struggle. The ruling classes used culture to create a society in their own interests. Interestingly, the classes opposing the ruling classes also used it as a weapon of struggle. Subsequent developments in the Soviet Union did not go in the direction Lunacharsky wanted. Classical realist forms were accepted as the main form of socialist realism and significantly complicated the development of the youth. This direction in the form would have a very negative impact on the development of art in the Soviet Union in the long term.

Anatoly Lunacharsky considered the old Russian (Cyrillic) alphabet an obstacle to Russia's cultural development. In order not to lag behind in cultural competition with the West, it was necessary to use its own tools. Since the policy of Latinization was initially risky, it was decided to apply it to non-Russian peoples, namely the Turkic peoples. Lunacharsky did not intend the cultural rise of the Turkic peoples. He was more concerned with Russia's backwardness from Europe. Therefore, he unknowingly played a major role in the Latinization of the Turkic peoples. This process continues today in the countries of Central Asia. The Kazakh state, which wants to implement a Latinization policy, is accelerating this process. By implementing this policy, the Kazakh state not only wants to reduce Russian influence, but also to more easily accept the developments taking place in Europe and to demonstrate to the world that it is an integrative state.

Keywords: Anatoly Lunacharsky, Latinization, Turkic peoples, God-building, Soviet Union

INTRODUCTION

Anatoly Lunacharsky can be considered one of the ideological founders of the Soviet Union. He is considered an elite intellectual with a broad worldview and critical thinking. He was considered one of the rare Bolsheviks who maintained cultural contacts with the outside world in the early years of the USSR. Lunacharsky had very extensive connections with the cultural elite of Europe. His correspondence with Bernard Shaw, Stefan Zweig, Henri Barbusse, Bertolt Brecht, and other thinkers has an important place in the history of Russian public and intellectual thought. Thus, he played a kind of bridge between the Western cultural world and the Soviet Union. Lunacharsky believed that when forming the cultural policy of the newly formed state, the artistic heritage of the autocracy should be taken into account. Indeed, Lunacharsky advocated pluralism in art, and his actions as People's Commissar of Education differed in many ways from the future cultural policy of the USSR (Anatoli Lunacharsky,2009).

Conceptual and main part

In the second half of the 19th century, the opponents of Russian “Slavism” – the “Westerners” – supported Russia’s integration towards the West. On this path, they first began to think about alphabet reform. It is true that various reforms were first carried out in this regard during the reign of Peter I, but it became difficult to conceptualize it. In the 19th century, the ideological and political situation was

more conducive to this. There were those who wanted to switch from the Russian language to the Latin alphabet. However, at that time, the idea of Latinization did not have serious political weight. Because the church and the state were against their ideas. In the second half of the 19th century, the church and the state, opposing the Westerners, supported Slavism. However, this idea, that is, the cultural measure related to the transition to the Latin language, strangely emerged during the Soviet period.

Anatoly Lunacharsky, who was the People's Commissar of Education (Minister of Education) of Soviet Russia, stood out among the Bolsheviks for his political views. Maxim Gorky, Bazarov, Bogdanov, and Lunacharsky were different from the hardline communists in terms of their political, philosophical, and some ideological views. They maintained contact with European social democrats and exchanged views on various social issues. Of course, they were in the minority among the communists. They can be considered a small faction in the Bolshevik party. They called themselves “Bogostroiteli,” that is, “God-builders.” This was not a new religion. Rather, they were looking for Christianity in Marxism. It can even be said that they wanted to find common criteria between Marxism and Christianity and compare them. This was very similar to the views of socialists in Europe on Christianity. Of course, there were also differences from them (Morozova, 2020). While Europeans wanted to identify socialism with Catholicism or Protestantism, the “God-builders” wanted to identify socialism with Proslavism. Asceticism was not possible in Russian Christianity. Since there was no asceticism, humanism could not arise. Since humanism could not arise, liberal ideas could not expand much. Therefore, Marxism in Russia took a militant, belligerent, authoritarian form. That is, unlike the reformist socialists in Europe, Russian Marxists became revolutionary. Historical conditions and adherence to the path taken gradually shaped the Russian communists.

According to Lunacharsky, a new religion without God is possible. According to his “god-making,” God is a supreme, universal being that can be established through collective labor. Religion is based on “the assumption of a higher power that is close to the individual, close to him, and on which he can pin his hopes.” Unlike the old religions, which were “characterized by the idea of individual immortality in the creations of the human spirit,” in the new religion man finds his immortality in the community, because for him reality is the species. Humanity and the individual are only a special expression of this essence (A.Lunacharsky,2022). But for the sake of the species, the individual finds himself ten times stronger by rejecting himself. Another difference between the new religion and the old religion is that the old religions “unconditionally guarantee the victory of goodness” and therefore lead to passivity. The new religion, on the other hand, is completely active, because that victory acts by testing its strength by struggling with hope. And yet, "the new religion, the religion of humanity, the religion of labor, offers no guarantees," and even without God and without guarantees-it remains such a religion, even without the mask of God."(Anatoli Lunacharsky 2022)

Unlike the old religions, which served to enslave people, the new religion, on the contrary, declares its power. This religion "saw its future kingdom, active, economic type." Let us briefly note that if we put aside religious terminology, we will see how close Lunacharsky's thoughts are to A. Bogdanov's thoughts about collectivism and the new man (Morozova,2020).

Finally, for Lunacharsky, whose emotionality was noted by many of his contemporaries, moments of universal inspiration and self-sacrifice also have a religious meaning. He writes: "Religion expresses those moments when a person, a mass or a class, living and dying in the light of the desired future for centuries, rises above itself like a soldier in a conquering army." Apparently, in this case, we can talk about using religious terminology to express feelings and impulses that have no religious meaning or significance in the traditional understanding of religious terms. A sense of unity with other individuals of the same thoughts and aspirations, a sense of enlightenment that comes from the consciousness of a fulfilled duty, from helping others - all these lofty feelings are in no way religious if we understand religion as a doctrine of God (Anatoli Lunaçarski 2009).

Taking all this into account, Lunacharsky distanced himself from the ideas of “God-building”, that is, the ideas of uniting Marxism and Christianity. However, he did not abandon the idea of transitioning the Russian language to Latin. Naturally, he voiced this idea on various platforms at the state level. Although before that, when the “Westerners” put forward this idea in the second half of the 19th century, they encountered resistance from the church, it was impossible for the Bolsheviks to face such problems.

There were quite a few people among the Bolsheviks who were against this idea. However, the fact that Lunacharsky was the Commissar of Education at that time created immunity against this resistance. Lunacharsky's main argument was that the Cyrillic alphabet had held Russia back from intellectual Europe for centuries. The old Cyrillic alphabet was cited as one of the reasons for Russia's technological backwardness (Potamias and Mandilara, 2025). Russia became acquainted with European religious texts and philosophy much later. Thus, according to Lunacharsky, if Russia switches from the Cyrillic alphabet to the Latin alphabet, we can soon eliminate Russia's backwardness from Europe. Russia can even catch up with Europe very quickly. The Soviet leadership did not reject Lunacharsky's ideas. Although Lenin accepted these ideas, he noted that there was no point in rushing to implement them. According to Anatoly Lunacharsky, the Latin alphabet would significantly facilitate the learning of the Russian language by "proletarians of all countries." Various discussion commissions were created regarding the transition to the Latin script. The reasonable proposal made by the mentioned discussion commissions was this: - Test this alphabet change among non-Russian peoples. Under Soviet rule, the Turks were considered the largest people after the Slavs. Of the Turkic peoples, the most active politically, culturally, and economically were, of course, the Azerbaijanis. Since the 19th century, the development of Azerbaijan's socio-political thought, theater, newspapers, and the central role of the Turkish-Muslim world had drawn attention to it. Of course, the establishment of the republic at the beginning of the 20th century, the export of ideas, and the certain influence it had on Anatolian Turkey led Soviet Russia to carry out these reforms precisely in Azerbaijan. Azerbaijan, which has been considered a crossroads of various cultures throughout history, could have been a favorable geography for the spread of these ideas

Another argument was that the Russian people were superior to the Turkic people in terms of literacy. For this reason, it was considered more difficult to change their alphabet. Changing the alphabet of a people with less literacy would be easier and less expensive. In fact, this was what was thought. If this process was successful, then it would be possible to implement it in other peoples, including the ruling Russian people. Thus, in February-March 1926, the First Turkological Congress was held in Baku. Even Anatoly Lunacharsky became an honorary member of the Presidium of the Congress. Naturally, when talking about the results of this congress, the Azerbaijani alphabet was switched to the Latin script in 1929, and the foundations of Latinization were laid. This process took place in Central Asia, the North Caucasus, and other Muslim peoples. In the subsequent historical course, the alphabet was changed again due to political processes. It turned out that these changes were more a manifestation of political interests than cultural events.(Революция не шутит, 2018)

In the second half of the 19th century and the beginning of the 20th century, Azerbaijani enlighteners had ideas about the transition to the Latin alphabet. However, in the absence of political will, the ideas of the enlighteners could not be realized. However, thanks to the political will of the enlightener Bolshevik Lunacharsky, we can say that we got acquainted with the Latin alphabet. Although the main goal was different, Lunacharsky's ideas had a positive impact on us. Therefore, there are various research works on the various reasons for Russia's backwardness compared to Europe. We can mention the choice of alphabet in Russia's history and its Orthodox Christian identity as invisible reasons for this.

By 1930, about 70 languages had been Latinized. Georgian, Armenian, and three Slavic languages were not touched. Lunacharsky, the main political ideologist of the transition to the Latin alphabet, had other arguments for the need to implement this reform. First, the Cyrillic alphabet is the legacy of Russia before the bourgeois revolution. And this separates the Russian worker from the West, where the world revolution will soon take place, and from the awakened East. Russians are isolated from everyone. Secondly, this is politically beneficial. Future Soviet citizens who learn the Latin alphabet will not be able to read all the ideologically harmful pre-revolutionary books written in the Cyrillic alphabet. According to Anatoly Lunacharsky's vision, the world revolution was to bring free humanity a world alphabet - the Latin alphabet . (Алфавитная революция,2021)

The process of Latinization began to accelerate among Muslim nations. Officially, the forced introduction of new alphabets was explained by the desire of the central authorities to liberate previously oppressed peoples as quickly as possible. However, in reality, the main focus was on peoples who were strongly influenced by Islam, and the main goal remained to separate the working masses from religious

education, which was inseparable from the Arabic alphabet, and, as a result, to eliminate their influence on religious authorities.

Lunacharsky admitted in 1930: “The People's Commissariat of Education of the RSFSR, faced with the problem of Latinizing the written languages of all these peoples, understood very well how easily these innovations, intended to be used against the Soviet government in order to alienate them from their beliefs, could be used against the Soviet government.” The situation changed significantly in 1928 when the Republic of Turkey, a friendly country of the USSR, adopted the Latin alphabet. Lunacharsky noted that “A significant relief in this matter was the participation of the Turkish government in these reforms. This reform initiated the parallel Latinization with great energy. It immediately eliminated the possibility of playing political games and explaining the Latinization of the alphabets by the Bolsheviks as a “persecution” of this old culture, based on loyalty to a purely Muslim and Turkish culture. But even without such help from the Turkish government, the process of Latinization continued apace.” Although the process of Latinization continued, many problems still remained (Анатолий Луначарский, 2022).

The report of the Propaganda Department of the Central Committee to Stalin and Kaganovich noted: “There have been and still are significant shortcomings in the work of the Committee on the New Alphabet. Here, first of all, it is necessary to note the fascination with the superficial quantitative aspect of the issue and the arbitrary nature of the process. Thus, an alphabet was created for the Aleuts, whose number is no more than 400 people throughout the USSR. Such concerns were especially widespread in Dagestan, where almost every one of the more than thirty peoples (including the smallest, whose population does not exceed a few hundred) is trying to create its own alphabet and even elementary school textbooks.” In early 1936, some regional party and government bodies began to ask for permission to switch to the Russian alphabet. In some cases, this was dictated by practical considerations: a complex alphabet created problems not only for education, but also for printing. Equipment for such alphabets was located in only two foundries, in Moscow and Leningrad. It was noted that the envoys from the republics and autonomous regions formed long queues. This also created problems in the acceleration of the future alphabet (Алфавитная революция,2021.) All this created conditions for the transition to the Russian alphabet. As a result of the planning carried out by Soviet Russia, action programs were prepared for the transition of the Turkic peoples to the Cyrillic alphabet. At the same time, the process of abolishing national languages was underway in the districts and village councils. National languages were abolished in schools and national pedagogical colleges where national languages were taught, and almost everywhere. The Russian language and the Cyrillic alphabet were introduced. Even in the Moldavian USSR, which was created in 1940 after the USSR occupied Bessarabia, the Latin script was immediately replaced by Cyrillic.

Conclusion

No matter what system-enlightenment monarchy, socialist republic, or democratic federation they start to build in Russia, you will see that in the end it is always an empire. Thus, Lunacharsky's idea played a role as a seed for the future and the single cultural unity of the Turkic peoples. In order to create a common alphabet for the Turkic peoples in the future, it is necessary to take advantage of this idea put forward by Lunacharsky. An independent alphabet policy is very important in moving away from the cultural influence of Russia and building their own national identity. A strange trend has formed throughout history. In order to become part of the modern world, it is necessary to move away from Moscow. In the past, Peter I also moved the capital from Moscow to a newly built city closer to Europe, St. Petersburg. In order to modernize, it is necessary to move away from Moscow.

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THE SILENT DECLINE IN BREAST MILK: EFFECTS OF SMOKING AND LACTATION DURATION ON THE CULTURABLE MICROBIOTA

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ABSTRACT

Breast milk contains culturable microorganisms that play a critical role in the formation of the newborn's gut microbiota. It is known that the microbial content of breast milk may vary according to maternal lifestyle factors and lactation duration. In this study, it was aimed to evaluate the effects of maternal smoking status and lactation duration on the culturable microbial load and diversity in breast milk.

Breast milk samples collected from smoking and non-smoking mothers at the 1st, 6th, 12th, and 24th months of lactation were analyzed using culture-based methods. The samples were inoculated onto appropriate selective and enriched media, colony-forming unit (CFU/mL) values were calculated after incubation, and microbial diversity was evaluated by colony morphology and microscopic observations.

The findings obtained showed that the total bacterial load and microbial diversity in milk samples from non-smoking mothers were higher than those in the smoking group during all lactation periods. In addition, a gradual decrease in the number and diversity of culturable bacteria in breast milk was observed as lactation duration progressed in both groups, and this decrease was found to be more pronounced in smoking mothers. Particularly, significant decreases in the CFU/mL values of beneficial bacterial groups were detected during the later stages of lactation.

In conclusion, it was determined that maternal smoking adversely affects the breast milk microbiota and that the culturable microbial content gradually decreases as lactation duration increases. This situation is thought to have long-term effects on the newborn's microbial colonization and immune system development.

Keywords: Breast milk, microbiota, smoking, lactation duration, culture-based methods.

ÖZET

Anne sütü, yenidoğanın bağırsak mikrobiyotasının oluşumunda kritik rol oynayan kültürlenebilir mikroorganizmalar içermektedir. Anne sütü mikrobiyal içeriğinin; annenin yaşam tarzı faktörleri ve laktasyon süresi ile değişkenlik gösterebildiği bilinmektedir. Bu çalışmada, annenin sigara içme

durumunun ve laktasyon süresinin anne sütündeki kültürlenebilir mikrobiyal yük ve çeşitlilik üzerine etkilerinin değerlendirilmesi amaçlanmıştır.

Sigara içen ve sigara içmeyen annelerden laktasyonun 1., 6., 12. ve 24. aylarında toplanan anne sütü örnekleri kültür temelli yöntemlerle analiz edilmiştir. Örnekler uygun seçici ve zenginleştirilmiş besiyerlerine ekilmiş, inkübasyon sonrası koloni oluşturan birim (KOB/mL) değerleri hesaplanmış ve mikrobiyal çeşitlilik koloni morfolojisi ve mikroskop gözlemleri ile değerlendirilmiştir.

Elde edilen bulgular, sigara içmeyen annelere ait süt örneklerinde tüm laktasyon dönemlerinde toplam bakteri yükü ve mikrobiyal çeşitliliğin sigara içen gruba kıyasla daha yüksek olduğunu göstermiştir. Ayrıca, her iki grupta da laktasyon süresi ilerledikçe anne sütündeki kültürlenebilir bakteri sayısı ve çeşitliliğinde kademeli bir azalma gözlenmiş; bu azalmanın sigara içen annelerde daha belirgin olduğu saptanmıştır. Özellikle laktasyonun ilerleyen dönemlerinde faydalı bakteri gruplarının KOB/mL değerlerinde anlamlı düşüşler tespit edilmiştir.

Sonuç olarak, maternal sigara kullanımının anne sütü mikrobiyotasını olumsuz etkilediği ve laktasyon süresi uzadıkça kültürlenebilir mikrobiyal içeriğin giderek azaldığı belirlenmiştir. Bu durumun, yenidoğanın mikrobiyal kolonizasyonu ve bağışıklık sistemi gelişimi üzerinde uzun vadeli etkiler oluşturabileceği düşünülmektedir.

Anahtar Kelimeler: Anne sütü, mikrobiyota, sigara kullanımı, laktasyon süresi, kültür temelli yöntemler

GİRİŞ

Anne sütü, yenidoğanın beslenmesinde temel bir rol üstlenmesinin yanı sıra, içerdiği canlı mikroorganizmalar sayesinde gastrointestinal mikrobiyotanın erken dönemde şekillenmesine katkıda bulunan biyolojik olarak aktif bir sıvıdır. Anne sütünde başta *Lactobacillus, Bifidobacterium, Staphylococcus* ve *Streptococcus* türleri olmak üzere çeşitli kültürlenebilir bakterilerin bulunduğu ve bu mikroorganizmaların yenidoğanın bağışıklık sistemi gelişimi ile yakından ilişkili olduğu bilinmektedir (Moossavi et al., 2019)

Anne sütü mikrobiyotasının bileşimi ve yoğunluğu statik olmayıp; doğum şekli, annenin beslenme durumu, çevresel maruziyetler ve yaşam tarzı alışkanlıkları gibi birçok faktörden etkilenmektedir (Bianco et al., 2024). Bununla birlikte, laktasyon süresinin ilerlemesiyle anne sütü içeriğinde meydana gelen mikrobiyal değişimler halen tam olarak aydınlatılamamıştır. Literatürde, erken laktasyon döneminde mikrobiyal çeşitliliğin daha yüksek olduğu, ilerleyen dönemlerde ise bazı bakteri gruplarının azaldığına dair sınırlı sayıda çalışma bulunmaktadır (Lyons et al., 2022). Ancak bu değişimin kültürlenebilir bakteri popülasyonları üzerindeki etkisi yeterince ortaya konmamıştır.

Sigara kullanımı, içerdiği nikotin, karbon monoksit ve oksidatif stres oluşturan toksik bileşikler nedeniyle maternal sağlık üzerinde olduğu kadar anne sütü bileşenleri üzerinde de olumsuz etkilere sahiptir (Zanardo et al., 2005). Sigara dumanına maruziyetin anne sütünde immünolojik bileşenleri ve bazı biyokimyasal parametreleri azalttığı bildirilmiş olsa da, anne sütü mikrobiyotasının kültürlenebilir bileşenleri üzerindeki etkileri sınırlı sayıda çalışmada ele alınmıştır (McLean et al., 2019). Özellikle sigara kullanımının, laktasyon süresi boyunca anne sütü mikrobiyal içeriğinde meydana gelen değişimlerle birlikte değerlendirilmesi literatürde önemli bir boşluk oluşturmaktadır.

Bu çalışmada, annenin sigara içme durumunun ve laktasyon süresinin (1., 6., 12. ve 24. ay) anne sütündeki kültürlenebilir mikrobiyal yük ve çeşitlilik üzerindeki etkisinin kültür temelli yöntemlerle değerlendirilmesi amaçlanmıştır. Elde edilecek bulguların, anne sütü mikrobiyotasının zaman içindeki dinamik yapısının anlaşılmasına ve maternal sigara kullanımının yenidoğan sağlığı üzerindeki dolaylı etkilerinin ortaya konmasına katkı sağlaması hedeflenmektedir.

MATERYAL VE YÖNTEM

Anne Sütü Örneklerinin Toplanması

Anne sütü örnekleri, postpartum 1., 6., 12. ve 24. ay dönemlerinde, meme başı %70 etil alkol ile temizlendikten sonra steril kaplara elle sağım yöntemiyle toplanmıştır. Örnekler soğuk zincir altında laboratuvara taşınmış ve aynı gün analiz edilmiştir.

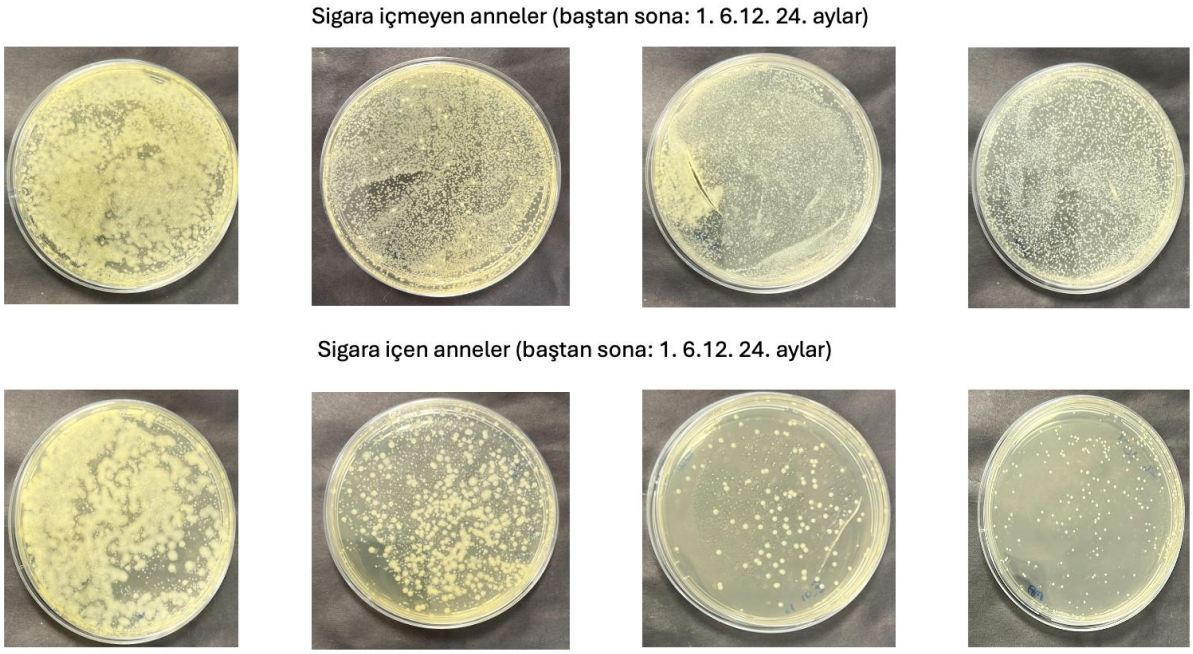
Mikrobiyolojik Analizler

Anne sütü örneklerinden seri dilüsyonlar hazırlanmış ve laktik asit bakterileri için MRS Agar, *Streptococcus* ve *Lactococcus* türleri için M17 Agar ve toplam aerob mezofilik bakteri sayımı için LB Agar besiyerlerine ekim yapılmıştır. Plaklar 30°C ve 37°C'de 48–72 saat inkübe edilmiştir. Gelişen koloniler sayılarak KOB/mL cinsinden hesaplanmıştır. Koloniler morfolojik özelliklerine göre değerlendirilmiş, Gram boyama ile mikroskop altında ön tanımlamaları yapılmıştır.

BULGULAR

Sigara içen ve sigara içmeyen annelerden laktasyonun 1., 6., 12. ve 24. aylarında toplanan anne sütü örneklerinin kültür temelli mikrobiyolojik analizleri sonucunda, toplam kültürlenebilir bakteri yükü ve mikrobiyal çeşitlilik açısından gruplar arasında belirgin farklılıklar saptanmıştır.

Sigara içmeyen annelere ait anne sütü örneklerinde toplam aerob mezofilik bakteri sayısının, sigara içen annelere kıyasla daha yüksek olduğu belirlenmiştir. MRS ve M17 agar üzerinde yapılan ekimler sonucunda, laktik asit bakterileri ve *Streptococcus/Lactococcus* gruplarına ait koloni sayılarının laktasyonun erken dönemlerinde (1. ve 6. ay) daha yüksek olduğu gözlenmiştir. Laktasyon süresi uzadıkça bu bakteri gruplarına ait KOB/mL değerlerinde her iki grupta da azalma tespit edilmiş, ancak sigara içen annelerde bu azalmanın daha erken başladığı ve daha keskin olduğu belirlenmiştir (Şekil 1).



Şekil 1. Sigara içen ve içmeyen annelerde laktasyon süresinin değişimi

Koloni morfolojisi, Gram boyama ve temel mikroskobik gözlemler ile yapılan ön tanımlamalar sonucunda, laktasyonun erken dönemlerinde anne sütünde daha fazla sayıda farklı koloni tipinin bulunduğu gözlenmiştir. Laktasyon süresi ilerledikçe koloni morfolojilerinin sayısında azalma olduğu ve mikrobiyal çeşitliliğin giderek düştüğü saptanmıştır.

Veriler ortalama ± standart sapma olarak ifade edilmiştir. Gruplar arasındaki farklılıklar iki yönlü ANOVA ve Tukey çoklu karşılaştırma testi ile değerlendirilmiştir. $p<0.05$ istatistiksel olarak anlamlı kabul edilmiştir.

TARTIŞMA

Bu çalışmada, annenin sigara içme durumunun ve laktasyon süresinin anne sütündeki kültürlenebilir mikrobiyal yük ve çeşitlilik üzerinde belirgin bir etkiye sahip olduğu gösterilmiştir. Elde edilen bulgular, sigara içmeyen annelere ait anne sütü örneklerinde tüm laktasyon dönemleri boyunca daha yüksek bakteri yükü ve çeşitliliği bulunduğunu, her iki grupta da laktasyon süresi uzadıkça mikrobiyal içeriğin kademeli olarak azaldığını ve bu azalmanın sigara içen annelerde daha belirgin olduğunu ortaya koymaktadır.

Anne sütü mikrobiyotasının dinamik bir yapıya sahip olduğu ve laktasyonun erken dönemlerinde daha zengin bir mikrobiyal içeriğin bulunduğu literatürde bildirilmektedir. Erken laktasyon döneminde yüksek mikrobiyal çeşitliliğin, yenidoğanın gastrointestinal sisteminin ilk kolonizasyonunda ve immün toleransın gelişiminde önemli rol oynadığı bilinmektedir. Bu çalışmada da 1. ve 6. ay anne sütü örneklerinde kültürlenebilir bakteri yükünün daha yüksek bulunması, anne sütü mikrobiyotasının zamanla değişen ve azalan bir yapıya sahip olduğunu desteklemektedir.

Sigara kullanımının anne sütü mikrobiyal içeriği üzerindeki olumsuz etkisi, sigara dumanında bulunan nikotin, ağır metaller ve oksidatif stres oluşturan toksik bileşiklerin mikroorganizmalar üzerindeki inhibitör etkileri ile açıklanabilir. Bu bileşiklerin sistemik dolaşıma geçerek anne sütüne aktarılması, süt ortamında mikroorganizmaların canlılığını ve çoğalmasını baskılayabilir. Çalışmamızda sigara içen annelerde tüm laktasyon dönemlerinde toplam kültürlenebilir bakteri yükünün ve özellikle faydalı bakteri gruplarının daha düşük bulunması, bu mekanizmayı destekler niteliktedir.

Laktasyon süresi ile sigara kullanımının birlikte değerlendirilmesi, mikrobiyal içerik üzerindeki baskılayıcı etkinin zamanla arttığını göstermektedir. Özellikle laktasyonun ilerleyen dönemlerinde (12. ve 24. ay), sigara içen annelerde mikrobiyal çeşitliliğin daha erken ve daha keskin şekilde azaldığı gözlenmiştir. Bu durum, sigaraya bağlı kronik maruziyetin zaman içerisinde anne sütü mikrobiyotasını daha belirgin şekilde etkileyebileceğini düşündürmektedir. Yenidoğanın ve süt çocuğunun bağırsak mikrobiyotasının gelişiminin devam ettiği bu dönemlerde, anne sütü kaynaklı mikrobiyal girdinin azalması, uzun vadede bağışıklık sistemi ve metabolik sağlık üzerinde olumsuz etkiler oluşturabilir.

Bu çalışmanın kültür temelli yöntemlerle gerçekleştirilmiş olması, anne sütünde canlı ve metabolik olarak aktif mikroorganizmaların değerlendirilmesine olanak sağlamıştır. Ancak kültür temelli yaklaşımların, kültüre edilemeyen mikroorganizmaları dışlaması çalışmanın bir kısıtlılığı olarak değerlendirilebilir. Buna karşın, elde edilen bulgular yenidoğan için biyolojik olarak anlamlı olan canlı bakteri popülasyonları hakkında önemli bilgiler sunmaktadır.

Anne sütü mikrobiyotasının laktasyon süresi boyunca dinamik bir değişim gösterdiği daha önce yapılan çalışmalarda da bildirilmiştir. Erken laktasyon döneminde anne sütünde mikrobiyal çeşitliliğin daha yüksek olduğu, ilerleyen dönemlerde ise özellikle faydalı bakteri gruplarının azalma eğiliminde olduğu belirtilmektedir (Cabrera-Rubio et al., 2012; Jost et al., 2014). Çalışmamızda 1. ve 6. ay süt örneklerinde daha yüksek kültürlenebilir bakteri yükü saptanması, bu bulgularla uyumludur.

Maternal yaşam tarzı faktörlerinin anne sütü mikrobiyotası üzerindeki etkisi giderek artan bir ilgi alanıdır. Sigara dumanına maruziyetin, oksidatif stres yoluyla hem konakçı hücreler hem de mikroorganizmalar üzerinde baskılayıcı etki oluşturduğu bilinmektedir (Yu et al., 2017). Daha önce yapılan bazı çalışmalar, sigara içen annelerin sütlerinde bağışıklıkla ilişkili biyolojik bileşenlerin azaldığını göstermiştir (Napierala et al., 2016). Ancak sigara kullanımının anne sütündeki kültürlenebilir mikrobiyal popülasyonlar üzerindeki etkisi sınırlı sayıda çalışmada ele alınmıştır. Bu çalışmada sigara içen annelerde tüm laktasyon dönemlerinde daha düşük bakteri yükünün ve çeşitliliğinin saptanması, sigaranın anne sütü mikrobiyotasını olumsuz etkilediğine dair mevcut sınırlı literatürü destekler niteliktedir.

Özellikle sigara içimi ile laktasyon süresinin birlikte değerlendirilmesi, mikrobiyal içerik üzerindeki baskılayıcı etkinin zamanla arttığını göstermesi açısından dikkat çekicidir. Yenidoğan ve süt çocuğunun bağırsak mikrobiyotasının gelişiminin devam ettiği 12. ve 24. aylarda anne sütü kaynaklı mikrobiyal girdinin azalması, bağışıklık sistemi maturasyonu açısından potansiyel riskler oluşturabilir (Walker, 2017). Bu yönüyle çalışma, maternal sigara kullanımının yalnızca erken dönem değil, uzun süreli emzirme sürecinde de etkili olabileceğini ortaya koymaktadır.

Sonuç olarak, bu çalışma maternal sigara kullanımının anne sütü mikrobiyotasını olumsuz yönde etkilediğini ve laktasyon süresi uzadıkça kültürlenebilir mikrobiyal içeriğin giderek azaldığını ortaya koymaktadır. Bulgular, emzirme döneminde sigara kullanımının sınırlandırılmasının ve anne sütü mikrobiyotasının korunmasının, yenidoğan ve süt çocuğu sağlığı açısından kritik öneme sahip olduğunu vurgulamaktadır.

SONUÇ

Bu çalışmanın en önemli güçlü yönü, anne sütü mikrobiyotasının kültür temelli yöntemlerle değerlendirilmiş olmasıdır. Bu yaklaşım, anne sütünde bulunan canlı ve metabolik olarak aktif mikroorganizmaların doğrudan incelenmesine olanak sağlamış ve yenidoğan açısından biyolojik olarak anlamlı mikrobiyal popülasyonlar hakkında bilgi sunmuştur. Ayrıca çalışmada laktasyonun farklı dönemlerine ait (1., 6., 12. ve 24. ay) anne sütü örneklerinin karşılaştırılması, anne sütü mikrobiyal içeriğinin zamana bağlı değişiminin ortaya konmasına katkı sağlamıştır. Sigara içimi ve laktasyon süresinin birlikte değerlendirilmesi ise çalışmanın özgünlüğünü artıran önemli bir diğer unsurdur.

Bununla birlikte, çalışmanın bazı sınırlılıkları da bulunmaktadır. Kültür temelli yöntemler, kültüre edilemeyen mikroorganizmaların değerlendirme dışı kalmasına neden olabilmektedir. Bu nedenle, anne sütü mikrobiyotasının tamamı yerine yalnızca kültürlenebilir bileşenleri analiz edilebilmiştir. Ayrıca sigara kullanımının süresi ve yoğunluğunun (paket-yıl gibi) daha ayrıntılı olarak sınıflandırılamamış olması, sigara maruziyeti ile mikrobiyal değişimler arasındaki doz-yanıt ilişkisinin değerlendirilmesini sınırlandırmıştır. Gelecekte yapılacak çalışmalarda kültür temelli yöntemlerin moleküler yaklaşımlar ile desteklenmesi, anne sütü mikrobiyotasının daha kapsamlı şekilde ortaya konmasına katkı sağlayacaktır.

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COMPARISON OF PREMENSTRUAL SYNDROME AND ANXIETY LEVELS AMONG WORKING AND NON-WORKING WOMEN AGED 18–55 IN TURKEY

TÜRKİYE'DE 18-55 YAŞ ARALIĞINDA ÇALIŞAN VE ÇALIŞMAYAN KADINLARDA PREMENSTRÜEL SENDROM İLE ANKSİYETE DÜZEYİNİN KARŞILAŞTIRILMASI

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Özet

Bu çalışma, Türkiye'de 18-55 yaş aralığındaki çalışan ve çalışmayan kadınlarda premenstrüel sendrom (PMS) ile anksiyete düzeyleri arasındaki ilişkiyi incelemek ve çalışma durumunun bu iki değişken üzerindeki olası etkisini ortaya koymak ve karşılaştırmak amacıyla nicel araştırma yöntemleri kapsamında nedensel karşılaştırma modeli kullanılarak gerçekleştirilmiştir. Araştırmanın evrenini Türkiye genelinde yaşayan çalışan ve çalışmayan kadınlar oluştururken, örneklem kota örnekleme yöntemiyle belirlenen 379 çalışan ve 381 çalışmayan kadın olmak üzere toplam 760 katılımcıdan meydana gelmiştir. Veriler sosyo-demografik bilgi formu, Premenstrüel Sendrom Ölçeği ve Beck Anksiyete Envanteri aracılığıyla toplanmış ve elde edilen sonuçlar uygun istatistiksel analiz teknikleriyle değerlendirilmiştir. Bulgular, her iki grupta da PMS düzeyi ile anksiyete arasında pozitif ve istatistiksel olarak anlamlı bir ilişki olduğunu göstermiştir. Çalışmayan kadınlarda ayrıca depresif duygulanım ile somatik semptomlar arasında negatif yönlü anlamlı bir ilişki saptanmıştır. Çalışan kadınlarda depresif duygulanım, sinirlilik, depresif düşünceler, şişkinlik ve subjektif kaygı alt boyut puanları anlamlı düzeyde daha yüksek bulunurken, çalışmayan kadınlarda ağrı ve uyku değişimleri alt boyut puanları anlamlı düzeyde daha yüksek çıkmıştır. Buna karşın, çalışma durumunun toplam PMS ve anksiyete düzeyleri açısından istatistiksel olarak anlamlı bir farklılık yaratmadığı sonucuna ulaşılmıştır. Bu bulgular doğrultusunda, PMS belirtileriyle baş etme sürecinde kadınlara yönelik farkındalık eğitimlerinin planlanması ve psikolojik destek hizmetlerinin daha erişilebilir ve yaygın hale getirilmesi önerilmektedir.

Anahtar Kelimeler: Çalışan ve Çalışmayan Kadınlar, Premenstrüel Sendrom, Anksiyete

ABSTRACT

This study was conducted to examine the relationship between Premenstrual Syndrome (PMS) and anxiety levels among employed and unemployed women aged 18–55 in Türkiye and to compare the potential effects of employment status on these variables. The research was carried out using a causal-comparative design within the framework of quantitative research methods. The study population consisted of employed and unemployed women residing throughout Türkiye. The sample comprised a total of 760 participants, including 379 employed women and 381 unemployed women, selected through quota sampling. Data were collected using a Sociodemographic Information Form, the Premenstrual Syndrome Scale, and the Beck Anxiety Inventory. The obtained data were analyzed using appropriate statistical techniques. The findings revealed a positive and statistically significant relationship between PMS levels and anxiety levels in both employed and unemployed women. Additionally, a significant negative relationship was identified between the depressive affect subdimension and somatic symptoms among unemployed women. The results further indicated that employed women scored significantly higher on the PMS subdimensions of depressive affect, irritability, depressive thoughts, bloating, and subjective anxiety. In contrast, unemployed women demonstrated significantly higher scores on the pain and sleep changes subdimensions. However, no statistically significant differences were found between employed and unemployed women in terms of overall PMS and anxiety levels. Based on these findings, it can be concluded that PMS symptoms are closely associated with anxiety among women regardless of their employment status. Accordingly, it is recommended that awareness-raising programs aimed at

enhancing women's coping skills regarding PMS symptoms be developed and implemented, and that psychological support services be made more accessible and widely available.

Keywords: Working And Non-Working Women, Premenstrual Syndrome, Anxiety

BÖLÜM I

Giriş

Kadın ve erkek arasındaki rol farklılıkları uzun süre biyolojik yapının doğal bir sonucu olarak kabul edilmiş olsa da, çağdaş psikoloji literatürü bu ayrımın büyük ölçüde kültürel olarak inşa edildiğini ve kuşaklar boyu süren bir toplumsal öğrenme süreciyle aktarıldığını ortaya koymaktadır (Yavuz, 2019). Bu öğrenme süreci, erken çocukluktan itibaren içselleştirilen cinsiyet kalıp yargıları aracılığıyla kadını özel alanla, yani ev içi bakım emeği ve annelik rolüyle özdeşleştirmekte ve benlik kavramının bu sınırlı roller etrafında şekillenmesine yol açmaktadır. Söz konusu rol dağılımı, kadınların öz-yeterlilik algılarını ve kariyer hedeflerine yönelik motivasyonlarını olumsuz etkileyerek, potansiyellerini gerçekleştirmelerinin önünde psikolojik bir bariyer oluşturmaktadır. Tarihsel olarak bakıldığında, çalışma edimi ile erkeklik kimliği arasında güçlü bir psikolojik bağ kurulmuş ve erkek için ev dışında gelir getirici bir işte çalışmak psikososyal gelişimin doğal bir parçası sayılırken, kadının birincil sorumluluğu ev içi emekle tanımlanmıştır (Konal, 2021). Kadınlar işgücüne katıldıklarında ise bu kez iş ve aile rolleri arasında sıkışmanın getirdiği rol çatışması ve suçluluk duygusu gibi psikolojik baskılarla yüzleşmek zorunda kalmışlardır. Savaş ve ekonomik kriz dönemlerinde kadın emeğinin yalnızca ikincil ve geçici bir kaynak olarak değerlendirilmesi, kadınlarda mesleki kimlik gelişimini sekteye uğratan bir diğer psikososyal etmen olmuştur. Günümüzde küreselleşmenin toplumsal normlar üzerindeki dönüştürücü etkisi, kadınların istihdamda daha görünür roller üstlenmesine zemin hazırlasa da (Nart, 2019), çalışan kadınlar iş ve ev içi sorumlulukların eşzamanlı yürütülmesinden doğan çifte yük ile başa çıkmak durumunda kalmaktadır. Bu çifte yük, kronik strese yol açarak tükenmişlik, anksiyete ve depresif belirtiler gibi ruh sağlığı sorunları açısından önemli bir risk faktörü oluşturmaktadır..

Kadınların iş hayatındaki artan görünürlüğü, onların yaşam döngülerine özgü biyopsikososyal süreçlerle etkileşime girmektedir. Bu süreçlerin başında, kadınların ruh sağlığını ve işlevselliğini önemli ölçüde etkileyen Premenstrüel Sendrom (PMS) gelmektedir. PMS, adet döngüsünün luteal fazında (yumurtlamayı takip eden hafta) ortaya çıkan ve menstrüasyonun başlamasıyla hafifleyen, fiziksel, duygusal, zihinsel ve davranışsal belirtilerle tanımlanan bir durumdur. Duygudurum dalgalanmaları, depresif hisler, benlik saygısında azalma, kaygı ve irritabilite gibi psikolojik belirtilerin yanında; karın ağrısı, yorgunluk, şişkinlik, meme hassasiyeti ve kilo artışı gibi fiziksel şikayetler de yaygın olarak gözlenmektedir (Baskın, 2025). Psikolojik literatür, PMS'in bilişsel işlevler ve duygu düzenleme üzerindeki olumsuz etkilerine dikkat çekmektedir. Özellikle dikkati toplama, karar verme ve stresle başa çıkma gibi iş yaşamında kritik öneme sahip becerilerde geçici düşüşler yaşanabilmektedir (Kurpanik vd., 2024; Lambert vd., 2025). Amerikan Obstetrik ve Jinekologlar Birliği (ACOG) kriterlerine göre, PMS tanısı için belirtilerin adet kanamasından önceki 5 gün içinde başlaması ve kanamayı takip eden 4 gün içinde sona ermesi gerekmektedir (Koçak, 2024).

Uluslararası Premenstrüel Bozukluklar Derneği, premenstrüel bozuklukları temel ve türev olmak üzere iki kategoride incelemektedir (Kadian ve O'Brien, 2012). Temel premenstrüel bozuklukların ayırt edici özelliği, semptomların başka bir psikiyatrik ya da fiziksel hastalığın alevlenmesine bağlı olmaksızın, yumurtlamayla ilişkili bir döngü içinde ortaya çıkmasıdır. Semptomların menstrüasyon başlangıcından yaklaşık on dört gün önce belirmesi, son beş günde en yoğun seviyeye ulaşması ve kanamanın başlamasından sonraki üç-dört gün içinde kaybolması temel PMB'nin önemli bir özelliğidir. Bu şikayetler yaşam kalitesini belirgin biçimde düşürmekte ve döngü içinde semptomsuz geçen yaklaşık bir haftalık bir dönem bulunmaktadır (Cary ve Simpson, 2023). Türev premenstrüel bozukluklar ise mevcut bir psikiyatrik ya da fiziksel hastalığın premenstrüel dönemde kötüleşmesi veya hormonal tedavilere bağlı olarak gelişen premenstrüel belirtileri içermektedir (O'Brien vd., 2011).

PMS ve Premenstrüel Disforik Bozukluk (PMDB), temel PMB kategorisi altında değerlendirilmektedir (Pasafçıoğlu, 2025). Bu bağlamda, PMS sürecinde görülen semptomlar, özellikle de anksiyete, kadınların ruh sağlığı için hassas bir zemin oluşturmaktadır. Anksiyete bozuklukları, dünya genelinde

en yaygın görülen ruh sağlığı sorunlarından biridir (Bayraktar, 2025). Bilişsel psikoloji perspektifinden anksiyete, bireyin gelecekte ortaya çıkabileceğini öngördüğü tehditlere karşı geliştirdiği, düşünce, duygu ve fizyolojik tepki bileşenlerinden oluşan bir durumdur (Çapan, 2026). Normal koşullarda adaptif bir savunma mekanizması olan anksiyete, tehlike anında 'savaş ya da kaç' tepkisini tetikleyerek organizmanın hayatta kalmasına yardımcı olur. Ancak bilişsel modellere göre, hissedilen tehdit gerçek dışı olduğunda veya anksiyete kronik bir hal aldığında, bu durum işlevselliği bozan patolojik bir olguya dönüşmektedir (Shermatova, 2024). İş yaşamındaki performans baskısı ve rol çatışmalarıyla birleştiğinde, PMS'in tetiklediği anksiyete belirtileri kadınların mesleki işlevselliklerini ve genel psikolojik iyi oluşlarını çok yönlü olarak tehdit etmektedir. Bu kapsamda, araştırmanın amacı, çalışma hayatında aktif olarak yer alan kadınların yaşadığı premenstrüel sendrom belirtileri ile anksiyete düzeyleri arasındaki ilişkiyi incelemek ve bu iki değişkenin iş yaşamındaki yansımalarını psikolojik bir çerçeveden değerlendirmektir.

BÖLÜM II

Kavramsal/Kuramsal Çerçeve ve İlgili Araştırmalar

Kadın

Toplumsal yaşam içerisinde kadınların konumu, geçmişten bugüne genellikle ev içi sorumluluklar, çocukların bakımı ve başarılı bir ev yöneticisi olma gibi kalıplarla çizilmiş bir çerçevede şekillenmiştir. Bu çerçeve, biyolojik farklılıkların toplumsal yorumlanışı olarak tanımlanabilecek toplumsal cinsiyet kavramıyla yakından ilişkilidir. Asırlardır devam edegelen toplumsal cinsiyet rolleri, toplumsal normlar ve ekonomik yapılar; kadınların sosyal statüsü, kişilik örüntüleri ve deneyimledikleri psikolojik zorluklar üzerinde doğrudan etkilidir. Kadın kavramı, tarihin farklı dönemlerinde ve farklı kültürlerde değişen anlamlar yüklenmiş bir olgu olmakla birlikte, ortak nokta kadının çoğunlukla ikincil bir konumda tanımlanmış olmasıdır. Kadına atfedilen duygusallık, zayıflık ve başkalarına bağımlılık gibi nitelikler, kadının kamusal alanda etkisizleşmesine hizmet etmektedir. Kadın kimliğinin yalnızca çocuk bakımı ve ev işleriyle özdeşleştirilmesi, toplumsal algının yarattığı kısıtlayıcı bir çerçevedir. Bu dar tanımlama, kadının potansiyelini gerçekleştirmesinin önünde görünmez bir engel teşkil etmekte ve bireysel gelişimini sınırlandırmaktadır. Tüm bu yapısal engeller ve kültürel baskılar, düşük sosyoekonomik imkânlarla birleşerek kadınları psikolojik iyi oluş açısından dezavantajlı bir gruba dönüştürmektedir (Karakurt, 2022).

Çalışan Kadın

On dokuzuncu yüzyılda ivme kazanan sanayileşme hareketleri, geleneksel yapı içerisinde ağır yükler taşıyan kadınlara eğitim olanakları, kişisel gelişim ve hane dışında ücret karşılığında çalışabilme imkânları sunmuştur (Akçagöz, 2017). Bu dönem, kadının ekonomik bir aktör olarak görünürlük kazanmaya başladığı kritik bir kırılma noktasını temsil etmektedir. Kadınların iş dünyasına katılımının artmasıyla birlikte, çalışan kadın olgusu zaman içinde toplumsal bir kabule dönüşmüş ve bu durum özellikle kadınlar arasında yeni bir toplumsal düzenin oluşmasına zemin hazırlamıştır. Kadının çalışma hayatına adım atması, ev içindeki işler açısından da ayrı bir düzen ortaya çıkarmış; bu sayede kadın, hem çalışan hem de düzenleyici bir konuma erişmiştir (Kırıcı, 2019). Çalışma hayatı, kadına ekonomik özgürlük kazandırmanın yanı sıra, aile içi karar alma mekanizmalarında daha etkin bir rol üstlenmesine de olanak tanımıştır.

Çalışmayan Kadın

Çalışma hayatına katılmayan veya katılamayan kadınların durumu, ayrı bir toplumsal kategori olarak incelenmeyi gerektirmektedir. Ev içindeki kadın emeği iki ana eksende değerlendirilebilmektedir. İlk olarak, bu çalışma biçimi finansal bir getirisi bulunmayan kadın emeğini kapsamaktadır. Kadınların ev faaliyetleri için harcadıkları bu emek; yemek yapma, temizlik, çocuk bakımı, yaşlı ve hasta yakınların bakımı gibi geniş bir yelpazeye yayılan görünmez bir iş gücünü ifade etmektedir. Bu emek biçimi, erkek iş gücünün sürekliliği ve toplumsal yapının idamesi bakımından kritik bir öneme sahip olmasına karşın, milli gelir istatistiklerinde yer bulamamaktadır (Lenk, 2019). Ev içi emeğin ekonomik değerinin yok sayılması, çalışmayan kadının toplumsal statüsünü belirsizleştiren ve emeğini değersizleştiren bir mekanizma işlevi görmektedir. İkinci boyutta ise ev sınırları dâhilinde icra edilen ve ekonomik kazanç

sağlayan kadın emeği bulunmaktadır. Kadınlar, kendi ikametgâhlarında, farklı konutlarda veya ticari alanlarda, el işi üretimi, gıda imalatı, çocuk bakıcılığı gibi maddi değeri olan üretim süreçlerinde aktif rol alabilmektedirler. Bu tür çalışma biçimi, genellikle kayıt dışı ekonominin bir parçası olarak varlık göstermekte ve sosyal güvenceden yoksun kalmaktadır.

Premenstruel Sendromun Tanımı ve Tarihçesi

Premenstrüel Sendrom, adet döngüsünün ovulasyon sonrasındaki luteal fazında başlayan, kanamanın başlamasıyla birlikte hafifleyen veya tamamen ortadan kalkan duygusal, davranışsal ve fiziksel belirtilerle kendini gösteren bir durumdur. Kadınların yaklaşık %75'i yaşamlarının bir döneminde PMS belirtilerini deneyimlemektedir. Bu belirtiler kadınların günlük yaşam kalitesini olumsuz etkilemekle birlikte, ciddi durumlarda fiziksel ve duygusal rahatsızlıklara yol açabilmektedir (Alkış, 2024).

Premenstrüel Sendrom'un tarihsel kökeni Hipokrat dönemine kadar uzanmaktadır. Hipokrat döneminde, psikolojik ve davranışsal şikayetlerin adet dönemleriyle bağlantılı olduğu düşünülmüştür. Adet öncesi hastalık tablosundan ise ilk kez 11. yüzyılda Trotula De Salerno tarafından kadın sağlığı, hastalıkları ve çocuk bakımı konulu kitabında bahsedilmiştir (Bayraktar, 2018). Psikolojik ve davranışsal yakınmalar adet dönemi huysuzluğu olarak 1847 yılında Dr. Ernst F. Von Feuchtersleben tarafından tanımlanmıştır. 1931 yılında ise Amerikalı nörolog Dr. Robert Frank, adet öncesi dönemde başlayan ve adetin başlamasıyla sona eren durumu premenstrüel gerginlik olarak adlandırmıştır (Çobanoğlu, 2018).

Premenstrüel Sendromun Epidemiyolojisi

Kadınların yaklaşık %80'i, adet döngüsünün adet öncesi evresinde en az bir psikolojik veya fiziksel belirti göstermektedir. Ancak bu belirtiler genellikle günlük yaşamı bozacak düzeyde bir bozulmaya yol açmamaktadır (Hasdemir, 2020). Premenstrüel belirtilerin genellikle otuzlu yaşlarda başladığını savunan yaklaşımlar bulunmakla birlikte, yapılan araştırmalar bu belirtilerin ergenlik döneminde veya ilk adet sonrasında yaşamın herhangi bir döneminde ortaya çıkabildiğini göstermektedir.

Premenstrüel Sendromun görülme sıklığı kültür ve ülkelere göre değişiklik göstermektedir. Birçok ülkede kadınların adet dönemlerinde üzüntü, ağrı, gerginlik ve sinirlilik gibi semptomlar deneyimlediği bilinmektedir. Premenstrüel Sendroma yönelik tutum ise kültürel değerler, toplumsal yargılar, tutumlar ve davranışların bu dönemde yaşanan ağrının algılanmasını ve ağrıya verilen tepkiyi etkilediği görülmüştür (Başağaç, 2019).

Premenstrüel Sendromun Etiyolojisi

Tarihsel süreç içerisinde kadınların adet dönemi, kanın küresel çapta bir korku motifi olarak kabul edilmesi nedeniyle olumsuz bir şekilde algılanmıştır. Adet dönemindeki kadınlar, toplum tarafından kirli olarak görülmüş ve bu anlayış neticesinde toplumun dışına itilmişlerdir. Bu durum, toplumdaki bireylerin adet dönemini (menstrüasyonu) olumsuz olarak değerlendirmesine yol açmış ve kadınların bu dönemde toplum tarafından olumsuz tutumlara maruz kalmasına neden olmuştur (Aydınay, 2019).

Premenstrüel Sendromun Semptomları

Premenstrüel Sendrom, adet öncesi dönemle birlikte başlayan ve adet döneminin başlamasıyla sonlanan duygusal, davranışsal ve fizyolojik belirtilerle ortaya çıkan psikoneuroendokrin bir bozukluktur (Bayduman, 2022). Yapılan araştırmalarda, kadınların premenstrüel döneminde 300'den fazla semptom bildirilmiştir. Bu semptomlar arasında en göze çarpanlar duygusal ve davranışsal değişikliklerdir. Duygusal belirtiler, Freeman tarafından yapılan çalışmalar kapsamında PMS yaşayan kadınlarda orta ve şiddetli düzeyde yaygın bir durum olarak görülmekte olup, bu durumun PMS'nin bir bileşeni olabileceği düşünülmektedir (Boran, 2024).

Premenstrüel Sendromun Risk Faktörleri

Genetik Faktörler

PMS’in anneden kız çocuğuna geçme ihtimali yüksektir. Kız çocukları ikiz ise, PMS’in görülme olasılığı dizigot (çift yumurta) ikizlerinde tekiz (monozigot) ikizlere göre daha fazladır. Bu durum, PMS’de genetik faktörlerin önemli bir etken olduğunu göstermektedir (Erdoğan, 2021).

Yaş

PMS belirtileri genellikle 25-35 yaşları arasında başlamasıyla birlikte, ilk menstruasyondan sonra herhangi bir yaşta da görülebilir. PMS için 26 yaş ortama başlangıç yaşı olarak bildirilmiştir. Yaş ilerledikçe semptomlar artar, menopoza yaklaşırken azalır. Bunun yanı sıra, doğurganlık çağındaki kadınların %20'sinde günlük yaşamını etkileyebilecek düzeyde premenstrüel şikâyetlerinin olduğu bazı çalışmalarda bildirilmiştir. Öte yandan yaş ile PMS arasında anlamlı bir ilişki olmadığını 1995 yılında Chuong ve Burgos çalışmasında belirtilmiştir (Özkan, 2023).

Medeni Durum

Yapılan araştırmalarda kadınların medeni durumu ile PMS ilişkisinin olabileceği bazı çalışmalar mevcuttur. Mosho vd. (yaptığı araştırmada ise evli olan kadınların PMS sıklığının daha fazla olduğu öne sürülmüştür. Ancak diğer bazı çalışmalarda ise PMS ile medeni durum arasında anlamlı bir ilişki bulunmadığı ifade edilmiştir (Bayduman, 2022).

Sosyoekonomik Durum

Oğur'un (2004) yaptığı araştırmada, maddi durumun PMS semptomlarının kadınlarda artışıyla ilişkili olduğu rapor edilmiştir. Demir vd. (2006) araştırması da bu bulguyu desteklemiştir. Duygusal dalgalanmalar, sinirlilik hali, baş ağrısı, kilo alımı ve depresyon gibi belirtilere; yüksek eğitim düzeyi ve gelir artıkça daha az rastlandığı tespit edilmiştir. Wood vd. (1979) tarafından 2343 kadın üzerinde yapılan araştırmada ise kramp, kilo alımı ve depresyon gibi belirtilerin yüksek gelir ve eğitim artıkça daha sık rastlandığı belirtilmiştir.

Çalışma Durumu, Eğitim Düzeyi ve Çocuk Sayısı

Literatürde, Kadınların çalışma durumu, eğitim düzeyi ve çocuk sayısına göre PMS belirtilerinin farklılık gösterdiği bildirilmektedir. Woosd vd. (1982) yaptığı araştırmaya göre çalışan kadınların çalışmayan kadınlara göre daha az sıkıntı yaşadığı ancak iş performansın PMS şikayetlere etkili olduğu gözlemlenmiştir (Akt: Şekeroğlu, 2018). Bu kapsamda yapılan araştırmalar incelendiğinde, çalışan kadınlarda PMS'nin iş hayatına etkilerini ölçmek için yapılan bir araştırmada, 22–45 yaş arası 174 çalışan kadın üzerinde yapılan incelemede, kadınların %44,3'ü PMS'nin iş hayatına yansıdığını ve bunun kendilerini olumsuz etkilediğini belirtmişlerdir. Çalışırken dikkat güçlüğü yaşandığı, yorgunluk belirtileri ve enerji düşüklüğü gibi iş hayatını olumsuz yönde etkileyen belirtiler gözlemlenmiştir (Erdoğan, 2021). Çalışmayan kadınlarda, düşük eğitim düzeyi ile ilişkisine bakıldığında ise PMS belirtileri fazla olduğu gözlemlenen çalışmalar mevcuttur. Aynı zamanda literatürde yüksek eğitim düzeyindekilerde PMS belirtileri de yüksek çıktığı bildiren çalışmalarda bulunmaktadır (Önal, 2011). Kebapçılar vd. (2012) 997 kadın katılımcı üzerinde yürüttüğü araştırmada, çocuk sahibi olmayanlar ile bir çocuğu bulunanların yer aldığı 667 kişilik grupta PMS görülme oranı %36,7 olarak kaydedilmiştir. Buna karşılık, iki veya daha fazla çocuğu olan 330 kadından oluşan diğer grupta ise bu oran %17,1 düzeyinde bulunmuş ve aradaki farkın istatistiksel açıdan anlamlı olduğu rapor edilmiştir.

Beslenme

Beslenme alışkanlıkları PMS semptomlarında rol oynayabilmektedir. Yeme davranışları ve iştah durumu, adet döngüsüne bağlı hormonal değişimlerin etkisi doğrultusunda farklılaşabilmektedir. Özellikle bazı besinlerin (şeker, çikolata, kahve ve asitli içecekler) tüketiminin menstrüel döngü döneminde artış gösterdiği bildirilmektedir. Bazı besinlerdeki artış ya da azalışın PMS varlığı ile ilişkilendirildiği belirtilmektedir (Elmas, 2024).

Stres

Premenstrüel Sendromun etiyolojisinde stres önemli bir risk faktörü olarak değerlendirilmektedir. Yapılan araştırmalar, stres düzeyi yüksek olan kadınlarda PMS semptomlarının daha şiddetli olduğunu göstermektedir. Nandakumar vd. (2023) sağlık bilimleri öğrencileri üzerinde yaptığı çalışmada, PMS prevalansı %76,35 olarak bulunmuş ve PMS'li kadınlarda algılanan stres düzeyinin (PSS ortalaması 19,5±4,9) PMS olmayan kadınlara göre anlamlı derecede yüksek olduğu tespit edilmiştir. Benzer şekilde, Trivedi vd. (2024) 473 genç kadın üzerinde yaptığı çalışmada, katılımcıların %84,4'ünün orta düzeyde strese sahip olduğu ve yüksek stres düzeyi ile PMS şiddeti arasında anlamlı pozitif bir ilişki bulunduğu rapor edilmiştir.

Sigara, Alkol ve Kafein Alımı

Premenstrüel sendrom için tanımlanan risk faktörleri arasında sigara ve alkol kullanımı ile kafein tüketim miktarı yer almaktadır. Bu çerçevede yürütülen bir araştırmada, 19-49 yaş aralığındaki sigara kullanan kadınlarda PMS semptomlarının daha yoğun olduğu saptanmıştır (Bayduman, 2022). Buna karşın, Thys-Jacobs vd. (1998) tarafından gerçekleştirilen ve hem sigara hem de alkol kullanımının PMS ile ilişkisini inceleyen çalışmada, bu değişkenler ile PMS arasında anlamlı bir ilişki bulunmamıştır. Benzer şekilde, Kroll-Desrosiers vd. (2017) araştırmasında da alkol ve kafein alımının PMS üzerinde anlamlı bir etkisinin olmadığı sonucuna ulaşılmıştır. Kafein tüketimi ile PMS arasında bir ilişki bulunmadığını gösteren bir diğer çalışma, Demir vd. (2006) çay ve kahve tüketimi üzerine yaptığı araştırmadır. Bu çalışmada da çay ve kahve tüketiminin PMS semptomlarını etkilemediği belirlenmiştir.

Premenstrüel Sendromun Klinik Olarak Değerlendirilmesi

Premenstrüel Sendrom tanısı, spesifik bir biyobelirteç veya laboratuvar testinin bulunmaması nedeniyle, büyük ölçüde kapsamlı bir klinik değerlendirmeye ve semptomların adet döngüsü ile ilişkisinin prospektif olarak izlenmesine dayanmaktadır (Freeman, 2003). Değerlendirme sürecinin ilk ve kritik aşaması, benzer klinik tablolara yol açabilen altta yatan organik patolojilerin dışlanmasıdır. Bu bağlamda, ayrıntılı bir jinekolojik muayene ve uygun laboratuvar tetkikleri büyük önem taşır (O'Brien vd., 2007). Özellikle anemi ve tiroid fonksiyon bozuklukları, PMS ile yüksek oranda örtüşen semptomlara (yorgunluk, halsizlik, irritabilite, duygudurum dalgalanmaları, menstrual düzensizlikler) neden olabilmektedir (Gudipally ve Sharma, 2023). Tiroid bezi patolojilerinde, özellikle hipotiroidizmde, irritabilite ve halsizlik gibi şikayetler sıklıkla gözlenir. Bu nedenle, klinik şüphe varlığında veya semptomların tipik olmadığı durumlarda mutlaka tiroid fonksiyon testleri (TSH, serbest T3, serbest T4) incelenmelidir (Kaya, 2021). Bunun yanı sıra, hiperprolaktinemi gibi endokrin bozukluklar da benzer semptomlara yol açabileceğinden, klinik gereklilik halinde prolaktin düzeyi analizi de değerlendirme sürecine dahil edilmelidir. Bu ayırıcı tanı basamağı, gereksiz tedavilerin önlenmesi ve altta yatan ciddi bir hastalığın gözden kaçırılmaması açısından hayati öneme sahiptir (Pearlstein ve Steiner, 2008).

Premenstrüel Sendromun Tedavi Süreci

Premenstrüel sendromun etiyolojisi tam olarak aydınlatılamamış olup, bu durum çok sayıda risk etkeninin etkisi altında şekillenmektedir. Bu nedenle PMS için tek ve kesin bir iyileştirme yönteminden söz etmek mümkün değildir. Uygulanan tedavilerin temel hedefi, günlük işleyişin aksamasına bağlı olarak kişinin aile içi ve toplumsal bağlarında ortaya çıkan olumsuzlukları en aza indirgemek ve bireyin olağan yaşamını sürdürebilmesine olanak tanımaktır. PMS belirtileri hafif ya da orta şiddet derecesinde ise, non-farmakolojik yöntemler, yani yaşam tarzı ve beslenme düzenine dikkat edilmesi önceliklidir. Ancak semptomların şiddeti artıp bireyin günlük yaşamını etkileyecek düzeye geldiğinde, farmakolojik tedavi seçeneği uygulanabilir (Yakıcı, 2025).

Anksiyete

Anksiyetenin Tanımı ve Tarihçesi

Korku ve anksiyete, insan davranışının evrimsel ve yapısal temel taşlarındandır. Tehlike karşısında bu duygular, hayatta kalma, mücadele etme ve kaçma gibi bireyin hayati işlevlerini yerine getirmesine olanak sağlar. Anksiyetenin ortaya çıkması için mutlak bir tehlike durumunun varlığı şart olmayıp, bir tehdit algısıyla da tetiklenebilmektedir (Steimer, 2022). Bu tetiklenmeler sağlıklı bir şekilde kontrol altına alındığında, insanın hayatta kalmasını ve çevresine uyum göstermesini kolaylaştırır. Bu bağlamda kaygı her zaman olumsuz bir duygu durumu değildir; bazı durumlarda bireyi hayatta tutan sağlıklı bir tepki olarak değerlendirilmektedir (Yetkin, 2024).

Anksiyetenin Epidemiyolojisi

Geniş kapsamlı araştırmalarda, anksiyete bozukluklarının yaşam boyu görülme oranının yaklaşık %33,7 olduğu saptanmıştır. Yıllık yaygınlığı ise %17,7 olarak bildirilmiş olup, kadınlarda daha sık görüldüğü ve sosyoekonomik düzey ile yaş faktörüyle ters yönlü bir ilişki içinde olduğu belirtilmektedir. En yaygın olarak 25-44 yaş aralığında görülürken, 65 yaş ve üzeri bireylerde en düşük görülme oranı kaydedilmiştir (Terlizzi ve Villarroel, 2020). Genellikle kronik ve dirençli bir seyir izleyen anksiyete

bozuklukları, sıklıkla diğer anksiyete bozuklukları, depresyon ve madde kullanım bozukluklarıyla birlikte ortaya çıkmaktadır (Uyanık, 2024). DSM-5 sınıflamasında yer alan anksiyete bozukluklarının genel yaygınlık ortalaması %6-7 düzeyinde seyretmektedir. Genel istatistikler incelendiğinde, her yaştan bireyin yaşam süresi boyunca anksiyete bozukluğu ile karşılaşma olasılığı yaklaşık %25 olarak bildirilmiştir (Kütükoğlu, 2024).

Anksiyetenin Etiyolojisi

Anksiyete bozukluklarının etiyolojisi, genetik, nörobiyolojik, çevresel ve psikolojik faktörlerin karmaşık bir etkileşimini içermektedir. Genetik faktörlerin anksiyete gelişiminde önemli bir rol oynadığına dair güçlü kanıtlar bulunmaktadır. İkiz çalışmaları, anksiyete bozukluklarındaki varyansın yaklaşık %50'sinin genetik faktörlere atfedilebileceğini göstermektedir (Haddad, 2018). Yaygın anksiyete bozukluğu için genetik kalıtılabilirlik oranı yaklaşık %30 olarak bildirilmiştir (Milne ve Munro, 2020). Genome-wide association çalışmaları, anksiyete ile ilişkili beş yeni gen bölgesi tanımlamış olup, bunlar arasında nörotisizm ile ilişkili kromozom 5 ve 9 üzerindeki bölgeler ile PDE4B genindeki varyantlar yer almaktadır (Qin, 2023).

Anksiyetenin Risk Faktörleri

Anksiyete bozukluklarının ortaya çıkmasında çeşitli sosyodemografik, psikososyal, genetik ve çevresel risk faktörleri rol oynamaktadır. Epidemiyolojik çalışmalar, kadın cinsiyetin anksiyete bozuklukları için en tutarlı risk faktörlerinden biri olduğunu göstermektedir. Kadınlarda anksiyete bozukluklarının görülme sıklığı erkeklere göre yaklaşık iki kat daha fazladır ve bu durum yaşam boyu devam etmektedir (Moreno-Peral vd., 2014). Yaş faktörü incelendiğinde, 30-54 yaş aralığının yaygın anksiyete bozukluğu için, 20-54 yaş aralığının ise panik bozukluk için riskli dönemler olduğu bildirilmiştir. Düşük sosyoekonomik düzey ve yetersiz maddi kaynaklar da her iki bozukluk için risk faktörleri arasında yer almaktadır. Evlilik durumu açısından, boşanmış veya dul olan bireylerde yaygın anksiyete bozukluğu görülme riskinin daha yüksek olduğu bulunmuştur (Moreno-Peral vd., 2014).

Anksiyete Bozukluklarının Sınıflandırılması ve Tedavi Yöntemleri

Anksiyete bozuklukları DSM-5'te kapsamlı bir şekilde sınıflandırılmıştır. Bu sınıflandırma sistemi dâhilinde, panik bozukluğu, yaygın anksiyete bozukluğu, agorafobi, özgül fobi, ayrılık anksiyetesi bozukluğu, sosyal anksiyete bozukluğu, seçici konuşmazlık (selektif mutizm), bir ilaç ya da maddeye bağlı gelişen anksiyete bozukluğu, başka bir tıbbi duruma ikincil olarak ortaya çıkan anksiyete bozukluğu, tanımlanmış diğer anksiyete bozuklukları ve tanımlanmamış anksiyete bozukluğu olmak üzere toplam on bir ayrı kategori altında ele alınmaktadır (APA, 2013). Bu sınıflandırma ile birlikte, daha önce sadece çocukluk ve ergenlik dönemi ile ilişkilendirilen ayrılma anksiyetesi bozukluğu ve seçici konuşmazlık da yetişkin anksiyete bozuklukları arasında yerini almıştır (Ströhle vd., 2018).

BÖLÜM III

Yöntem

Araştırmanın Modeli

Bu araştırmada, Türkiye'de 18-55 yaş aralığında bulunan çalışan ve çalışmayan kadınlarda premenstrüel sendrom ile anksiyete düzeyleri arasındaki ilişkinin incelenmesi amaçlanmaktadır. Bu amaç doğrultusunda nicel araştırma yöntemlerinden nedensel karşılaştırma modeli kullanılmıştır. Nedensel karşılaştırma modeli, bir olay ya da değişkenin bir diğeri üzerindeki etkisini veya neden-sonuç ilişkisini, araştırmacının herhangi bir müdahalesi olmaksızın incelemeyi amaçlayan bir araştırma desenidir (Karasar, 2015). Bu tür araştırmalarda, ilgilenilen durum bir eylem ya da olay gerçekleştikten sonra ele alınır ve bağımsız ve bağımlı değişkenler arasındaki ilişkiler, herhangi bir deneysel manipülasyona gidilmeden gözlemlenmeye çalışılır. Araştırmacının temel amacı, iki ya da daha fazla grubu karşılaştırarak bağımsız değişkenin bağımlı değişken üzerinde anlamlı bir etkisinin olup olmadığını tespit etmektir. Başka bir ifadeyle, araştırmaya konu olan durum doğal koşullar altında ortaya çıkmıştır ve araştırmacı bu durumu yalnızca var olan hâliyle ele alarak, söz konusu durumun hangi değişkenlerden etkilendiğini ve olası nedenlerini belirlemeye çalışır (Cohen ve Manion, 1994; Büyüköztürk vd., 2008).

Evren ve Örneklem

Bu araştırmanın evrenini Türkiye'de yaşayan, 18–55 yaş aralığındaki çalışan ve çalışmayan kadınlar oluşturmuştur. Bu yaş aralığının tercih edilmesinde, 18 yaşın yasal yetişkinlik döneminin başlangıcını temsil etmesi, 55 yaşın ise kadınlarda menopozun ortalama olarak tamamlandığı ve üreme hormonlarındaki değişimlerin biyolojik, psikolojik ve sosyal açıdan önemli farklılıklara yol açtığı bir dönem olarak kabul edilmesi etkili olmuştur (McKinlay, 1996; Thurston vd., 2025). Bu bağlamda, 18-55 yaş aralığı, kadınların üreme döneminin başlangıcından menopoz sonrası döneme kadar olan süreci kapsaması nedeniyle, çalışan ve çalışmayan kadınların yaşam deneyimlerini karşılaştırmak için anlamlı ve kapsayıcı bir çerçeve sunmaktadır.

Araştırma evreninin tamamına ulaşmanın zaman, maliyet ve uygulama güçlükleri nedeniyle mümkün olmaması sebebiyle örneklem alma yoluna gidilmiştir. Araştırmada, çalışan ve çalışmayan kadınların belirli demografik özellikler bakımından dengeli bir biçimde temsil edilmesini sağlamak amacıyla kota örnekleme yöntemi tercih edilmiştir. Kota örnekleme, araştırma evrenini temsil ettiği düşünülen alt grupların belirlenmesi ve her bir gruptan önceden belirlenen sayıda katılımcıya ulaşılması esasına dayanan bir örnekleme yöntemidir (Yağar ve Dökme, 2018).

Çalışmanın örneklemi belirlenirken katılımcılar çalışma durumu (çalışan/çalışmayan), yaş grubu (18–25, 26–35, 36–45 ve 46–55 yaş) ve eğitim düzeyi değişkenleri dikkate alınarak alt gruplara ayrılmış, her grup için belirlenen kota sayısına ulaşılmaya çalışılmıştır. Böylece örneklemin farklı yaş, eğitim ve çalışma özelliklerine sahip kadınları içermesi hedeflenmiştir.

Araştırma verileri çevrimiçi anket yöntemiyle toplanmıştır. Veri toplama aracı dijital ortamda hazırlanmış ve katılımcılara sosyal medya platformları, kadın dayanışma grupları, mesleki topluluklar ve çeşitli çevrimiçi ağlar aracılığıyla ulaştırılmıştır. Veri toplama sürecinde farklı sosyoekonomik düzeylerden, yaş gruplarından ve eğitim düzeylerinden kadınların araştırmaya katılım göstermesine özen gösterilmiştir. Bu yaklaşım, örneklem çeşitliliğinin artırılmasına ve araştırma bulgularının farklı kadın gruplarını yansıtmasına katkı sağlamıştır.

Araştırmaya katılan bireylere anketin başlangıcında araştırmanın amacı, kapsamı ve gönüllülük esasları hakkında bilgi verilmiş, yalnızca araştırmaya katılmayı kabul eden bireylerden veri toplanmıştır. Katılımcılardan elde edilen bilgiler gizlilik ve anonimlik ilkeleri çerçevesinde değerlendirilmiştir.

Araştırma evreninde yer alan çalışan ve çalışmayan kadınların sayısı kesin olarak bilinmediğinden örneklem büyüklüğünün belirlenmesinde evreni bilinmeyen örneklem formülünden yararlanılmıştır. %95 güven düzeyi ve %5 örnekleme hatası esas alınarak her grup için en az 384 katılımcıya ulaşılması hedeflenmiştir. Bu doğrultuda araştırmada 379 çalışan ve 381 çalışmayan kadın olmak üzere toplam 760 katılımcı yer almıştır.

BÖLÜM IV

BULGULAR

Tablo 1.

Çalışan ve Çalışmayan Kadınların Sosyodemografik Özelliklerinin Dağılımı

	Çalışan		Çalışmayan		X^2	p
	n	%	n	%		
Yaş ($\bar{x}$±s)	31,52±7,53		32,36±11,76		-1,179	0,239
Medeni durum						
Bekar	224	59,10	190	49,87		
Evli	142	37,47	171	44,88	6,959	0,031*
Boşanmış	13	3,43	20	5,25		
Eğitim durumu						
İlköğretim	25	6,60	52	13,65	73,002	0,000*

Lise	51	13,46	83	21,78		
Üniversite	271	71,50	158	41,47		
Lisansüstü	32	8,44	88	23,10		
Annenin eğitim durumu						
Diplomasız	46	12,14	85	22,31		
İlkokul	148	39,05	136	35,70		
Ortaokul	35	9,23	59	15,49	32,143	0,000*
Lise	115	30,34	65	17,06		
Lisans ve üstü	35	9,23	36	9,45		
Babanın eğitim durumu						
Diplomasız	0	0,00	15	3,94		
İlkokul	75	19,79	66	17,32		
Ortaokul	34	8,97	47	12,34	26,500	0,000*
Lise	187	49,34	203	53,28		
Lisans ve üstü	83	21,90	50	13,12		

**p<0,05*

Tablo 3'te çalışan ve çalışmayan kadınların sosyodemografik özelliklerine göre dağılımı verilmiştir.

Araştırmada yer alan çalışan kadınların yaş ortalamasının 31,52 ± 7,53, çalışmayan kadınların yaş ortalamasının ise 32,36 ± 11,76 olduğu görülmüştür. Kadınların çalışma durumuna göre yaş ortalamaları arasında istatistiksel olarak anlamlı bir fark olmadığı saptanmıştır (p>0,05).

Çalışan kadınların %59,10'unun bekar, %37,47'sinin evli ve %3,43'ünün boşanmış olduğu; çalışmayan kadınların ise %49,87'sinin bekar, %44,88'inin evli ve %5,25'inin boşanmış olduğu görülmüştür. Kadınların çalışma durumuna göre medeni durumları arasında istatistiksel olarak anlamlı fark olduğu saptanmıştır (p<0,05). Çalışan kadınların bekar olma oranı, çalışmayan kadınlara göre daha yüksek bulunmuştur.

Çalışan kadınların %6,60'ının ilköğretim, %13,46'sının lise, %71,50'sinin üniversite ve %8,44'ünün lisansüstü mezunu olduğu; çalışmayan kadınların ise %13,65'inin ilköğretim, %21,78'inin lise, %41,47'sinin üniversite ve %23,10'unun lisansüstü mezunu olduğu belirlenmiştir. Kadınların çalışma durumuna göre eğitim düzeyleri arasında istatistiksel olarak anlamlı fark olduğu saptanmıştır (p<0,05). Üniversite mezunu olma oranının çalışan kadınlarda, lisansüstü mezuniyet oranının ise çalışmayan kadınlarda daha yüksek olduğu görülmüştür.

Araştırma kapsamındaki çalışan kadınların annelerinin %12,14'ünün diplomasız, %39,05'inin ilkokul, %9,23'ünün ortaokul, %30,34'ünün lise ve %9,23'ünün lisans ve üstü mezunu olduğu; çalışmayan kadınların annelerinin ise %22,31'inin diplomasız, %35,70'inin ilkokul, %15,49'unun ortaokul, %17,06'sının lise ve %9,45'inin lisans ve üstü mezunu olduğu saptanmıştır. Kadınların çalışma durumuna göre annelerinin eğitim düzeyleri arasında istatistiksel olarak anlamlı fark olduğu belirlenmiştir (p<0,05). Diplomasız anne oranının çalışmayan kadınlarda daha yüksek olduğu görülmüştür.

Çalışan kadınların babalarının %19,79'unun ilkokul, %8,97'sinin ortaokul, %49,34'ünün lise ve %21,90'ının lisans ve üstü mezunu olduğu; çalışmayan kadınların babalarının ise %3,94'ünün diplomasız, %17,32'sinin ilkokul, %12,34'ünün ortaokul, %53,28'inin lise ve %13,12'sinin lisans ve üstü mezunu olduğu belirlenmiştir. Kadınların çalışma durumuna göre babalarının eğitim düzeyleri arasında istatistiksel olarak anlamlı fark olduğu saptanmıştır (p<0,05). Lisans ve üstü mezun babaya sahip olma oranının çalışan kadınlarda daha yüksek olduğu görülmüştür.

Tablo 2.

Çalışan ve Çalışmayan Kadınların Adet ve Doğum Yapma Durumlarının Dağılımı

	Çalışan		Çalışmayan		X^2	p
	n	%	n	%		
İlk adet görme yaşı						
12 yaş ve altı	72	19,00	116	30,45		
13 - 14 yaş	230	60,69	233	61,15	28,890	0,000*
15 yaş ve üzeri	77	20,32	32	8,40		
Adet durumu						
Düzenli	314	82,85	253	66,40		
Düzensiz	54	14,25	87	22,83	31,589	0,000*
Menapoz	11	2,90	41	10,76		
Ortalama adet süresi						
1-3 gün	16	4,22	32	8,40		
4-5 gün	211	55,67	168	44,09	26,691	0,000*
6-7 gün	117	30,87	166	43,57		
8 gün ve üzeri	35	9,23	15	3,94		
Adet öncesi/sırasında ağrı kesici kullanımı						
Evet	85	22,43	82	21,52		
Ara sıra	153	40,37	116	30,45	10,582	0,005*
Hayır	141	37,20	183	48,03		
Doğum yapma durumu						
Evet	105	27,70	130	34,12	3,662	0,056
Hayır	274	72,30	251	65,88		
Doğum sayısı (n1=103, n2=130)						
Bir	60	58,25	57	43,85		
İki	34	33,01	29	22,31	20,737	0,000*
Üç ve üstü	9	8,74	44	33,85		
Doğum yöntemi (n1=103, n2=130)						
Normal	25	24,27	110	84,62	85,869	0,000*
Sezaryen	78	75,73	20	15,38		

**p<0,05*

Tablo 4'te araştırma kapsamına alınan çalışan ve çalışmayan kadınların adet ve doğum yapma durumlarının dağılımı incelenmiştir.

Araştırmada yer alan çalışan kadınların %19,00'unun 12 yaş ve altında, %60,69'unun 13–14 yaş arasında ve %20,32'sinin 15 yaş ve üzerinde ilk adet gördüğü; çalışmayan kadınların ise %30,45'inin 12 yaş ve altında, %61,15'inin 13–14 yaş arasında ve %8,40'ının 15 yaş ve üzerinde ilk adet gördüğü görülmüştür. Kadınların çalışma durumuna göre ilk adet görme yaşları arasında istatistiksel olarak anlamlı fark olduğu saptanmıştır ($p<0,05$). Çalışmayan kadınların 12 yaş ve altında ilk adet görme oranı, çalışan kadınlara göre daha yüksek bulunmuştur.

Çalışan kadınların %82,85'inin düzenli, %14,25'inin düzensiz adet gördüğü ve %2,90'ının menopozda olduğu; çalışmayan kadınların ise %66,40'ının düzenli, %22,83'ünün düzensiz adet gördüğü ve %10,76'sının menopozda olduğu belirlenmiştir. Kadınların çalışma durumuna göre adet durumu

arasında istatistiksel olarak anlamlı fark olduğu saptanmıştır (p<0,05). Düzenli adet görme oranının çalışan kadınlarda daha yüksek olduğu görülmüştür.

Çalışan kadınların %4,22'sinin 1–3 gün, %55,67'sinin 4–5 gün, %30,87'sinin 6–7 gün ve %9,23'ünün 8 gün ve üzeri süreyle adet gördüğü; çalışmayan kadınların ise %8,40'ının 1–3 gün, %44,09'unun 4–5 gün, %43,57'sinin 6–7 gün ve %3,94'ünün 8 gün ve üzeri süreyle adet gördüğü saptanmıştır. Kadınların çalışma durumuna göre ortalama adet süresi arasında istatistiksel olarak anlamlı fark olduğu belirlenmiştir (p<0,05). Çalışmayan kadınlarda 6–7 gün süren adet görme oranı daha yüksek bulunmuştur.

Çalışan kadınların %22,43'ünün adet öncesi veya sırasında ağrı kesici kullandığı, %40,37'sinin ara sıra kullandığı ve %37,20'sinin kullanmadığı; çalışmayan kadınların ise %21,52'sinin kullandığı, %30,45'inin ara sıra kullandığı ve %48,03'ünün kullanmadığı görülmüştür. Kadınların çalışma durumuna göre adet öncesi veya sırasında ağrı kesici kullanımı arasında istatistiksel olarak anlamlı fark olduğu saptanmıştır (p<0,05). Ara sıra ağrı kesici kullanma oranı çalışan kadınlarda daha yüksek bulunmuştur.

Araştırmada yer alan çalışan kadınların %27,70'inin doğum yaptığı, %72,30'unun doğum yapmadığı; çalışmayan kadınların ise %34,12'sinin doğum yaptığı, %65,88'inin doğum yapmadığı belirlenmiştir. Kadınların çalışma durumuna göre doğum yapma durumu arasında istatistiksel olarak anlamlı bir fark olmadığı saptanmıştır (p>0,05).

Doğum yapan çalışan kadınların %58,25'inin bir, %33,01'inin iki ve %8,74'ünün üç ve üzeri doğum yaptığı; çalışmayan kadınların ise %43,85'inin bir, %22,31'inin iki ve %33,85'inin üç ve üzeri doğum yaptığı görülmüştür. Kadınların çalışma durumuna göre doğum sayıları arasında istatistiksel olarak anlamlı fark olduğu belirlenmiştir (p<0,05). Üç ve üzeri doğum yapma oranı çalışmayan kadınlarda daha yüksek bulunmuştur.

Araştırma kapsamına alınan çalışan kadınların %24,27'sinin normal doğum, %75,73'ünün sezaryen doğum yaptığı; çalışmayan kadınların ise %84,62'sinin normal doğum, %15,38'inin sezaryen doğum yaptığı belirlenmiştir. Kadınların çalışma durumuna göre doğum yöntemi arasında istatistiksel olarak anlamlı fark olduğu saptanmıştır (p<0,05). Normal doğum yapma oranı çalışmayan kadınlarda, sezaryen doğum yapma oranı ise çalışan kadınlarda daha yüksek bulunmuştur.

Tablo 3.

Çalışan ve Çalışmayan Kadınların Psikiyatrik Öykü, Şekerli Gıda Tüketimi ve Egzersiz Yapma Durumlarının Dağılımı

	Çalışan		**Çalışmayan**		**X^2**	**p**
	n	**%**	**n**	**%**		
Psikiyatrik tanı öyküsü						
Evet	54	14,25	102	26,77	18,267	0,000*
Hayır	325	85,75	279	73,23		
Psikolojik destek alma durumu						
Evet	42	11,08	27	7,09	3,674	0,055
Hayır	337	88,92	354	92,91		
Psikiyatrik/hormonal ilaç kullanımı						
Evet	19	5,01	49	12,86	14,363	0,000*
Hayır	360	94,99	332	87,14		
Adet öncesi dönemde psikolojik sorun yaşama durumu						
Evet	213	56,20	239	62,73	3,360	0,067
Hayır	166	43,80	142	37,27		
Öfke kontrolü zorluğunun						

en sık yaşandığı dönem						
Adet öncesi	223	58,84	338	88,71	90,714	0,000*
Adetliyken	116	30,61	28	7,35		
Adet sonrası	6	1,58	0	0,00		
Hiçbir zaman	34	8,97	15	3,94		
Şekerli gıda tüketim durumu						
Evet	341	89,97	348	91,34	0,418	0,518
Hayır	38	10,03	33	8,66		
Egzersiz yapma durumu						
Evet	167	44,06	127	33,33	9,222	0,002*
Hayır	212	55,94	254	66,67		

**p<0,05*

Çalışan ve çalışmayan kadınların psikiyatrik öykü, şekerli gıda tüketimi ve egzersiz yapma durumlarının dağılımı Tablo 5'te gösterilmiştir.

Tablo 5 incelendiğinde çalışan kadınların %14,25'inin psikiyatrik tanı öyküsünün olduğu, %85,75'inin ise psikiyatrik tanı öyküsünün olmadığı; çalışmayan kadınların ise %26,77'sinin psikiyatrik tanı öyküsünün olduğu, %73,23'ünün olmadığı görülmüştür. Kadınların çalışma durumuna göre psikiyatrik tanı öyküsü açısından istatistiksel olarak anlamlı fark olduğu saptanmıştır (p<0,05). Psikiyatrik tanı öyküsüne sahip olma oranı çalışmayan kadınlarda daha yüksek bulunmuştur.

Çalışan kadınların %11,08'inin psikolojik destek aldığı, %88,92'sinin psikolojik destek almadığı; çalışmayan kadınların ise %7,09'unun psikolojik destek aldığı, %92,91'inin psikolojik destek almadığı belirlenmiştir. Kadınların çalışma durumuna göre psikolojik destek alma durumu arasında istatistiksel olarak anlamlı bir fark olmadığı görülmüştür (p>0,05).

Araştırmada yer alan çalışan kadınların %5,01'inin psikiyatrik veya hormonal ilaç kullandığı, %94,99'unun kullanmadığı; çalışmayan kadınların ise %12,86'sının psikiyatrik veya hormonal ilaç kullandığı, %87,14'ünün kullanmadığı saptanmıştır. Kadınların çalışma durumuna göre psikiyatrik/hormonal ilaç kullanımı açısından istatistiksel olarak anlamlı fark olduğu belirlenmiştir (p<0,05). Psikiyatrik veya hormonal ilaç kullanma oranı çalışmayan kadınlarda daha yüksek bulunmuştur.

Araştırma kapsamındaki çalışan kadınların %56,20'sinin adet öncesi dönemde psikolojik sorun yaşadığı, %43,80'inin yaşamadığı; çalışmayan kadınların ise %62,73'ünün adet öncesi dönemde psikolojik sorun yaşadığı, %37,27'sinin yaşamadığı görülmüştür. Kadınların çalışma durumuna göre adet öncesi dönemde psikolojik sorun yaşama durumu arasında istatistiksel olarak anlamlı bir fark olmadığı saptanmıştır (p>0,05).

Öfke kontrolü zorluğunun en sık yaşandığı dönem incelendiğinde, çalışan kadınların %58,84'ünün adet öncesi, %30,61'inin adetliyken, %1,58'inin adet sonrası ve %8,97'sinin hiçbir zaman yanıtını verdiği; çalışmayan kadınların ise %88,71'inin adet öncesi, %7,35'inin adetliyken ve %3,94'ünün hiçbir zaman yanıtını verdiği belirlenmiştir. Kadınların çalışma durumuna göre öfke kontrolü zorluğunun en sık yaşandığı dönem açısından istatistiksel olarak anlamlı fark olduğu saptanmıştır (p<0,05). Adet öncesi dönemde öfke kontrolü zorluğu yaşama oranı çalışmayan kadınlarda daha yüksek bulunmuştur.

Araştırmada yer alan çalışan kadınların %89,97'sinin şekerli gıda tükettiği, %10,03'ünün tüketmediği; çalışmayan kadınların ise %91,34'ünün şekerli gıda tükettiği, %8,66'sının tüketmediği görülmüştür. Kadınların çalışma durumuna göre şekerli gıda tüketimi açısından istatistiksel olarak anlamlı bir fark olmadığı belirlenmiştir (p>0,05).

Çalışan kadınların %44,06'sının egzersiz yaptığı, %55,94'ünün egzersiz yapmadığı; çalışmayan kadınların ise %33,33'ünün egzersiz yaptığı, %66,67'sinin egzersiz yapmadığı saptanmıştır. Kadınların

çalışma durumuna göre egzersiz yapma durumu arasında istatistiksel olarak anlamlı fark olduğu belirlenmiştir (p<0,05). Egzersiz yapma oranı çalışan kadınlarda daha yüksek bulunmuştur.

Tablo 4.

Çalışan ve Çalışmayan Kadınların Premenstrüel Sendrom Ölçeği Puanlarının Karşılaştırılması

	Çalışma durumu	**n**	$\bar{x}$	**s**	**t**	**p**
Depresif Duygulanım	Çalışan	379	21,79	7,79	1,965	0,049*
	Çalışmayan	381	20,88	4,61		
Anksiyete	Çalışan	379	15,75	6,45	1,741	0,082
	Çalışmayan	381	14,97	5,90		
Yorgunlu	Çalışan	379	15,75	6,45	1,741	0,082
	Çalışmayan	381	14,97	5,90		
Sinirlilik	Çalışan	379	15,84	5,73	4,248	0,000*
	Çalışmayan	381	14,21	4,81		
Depresif düşünceler	Çalışan	379	18,01	7,94	2,337	0,020*
	Çalışmayan	381	16,78	6,45		
Ağrı	Çalışan	379	8,92	3,35	-2,279	0,023*
	Çalışmayan	381	9,42	2,75		
İştah değişimleri	Çalışan	379	9,54	3,84	-0,697	0,486
	Çalışmayan	381	9,70	2,31		
Uyku değişimleri	Çalışan	379	8,26	3,09	-5,145	0,000*
	Çalışmayan	381	9,46	3,34		
Şişkinlik	Çalışan	379	10,51	3,57	4,024	0,000*
	Çalışmayan	381	9,61	2,51		
Premenstrüel Sendrom Ölçeği	Çalışan	379	128,07	41,86	1,868	0,062
	Çalışmayan	381	123,37	25,63		

**p<0,05*

Tablo 6'da araştırma kapsamına alınan çalışan ve çalışmayan kadınların Premenstrüel Sendrom Ölçeği puanlarının karşılaştırılmasında kullanılan t testi sonuçları gösterilmiştir.

Araştırmada yer alan çalışan kadınların Depresif Duygulanım alt boyutu puan ortalamasının 21,79 ± 7,79, çalışmayan kadınların ise 20,88 ± 4,61 olduğu görülmüştür. Kadınların çalışma durumuna göre Depresif Duygulanım alt boyutu puanları arasında istatistiksel olarak anlamlı fark olduğu saptanmıştır (p<0,05). Depresif Duygulanım puanlarının çalışan kadınlarda daha yüksek olduğu belirlenmiştir.

Çalışan kadınların Anksiyete alt boyutu puan ortalamasının 15,75 ± 6,45, çalışmayan kadınların puan ortalamasının ise 14,97 ± 5,90 olduğu belirlenmiştir. Kadınların çalışma durumuna göre Anksiyete alt boyutu puanları arasında istatistiksel olarak anlamlı bir fark olmadığı görülmüştür (p>0,05).

Çalışan kadınların Yorgunluk alt boyutu puan ortalamasının 15,75 ± 6,45, çalışmayan kadınların ise 14,97 ± 5,90 olduğu saptanmıştır. Kadınların çalışma durumuna göre Yorgunluk alt boyutu puanları arasında istatistiksel olarak anlamlı bir fark olmadığı belirlenmiştir (p>0,05).

Çalışan kadınların Sinirlilik alt boyutu puan ortalamasının 15,84 ± 5,73, çalışmayan kadınların puan ortalamasının ise 14,21 ± 4,81 olduğu görülmüştür. Kadınların çalışma durumuna göre Sinirlilik alt boyutu puanları arasında istatistiksel olarak anlamlı fark olduğu saptanmıştır (p<0,05). Sinirlilik puanlarının çalışan kadınlarda daha yüksek olduğu belirlenmiştir.

Araştırma kapsamına alınan çalışan kadınların Depresif Düşünceler alt boyutu puan ortalamasının 18,01 ± 7,94, çalışmayan kadınların ise 16,78 ± 6,45 olduğu belirlenmiştir. Kadınların çalışma durumuna göre Depresif Düşünceler alt boyutu puanları arasında istatistiksel olarak anlamlı fark olduğu saptanmıştır (p<0,05). Depresif Düşünceler puanlarının çalışan kadınlarda daha yüksek olduğu görülmüştür.

Çalışan kadınların Ağrı alt boyutu puan ortalamasının 8,92 ± 3,35, çalışmayan kadınların puan ortalamasının ise 9,42 ± 2,75 olduğu saptanmıştır. Kadınların çalışma durumuna göre Ağrı alt boyutu puanları arasında istatistiksel olarak anlamlı fark olduğu belirlenmiştir (p<0,05). Ağrı puanlarının çalışmayan kadınlarda daha yüksek olduğu görülmüştür.

Araştırmada yer alan çalışan kadınların İştah Değişimleri alt boyutu puan ortalamasının 9,54 ± 3,84, çalışmayan kadınların ise 9,70 ± 2,31 olduğu belirlenmiştir. Kadınların çalışma durumuna göre İştah Değişimleri alt boyutu puanları arasında istatistiksel olarak anlamlı bir fark olmadığı saptanmıştır (p>0,05).

Çalışan kadınların Uyku Değişimleri alt boyutu puan ortalamasının 8,26 ± 3,09, çalışmayan kadınların puan ortalamasının ise 9,46 ± 3,34 olduğu görülmüştür. Kadınların çalışma durumuna göre Uyku Değişimleri alt boyutu puanları arasında istatistiksel olarak anlamlı fark olduğu belirlenmiştir (p<0,05). Uyku Değişimleri puanlarının çalışmayan kadınlarda daha yüksek olduğu saptanmıştır.

Çalışan kadınların Şişkinlik alt boyutu puan ortalamasının 10,51 ± 3,57, çalışmayan kadınların ise 9,61 ± 2,51 olduğu belirlenmiştir. Kadınların çalışma durumuna göre Şişkinlik alt boyutu puanları arasında istatistiksel olarak anlamlı fark olduğu saptanmıştır (p<0,05). Şişkinlik puanlarının çalışan kadınlarda daha yüksek olduğu görülmüştür.

Çalışan kadınların Premenstrüel Sendrom Ölçeği toplam puan ortalamasının 128,07 ± 41,86, çalışmayan kadınların ise 123,37 ± 25,63 olduğu saptanmıştır. Kadınların çalışma durumuna göre Premenstrüel Sendrom Ölçeği toplam puanları arasında istatistiksel olarak anlamlı bir fark olmadığı belirlenmiştir (p>0,05).

Tablo 5.

Çalışan ve Çalışmayan Kadınların Beck Anksiyete Envanteri Puanlarının Karşılaştırılması

	Çalışma durumu	**n**	$\bar{x}$	**s**	**t**	**p**
Subjektif Kaygı	Çalışan	379	7,79	6,87	3,265	0,001*
	Çalışmayan	381	6,46	3,99		
Somatik Semptomlar	Çalışan	379	5,45	4,82	-0,953	0,341
	Çalışmayan	381	5,72	2,94		
Beck Anksiyete Envanteri	Çalışan	379	13,24	11,24	1,627	0,104
	Çalışmayan	381	12,18	5,77		

**p<0,05*

Tablo 7'de araştırmadaki çalışan ve çalışmayan kadınların Beck Anksiyete Envanteri puanlarının karşılaştırılmasında kullanılan t testi sonuçları verilmiştir.

Araştırma kapsamına alınan çalışan kadınların Subjektif Kaygı alt boyutu puan ortalamasının 7,79 ± 6,87, çalışmayan kadınların ise 6,46 ± 3,99 olduğu görülmüştür. Kadınların çalışma durumuna göre Subjektif Kaygı alt boyutu puanları arasında istatistiksel olarak anlamlı fark olduğu saptanmıştır (p<0,05). Subjektif Kaygı puanlarının çalışan kadınlarda daha yüksek olduğu belirlenmiştir.

Çalışan kadınların Somatik Semptomlar alt boyutu puan ortalamasının 5,45 ± 4,82, çalışmayan kadınların puan ortalamasının ise 5,72 ± 2,94 olduğu belirlenmiştir. Kadınların çalışma durumuna göre Somatik Semptomlar alt boyutu puanları arasında istatistiksel olarak anlamlı bir fark olmadığı görülmüştür (p>0,05).

Araştırmada yer alan çalışan kadınların Beck Anksiyete Envanteri toplam puan ortalamasının 13,24 ± 11,24, çalışmayan kadınların ise 12,18 ± 5,77 olduğu saptanmıştır. Kadınların çalışma durumuna göre Beck Anksiyete Envanteri toplam puanları arasında istatistiksel olarak anlamlı bir fark olmadığı belirlenmiştir (p>0,05).

Tablo 6.

Çalışan Kadınların Premenstrüel Sendrom Ölçeği ile Beck Anksiyete Envanteri Puanlarının Arasındaki Korelasyonlar

		Subjektif Kaygı	**Somatik Semptomlar**	**Beck Anksiyete Ölçeği**
Depresif Duygulanım	r	,574*	,442*	,541*
	p	0,000	0,000	0,000
	N	379	379	379
Anksiyete	r	,780*	,619*	,742*
	p	0,000	0,000	0,000
	N	379	379	379
Yorgunluk	r	0,579*	0,497*	0,567*
	p	0,000	0,000	0,000
	N	379	379	379
Sinirlilik	r	,435*	,381*	,429*
	p	0,000	0,000	0,000
	N	379	379	379
Depresif düşünceler	r	,621*	,570*	,624*
	p	0,000	0,000	0,000
	N	379	379	379
Ağrı	r	,621*	,594*	,635*
	p	0,000	0,000	0,000
	N	379	379	379
İştah değişimleri	r	,364*	,305*	,354*
	p	0,000	0,000	0,000
	N	379	379	379
Uyku değişimleri	r	,568*	,494*	,559*
	p	0,000	0,000	0,000
	N	379	379	379
Şişkinlik	r	,481*	,482*	,501*
	p	0,000	0,000	0,000
	N	379	379	379
Premenstrüel Sendrom Ölçeği	r	,668*	,575*	,655*
	p	0,000	0,000	0,000
	N	379	379	379

**p<0,05*

Tablo 8'de araştırma kapsamına alınan çalışan kadınların Premenstrüel Sendrom Ölçeği ile Beck Anksiyete Envanteri puanları arasındaki ilişkilere ait Pearson testi bulguları verilmiştir.

Tablo 8 incelendiğinde araştırmadaki çalışan kadınların Depresif Duygulanım alt boyutu puanları ile Subjektif Kaygı, Somatik Semptomlar ve Beck Anksiyete Envanteri toplam puanı arasında pozitif yönde, istatistiksel olarak anlamlı ve orta kuvvette ilişkiler olduğu belirlenmiştir (p<0,05).

Çalışan kadınların Anksiyete alt boyutu puanları ile Subjektif Kaygı, Somatik Semptomlar ve Beck Anksiyete Envanteri toplam puanı arasında pozitif yönde, istatistiksel olarak anlamlı ve yüksek kuvvette ilişkiler olduğu saptanmıştır (p<0,05).

Çalışan kadınların Yorgunluk alt boyutu puanları ile Subjektif Kaygı, Somatik Semptomlar ve Beck Anksiyete Envanteri toplam puanı arasında pozitif yönde, istatistiksel olarak anlamlı ve orta kuvvette ilişkiler olduğu görülmüştür (p<0,05).

Çalışan kadınların Sinirlilik alt boyutu puanları ile Subjektif Kaygı, Somatik Semptomlar ve Beck Anksiyete Envanteri toplam puanı arasında pozitif yönde, istatistiksel olarak anlamlı ve düşük–orta kuvvette ilişkiler olduğu belirlenmiştir (p<0,05).

Çalışan kadınların Depresif Düşünceler alt boyutu puanları ile Subjektif Kaygı, Somatik Semptomlar ve Beck Anksiyete Envanteri toplam puanı arasında pozitif yönde, istatistiksel olarak anlamlı ve orta kuvvette ilişkiler olduğu saptanmıştır (p<0,05).

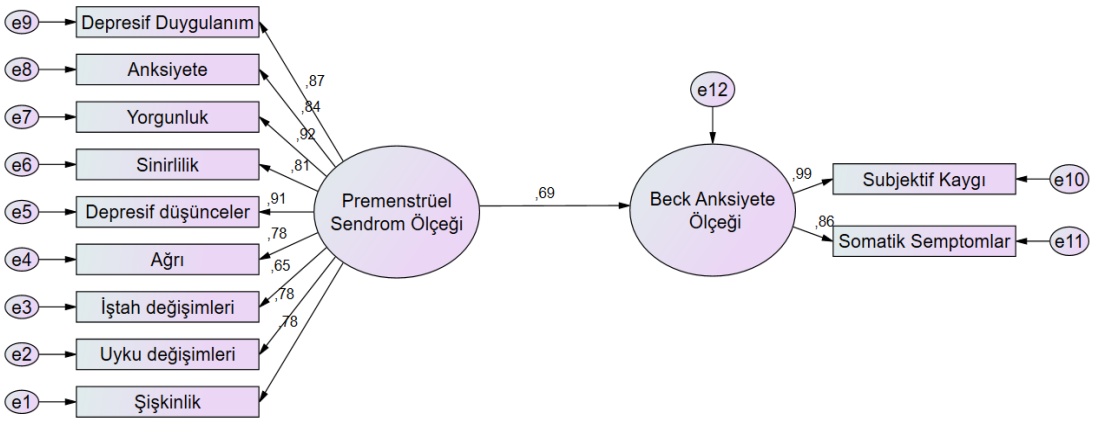
Çalışan kadınların Ağrı alt boyutu puanları ile Subjektif Kaygı, Somatik Semptomlar ve Beck Anksiyete Envanteri toplam puanı arasında pozitif yönde, istatistiksel olarak anlamlı ve orta kuvvette ilişkiler olduğu belirlenmiştir (p<0,05).

Çalışan kadınların İştah Değişimleri alt boyutu puanları ile Subjektif Kaygı, Somatik Semptomlar ve Beck Anksiyete Envanteri toplam puanı arasında pozitif yönde, istatistiksel olarak anlamlı ve düşük–orta kuvvette ilişkiler olduğu görülmüştür (p<0,05).

Çalışan kadınların Uyku Değişimleri alt boyutu puanları ile Subjektif Kaygı, Somatik Semptomlar ve Beck Anksiyete Envanteri toplam puanı arasında pozitif yönde, istatistiksel olarak anlamlı ve orta kuvvette ilişkiler olduğu saptanmıştır (p<0,05).

Çalışan kadınların Şişkinlik alt boyutu puanları ile Subjektif Kaygı, Somatik Semptomlar ve Beck Anksiyete Envanteri toplam puanı arasında pozitif yönde, istatistiksel olarak anlamlı ve orta kuvvette ilişkiler olduğu belirlenmiştir (p<0,05).

Araştırma kapsamındaki çalışan kadınların Premenstrüel Sendrom Ölçeği toplam puanı ile Subjektif Kaygı, Somatik Semptomlar ve Beck Anksiyete Envanteri toplam puanı arasında pozitif yönde, istatistiksel olarak anlamlı ve orta–yüksek kuvvette ilişkiler olduğu saptanmıştır (p<0,05).



Şekil 1. *Çalışan Kadınların Premenstrüel Sendrom Ölçeği puanlarının Beck Anksiyete Envanteri Puanlarını Yordayıcılığı*

Şekil 1'de çalışan kadınların Premenstrüel Sendrom Ölçeği puanlarının Beck Anksiyete Envanteri puanlarını yordamasına ilişkin yapısal eşitlik modeli sonuçları gösterilmiştir.

Şekil 1 incelendiğinde, araştırma kapsamındaki çalışan kadınların Premenstrüel Sendrom Ölçeği puanlarının Beck Anksiyete Envanteri puanlarını pozitif yönde yordadığı görülmektedir (β=0,69;p<0,05). Bu bağlamda çalışan kadınlarda premenstrüel sendrom belirtilerinin artmasının anksiyete düzeylerini anlamlı ve güçlü biçimde yordadığını göstermektedir.

Tablo 7.

Çalışmayan Kadınların Premenstrüel Sendrom Ölçeği ile Beck Anksiyete Envanteri Puanlarının Arasındaki Korelasyonlar

		Subjektif Kaygı	**Somatik Semptomlar**	**Beck Anksiyete Ölçeği**
Depresif Duygulanım	r	-0,023	-,114*	-0,074
	p	0,648	0,026	0,148
	N	381	381	381
Anksiyete	r	,609*	,221*	,534*
	p	0,000	0,000	0,000
	N	381	381	381
Yorgunluk	r	0,328*	0,189*	0,323*
	p	0,000	0,000	0,000
	N	381	381	381
Sinirlilik	r	0,091	0,006	0,066
	p	0,075	0,904	0,197
	N	381	381	381
Depresif düşünceler	r	,439*	,101*	,355*
	p	0,000	0,049	0,000
	N	381	381	381
Ağrı	r	0,063	,284*	,189*
	p	0,217	0,000	0,000
	N	381	381	381
İştah değişimleri	r	0,004	,106*	0,057
	p	0,937	0,038	0,267
	N	381	381	381
Uyku değişimleri	r	,196*	,271*	,274*
	p	0,000	0,000	0,000
	N	381	381	381
Şişkinlik	r	-0,046	-0,004	-0,034
	p	0,370	0,935	0,509
	N	381	381	381
Premenstrüel Sendrom Ölçeği	r	,363*	,173*	,339*
	p	0,000	0,001	0,000

N	381	381	381

**p<0,05*

Araştırmadaki çalışmayan kadınların Premenstrüel Sendrom Ölçeği ile Beck Anksiyete Envanteri puanları arasındaki ilişkilere ait Pearson testi bulguları Tablo 9'da verilmiştir.

Çalışmayan kadınların Depresif Duygulanım alt boyutu puanları ile Somatik Semptomlar arasında negatif yönde, istatistiksel olarak anlamlı ve düşük kuvvette bir ilişki olduğu belirlenmiştir (p<0,05). Depresif Duygulanım alt boyutu puanları ile Subjektif Kaygı ve Beck Anksiyete Envanteri toplam puanı arasında ise istatistiksel olarak anlamlı bir ilişki olmadığı saptanmıştır (p>0,05).

Çalışmayan kadınların Anksiyete alt boyutu puanları ile Subjektif Kaygı, Somatik Semptomlar ve Beck Anksiyete Envanteri toplam puanı arasında pozitif yönde, istatistiksel olarak anlamlı ve orta kuvvette ilişkiler olduğu belirlenmiştir (p<0,05).

Çalışmayan kadınların Yorgunluk alt boyutu puanları ile Subjektif Kaygı, Somatik Semptomlar ve Beck Anksiyete Envanteri toplam puanı arasında pozitif yönde, istatistiksel olarak anlamlı ve düşük–orta kuvvette ilişkiler olduğu saptanmıştır (p<0,05).

Çalışmayan kadınların Sinirlilik alt boyutu puanları ile Subjektif Kaygı, Somatik Semptomlar ve Beck Anksiyete Envanteri toplam puanı arasında istatistiksel olarak anlamlı bir ilişki olmadığı görülmüştür (p>0,05).

Çalışmayan kadınların Depresif Düşünceler alt boyutu puanları ile Subjektif Kaygı ve Beck Anksiyete Envanteri toplam puanı arasında pozitif yönde, istatistiksel olarak anlamlı ve orta kuvvette; Somatik Semptomlar ile ise pozitif yönde, istatistiksel olarak anlamlı ve düşük kuvvette bir ilişki olduğu belirlenmiştir (p<0,05).

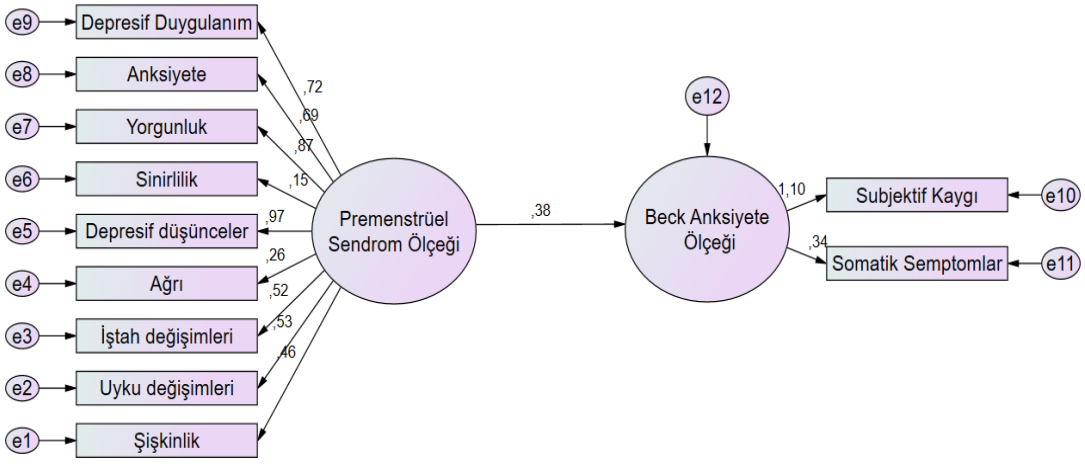
Araştırmadaki çalışmayan kadınların Ağrı alt boyutu puanları ile Somatik Semptomlar ve Beck Anksiyete Envanteri toplam puanı arasında pozitif yönde, istatistiksel olarak anlamlı ve düşük–orta kuvvette ilişkiler olduğu saptanmıştır (p<0,05). Ağrı alt boyutu puanları ile Subjektif Kaygı arasında ise istatistiksel olarak anlamlı bir ilişki olmadığı görülmüştür (p>0,05).

Çalışmayan kadınların İştah Değişimleri alt boyutu puanları ile Somatik Semptomlar arasında pozitif yönde, istatistiksel olarak anlamlı ve düşük kuvvette bir ilişki olduğu belirlenmiş; Subjektif Kaygı ve Beck Anksiyete Envanteri toplam puanı ile istatistiksel olarak anlamlı bir ilişki olmadığı saptanmıştır (p>0,05).

Çalışmayan kadınların Uyku Değişimleri alt boyutu puanları ile Subjektif Kaygı, Somatik Semptomlar ve Beck Anksiyete Envanteri toplam puanı arasında pozitif yönde, istatistiksel olarak anlamlı ve düşük–orta kuvvette ilişkiler olduğu belirlenmiştir (p<0,05).

Çalışmayan kadınların Şişkinlik alt boyutu puanları ile Subjektif Kaygı, Somatik Semptomlar ve Beck Anksiyete Envanteri toplam puanı arasında istatistiksel olarak anlamlı bir ilişki olmadığı görülmüştür (p>0,05).

Araştırmaya dahil edilen çalışmayan kadınların Premenstrüel Sendrom Ölçeği toplam puanı ile Subjektif Kaygı, Somatik Semptomlar ve Beck Anksiyete Envanteri toplam puanı arasında pozitif yönde, istatistiksel olarak anlamlı ve düşük–orta kuvvette ilişkiler olduğu saptanmıştır (p<0,05).



Şekil 2. *Çalışmayan Kadınların Premenstrüel Sendrom Ölçeği Puanlarının Beck Anksiyete Envanteri Puanlarını Yordayıcılığı*

Şekil 2'de araştırmaya dahil edilen çalışmayan kadınların Premenstrüel Sendrom Ölçeği puanlarının Beck Anksiyete Envanteri puanlarını yordamasına ilişkin yapısal eşitlik modeli sonuçları gösterilmiştir.

Şekil 2 incelendiğinde, çalışmayan kadınların Premenstrüel Sendrom Ölçeği puanlarının Beck Anksiyete Envanteri puanlarını pozitif yönde yordadığı görülmektedir (β=0,38). Buna göre çalışmayan kadınlarda premenstrüel sendrom belirtilerinin artmasının anksiyete düzeylerini anlamlı düzeyde yordadığını göstermektedir.

BÖLÜM V

Tartışma

Bu araştırmanın temel amacı, Türkiye'de 18-55 yaş aralığında bulunan çalışan ve çalışmayan kadınlarda premenstrüel sendrom ile anksiyete düzeyleri arasındaki ilişkinin karşılaştırmalı olarak incelenmesidir. Bu temel amaç doğrultusunda belirlenen alt amaçlara yönelik elde edilen bulgular, ilgili literatür eşliğinde aşağıda sırasıyla tartışılmıştır.

Araştırmanın ilk alt amacı, çalışan ve çalışmayan kadınların premenstrüel sendrom düzeyleri arasında anlamlı bir fark olup olmadığının incelenmesidir. Elde edilen bulgular, çalışma durumunun PMS semptomlarının doğası ve dağılımı üzerinde belirleyici bir rol oynadığını, ancak bu etkinin tüm semptomlar için aynı yönde olmadığını göstermektedir. Araştırma sonucunda, çalışan kadınların ölçeğin depresif duygulanım, sinirlilik ve depresif düşünceler gibi psikolojik semptom alt boyutlarındaki puanlarının, çalışmayan kadınlara göre daha yüksek olduğu tespit edilmiştir. Bu bulgu, iş yaşamının getirdiği rol belirsizlikleri, performans baskısı, yoğun iş temposu ve iş-yaşam dengesini sağlama çabası gibi kronik stresörlerin, premenstrüel dönemde kadınların duygudurumları üzerinde olumsuz bir etki yarattığını göstermektedir. Çalışan kadınlar, iş yerinde karşılaştıkları zorluklar ve sorumluluklar nedeniyle, luteal fazda zaten hassas olan duygusal dengelerinin daha kolay bozulduğu bir durumla karşı karşıya kalabilmektedirler. Literatürde bu bulguyu destekleyen çalışmalar mevcuttur. Örneğin Fazal vd. (2024), tıp ve tıp dışı mesleklerde çalışan kadınların depresyon düzeylerinin ev hanımlarına göre anlamlı ölçüde daha yüksek olduğunu rapor etmişlerdir. Benzer şekilde, İkram vd. (2017) tarafından yürütülen bir çalışmada, çalışan kadınlarda en sık bildirilen PMS semptomunun sinirlilik olduğu ve bu oranın ev hanımlarına göre belirgin şekilde yüksek bulunduğu, ayrıca çalışan kadınlarda depresyon ve ilgi kaybı gibi diğer psikolojik semptomların da daha sık görüldüğü vurgulanmıştır. Çalışma hayatının doğasında var olan bu psikososyal zorlukların, Beddig vd. (2020) premenstrüal disforik bozukluğu olan kadınlarda gösterdiği gibi, luteal fazda tekrarlayıcı olumsuz düşünceler artmakta ve bu durum negatif duygulanımı şiddetlendirmektedir. Çalışan kadınların işle ilgili endişeleri, bu olumsuz bilişsel döngüyü besleyerek depresif duygulanım ve sinirlilik düzeylerindeki artışa zemin hazırlamaktadır.

Araştırmanın ikinci alt amacı, çalışan ve çalışmayan kadınların anksiyete düzeyleri arasında anlamlı bir fark olup olmadığının incelenmesidir. Bulgular, anksiyetenin çok boyutlu yapısı göz önüne alındığında, çalışma durumunun bu yapının farklı bileşenleri üzerinde farklı etkilere sahip olabileceğini göstermektedir. Araştırma sonucunda, çalışan ve çalışmayan kadınların anksiyete puanları karşılaştırıldığında, subjektif kaygı alt boyutunda gruplar arasında anlamlı bir fark olduğu ve çalışan kadınların bu alt boyuttaki puanlarının çalışmayan kadınlara göre daha yüksek olduğu bulunmuştur. Subjektif kaygı, bireyin kendi bildirdiği endişe, sinirlilik, huzursuzluk, korku, kontrolü kaybetme hissi ve felaket senaryoları kurma gibi öznel bilişsel ve duygusal deneyimlerini yansıtmaktadır. Çalışan kadınlarda bu puanların daha yüksek olması, iş yaşamının beraberinde getirdiği rol belirsizlikleri, performans baskısı, iş güvencesizliği, kariyer gelişimi kaygısı ve iş-yaşam dengesini sağlama çabalarının, bireylerin öznel kaygı düzeylerini artıran temel faktörler olduğunu göstermektedir. İş ortamı, sürekli bir değerlendirme ve rekabet ortamı sunmakta, bu da çalışan kadınların kendilerini sürekli olarak kanıtlama ve yeterli olma baskısı hissetmelerine neden olabilmektedir. Nitekim Shimoda vd. (2025) Japon çalışan kadınlarla yaptıkları geniş çaplı bir çalışmada, düzensiz istihdam, uzun çalışma saatleri ve küçük ölçekli işletmelerde çalışmanın anksiyete riskini anlamlı düzeyde artırdığını göstermişlerdir. Bu bulguyla paralel biçimde, Kaya (2021) tarafından aktarılan araştırmada da adet öncesi gerginliğin şiddetlendiği evrelerde kadınlarda tedirginlik, aşırı öfke hali, panik nöbetleri ve uykusuzluk gibi belirtilerin arttığı bildirilmiştir. Çalışan kadınların işle ilgili sürekli kaygıları, premenstrüel dönemde hormonal dalgalanmaların da etkisiyle daha da yoğunlaşarak subjektif kaygı düzeylerindeki bu farkı belirginleştirmektedir.

Araştırmanın üçüncü alt amacı, çalışan kadınların premenstrüel sendrom düzeyleri ile anksiyete düzeyleri arasında anlamlı bir ilişki olup olmadığının incelenmesidir. Elde edilen bulgular, çalışan kadınlarda PMS şiddeti ile anksiyete arasında güçlü ve pozitif yönde bir ilişki olduğunu ortaya koymaktadır. Başka bir ifadeyle, çalışan kadınlarda PMS semptomlarının şiddeti arttıkça, anksiyete düzeylerinin de anlamlı ölçüde arttığı görülmektedir. Bu güçlü ilişki, PMS ve anksiyete bozukluklarının ortak nörobiyolojik mekanizmaları paylaşmasıyla açıklanabilir. Serotonerjik, GABAerjik ve noradrenerjik sistemlerdeki disregülasyon, hem PMS'nin duygusal semptomlarının hem de anksiyetenin patofizyolojisinde merkezi bir rol oynamaktadır (Dilbaz ve Aksan, 2021). Premenstrüel dönemde östrojen ve progesteron gibi gonad hormonlarındaki dalgalanmalar, bu nörotransmitter sistemlerini doğrudan etkileyerek duygudurumda değişkenliğe ve anksiyete yatkınlığında artışa neden olabilmektedir. Bunun yanında, çalışan kadınlarda iş yerindeki performans baskısı, zaman yönetimi zorlukları, mesleki rol beklentileri ve kişilerarası çatışmalar gibi ek psikososyal stresörler, luteal fazda zaten hassas olan duygudurum dengesini daha da olumsuz etkileyebilmektedir. Bu çift yönlü ve karşılıklı olarak güçlendirici etki, PMS ve anksiyete arasındaki ilişkinin çalışan kadınlarda daha da belirginleşmesine zemin hazırlamaktadır. Nitekim Shimoda vd. (2025), Japon çalışan kadınlarda uzun çalışma saatleri ve düzensiz iş koşullarının PMS riskini anlamlı ölçüde artırdığını göstermiştir. Benzer şekilde, Al-Hmaid vd. (2024) da hemşirelerde gece vardiyasında çalışmanın ve iş yerindeki stresin PMS ile anksiyete arasındaki ilişkiyi güçlendirdiğini bildirmiştir.

BÖLÜM VI

Sonuç ve Öneriler

Sonuç

Bu araştırmada, Türkiye’de 18-55 yaş grubundaki çalışan ve çalışmayan kadınların premenstrüel sendrom ile anksiyete seviyelerinin karşılaştırılması amaçlanmıştır. Araştırmada, çalışan kadınların Premenstrüel Sendrom Ölçeği'nin depresif duygulanım, sinirlilik ve depresif düşünceler alt boyut puan ortalamalarının, çalışmayan kadınlara göre anlamlı düzeyde daha yüksek olduğu bulunmuştur. Çalışan ve çalışmayan kadınlar arasında anksiyete, yorgunluk ve iştah değişimleri alt boyut puanları açısından anlamlı bir farklılık bulunmamıştır. Çalışmayan kadınların ağrı ve uyku değişimleri alt boyut puan ortalamalarının çalışan kadınlara göre anlamlı düzeyde daha yüksek olduğu tespit edilirken, çalışan kadınların şişkinlik alt boyut puan ortalamaları çalışmayan kadınlara göre daha yüksek bulunmuştur. Çalışan ve çalışmayan kadınların Premenstrüel Sendrom Ölçeği toplam puan ortalamaları arasında anlamlı bir fark bulunmamıştır.

1.1. Öneriler

Araştırma Sonuçlarına Yönelik Öneriler

Araştırma bulguları, çalışan kadınlarda premenstrüel dönemde psikolojik semptomların (depresif duygulanım, sinirlilik, depresif düşünceler) daha baskın olduğunu göstermektedir. Bu nedenle, iş yerlerinde kadın çalışanlara yönelik psikolojik destek hizmetlerinin güçlendirilmesi, insan kaynakları birimleri ve iş yeri hekimlikleri aracılığıyla premenstrüel dönemde sık karşılaşılan duygudurum değişiklikleri konusunda farkındalığın artırılması önerilebilir. Özellikle performans değerlendirme sistemlerinde, premenstrüel dönemdeki geçici verim düşüşlerinin kalıcı bir performans sorunu olarak değerlendirilmemesi için yöneticilere yönelik bilgilendirme programları düzenlenmelidir.

İleride Yapılacak Araştırmalara Yönelik Öneriler

Mevcut araştırma kesitsel tipte olduğu için PMS ile anksiyete arasındaki ilişkide nedensellik kurulamamıştır. PMS semptomlarındaki değişimlerin anksiyete düzeylerini nasıl etkilediğini ve bu ilişkide çalışma durumunun zaman içindeki rolünün daha belirgin bir şekilde ortaya konulabilmesi için boylamsal çalışmalar yapılması önerilebilir. En az bir yıl boyunca birden fazla adet döngüsünü kapsayan, günlük semptom takvimi tutulan prospektif çalışmalar, hem PMS tanısının doğruluğunu artıracak hem de semptom-anksiyete ilişkisinin zamansal seyrini aydınlatma potansiyeline sahiptir.

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EMPLOYABILITY SKILLS IN THE ERA OF GENERATIVE ARTIFICIAL INTELLIGENCE: DEVELOPING A COMPETENCY FRAMEWORK FOR HIGHER EDUCATION

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ABSTRACT

Generative artificial intelligence is driving significant transformations in the organization of work, decision-making processes, and the competencies required for professional success. In this context, higher education institutions face the challenge of redefining the concept of employability and preparing graduates who are able to collaborate effectively, critically, and responsibly with artificial intelligence-based technologies. Traditional employability competency models, focused on communication, critical thinking, problem-solving, and general digital skills, require further development in order to meet the demands of a professional environment augmented by generative artificial intelligence.

The aim of this article is to develop an employability competency framework adapted to the era of generative artificial intelligence and designed for integration into curriculum development strategies in higher education. The study is based on an analysis of the scientific literature on graduate employability, artificial intelligence literacy, digital competencies, and future skills. The proposed framework integrates key dimensions such as AI literacy, human–artificial intelligence collaboration, critical thinking and evaluation of AI-generated information, AI-assisted professional communication, creativity and innovation, ethical use of intelligent technologies, and the capacity for adaptation and life-long learning.

The conceptual findings highlight that AI literacy represents only the starting point of professional preparation. A graduate prepared for AI-influenced workplaces must be able to use intelligent technologies strategically, critically evaluate AI-generated outputs, communicate effectively in technologically augmented environments, and make ethically responsible decisions.

By integrating the perspective of generative artificial intelligence into the employability literature, this article contributes to the development of a new conceptual model for preparing graduates in the context of the digital transformation of the labour market. The proposed framework can support universities in designing educational curricula, assessing students' competencies, and developing training strategies aligned with the requirements of future workplaces.

Keywords: generative artificial intelligence, employability competencies, higher education, AI literacy, digital competencies, human–artificial intelligence collaboration.

INTRODUCTION

The accelerated transformations generated by technological progress, particularly by the development of generative artificial intelligence (AI), are fundamentally changing the way professional activities are performed and the competencies required for success in the labour market. Tools based on large language models (LLMs), capable of generating texts, analysing information, and supporting decision-making processes, have moved beyond the stage of experimental use and have become part of organizational practices across numerous fields. This evolution requires a reconsideration of the relationship between human competencies and intelligent technologies, as future employees will not merely use digital tools but will collaborate with artificial intelligence systems in activities involving analysis, communication, creativity, and problem-solving.

In this context, the concept of employability in higher education requires redefinition. Traditionally, graduate employability has been associated with the development of a set of transferable competencies,

including effective communication, critical thinking, collaboration, adaptability, problem-solving, and general digital skills. These competencies remain highly relevant; however, the emergence of generative artificial intelligence introduces new requirements regarding graduates' ability to use, evaluate, and responsibly integrate intelligent technologies into professional activities. Thus, general digital competence is no longer sufficient; graduates need to develop specific competencies related to interaction with AI systems, critical evaluation of automatically generated outputs, and decision-making in professional environments where humans and technology collaborate.

Recent literature demonstrates a growing interest in artificial intelligence literacy (AI literacy), which is increasingly considered an essential competency for future education. Existing studies have primarily examined individuals' ability to understand fundamental AI concepts, use AI-based tools, and recognize the ethical implications associated with these technologies. However, most AI literacy models are formulated at a general level and do not sufficiently address the relationship between artificial intelligence and the employability competencies required by higher education graduates. Similarly, established models of graduate employability do not explicitly incorporate the competencies required for professional collaboration with generative AI.

This research gap becomes particularly significant in a context where employers increasingly seek graduates capable of combining human competencies with the effective use of emerging technologies. Future professionals need not only to use artificial intelligence tools but also to formulate appropriate instructions for these systems, evaluate the quality of generated outputs, identify the limitations and risks associated with AI use, and maintain human responsibility in decision-making processes. Therefore, employability in the era of generative AI must be examined from the perspective of effective collaboration between human capabilities and technological capacities.

Within this framework, developing an employability competency model adapted to the era of generative artificial intelligence represents an important research direction for higher education. Such a framework can contribute to guiding curriculum development, designing relevant learning experiences, and assessing students' preparedness for the requirements of a digitally transformed labour market.

Therefore, the objective of this article is to develop a conceptual employability competency framework for higher education graduates in the context of generative artificial intelligence adoption. The study aims to identify the main competency dimensions that need to be developed in order to enable graduates to collaborate effectively, critically, and responsibly with AI systems in professional contexts.

To achieve this objective, the article addresses the following research questions:

RQ1: What are the main employability competencies required by graduates in the context of the development of generative artificial intelligence?

RQ2: What conceptual dimensions can structure an employability competency framework adapted to the era of generative AI?

RQ3: How can such a framework contribute to curriculum development in higher education?

By addressing these questions, the study contributes to expanding research on graduate employability through the integration of the human–artificial intelligence collaboration perspective and proposes a conceptual foundation for developing educational programs oriented toward the competencies required for future workplaces.

LITERATURE REVIEW

Graduate Employability in a Changing Labour Market

Graduate employability represents a multidimensional concept referring to an individual's ability to obtain employment, adapt to workplace requirements, and develop a sustainable professional career. Contemporary approaches emphasize that employability is not limited to academic knowledge or technical expertise but involves a combination of competencies, personal attributes, experiences, and attitudes that enable individuals to respond effectively to changing professional environments.

Previous research has highlighted the importance of transferable competencies, including communication, teamwork, problem-solving, creativity, adaptability, and self-directed learning. These competencies are valued because they enable graduates to operate across diverse professional contexts and manage uncertainty. As labour markets become increasingly dynamic, the capacity for continuous development has become a fundamental element of employability.

Digital transformation has expanded traditional employability models by introducing digital competence as an essential professional requirement. Graduates are expected to use digital technologies effectively, manage information, communicate through technological platforms, and adapt to emerging digital tools. Frameworks such as the European Digital Competence Framework (DigComp) have contributed to defining the knowledge, skills, and attitudes required for effective participation in digital societies.

However, the emergence of generative AI challenges existing approaches to digital competence. Traditional digital skills generally focus on using technological applications and managing digital information, whereas AI-enabled environments require additional abilities related to interaction, evaluation, and decision-making. Graduates must not only operate digital systems but also collaborate with technologies capable of producing information, suggesting solutions, and influencing professional processes.

Therefore, contemporary employability frameworks require further development to incorporate competencies associated with human–AI interaction. The future professional profile is likely to involve individuals who combine disciplinary expertise, transferable human skills, digital competence, and the ability to use artificial intelligence responsibly.

Generative Artificial Intelligence and Emerging Professional Competencies

Generative artificial intelligence represents a significant technological development because it enables systems to produce new content based on learned patterns from large datasets. Applications based on large language models can generate texts, summarize information, support communication, assist programming activities, and contribute to creative processes.

The integration of these technologies into professional environments changes the nature of work. Instead of replacing human activity completely, AI increasingly functions as a collaborative technology that extends human capabilities. Artificial intelligence can provide rapid information processing, pattern recognition, and alternative solutions, while humans contribute contextual understanding, ethical judgment, creativity, and responsibility.

This relationship requires the development of new professional competencies. Employees need to understand when AI can create value, how to communicate effectively with AI systems, and how to evaluate the quality of generated outputs. These requirements indicate a transition from traditional digital competence toward AI-enhanced professional competence.

One important emerging concept in this context is artificial intelligence literacy. AI literacy includes not only knowledge about AI technologies but also the ability to use them effectively, critically assess their outputs, and understand their social and ethical implications. For higher education, AI literacy becomes a transversal competency relevant across academic disciplines, not only in technology-related fields.

However, AI literacy should not be viewed as an isolated technical capability. Its professional relevance emerges through integration with broader employability competencies, including communication, creativity, critical thinking, ethical reasoning, and adaptability.

Towards an AI-Enhanced Employability Competency Framework

The analysis of existing literature demonstrates that employability, digital competence, and artificial intelligence literacy have been extensively studied as separate areas. However, the increasing integration of generative AI into professional environments requires a more comprehensive approach that connects these perspectives.

Future graduates will require competencies that enable them not only to use artificial intelligence tools but also to integrate them effectively into professional activities while maintaining human judgment and responsibility. Therefore, AI-enhanced employability should be conceptualized as a multidimensional

construct that combines technological understanding, cognitive abilities, professional communication, ethical awareness, and adaptive capacity.

Based on the synthesis of employability literature, AI literacy research, and future skills frameworks, this study proposes the **AI-Enhanced Employability Competency Framework (AEE-CF)**. The framework consists of seven interconnected dimensions:

1. **Artificial Intelligence Literacy**
2. **Human–AI Collaboration**
3. **Critical Thinking and Evaluation of AI-Generated Information**
4. **AI-Augmented Professional Communication**
5. **AI-Assisted Creativity and Innovation**
6. **Ethical and Responsible Use of Artificial Intelligence**
7. **Professional Adaptability and Continuous Learning**

These dimensions reflect the understanding that employability in the era of generative AI is not defined exclusively by technological ability but by the capacity to combine human competencies with intelligent technologies.

DEVELOPMENT OF THE EMPLOYABILITY COMPETENCY FRAMEWORK IN THE ERA OF GENERATIVE ARTIFICIAL INTELLIGENCE

Foundation of the Proposed Framework

The digital transformation driven by generative artificial intelligence requires a reconsideration of how employability competencies developed in higher education are defined. Traditional models of professional preparation have been built around the assumption that graduates need to acquire a stable set of knowledge and transferable skills that enable their integration into the labour market. However, the dynamic nature of artificial intelligence-based technologies is changing the nature of professional activities and creating the need for competencies oriented toward effective collaboration between humans and intelligent systems.

The competency framework proposed in this study is based on the premise that employability in the era of generative artificial intelligence should not be understood as merely the ability to use technological tools, but rather as the ability to integrate these tools into complex professional activities while maintaining human control, critical judgment, and ethical responsibility.

Therefore, the proposed framework integrates three major categories of competencies:

1. **Technological competencies**, which enable the understanding and effective use of AI systems;
2. **Cognitive and professional competencies**, which enable the evaluation, adaptation, and application of AI-generated outputs;
3. **Ethical and adaptive competencies**, which ensure the responsible and sustainable use of intelligent technologies.

Based on the analysis of literature concerning employability, AI literacy, and future competencies, this study proposes the **AI-Enhanced Employability Competency Framework (AEE-CF)**, consisting of seven interrelated dimensions:

Dimension 1. Artificial Intelligence Literacy (AI Literacy)

Artificial intelligence literacy represents the foundational dimension of the proposed framework. It refers to graduates' ability to understand the principles, capabilities, and limitations of AI systems and to recognize their potential applications in professional contexts. Unlike traditional digital competence, AI literacy requires an understanding of how intelligent systems generate outputs, the factors influencing their reliability, and the situations in which their use is appropriate. Graduates do not necessarily need

advanced technical knowledge of AI development; however, they need sufficient understanding to interact effectively with AI-based technologies.

Key competencies include:

- understanding fundamental concepts related to generative artificial intelligence;
- identifying professional situations where AI can provide value;
- selecting appropriate AI tools for specific tasks;
- recognizing limitations, inaccuracies, and risks associated with AI systems.

AI literacy provides the foundation for meaningful interaction with artificial intelligence and enables graduates to become informed users rather than passive consumers of technological solutions.

Dimension 2. Human–AI Collaboration

The second dimension focuses on the ability to collaborate effectively with artificial intelligence systems. In AI-enhanced workplaces, professional success will increasingly depend on the ability to combine human expertise with technological capabilities. Human–AI collaboration involves understanding which tasks can be supported by AI and which require human judgment, creativity, and ethical reasoning. The objective is not to replace human decision-making but to establish productive cooperation between employees and intelligent systems.

Key competencies include:

- integrating AI tools into professional workflows;
- distributing tasks effectively between humans and AI systems;
- using AI-generated suggestions to improve professional outcomes;
- maintaining human responsibility for final decisions.

This dimension represents a shift from the concept of a digital technology user toward the concept of an AI-augmented professional capable of managing collaboration with intelligent systems.

Dimension 3. Critical Thinking and Evaluation of AI-Generated Information

Generative AI systems can produce responses that appear accurate and coherent; however, their outputs may contain errors, incomplete information, or misleading interpretations. Therefore, critical evaluation represents a fundamental employability competency in AI-supported professional environments.

Graduates need to develop the ability to analyse AI-generated content, verify information, and make independent judgments. Critical thinking becomes even more important because professional decisions increasingly involve information produced or influenced by artificial intelligence.

Key competencies include:

- evaluating the accuracy and relevance of AI-generated information;
- identifying potential errors or limitations in AI outputs;
- comparing AI-generated content with reliable sources;
- applying professional judgment when using AI-supported recommendations.

This dimension reinforces the continuing importance of human cognitive abilities in contexts where technological systems increasingly contribute to knowledge production.

Dimension 4. AI-Augmented Professional Communication

Communication remains one of the most important employability competencies; however, generative AI is transforming how professional communication is produced, adapted, and evaluated. Professionals increasingly use AI tools for drafting documents, improving written communication, preparing presentations, and adapting messages for different audiences. Nevertheless, effective AI-supported

communication requires human supervision, contextual understanding, and the ability to evaluate whether generated content reflects professional objectives.

Key competencies include:

- using AI tools to support professional writing and communication;
- formulating effective prompts and instructions;
- adapting AI-generated messages to organizational and cultural contexts;
- evaluating the quality, accuracy, and appropriateness of AI-assisted communication.

This dimension is particularly relevant for fields such as business, management, education, marketing, and international relations, where communication quality directly influences professional effectiveness.

Dimension 5. AI-Assisted Creativity and Innovation

Generative AI introduces new possibilities for creativity by supporting idea generation, exploration of alternatives, and development of innovative solutions. Rather than reducing human creativity, AI can function as a cognitive partner that expands creative processes.

However, meaningful innovation requires the integration of AI-generated possibilities with human expertise, experience, and contextual understanding. Creativity in AI-enhanced environments becomes a collaborative process between human imagination and computational capabilities.

Key competencies include:

- using AI tools to generate and explore ideas;
- developing solutions through human–AI interaction;
- combining AI-generated perspectives with professional expertise;
- applying AI in innovation and problem-solving processes.

This dimension highlights that future creativity will increasingly involve the ability to manage and direct interactions with intelligent systems.

Dimension 6. Ethical and Responsible Use of Artificial Intelligence

The adoption of generative AI raises significant ethical challenges related to privacy, transparency, intellectual property, misinformation, and algorithmic bias. Therefore, responsible AI use represents an essential component of graduate employability. Professionals must understand not only how to use AI technologies but also the consequences of their implementation. Ethical competence ensures that AI is integrated into professional activities in ways that respect social values and organizational responsibilities.

Key competencies include:

- applying ethical principles when using AI technologies;
- protecting confidential and personal information;
- recognizing potential algorithmic bias;
- ensuring transparency regarding AI-generated content;
- understanding responsibility for AI-supported decisions.

This dimension emphasizes that technological competence without ethical awareness is insufficient for professional success in AI-driven environments.

Dimension 7. Professional Adaptability and Continuous Learning

The rapid evolution of artificial intelligence technologies makes adaptability a central employability competency. Specific AI tools and applications will continue to change, meaning that graduates must develop the capacity for continuous learning rather than rely on fixed technological knowledge.

Professional sustainability increasingly depends on individuals' ability to update their competencies, explore emerging technologies, and adapt to changing organizational requirements.

Key competencies include:

- continuously developing knowledge about emerging AI technologies;
- adapting to workplace transformations generated by AI;
- engaging in autonomous learning activities;
- exploring new applications of intelligent technologies.

Adaptability ensures that graduates remain professionally relevant in labour markets characterized by continuous technological transformation.

RESEARCH METHODOLOGY

The objective of this study is to develop an employability competency framework adapted to the era of generative artificial intelligence. To achieve this objective, the research adopts a sequential mixed-methods design combining conceptual analysis and quantitative assessment.

The research methodology consists of two main stages:

1. **Literature-based conceptual development** – identification of relevant employability and AI-related competencies;
2. **Quantitative validation through questionnaire research** – assessment of the framework structure among higher education students.

This methodological approach enables the transition from theoretical conceptualization toward an empirically supported competency model.

The ***first stage*** involved analysing international research related to:

- graduate employability competencies;
- future skills and digital competencies;
- artificial intelligence literacy;
- human–AI collaboration;
- responsible AI use in education and professional contexts.

The literature analysis was used to identify recurring competency dimensions and establish the initial structure of the AI-Enhanced Employability Competency Framework. The conceptual analysis demonstrated that existing employability frameworks require expansion because general digital competence does not fully capture the abilities required for interaction with generative AI systems.

Questionnaire Development

To measure AI-enhanced employability competencies among higher education students, there has been developed a questionnaire.

The questionnaire is structured according to the seven dimensions of the AEE-CF:

1. Artificial Intelligence Literacy;
2. Human–AI Collaboration;
3. Critical Thinking and AI Evaluation;
4. AI-Augmented Professional Communication;
5. AI-Assisted Creativity and Innovation;
6. Ethical and Responsible AI Use;
7. Professional Adaptability and Continuous Learning.

Each competency indicator is evaluated using a five-point Likert scale ranging from:

1 – Strongly disagree
2 – Disagree
3 – Neither agree nor disagree
4 – Agree
5 – Strongly agree

The instrument aims to assess students' perceived preparedness for professional environments influenced by generative artificial intelligence.

RESEARCH RESULTS

The analysis of the specialized literature and the expert validation process resulted in the identification of seven key dimensions required for graduate employability in the era of generative artificial intelligence. The findings confirm that traditional employability models, although still relevant, require extension to incorporate competencies related to collaboration with intelligent technologies.

The proposed **AI-Enhanced Employability Competency Framework (AEE-CF)** includes the following dimensions:

1. **Artificial Intelligence Literacy** – understanding AI concepts, capabilities, limitations, and professional applications;

2. **Human–AI Collaboration** – the ability to integrate AI systems into professional activities while maintaining human judgment and responsibility;

3. **Critical Thinking and AI Output Evaluation** – assessing the accuracy, relevance, and reliability of AI-generated information;

4. **AI-Augmented Professional Communication** – using AI tools to support writing, communication, and information exchange;

5. **AI-Assisted Creativity and Innovation** – leveraging AI technologies for idea generation, problem-solving, and innovation processes;

6. **Ethical and Responsible AI Use** – understanding issues related to transparency, privacy, bias, and accountability;

7. **Professional Adaptability and Continuous Learning** – developing the capacity to adapt to rapidly changing technological environments.

The Delphi validation process confirmed the relevance of these dimensions and highlighted that AI competence should not be understood exclusively as the ability to operate technological tools. Experts emphasized that future professionals require a combination of technological understanding, critical evaluation skills, ethical awareness, and adaptive capacity.

The results support the argument that employability in the context of generative AI represents a multidimensional construct that integrates human competencies with technology-related capabilities.

The findings contribute to current discussions regarding the transformation of graduate employability under conditions of technological disruption. Previous employability frameworks have traditionally emphasized transferable competencies such as communication, teamwork, problem-solving, and adaptability. These competencies remain essential; however, generative AI changes how they are applied in professional environments.

The proposed framework extends existing approaches by introducing **human–AI collaboration** as a central component of employability. In future workplaces, professionals will increasingly operate within hybrid environments where artificial intelligence systems support analysis, communication, creativity, and decision-making. Therefore, employability should no longer be viewed only as the ability to perform tasks independently but as the ability to effectively combine human expertise with technological capabilities.

A significant finding of this study is that AI literacy represents a foundation rather than a complete employability competency. Graduates need more than technical familiarity with AI applications. They must understand when AI can provide value, recognize its limitations, evaluate generated information, and make responsible decisions regarding its use.

The inclusion of critical thinking and ethical responsibility within the framework reflects the continuing importance of uniquely human capabilities. Although generative AI can generate complex outputs rapidly, human professionals remain responsible for interpretation, contextual understanding, and ethical decision-making.

Furthermore, the identification of AI-augmented professional communication as a separate competency dimension highlights the transformation of communication practices. In many professional fields, graduates will increasingly need to combine communication expertise with the ability to formulate effective prompts, evaluate AI-generated messages, and adapt technological outputs to organizational and cultural contexts.

Overall, the results indicate that the future of employability is not characterized by the replacement of human competencies by artificial intelligence but by the development of complementary relationships between human intelligence and technological systems.

Final Structure of the Competency Framework

Based on the results of the literature analysis and the Delphi process, the final **AI-Enhanced Employability Competency Framework (AEE-CF)** consists of seven dimensions and 35 competency indicators.

Table 1.

Dimensions	***Description***	***Examples of Competencies***
AI Literacy	Understanding the principles and functions of generative AI	Using AI tools, understanding limitations
Numan-AI Collaboration	Integrating AI into professional activities	Task distribution, using AI feedback
AI Critical Thinking	Evaluating automatically generated outputs	Information verification, identifying errors
AI-Augmented Professional Communication	Using AI for effective communication	Writing, adapting messages, prompt engineering
Creativity and Innovation	Using AI for solution generation	Idea development, exploring alternatives
Ethics and Responsibility	Responsible use of AI	Privacy, transparency, bias reduction
Professional Adaptability	Capacity for continuous development	Lifelong learning, technological adaptation

Source: Elaborated by the author

The resulting model highlights that employability competencies in the era of generative AI are not represented exclusively by technological competencies but by their integration with cognitive, social, and ethical abilities.

PRACTICAL IMPLICATIONS AND RECOMMENDATIONS FOR HIGHER EDUCATION INSTITUTIONS

The Need for Competency-Oriented Curricular Transformation for the Era of Generative AI

The findings of this study demonstrate that the integration of generative artificial intelligence into society and professional environments requires a reconsideration of the role of higher education in developing graduate employability. Universities can no longer approach professional preparation exclusively through the transmission of disciplinary knowledge; instead, they must develop students' ability to use, evaluate, and integrate intelligent technologies within complex professional contexts. The proposed competency framework provides a foundation for designing curricular strategies that

incorporate generative AI-related competencies as a transversal element of university education. This approach does not imply the mandatory introduction of technical AI courses for all students, but rather the integration of responsible AI use principles according to the specific requirements of each academic discipline. For example, business students can develop competencies related to the use of AI for market analysis, professional communication, and decision-making, while students in social sciences can use AI for information analysis, research activities, and the development of communication competencies.

Integrating the Competency Framework into Educational Program Design

The **AI-Enhanced Employability Competency Framework** can be used as a tool for analysing and developing university programs.

Higher education institutions can use the seven framework dimensions to:

- evaluate the extent to which existing programs develop competencies relevant to the AI era;
- identify curricular gaps;
- design learning activities focused on human–AI collaboration;
- formulate learning outcomes associated with emerging competencies.

The integration of the framework can be achieved through three levels of intervention:

Level 1: AI Awareness and Literacy At this level, students acquire fundamental knowledge about the functioning, benefits, and limitations of generative AI systems.

Learning objectives:

- understanding basic AI concepts;
- identifying opportunities and risks associated with AI use;
- developing a critical attitude toward automatically generated content.

1.2. ***Level 2: Professional Application of AI*** Students use AI tools in contexts specific to their academic and professional fields.

1.3. **Examples include:**

- drafting and optimizing professional communication;
- data analysis;
- generating and evaluating ideas;
- supporting research processes.

1.4. Level 3: Strategic and Responsible AI Use Students develop the ability to integrate AI into complex decision-making processes while maintaining human responsibility and ethical principles.

Implications for Academic Staff Competency Development

The effective implementation of a competency framework for the era of generative AI largely depends on the preparation of academic staff. University educators need to develop their own competencies related to the pedagogical and responsible use of AI technologies.

Faculty development programs should include:

- understanding the principles underlying generative AI systems;
- using AI tools for designing educational activities;
- developing assessment methods adapted to AI-supported learning environments;
- managing ethical issues related to student use of AI.

An important aspect concerns the changing role of university educators. In the context of generative AI, the professor is no longer only a provider of information, as access to information is increasingly

facilitated by technology. Instead, the educator becomes a learning facilitator, a guide for developing critical thinking, and a mentor in the responsible use of intelligent technologies.

Implications for Student Competency Assessment

The widespread use of generative AI requires a reconsideration of traditional academic assessment methods. Assessments based exclusively on information reproduction become less relevant in a context where AI systems can rapidly generate complex responses.

Higher education institutions should develop assessment approaches that measure:

- analytical and interpretative abilities;
- critical use of AI tools;
- justification of decisions;
- creativity and application of knowledge in authentic contexts;
- responsibility regarding AI use.

Assessment of AI-enhanced employability competencies may include:

- real-world problem-based projects;
- digital portfolios;
- reflective presentations on AI use;
- professional case studies;
- human–AI collaborative activities.

Implications for the Relationship Between Universities and the Labour Market

A fundamental objective of higher education is preparing graduates for current and future professional requirements. In this context, collaboration between universities and employers becomes essential for defining relevant competencies.

The proposed framework can facilitate dialogue between academia and organizations by providing a shared reference structure regarding the competencies required by employees in AI-influenced professional environments.

Employers can use the framework for:

- defining professional profiles;
- developing internal training programs;
- identifying emerging competencies;
- assessing graduate preparedness.

At the same time, universities can use employer feedback to continuously update educational programs.

The Role of Professional Communication Competencies in the Era of Generative AI

An important implication of the proposed framework concerns the reconsideration of professional communication competencies. In an environment where AI can generate texts, reports, and professional messages, the value of human communication does not disappear but is transformed.

For graduates in fields such as business, economics, management, and international relations, communication competency will include:

- the ability to use AI to improve writing processes;
- the ability to formulate clear and effective requirements for AI systems;
- evaluating the quality and relevance of generated messages;
- adapting communication to intercultural and organizational contexts.

In this regard, the development of Business English competencies can benefit from the responsible integration of generative AI, as students need to learn not only professional language skills but also how technology-assisted communication is used in international business environments.

Strategic Recommendations for Higher Education Institutions

Based on the proposed framework, the following recommendations can be formulated:

- *Develop an Institutional AI Strategy* Universities should establish clear policies regarding AI use in teaching, research, and assessment.
- *Integrate AI Competencies Across Academic Disciplines* AI should not be considered relevant only for computer science-related fields but should be approached as a transversal competency.
- *Develop Academic Staff Training Programs* Educators should receive support to use AI in pedagogically effective and responsible ways.
- *Create Authentic Learning Contexts* Students should use AI to solve real-world problems rather than only complete technical exercises.
- *Develop AI Competency Assessment Instruments* Universities should monitor students' preparedness levels and evaluate the impact of educational interventions.

Practical Implications

The proposed competency framework demonstrates that preparing graduates for the era of generative artificial intelligence requires a balanced approach in which technology is integrated with fundamental human competencies. Universities have the responsibility to educate professionals who are not only capable of using AI tools but also able to collaborate with them in a critical, creative, and ethical manner.

By integrating AI literacy, AI-augmented professional communication, critical thinking, and digital responsibility into higher education, universities can contribute to the development of sustainable employability in an economy characterized by continuous technological transformation.

CONCLUSIONS

The rapid development of generative artificial intelligence is fundamentally transforming the nature of work, redefining the competencies required for the professional integration and success of higher education graduates. In this context, traditional employability models, built around transferable skills and general digital competencies, require expansion in order to reflect new professional realities in which collaboration between humans and intelligent systems becomes a central component of organizational activity.

This study aimed to develop an employability competency framework adapted to the era of generative artificial intelligence and designed for higher education institutions. The analysis of the specialized literature and the conceptual foundation demonstrated that future employability cannot be reduced to the ability to use digital technologies but requires the development of an integrated set of technological, cognitive, social, and ethical competencies.

The proposed framework, entitled the AI-Enhanced Employability Competency Framework (AEE-CF), integrates seven fundamental dimensions: artificial intelligence literacy, human–artificial intelligence collaboration, critical thinking and evaluation of AI-generated outputs, AI-augmented professional communication, AI-assisted creativity and innovation, ethical and responsible AI use, and professional adaptability and continuous learning.

The main contribution of this study lies in integrating two research areas that have frequently been examined separately: graduate employability literature and research on competencies required for effective artificial intelligence use. Through this integration, the study proposes a new perspective on professional preparation, in which human competencies and technological capabilities are considered complementary elements of a future-oriented professional profile.

The conceptual findings highlight that AI literacy represents only the starting point of professional preparation. A graduate prepared for AI-influenced workplaces must be able to use intelligent technologies strategically, critically evaluate AI-generated outputs, communicate effectively in technologically augmented environments, and make ethically responsible decisions.

For higher education institutions, the proposed framework provides a foundation for curriculum development, the design of authentic learning experiences, and the creation of assessment instruments for emerging competencies. At the same time, it can facilitate dialogue between universities and employers regarding the graduate profile required in a digitalized economy.

However, this study has several limitations. First, the proposed framework is based on literature analysis and conceptual development; therefore, empirical validation in different educational and cultural contexts is required. Second, the rapid evolution of artificial intelligence technologies may lead to the emergence of new competencies and changes in the relevance of certain dimensions over time. Furthermore, future research should incorporate multiple perspectives, including those of students, academic staff, employers, and institutional decision-makers.

Future research directions may include the statistical validation of the framework through large-scale quantitative studies, the analysis of differences across academic disciplines, the development of standardized assessment instruments for AI-enhanced employability competencies, and the investigation of the impact of curricular interventions based on this model.

In conclusion, the era of generative artificial intelligence does not eliminate the importance of human competencies; rather, it transforms the ways in which these competencies are applied and valued. Universities have a crucial role in preparing graduates who are able to combine professional expertise, critical thinking, creativity, and ethical responsibility with the opportunities provided by intelligent technologies. The proposed competency framework represents a step toward redefining graduate employability for a society in which human–artificial intelligence collaboration becomes a fundamental professional reality.

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ARTIFICIAL INTELLIGENCE AND AUTOMATION IN MANAGEMENT OF CROSS-BORDER ONLINE TRANSACTIONS: AUTOMATED FRAUD DETECTION, RISC SCORING, ETHICAL AND LEGAL IMPLICATIONS

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ABSTRACT

Cross-border online transactions represent an essential component of global digital commerce, facilitating economic exchanges between countries and providing access to international markets. In the context of the growing volume and complexity of these transactions, artificial intelligence (AI) and automation have become indispensable tools for the efficient and secure management of financial flows. By analysing large volumes of data in real time and identifying behavioural patterns, these technologies enable the detection of fraudulent activities, risk assessment, and the optimization of financial processes, while reducing errors and operational costs.

The integration of AI-based systems into cross-border digital transactions contributes to improving the accuracy of fraud prevention mechanisms through machine learning algorithms capable of identifying suspicious activities and adapting to new forms of cybercrime. Automated risk scoring systems allow financial institutions and online platforms to evaluate transaction reliability, assess customer behaviour, and implement preventive measures against financial losses. However, the extensive use of artificial intelligence also raises significant ethical and legal challenges, including issues related to data protection, algorithmic transparency, accountability, and the protection of fundamental rights.

This research examines the role of artificial intelligence and automation in enhancing the security and efficiency of cross-border online transactions, focusing on automated fraud detection, risk assessment mechanisms, and the regulatory challenges associated with the digital transformation of financial services. The study emphasizes the need for a balanced approach that combines technological innovation with effective legal safeguards to ensure trust, security, and fairness in the global digital economy.

Keywords: Artificial intelligence; Cross-border online transactions; Fraud detection; Risk scoring; Digital financial security.

INTRODUCTION

The COVID-19 pandemic marked a turning point in the development of cross-border online commerce, significantly accelerating the digital transformation of businesses, financial services, and consumer behaviour worldwide. Lockdowns, travel restrictions, and social distancing measures forced companies and consumers to rely increasingly on digital platforms for commercial transactions, resulting in an unprecedented increase in cross-border e-commerce and electronic payments. International organizations, including the World Trade Organization (WTO) and the United Nations Conference on Trade and Development (UNCTAD), have recognized that the pandemic substantially accelerated the adoption of digital technologies and strengthened the role of e-commerce in maintaining global trade during periods of economic disruption (UNCTAD, 2021).

The rapid expansion of cross-border online transactions also exposed significant challenges related to cybersecurity, payment fraud, identity theft, money laundering, and regulatory compliance. The growing volume and complexity of digital financial operations made traditional fraud detection and risk management mechanisms increasingly inadequate. Consequently, financial institutions, payment service providers, and e-commerce platforms have accelerated the adoption of artificial intelligence (AI) and automation to strengthen transaction monitoring, improve operational efficiency, and ensure the security of international digital payments. Machine learning algorithms are capable of processing massive volumes of transactional data in real time, detecting anomalies, identifying suspicious behavioural patterns, and generating predictive risk scores that enable institutions to respond proactively to emerging threats (Reddy et. al, 2024).

Artificial intelligence and automation have therefore become key drivers of modern cross-border online transaction management. Beyond improving operational efficiency and reducing processing costs, AI-powered systems enhance fraud detection, automate compliance procedures, and support more accurate risk assessment. However, the increasing reliance on automated decision-making also raises important legal and ethical concerns regarding algorithmic transparency, accountability, data protection, privacy, non-discrimination, and the protection of fundamental rights. As AI systems increasingly influence financial decisions with legal and economic consequences, ensuring compliance with international legal standards and establishing appropriate governance frameworks have become essential for maintaining consumer trust and safeguarding the integrity of the global digital economy.

CONCEPTUAL FRAMEWORK

The COVID-19 pandemic marked a fundamental turning point in the evolution of global electronic commerce and cross-border online transactions, fundamentally reshaping the way businesses, financial institutions, and consumers engage in international trade. Before the pandemic, digital commerce had already been experiencing steady growth; however, the health crisis dramatically accelerated this process by forcing governments, enterprises, and individuals to adopt digital solutions at an unprecedented pace. The widespread implementation of lockdowns, travel restrictions, border controls, social distancing measures, and the temporary closure of physical retail outlets significantly limited traditional commercial activities. As a result, businesses increasingly shifted their operations to online platforms, while consumers relied more heavily on digital channels to purchase goods and services from domestic and international markets.

This rapid digital transformation led to a substantial increase in the volume and value of cross-border online transactions. Digital payment systems, electronic marketplaces, online banking services, and financial technology (FinTech) solutions became essential instruments for maintaining economic activity during the pandemic. Small and medium-sized enterprises (SMEs), which had previously relied primarily on traditional distribution channels, increasingly embraced e-commerce to reach international customers and sustain business continuity. At the same time, consumers demonstrated greater confidence in digital payment methods, contributing to the expansion of the global digital economy and strengthening international commercial connectivity.

Nevertheless, the accelerated growth of cross-border digital commerce also exposed significant vulnerabilities within the global financial ecosystem. The unprecedented increase in online transactions created new opportunities for cybercriminals to exploit weaknesses in digital payment infrastructures. Financial fraud, identity theft, phishing campaigns, payment card fraud, account takeover attacks, money laundering schemes, and other forms of cybercrime increased considerably during the COVID-19 period. Traditional fraud detection mechanisms, which often relied on manual verification procedures or rule-based systems, proved insufficient to cope with the growing complexity, speed, and scale of international digital transactions. Consequently, financial institutions, payment service providers, regulatory authorities, and e-commerce platforms faced increasing pressure to modernize their risk management systems and adopt more sophisticated technological solutions.

In response to these challenges, artificial intelligence (AI), machine learning, and automation emerged as indispensable technologies for strengthening the security, efficiency, and resilience of cross-border online transactions. AI-powered systems enabled the real-time analysis of massive volumes of

transactional data, allowing financial institutions to identify suspicious behavioural patterns, detect anomalies, assess transaction risks, and prevent fraudulent activities more effectively than traditional monitoring methods. These intelligent systems also contributed to reducing operational costs, improving customer experience, accelerating transaction processing, and supporting regulatory compliance in an increasingly complex international financial environment.

International organizations have recognized the transformative impact of the COVID-19 pandemic on digital trade and financial services. The United Nations Conference on Trade and Development (UNCTAD), among other international institutions, has emphasized that the pandemic significantly accelerated digital transformation across both developed and developing economies. According to UNCTAD, the crisis reinforced the strategic importance of digital technologies and cross-border e-commerce as essential mechanisms for maintaining business continuity, supporting international trade, and enhancing economic resilience during periods of global disruption. The pandemic demonstrated that digital commerce is no longer merely an alternative distribution channel but has become a fundamental pillar of the modern global economy, requiring continuous technological innovation alongside effective legal, regulatory, and cybersecurity frameworks to ensure secure, transparent, and trustworthy cross-border transactions (UNCTAD, 2022).

The exponential growth in the volume of cross-border online transactions has fundamentally transformed the global financial landscape, creating an urgent need for more sophisticated, scalable, and intelligent mechanisms capable of managing increasingly complex digital payment ecosystems. As international electronic commerce expanded rapidly particularly following the acceleration of digitalization during the COVID-19 pandemic financial institutions and payment service providers were required to process millions of transactions originating from different jurisdictions, currencies, regulatory environments, and technological infrastructures. Traditional monitoring systems, which largely relied on predefined rules and manual verification procedures, became increasingly inadequate for handling the speed, complexity, and scale of modern cross-border financial operations.

The vast amount of transactional data generated every second requires advanced technologies capable of analysing information in real time while simultaneously identifying suspicious activities, detecting emerging fraud patterns, and assessing potential financial risks without disrupting legitimate commercial transactions. In this context, organizations can no longer rely solely on conventional compliance procedures or human intervention. Instead, they require intelligent systems that continuously learn from historical and real-time data, adapt to evolving fraud techniques, and support rapid decision-making under dynamic market conditions.

Consequently, artificial intelligence (AI), machine learning (ML), and intelligent automation have become indispensable components of the digital infrastructure supporting international financial services and cross-border electronic commerce. These technologies are now extensively deployed by banks, financial institutions, payment processors, FinTech companies, electronic marketplaces, and digital payment platforms to improve operational efficiency while strengthening transaction security and regulatory compliance.

Artificial intelligence enables the processing and interpretation of enormous datasets that would be impossible to analyse manually within an acceptable timeframe. Machine learning algorithms continuously examine transactional patterns, customer behaviour, geographical information, device characteristics, payment histories, and numerous other variables to distinguish legitimate financial activities from potentially fraudulent ones. Unlike traditional rule-based systems, machine learning models are capable of continuously improving their predictive performance by learning from newly available data and adapting to previously unseen fraud strategies. This adaptive capability significantly enhances the resilience of financial systems against increasingly sophisticated cyber threats and organized financial crime.

Another essential contribution of artificial intelligence lies in automated fraud detection. AI-powered monitoring systems analyse transactions almost instantaneously, identifying anomalies that may indicate payment fraud, identity theft, account takeover attempts, money laundering activities, or other forms of financial misconduct. By assigning risk indicators to each transaction, these systems enable financial institutions to intervene immediately when suspicious behaviour is detected while allowing legitimate

transactions to proceed with minimal delay. As a result, artificial intelligence not only minimizes financial losses but also improves customer confidence in digital payment systems by providing faster, safer, and more reliable transaction processing.

In addition to fraud detection, artificial intelligence plays a critical role in automated risk assessment. Advanced predictive analytics models evaluate multiple financial, behavioural, and contextual variables to calculate the probability that a transaction or customer represents a potential risk. These automated risk-scoring mechanisms assist financial institutions in determining whether a transaction should be approved, rejected, temporarily suspended, or subjected to additional verification procedures. Such capabilities are particularly valuable in cross-border transactions, where differences in regulatory frameworks, currencies, customer profiles, and geopolitical risks substantially increase operational complexity.

Artificial intelligence and automation also contribute significantly to the optimization of operational processes throughout the financial sector. Numerous repetitive and time-consuming activities including customer identity verification (Know Your Customer – KYC), anti-money laundering (AML) screening, transaction reconciliation, document validation, sanctions screening, compliance monitoring, and reporting can now be performed automatically with greater speed and accuracy than traditional manual procedures. This automation reduces administrative burdens, minimizes human error, shortens transaction processing times, and allows financial professionals to focus on higher-value strategic, analytical, and supervisory responsibilities.

Furthermore, intelligent technologies have become increasingly important for ensuring regulatory compliance in an environment characterized by constantly evolving legal and supervisory requirements. Financial institutions operating internationally must comply with complex regulations concerning anti-money laundering, counter-terrorist financing, data protection, consumer protection, sanctions enforcement, and financial reporting. AI-powered compliance systems continuously monitor transactions, identify regulatory risks, generate alerts, and produce documentation that supports auditability and supervisory oversight. This significantly improves institutional capacity to comply with both national and international regulatory standards while reducing compliance costs and increasing operational transparency.

Overall, the rapid expansion of cross-border online transactions has accelerated the transition from conventional financial management systems toward intelligent, data-driven digital ecosystems. Artificial intelligence, machine learning, and automation are no longer optional technological innovations but have become fundamental pillars of the modern global financial infrastructure. Their ability to process vast amounts of information in real time, detect fraudulent activities, evaluate risks with high precision, automate complex operational processes, and facilitate regulatory compliance has made them indispensable for ensuring the security, efficiency, resilience, and sustainability of cross-border digital financial services in the increasingly interconnected global economy.

From a conceptual perspective, the application of artificial intelligence (AI) in the management of cross-border online transactions can be understood through a multidimensional framework that encompasses four closely interconnected and mutually reinforcing components: automated fraud detection, risk scoring, process automation, and the ethical and legal implications arising from the deployment of AI-driven systems. Rather than functioning as isolated technological capabilities, these dimensions interact to create an integrated digital ecosystem that enhances the security, efficiency, transparency, and resilience of international financial transactions. Together, they provide a comprehensive analytical framework for examining how artificial intelligence has transformed the operation of cross-border digital commerce and international payment systems.

The first dimension, automated fraud detection, focuses on the ability of artificial intelligence to identify suspicious activities, fraudulent transaction patterns, and cyber threats through advanced data analytics and machine learning algorithms. By continuously monitoring large volumes of transactional data in real time, AI systems can recognize anomalies that may indicate unauthorized access, identity theft, payment fraud, money laundering, or other forms of financial misconduct. This capability has become increasingly important as the rapid expansion of digital commerce has exposed financial institutions to more sophisticated and constantly evolving cyber risks.

The second dimension, risk scoring, concerns the use of predictive analytics and intelligent algorithms to evaluate the likelihood that a transaction, customer, or business relationship presents financial or regulatory risks. AI-based risk assessment systems analyse a wide range of variables including historical transaction records, behavioural patterns, geographical information, device characteristics, and customer profiles to generate dynamic risk scores that support decision-making. These automated assessments enable financial institutions to authorize transactions more efficiently, prioritize compliance efforts, and allocate resources to higher-risk activities while maintaining a balance between security and operational efficiency.

The third dimension, process automation, emphasizes the transformative role of artificial intelligence in optimizing operational workflows across the financial sector. AI-powered automation extends beyond fraud prevention and risk assessment by streamlining numerous administrative and compliance-related tasks, including customer identity verification (Know Your Customer – KYC), anti-money laundering (AML) monitoring, transaction reconciliation, document verification, sanctions screening, and regulatory reporting. By reducing manual intervention and minimizing human error, intelligent automation improves processing speed, lowers operational costs, increases productivity, and enables organizations to manage the growing complexity of international financial transactions more effectively.

The fourth dimension encompasses the ethical and legal implications associated with the deployment of artificial intelligence in cross-border financial services. Although AI offers significant operational and security advantages, its increasing use also raises complex questions regarding algorithmic transparency, accountability, explainability, fairness, privacy, data protection, and non-discrimination. Many advanced AI systems operate as highly sophisticated "black-box" models whose decision-making processes may not be easily understood or explained by users, regulators, or even developers. Consequently, concerns have emerged regarding the legal responsibility for automated decisions, the protection of individual rights, and the potential risks of algorithmic bias or unjustified discrimination in financial decision-making. These issues have prompted governments and international organizations to develop regulatory frameworks aimed at ensuring that AI technologies are deployed responsibly, transparently, and in compliance with fundamental legal principles.

Collectively, these four dimensions constitute the theoretical foundation of the present study and provide a comprehensive conceptual framework for analysing the evolving role of artificial intelligence in the management of cross-border online transactions. They illustrate how technological innovation has fundamentally reshaped international financial services by integrating intelligent decision-making, predictive analytics, and automated operational processes into modern digital payment infrastructures.

Moreover, these dimensions reflect the profound structural changes that have taken place within the global financial sector following the COVID-19 pandemic. The unprecedented acceleration of digital transformation during and after the pandemic significantly increased reliance on electronic commerce, digital payment systems, cloud-based financial services, and artificial intelligence technologies. As financial institutions sought to manage higher transaction volumes, respond to increasingly sophisticated cyber threats, and comply with evolving regulatory requirements, AI became an essential component of digital financial infrastructure. Therefore, examining automated fraud detection, risk scoring, process automation, and the associated ethical and legal challenges provides a comprehensive understanding of how artificial intelligence contributes to the security, efficiency, resilience, and sustainability of cross-border online transactions in the post-pandemic digital economy.

Automated Fraud Detection

Automated fraud detection is widely recognized as one of the most significant and impactful applications of artificial intelligence in the field of international electronic commerce and cross-border online financial transactions. As global digital commerce continues to expand and millions of transactions are processed every minute across multiple jurisdictions, currencies, and payment platforms, traditional fraud prevention methods have become increasingly inadequate. Conventional approaches, which primarily rely on predefined rules, manual reviews, and static verification procedures, are often unable to respond effectively to the speed, complexity, and constantly evolving nature of modern financial

fraud. Consequently, artificial intelligence has emerged as a critical technological solution capable of enhancing the security, efficiency, and reliability of digital payment systems.

AI-powered fraud detection systems are primarily based on machine learning algorithms that continuously analyse enormous volumes of transactional data in real time. These intelligent systems examine multiple variables simultaneously, including transaction amounts, payment frequency, geographic location, device information, purchasing behaviour, login patterns, IP addresses, customer profiles, and historical financial records. By processing this information almost instantaneously, machine learning models are capable of recognizing complex behavioural patterns that may indicate suspicious or fraudulent activities. Unlike conventional rule-based systems, artificial intelligence can identify subtle relationships and hidden correlations among large datasets that would be impossible for human analysts to detect within a reasonable timeframe.

A fundamental advantage of machine learning lies in its ability to recognize unusual behavioural patterns and transactional anomalies that deviate from established customer profiles. For example, if a customer who normally conducts low-value domestic transactions suddenly initiates several high-value international payments from an unfamiliar location or device, the AI system can immediately classify this activity as potentially suspicious. Similarly, abrupt changes in purchasing behaviour, repeated failed authentication attempts, rapid sequences of transactions, or unusual payment destinations may trigger automated alerts for further investigation. Through continuous behavioural analysis, artificial intelligence can distinguish between legitimate changes in consumer activity and patterns that are consistent with fraudulent conduct.

Another important characteristic of AI-based fraud detection systems is their ability to learn and improve continuously over time. Machine learning algorithms are trained using extensive historical datasets containing both legitimate and fraudulent transactions. During this training process, the system learns to identify distinguishing characteristics associated with various types of financial fraud, including payment card fraud, account takeover, identity theft, phishing-related transactions, money laundering schemes, synthetic identity fraud, and other forms of cyber-enabled financial crime. As new transactional data become available, these algorithms continuously update their predictive models, allowing them to adapt to emerging fraud techniques and increasingly sophisticated criminal strategies. This adaptive learning capability represents a major advantage over traditional fraud detection systems, which require frequent manual updates to predefined detection rules.

In addition to historical transaction records, modern AI systems also incorporate behavioural analytics into their decision-making processes. Behavioural indicators including typing speed, navigation patterns, device usage, login frequency, transaction timing, purchasing preferences, and customer interaction habits provide valuable contextual information that helps distinguish genuine users from potential fraudsters. By combining historical financial data with real-time behavioural information, artificial intelligence can generate a comprehensive risk profile for each transaction, significantly improving the accuracy of fraud detection while reducing unnecessary interruptions for legitimate customers.

The implementation of automated fraud detection systems provides substantial benefits for financial institutions, payment service providers, and e-commerce platforms. One of the most important advantages is the significant reduction of financial losses resulting from fraudulent transactions. By identifying suspicious activities before transactions are completed or shortly thereafter, AI systems enable organizations to intervene rapidly, block unauthorized payments, initiate additional verification procedures, and prevent further criminal activity. At the same time, automated fraud detection contributes to strengthening consumer confidence in digital payment systems by providing a safer and more secure online shopping environment.

Furthermore, artificial intelligence improves operational efficiency by reducing dependence on manual transaction reviews. Instead of requiring human analysts to examine every potentially suspicious payment, AI systems automatically prioritize high-risk cases and generate risk-based alerts for further investigation. This allows fraud investigators to focus their attention on the most significant threats while enabling the vast majority of legitimate transactions to be processed without delay. Consequently,

financial institutions benefit from lower operational costs, faster transaction processing, improved customer satisfaction, and enhanced overall system performance.

Despite these considerable advantages, automated fraud detection is not without limitations. The effectiveness of AI models depends heavily on the quality, diversity, and representativeness of the data used during the training process. Incomplete, outdated, biased, or inaccurate datasets may negatively affect algorithm performance and reduce detection accuracy. Additionally, fraud detection systems may produce false positives, in which legitimate transactions are incorrectly classified as fraudulent, causing unnecessary payment interruptions and customer dissatisfaction. Conversely, false negatives may occur when genuinely fraudulent transactions are mistakenly identified as legitimate, allowing financial criminals to evade detection and potentially cause significant financial losses. Therefore, maintaining high levels of algorithmic accuracy requires continuous model training, regular performance evaluation, high-quality data governance, and ongoing adaptation to newly emerging fraud techniques.

Overall, automated fraud detection has become an indispensable component of contemporary cross-border online transaction management. By combining artificial intelligence, machine learning, behavioural analytics, and real-time data processing, these systems significantly enhance the security, efficiency, and resilience of global digital payment infrastructures. As international electronic commerce continues to expand and cyber threats become increasingly sophisticated, AI-driven fraud detection will remain a cornerstone of modern financial risk management and an essential mechanism for safeguarding the integrity and trustworthiness of the global digital economy (Tax et. al., 2021).

The COVID-19 pandemic significantly altered the global digital landscape by accelerating the adoption of electronic commerce, online banking, and cross-border digital payment systems. While this rapid digital transformation created substantial economic opportunities and ensured business continuity during periods of lockdown and social distancing, it also provided cybercriminals with new avenues for exploiting vulnerabilities within digital financial ecosystems. As millions of consumers and businesses shifted their commercial activities to online platforms, the volume of electronic transactions increased dramatically, creating a broader attack surface for financial fraud and cybercrime. Consequently, the pandemic period was accompanied by a substantial rise in online fraud, identity theft, phishing campaigns, account takeover attacks, payment card fraud, business email compromise, social engineering schemes, and other forms of cyber-enabled financial crime.

The unprecedented expansion of cross-border e-commerce also enabled fraudsters to exploit differences in national regulatory frameworks, payment infrastructures, and cybersecurity capabilities across jurisdictions. Criminal organizations rapidly adapted their methods to take advantage of increased consumer reliance on digital services, using sophisticated techniques that combined artificial intelligence, automated malware, fake online marketplaces, fraudulent payment requests, and stolen personal information to bypass traditional security mechanisms. At the same time, many first-time users of digital payment platforms lacked sufficient awareness of cybersecurity risks, making them particularly vulnerable to deception and financial exploitation.

These evolving threats exposed the limitations of conventional fraud prevention systems, which were largely based on predefined rules, manual transaction reviews, and static risk indicators. Such approaches proved insufficient to cope with the enormous increase in transaction volumes and the constantly changing tactics employed by cybercriminals. Financial institutions, payment service providers, and e-commerce platforms therefore recognized the urgent need to modernize their fraud prevention strategies by adopting more adaptive, intelligent, and scalable technological solutions.

In response to these challenges, financial institutions significantly accelerated the implementation of artificial intelligence (AI), machine learning, and automated analytics as integral components of their fraud detection and risk management frameworks. AI-powered monitoring systems enabled continuous, real-time surveillance of millions of domestic and international transactions, allowing organizations to identify suspicious activities with a level of speed and accuracy that would be impossible through manual analysis alone. By continuously examining transactional data, customer behaviour, geographical patterns, device characteristics, payment histories, and numerous contextual variables, these intelligent systems could rapidly detect anomalies that might indicate fraudulent activity.

Machine learning algorithms also offered an important advantage through their ability to continuously improve their predictive capabilities. Rather than relying exclusively on predefined fraud rules, AI systems learned from historical transaction data and adapted to newly emerging fraud techniques as additional information became available. This adaptive learning process enabled financial institutions to respond more effectively to increasingly sophisticated cyber threats while minimizing unnecessary disruptions to legitimate transactions.

Furthermore, the widespread deployment of AI-based fraud detection systems during and after the COVID-19 pandemic contributed not only to strengthening financial security but also to improving operational efficiency. Automated monitoring reduced the workload associated with manual transaction reviews, accelerated decision-making processes, and enabled institutions to allocate investigative resources more effectively toward high-risk cases. As a result, artificial intelligence became an essential component of modern digital financial infrastructure, supporting both the resilience of cross-border payment systems and the continued growth of the global digital economy in the post-pandemic era (UNCTAD, 2022).

Despite the significant advantages offered by artificial intelligence in the detection and prevention of financial fraud, the effectiveness and reliability of these systems are highly dependent on the quality, accuracy, completeness, and representativeness of the data used to develop and train their underlying algorithms. Machine learning models derive their predictive capabilities from historical datasets that contain information about both legitimate and fraudulent transactions. Consequently, if the training data are incomplete, outdated, inaccurate, inconsistent, or biased, the algorithm's ability to distinguish between normal and suspicious transactional behaviour may be substantially compromised. High-quality data therefore constitute the foundation upon which effective AI-based fraud detection systems are built, making data governance, validation, and continuous quality control essential components of successful implementation.

Moreover, the dynamic nature of cybercrime requires predictive models to be updated and retrained on a continuous basis. Fraudsters constantly develop new techniques, modify their behavioural patterns, and exploit emerging technological vulnerabilities to circumvent existing security measures. As a result, machine learning algorithms that are not regularly updated may gradually lose their predictive accuracy, becoming less effective at recognizing newly emerging forms of financial fraud. Continuous model retraining using recent transactional data enables artificial intelligence systems to adapt to evolving criminal strategies, improve their detection capabilities, and maintain high levels of operational performance within rapidly changing digital financial environments.

Another critical challenge associated with AI-based fraud detection concerns the occurrence of classification errors, commonly referred to as false positives and false negatives. A false positive occurs when the system incorrectly classifies a legitimate transaction as fraudulent or suspicious. In such cases, genuine customers may experience unnecessary payment declines, temporary account restrictions, additional identity verification procedures, or delays in completing financial transactions. These interruptions can negatively affect customer satisfaction, reduce confidence in digital payment platforms, and impose additional operational costs on financial institutions that must manually investigate transactions that ultimately prove to be legitimate.

Conversely, a false negative occurs when an actual fraudulent transaction is incorrectly classified as legitimate and is therefore allowed to proceed without intervention. This type of error may expose financial institutions, businesses, and consumers to substantial financial losses, identity theft, money laundering activities, or other forms of cyber-enabled financial crime. False negatives are particularly concerning because they undermine the primary objective of fraud detection systems, namely the timely identification and prevention of illicit financial activities before significant damage occurs.

Achieving an appropriate balance between minimizing false positives and reducing false negatives remains one of the most challenging aspects of designing and deploying artificial intelligence systems for financial fraud detection. Excessively sensitive algorithms may generate a large number of false alerts, creating inconvenience for customers and increasing operational workloads for fraud investigators. Conversely, models designed to minimize customer disruption may become overly

permissive, allowing sophisticated fraudulent transactions to evade detection. Financial institutions must therefore continuously calibrate their predictive models to optimize both security and user experience.

In addition to algorithmic refinement, maintaining high detection accuracy requires continuous monitoring of model performance, regular validation against new datasets, rigorous testing under diverse transactional scenarios, and ongoing evaluation of emerging fraud patterns. Human oversight also remains an important component of effective fraud prevention, as experienced analysts can review complex or ambiguous cases that automated systems may find difficult to classify accurately. Consequently, the most effective fraud detection strategies combine advanced artificial intelligence with expert human judgment, ensuring that technological innovation is complemented by appropriate governance, supervision, and accountability.

Risk Scoring

Risk scoring represents an advanced analytical process through which artificial intelligence algorithms evaluate and predict the likelihood of a potential adverse event occurring by examining extensive amounts of historical, financial, transactional, and behavioural data associated with users and their activities. In the context of cross-border online transactions, risk scoring systems function as intelligent decision-support mechanisms that enable financial institutions, payment service providers, and digital commerce platforms to assess the level of risk associated with individual transactions, customers, or business relationships. By analysing multiple variables simultaneously, these systems generate risk assessments that help determine whether a transaction should be approved, subjected to additional verification procedures, temporarily restricted, or rejected due to potential security concerns.

Modern AI-driven risk scoring models rely on machine learning algorithms capable of identifying complex relationships and behavioural patterns that may not be visible through traditional analytical methods. These systems evaluate factors such as transaction history, payment frequency, geographical location, device characteristics, spending behaviour, account activity, and previous risk indicators in order to calculate a dynamic risk profile. Unlike conventional assessment methods based on fixed criteria, artificial intelligence allows risk evaluations to be continuously updated as new data become available, improving the accuracy and responsiveness of financial decision-making processes.

The implementation of automated risk scoring has significantly transformed the way financial institutions manage transaction authorization and fraud prevention. Instead of relying exclusively on manual reviews, organizations can now make near-instantaneous decisions regarding transaction legitimacy while maintaining a high level of security. When an AI system identifies a transaction with an elevated risk level, it can automatically trigger additional authentication measures, request supplementary customer verification, or initiate further compliance checks. Conversely, low-risk transactions can be processed rapidly with minimal disruption, improving both operational efficiency and customer experience.

The post-COVID-19 period further accelerated the adoption of AI-based risk scoring systems due to the substantial increase in the volume and complexity of international digital transactions. The rapid expansion of cross-border e-commerce, online payments, and remote financial services made manual risk assessment practically impossible, as human-based evaluation methods could no longer effectively process the scale and speed of modern digital transactions. Consequently, financial institutions increasingly turned to predictive analytics and machine learning models to manage growing transaction flows and respond more efficiently to emerging financial risks.

By automating risk assessment procedures, artificial intelligence contributes to reducing operational costs, minimizing human errors, and improving the overall effectiveness of fraud prevention strategies. These systems allow institutions to allocate resources more efficiently by focusing human expertise on complex or high-risk cases while routine assessments are handled automatically. At the same time, faster and more accurate decision-making enhances user experience by reducing transaction delays and unnecessary security interventions.

However, despite their advantages, AI-based risk scoring systems also present important challenges related to data quality, algorithmic transparency, and potential bias. Since these models rely heavily on

historical data, inaccurate or incomplete information may influence the accuracy of risk predictions. Furthermore, biased training datasets may lead to unfair outcomes or disproportionate risk assessments for certain categories of users. Therefore, ensuring transparency, accountability, continuous monitoring, and compliance with data protection principles remains essential for the responsible implementation of artificial intelligence in financial risk management (United Nations, 2023).

Process Automation

Automation has become one of the fundamental pillars of the digital transformation of financial services, significantly reshaping the way institutions manage, process, and monitor modern financial operations. In the context of increasingly complex cross-border online transactions, automation provides the technological foundation necessary for handling large volumes of financial activities with greater speed, accuracy, and reliability. By integrating artificial intelligence, machine learning, robotic process automation (RPA), and advanced data analytics, financial organizations are able to replace numerous time-consuming manual procedures with intelligent, automated workflows that improve operational efficiency and strengthen transaction security.

Artificial intelligence enables the automation of a wide range of financial and administrative processes that traditionally required significant human involvement. Among the most important applications are transaction validation, customer identity verification procedures (Know Your Customer – KYC), anti-money laundering (AML) monitoring, regulatory compliance assessment, payment reconciliation, document verification, fraud monitoring, and the analysis of commercial and financial documentation. Through automated systems, these activities can be performed continuously and in real time, reducing processing delays and ensuring a higher degree of consistency in decision-making.

One of the most important contributions of artificial intelligence-based automation is the optimization of transaction verification and authorization processes. In traditional financial systems, transaction approval often involved multiple manual checks, which could slow down payment processing and increase administrative costs. Automated systems, however, are capable of instantly analysing transactional information, comparing it with predefined regulatory requirements and risk indicators, and determining whether additional verification measures are necessary. This capability is particularly valuable in cross-border transactions, where differences in legal frameworks, currencies, payment infrastructures, and compliance requirements create additional operational complexity.

Customer identification and verification processes have also been significantly transformed through automation. AI-powered KYC solutions can analyse identification documents, biometric information, customer profiles, and behavioural patterns to verify identities more efficiently and accurately. These technologies help financial institutions comply with regulatory obligations related to customer due diligence while simultaneously improving the user experience by reducing verification times and simplifying access to digital financial services.

Another important application of automation concerns compliance monitoring and regulatory reporting. Financial institutions operating internationally must comply with numerous legal requirements related to financial transparency, anti-money laundering measures, sanctions screening, data protection, and consumer protection. Automated compliance systems continuously monitor transactions, identify potential regulatory violations, generate alerts, and support the preparation of compliance reports. This reduces the administrative burden on institutions and improves their ability to respond rapidly to regulatory changes and emerging risks.

The COVID-19 pandemic significantly accelerated the adoption of automation technologies within the financial sector and digital commerce environment. The restrictions imposed during the pandemic, combined with the rapid increase in online shopping, remote banking, and electronic payments, created an urgent need for financial institutions and e-commerce platforms to expand their digital capabilities. Organizations were required to manage substantially higher volumes of online transactions while maintaining service continuity, security, and compliance with regulatory obligations. As a result, automation became an essential instrument for ensuring operational resilience during periods of economic and social uncertainty.

The increased reliance on digital services after the pandemic further reinforced the importance of automated financial processes. Banks, payment providers, and electronic commerce platforms increasingly adopted intelligent automation solutions to improve scalability, reduce dependence on manual procedures, and respond more effectively to changing customer expectations. Automated systems allowed organizations to process larger transaction volumes without a proportional increase in operational resources, thereby supporting the continued expansion of global digital commerce.

From an economic perspective, process automation provides significant advantages by reducing processing times, lowering operational expenses, and minimizing the risk of human error. Repetitive and routine activities can be performed more efficiently by automated systems, allowing employees to focus on more complex analytical, strategic, and supervisory tasks. Furthermore, automation contributes to greater accuracy and consistency in financial operations, reducing the probability of mistakes that may generate financial losses or compliance issues.

However, the implementation of automated systems also requires careful consideration of technological, legal, and organizational challenges. Dependence on digital infrastructures increases exposure to cybersecurity risks, system failures, and potential misuse of automated decision-making mechanisms. In addition, organizations must ensure that automated processes comply with principles of transparency, accountability, data protection, and fairness, particularly when these systems influence decisions affecting customers and financial transactions.

Overall, process automation represents a central component of the digital evolution of international financial services and cross-border online commerce. By integrating artificial intelligence and intelligent automation technologies, financial institutions can improve transaction efficiency, enhance security mechanisms, reduce operational costs, and strengthen their capacity to manage the growing complexity of the global digital economy. In the post-COVID-19 environment, automation has become not merely a technological advantage but a strategic necessity for ensuring the competitiveness, resilience, and sustainability of modern financial systems (United Nations, 2023).

Ethical and Legal Implications

The rapid expansion of artificial intelligence (AI) applications in cross-border online transactions has generated a wide range of complex ethical, legal, and regulatory challenges that must be carefully addressed to ensure the responsible and sustainable development of the digital financial ecosystem. Although AI technologies provide significant advantages in terms of fraud prevention, risk assessment, transaction efficiency, and operational optimization, their increasing influence on financial decision-making processes raises fundamental questions regarding transparency, accountability, fairness, privacy protection, and the preservation of individual rights.

One of the most significant challenges associated with the use of artificial intelligence in digital financial services concerns the limited transparency of certain algorithmic decision-making systems. Many advanced machine learning models, particularly those based on deep learning techniques, operate as complex computational structures whose internal decision-making mechanisms are difficult to interpret even by their developers. These systems are frequently described as "*black-box algorithms*", as they can generate accurate predictions or classifications without providing a clear and understandable explanation of how specific decisions were reached. In the context of cross-border financial transactions, this lack of explainability creates important concerns because automated decisions may directly influence whether a transaction is approved, delayed, rejected, or subjected to additional verification procedures.

The absence of sufficient algorithmic transparency may create difficulties in establishing responsibility when errors occur. For example, if an AI-based fraud detection system incorrectly blocks a legitimate transaction or inaccurately identifies a customer as high-risk, questions arise regarding who should bear legal responsibility for the consequences of such automated decisions the financial institution, the technology provider, the developers of the algorithm, or another involved entity. Therefore, ensuring clear accountability mechanisms represents a fundamental requirement for the responsible deployment of artificial intelligence in financial environments.

Another major ethical and legal concern relates to the extensive processing of personal data required for the effective operation of AI systems. Artificial intelligence algorithms used in fraud detection, risk scoring, and customer verification processes rely on the analysis of large quantities of information, including transactional histories, behavioural patterns, location data, device characteristics, and identity-related information. While such data processing can significantly improve security and efficiency, it also creates potential risks regarding privacy violations, unauthorized data use, excessive surveillance, and inadequate protection of personal information.

Consequently, the implementation of AI-driven systems must comply with fundamental principles of data protection, including lawfulness, fairness, transparency, purpose limitation, data minimization, proportionality, and security of processing. Financial institutions and digital service providers must ensure that personal data are collected and processed only for legitimate purposes, that users are adequately informed about automated decision-making processes, and that appropriate technical and organizational safeguards are implemented to prevent misuse, unauthorized access, or security breaches.

Furthermore, algorithmic bias represents another important ethical challenge associated with artificial intelligence-based decision-making. AI systems learn from historical datasets, and if these datasets contain existing social, economic, or institutional biases, the resulting algorithms may reproduce or amplify such patterns. In financial services, biased risk assessment models may lead to unfair treatment of certain groups of customers, unjustified transaction restrictions, or unequal access to digital financial services. Therefore, ensuring fairness and non-discrimination requires continuous monitoring, testing, and evaluation of AI systems throughout their operational lifecycle.

The emergence of regulatory frameworks specifically designed to govern artificial intelligence reflects the increasing importance of addressing these challenges. At the European level, the adoption of the Artificial Intelligence Act (AI Act) demonstrates the efforts of policymakers to establish a risk-based regulatory approach aimed at ensuring that AI systems are developed and used in a manner consistent with fundamental rights, transparency obligations, and accountability principles. The financial sector represents one of the areas where AI applications require particular attention due to the potential impact of automated decisions on consumers, businesses, and the stability of financial markets.

The AI Act introduces obligations related to risk management, data governance, technical documentation, human oversight, transparency, and monitoring for high-risk AI systems. These requirements are particularly relevant for financial institutions that use artificial intelligence for credit assessment, fraud prevention, identity verification, and other processes that may significantly affect individuals' economic interests. By establishing regulatory safeguards, the European approach seeks to create a balance between encouraging technological innovation and preventing potential harms associated with uncontrolled or irresponsible AI deployment.

Therefore, the integration of artificial intelligence into cross-border online transactions must be accompanied by effective governance mechanisms, algorithmic auditing procedures, and comprehensive legal safeguards aimed at protecting fundamental rights and maintaining public trust. Organizations implementing AI-based financial systems should adopt responsible AI principles, including transparency, explainability, human supervision, cybersecurity protection, and continuous risk assessment. Algorithmic audits and independent evaluations can contribute to identifying potential vulnerabilities, reducing bias, and ensuring compliance with applicable legal standards.

In conclusion, while artificial intelligence provides significant opportunities for enhancing the security and efficiency of cross-border online transactions, its implementation must be carefully balanced with ethical responsibilities and legal obligations. The future development of AI-driven financial systems depends not only on technological capabilities but also on the establishment of transparent, accountable, and rights-oriented governance frameworks. Ensuring that innovation operates within the boundaries of the rule of law and consumer protection will be essential for maintaining confidence in the global digital economy and achieving sustainable digital transformation (UNCTAD, 2024).

METHODOLOGY

This research adopts a multidisciplinary methodological framework designed to investigate the role and impact of artificial intelligence (AI) and automation in the management of cross-border online transactions, focusing particularly on four essential areas: automated fraud detection, risk assessment through scoring mechanisms, operational process automation, and the ethical and legal challenges associated with the implementation of AI-driven systems. The methodological design aims to provide a comprehensive examination of the technological transformation of digital financial services, with particular attention to the accelerated digitalization process triggered by the COVID-19 pandemic. The global health crisis significantly reshaped patterns of economic interaction by increasing reliance on electronic commerce platforms, digital payment infrastructures, and automated financial technologies. While this transformation created new opportunities for international trade and financial inclusion, it also generated additional risks related to cybersecurity, online fraud, data protection, and regulatory compliance.

The research follows a qualitative and analytical methodological approach, integrating theoretical investigation, comparative assessment, and critical evaluation of scientific literature, institutional reports, and regulatory documents concerning artificial intelligence, digital commerce, cybersecurity, financial technologies, and digital governance. The study examines relevant academic research, publications issued by international organizations, and strategic policy documents that analyse the evolution of electronic commerce and digital transformation processes during and after the COVID-19 pandemic. This approach allows for the identification of major technological trends, emerging challenges, and regulatory responses associated with the increasing adoption of AI in international financial activities.

A conceptual analytical method is employed to establish the theoretical foundation of the research and to examine the main dimensions through which artificial intelligence influences cross-border online transactions. The conceptual framework developed in this study is structured around four interconnected elements: (1) automated fraud detection, (2) AI-based risk scoring, (3) process automation, and (4) ethical and legal implications. The analysis of these dimensions provides a comprehensive perspective on the contribution of artificial intelligence to enhancing transaction security, improving operational performance, increasing financial efficiency, and supporting compliance with evolving regulatory requirements within the global digital financial ecosystem.

Furthermore, the research applies a comparative methodology to assess the differences between conventional transaction monitoring mechanisms and AI-based technological solutions. Traditional approaches, generally dependent on predefined rules, static indicators, and manual verification procedures, are examined in comparison with machine learning models capable of processing extensive datasets, identifying complex behavioural patterns, and adapting to constantly changing fraud strategies. This comparative perspective highlights the advantages of AI systems in terms of speed, predictive capacity, scalability, and adaptability, while also emphasizing their limitations related to accuracy, transparency, and dependence on high-quality data.

A systematic literature review methodology is also incorporated to identify the main scientific developments and research directions concerning the application of artificial intelligence in fraud prevention and financial risk management. The literature analysis focuses on key themes such as machine learning algorithms, predictive analytics, automated decision-making, cybersecurity mechanisms, algorithmic transparency, data governance, and privacy protection. Particular attention is given to studies addressing the limitations and risks associated with AI implementation, including algorithmic bias, inaccurate predictions, false positive and false negative outcomes, limited explainability, and challenges related to responsible AI deployment.

The study additionally applies a legal and regulatory analysis methodology in order to examine the implications of artificial intelligence adoption within cross-border financial transactions. This approach evaluates fundamental legal principles related to personal data protection, transparency, accountability, consumer rights, non-discrimination, and responsible technological governance. The research considers emerging regulatory developments, particularly the European Union’s regulatory approach toward artificial intelligence, including mechanisms aimed at ensuring adequate supervision, transparency

requirements, and risk management obligations for high-risk AI applications in areas such as financial services.

A practical, case-oriented analytical perspective is also incorporated to examine how artificial intelligence technologies are applied by financial institutions, payment service providers, and digital commerce platforms. The research explores practical implementations of AI-based systems in areas such as fraud monitoring, automated compliance verification, transaction authorization, customer identification procedures, and financial risk management. This applied dimension enables the identification of both the benefits and operational challenges associated with integrating artificial intelligence into real-world digital financial infrastructures.

The methodology further incorporates an interdisciplinary perspective by combining knowledge from multiple fields, including information technology, financial management, cybersecurity, legal studies, and ethics. Such an integrated approach is necessary because artificial intelligence in cross-border transactions represents a complex phenomenon that extends beyond technological innovation, involving significant economic, social, regulatory, and legal implications. The interaction between technological capabilities and legal safeguards is therefore essential for understanding the sustainable development of AI-based financial systems.

The temporal scope of the research emphasizes the period during and after the COVID-19 pandemic, when electronic commerce, digital payment systems, and automated financial services experienced accelerated adoption worldwide. The pandemic is considered a significant contextual factor that influenced the increased demand for intelligent security mechanisms, predictive risk evaluation tools, and automated solutions capable of supporting the growing volume and complexity of online transactions.

Overall, the proposed methodological framework enables a comprehensive assessment of the opportunities, challenges, and future implications associated with the integration of artificial intelligence into cross-border online transactions. By combining conceptual analysis, comparative research, systematic literature review, legal examination, and practical evaluation, the study demonstrates that AI and automation represent essential instruments for strengthening the security, efficiency, and resilience of the global digital economy. At the same time, the research emphasizes the necessity of appropriate governance mechanisms, ethical standards, and legal safeguards to ensure transparency, accountability, consumer protection, and respect for fundamental rights in the increasingly automated financial environment.

CONCLUSION AND DISCUSSION

The findings of this study reveal that artificial intelligence and automation have become key drivers of transformation in cross-border online transactions, particularly following the accelerated digitalization caused by the COVID-19 pandemic. The rapid expansion of e-commerce, digital payments, and online platforms created new economic opportunities while also increasing exposure to cyber fraud, data security risks, and financial vulnerabilities. Consequently, organizations have increasingly adopted AI-based solutions to improve the security, efficiency, and resilience of digital financial systems.

The analysis demonstrates that automated fraud detection is one of the most significant applications of AI in cross-border commerce. Machine learning algorithms enable financial institutions and digital platforms to analyse large volumes of transactional data in real time, identify suspicious patterns, and detect fraudulent activities more effectively than traditional methods. However, the reliability of these systems depends on data quality, continuous algorithmic improvement, and the reduction of false positive and false negative outcomes.

AI-driven risk scoring mechanisms also play an essential role in modern financial management by enabling faster and more accurate evaluation of transaction risks. These systems support automated decision-making, improve fraud prevention strategies, and allow institutions to manage increasing transaction volumes while maintaining operational efficiency.

Furthermore, automation contributes to the optimization of financial processes by improving the speed and accuracy of activities such as customer verification, compliance monitoring, payment processing, and document analysis. Nevertheless, the widespread adoption of AI raises important ethical and legal concerns related to transparency, accountability, privacy protection, algorithmic bias, and the explainability of automated decisions.

The study emphasizes that effective AI governance requires a balance between technological innovation and legal safeguards. Responsible implementation of artificial intelligence should include human oversight, data protection mechanisms, algorithmic auditing, and compliance with regulatory standards. In the context of cross-border transactions, international cooperation and harmonized regulatory approaches are essential for ensuring secure and sustainable digital commerce.

In conclusion, artificial intelligence and automation represent strategic tools for strengthening the security, efficiency, and resilience of global digital financial systems. Their successful integration requires not only technological development but also ethical responsibility, legal certainty, and consumer protection to maintain trust in the continuously evolving digital economy.

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AUTONOMOUS DESIGN SYSTEMS IN ARCHITECTURE: INTEGRATING EXPLAINABLE AI, LARGE LANGUAGE MODELS, AND DIGITAL TWIN TECHNOLOGIES

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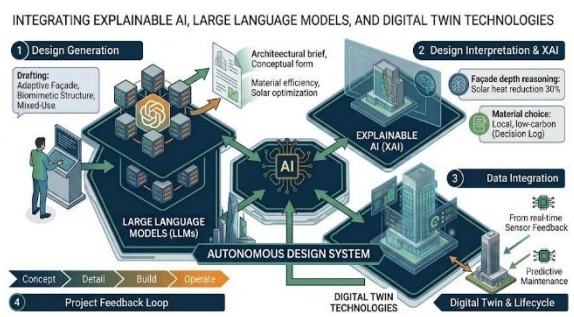
ABSTRACT

The architecture, engineering, and construction (AEC) industry is undergoing a profound digital transformation through the convergence of Artificial Intelligence (AI), Large Language Models (LLMs), Explainable Artificial Intelligence (XAI), and Digital Twin technologies. Autonomous design systems represent the next generation of intelligent architectural platforms capable of generating, evaluating, optimizing, and managing building designs with minimal human intervention while maintaining transparency, accountability, and sustainability. Unlike conventional Computer-Aided Design (CAD) and Building Information Modeling (BIM) tools, autonomous systems continuously integrate real-time sensor data, predictive analytics, and knowledge-driven reasoning to support adaptive decision-making throughout the building lifecycle. Recent advances in transformer-based LLMs have significantly enhanced design automation by enabling natural language interaction, automated code interpretation, generative design, and multidisciplinary collaboration. Simultaneously, Digital Twins provide continuously synchronized virtual representations of physical assets, facilitating predictive maintenance, performance optimization, and lifecycle management, while XAI addresses the longstanding challenge of AI opacity by improving the interpretability and trustworthiness of autonomous recommendations. This paper reviews recent developments in autonomous architectural design systems, synthesizing contemporary literature on intelligent design automation, explainable machine learning, LLM-enabled design assistants, and Digital Twin integration. The study further discusses emerging computational frameworks, implementation challenges, ethical considerations, interoperability issues, cybersecurity risks, and future research opportunities. The findings suggest that integrating XAI, LLMs, and Digital Twins substantially enhances design efficiency, decision transparency, sustainability, and operational intelligence while supporting human-centered architectural innovation. Nevertheless, challenges concerning governance, data quality, computational scalability, and regulatory compliance remain significant barriers to widespread implementation. The paper contributes a comprehensive perspective on the future evolution of autonomous architectural practice within intelligent built environments.

Keywords: Autonomous Design Systems; Digital Twin Technology; Explainable Artificial Intelligence (XAI); Large Language Models (LLMs).

INTRODUCTION



The rapid advancement of Artificial Intelligence (AI) has fundamentally transformed computational design methodologies within contemporary architecture. Traditional architectural design processes have progressively evolved from manual drafting to Computer-Aided Design (CAD), Building Information Modeling (BIM), and, more recently, intelligent autonomous design environments capable of generating optimized architectural solutions with minimal human intervention. Autonomous Design Systems (ADS) combine machine learning, deep neural networks, reinforcement learning, optimization algorithms, and knowledge-based reasoning to automate complex design tasks while continuously learning from historical projects and environmental data. Recent developments in Large Language Models (LLMs) have further revolutionized architectural workflows by enabling natural language interaction, automated design documentation, regulatory interpretation, and multidisciplinary collaboration across architecture, engineering, and construction teams. Concurrently, Digital Twin technology has emerged as a transformative cyber-physical paradigm that creates dynamic virtual replicas of physical buildings, continuously synchronizing operational data through IoT sensors to support predictive maintenance, lifecycle optimization, and sustainable building management. Explainable Artificial Intelligence (XAI) complements these technologies by addressing the "black-box" limitations of deep learning models, thereby enhancing transparency, accountability, and user trust in AI-assisted architectural decision-making. Collectively, these innovations are redefining architectural practice by shifting designers' roles from manual creators toward intelligent supervisors of autonomous computational systems. Recent studies demonstrate that integrating generative AI with Digital Twins significantly improves design exploration, scenario simulation, sustainability assessment, and real-time operational optimization while supporting resilient smart-city development. However, several technical and organizational challenges continue to limit widespread implementation, including interoperability among heterogeneous BIM platforms, algorithmic bias, cybersecurity vulnerabilities, governance frameworks, ethical accountability, computational costs, and insufficient explainability of AI-generated recommendations. As architectural projects become increasingly data-intensive and multidisciplinary, the integration of XAI, LLMs, and Digital Twins presents an unprecedented opportunity to establish transparent, adaptive, and human-centered autonomous design ecosystems. Consequently, this paper investigates current advances in autonomous architectural design systems, synthesizes contemporary research trends, evaluates their technological implications, and identifies future directions for intelligent architectural practice capable of supporting sustainable, resilient, and digitally connected built environments.

LITERATURE REVIEW

Evolution of Autonomous Design Systems in Architecture

The evolution of Autonomous Design Systems (ADS) in architecture reflects a progressive shift from computer-assisted drafting to intelligent computational environments capable of autonomous reasoning, design generation, optimization, and lifecycle management. Early architectural computing primarily relied on Computer-Aided Design (CAD) software to automate drafting tasks, followed by the emergence of Building Information Modeling (BIM), which introduced integrated digital representations of building geometry, materials, schedules, and operational information. While BIM significantly enhanced multidisciplinary collaboration, it remained dependent on human-directed modeling and decision-making (Eastman et al., 2018). Recent advances in Artificial Intelligence (AI) have transformed this paradigm by enabling systems that autonomously generate multiple design alternatives, evaluate performance indicators, and recommend optimal architectural solutions using data-driven algorithms. Contemporary autonomous design systems combine machine learning, deep learning, evolutionary optimization, reinforcement learning, and knowledge-based reasoning to perform

design exploration beyond human cognitive limitations. Generative Artificial Intelligence has further accelerated this transformation by introducing foundation models capable of understanding natural language instructions and translating them into conceptual architectural designs. Unlike conventional parametric modeling tools, modern autonomous systems leverage transformer-based Large Language Models (LLMs) to interpret client requirements, analyze planning regulations, generate design documentation, and facilitate interdisciplinary communication. These capabilities significantly reduce design iteration time while improving adaptability and collaborative decision-making across architecture, engineering, and construction (AEC) disciplines. Recent reviews indicate that LLM-assisted architectural workflows are increasingly integrated with Building Information Modeling (BIM), Computer Vision, and semantic reasoning frameworks, enabling more intelligent conceptual design and automated regulatory compliance checking. Parallel developments in Digital Twin technologies have expanded autonomous design beyond the pre-construction phase toward continuous lifecycle intelligence. Digital Twins synchronize real-time operational data from Internet of Things (IoT) devices with virtual building models, allowing autonomous systems to monitor structural performance, simulate environmental scenarios, predict maintenance requirements, and optimize operational efficiency throughout a building's lifespan. Explainable Artificial Intelligence (XAI) complements these developments by improving transparency and accountability in AI-assisted architectural decisions, thereby strengthening professional trust and regulatory acceptance. Human-centered explainability enables architects to understand the rationale behind algorithmic recommendations rather than relying solely on opaque "black-box" predictions. Consequently, contemporary autonomous design systems are evolving from isolated computational tools into intelligent, explainable, and adaptive cyber-physical ecosystems capable of supporting resilient, sustainable, and human-centered architectural practice.

Explainable Artificial Intelligence (XAI) for Transparent and Trustworthy Autonomous Architectural Design Systems

The increasing adoption of Artificial Intelligence (AI) in architectural design has significantly improved automation, optimization, and predictive decision-making. However, many AI models, particularly deep neural networks and transformer-based systems, operate as "black-box" algorithms whose internal decision processes are difficult for architects, engineers, and regulatory authorities to interpret. This lack of transparency has become a major obstacle to the widespread adoption of autonomous design systems, especially for safety-critical applications where design decisions directly affect structural integrity, occupant safety, environmental sustainability, and regulatory compliance (Adadi & Berrada, 2018). Explainable Artificial Intelligence (XAI) has consequently emerged as a critical research area aimed at making AI-generated recommendations understandable, interpretable, and trustworthy for human decision-makers. According to Guidotti et al. (2019), XAI encompasses computational techniques that provide human-understandable explanations of machine learning outputs without substantially compromising predictive performance. Within architectural practice, XAI enables designers to understand why an autonomous system recommends a particular spatial configuration, structural material, energy optimization strategy, or building orientation. Rather than replacing architects, explainable systems strengthen human-AI collaboration by supporting informed professional judgment throughout the design process. Arrieta et al. (2020) further argue that transparency, interpretability, fairness, and accountability constitute the four fundamental pillars of trustworthy AI systems, particularly in domains where algorithmic decisions have legal, ethical, and societal implications. Recent advances in Explainable AI have introduced several visualization and interpretation techniques applicable to autonomous architectural systems. Methods such as SHapley Additive exPlanations (SHAP), Local Interpretable Model-Agnostic Explanations (LIME), attention visualization, feature importance analysis, and counterfactual explanations allow architects to examine the variables influencing AI-generated design recommendations (Lundberg & Lee, 2017; Ribeiro et al., 2016). These approaches improve confidence in autonomous optimization by revealing how environmental factors, sustainability indicators, occupancy patterns, cost constraints, and regulatory requirements influence computational design outcomes. In Digital Twin environments, XAI also facilitates real-time interpretation of predictive maintenance alerts, structural health assessments, and energy optimization decisions, thereby supporting more reliable lifecycle management of intelligent buildings. Large

Language Models (LLMs) further enhance explainability by generating natural-language justifications for AI-driven recommendations, translating complex computational outputs into understandable narratives for architects, engineers, clients, and policymakers. Recent studies demonstrate that integrating LLMs with XAI significantly improves transparency during conceptual design, automated code compliance checking, BIM-based decision support, and multidisciplinary collaboration within Architecture, Engineering, and Construction (AEC) workflows (Bommasani et al., 2022; OpenAI, 2025). Nevertheless, challenges remain regarding explanation fidelity, computational overhead, bias mitigation, privacy preservation, and standardized evaluation metrics. Consequently, integrating XAI into autonomous architectural design systems is increasingly recognized as essential for establishing trustworthy, ethical, and human-centered intelligent design environments capable of supporting future smart cities and sustainable infrastructure.

Large Language Models (LLMs) as Intelligent Design Assistants in Autonomous Architectural Systems

Large Language Models (LLMs) have emerged as one of the most transformative technologies in autonomous architectural design by enabling natural language understanding, contextual reasoning, knowledge retrieval, and human–computer interaction. Built upon transformer architectures, LLMs process vast repositories of textual and technical information to perform tasks such as design ideation, regulatory interpretation, Building Information Modeling (BIM) authoring, automated documentation, and multidisciplinary coordination. Unlike traditional rule-based computer-aided design systems, LLMs allow architects to communicate with intelligent design platforms using conversational language, thereby significantly reducing the complexity associated with conventional modeling interfaces. This paradigm shifts architectural computing from command-driven workflows toward knowledge-driven and user-centric autonomous design environments. Recent advances demonstrate that LLMs can function as intelligent design assistants throughout the architectural lifecycle. During conceptual design, LLMs analyze client requirements, sustainability objectives, zoning regulations, and historical design precedents to generate multiple design alternatives that satisfy functional and environmental constraints. Integration with Generative AI further enables text-to-design and text-to-BIM workflows, allowing architects to transform natural-language prompts directly into editable BIM models. For example, Text2BIM employs a multi-agent LLM framework capable of generating semantically rich building models from textual instructions while incorporating automated rule checking to improve model quality. Similarly, Speech-to-BIM systems enable voice-driven architectural modeling, reducing cognitive workload and improving productivity during early-stage design development. Beyond conceptual design, LLMs substantially enhance collaboration within Architecture, Engineering, and Construction (AEC) projects by interpreting building codes, summarizing technical specifications, generating construction documentation, and facilitating interdisciplinary communication among architects, structural engineers, mechanical engineers, and facility managers. When integrated with Digital Twins, LLMs provide intelligent interfaces for querying real-time building performance, explaining sensor anomalies, supporting predictive maintenance, and recommending operational improvements through natural-language dialogue. These capabilities bridge the gap between complex engineering data and human decision-making, enabling more accessible and explainable building intelligence. Emerging LLM-driven Digital Twin frameworks further demonstrate autonomous reasoning, semantic knowledge integration, and adaptive decision support across cyber-physical systems. Despite these advances, significant challenges remain. LLMs are susceptible to hallucinations, inaccurate regulatory interpretations, domain-specific knowledge gaps, privacy concerns, and high computational costs. Reliable deployment therefore requires retrieval-augmented generation (RAG), domain-specific fine-tuning, BIM validation engines, and human-in-the-loop verification to ensure factual accuracy and regulatory compliance. Consequently, LLMs should be viewed not as replacements for architects but as collaborative cognitive partners that augment creativity, automate repetitive tasks, and enhance evidence-based decision-making. As multimodal AI continues to evolve, the convergence of LLMs with Explainable AI, Computer Vision, BIM, and Digital Twin technologies is expected to establish the foundation for next-generation autonomous architectural ecosystems capable of delivering intelligent, sustainable, and resilient built environments.

Digital Twin Technologies for Intelligent and Autonomous Architectural Design Systems

Digital Twin (DT) technology has become a foundational component of autonomous design systems by creating dynamic, real-time virtual representations of physical buildings and infrastructure throughout their lifecycle. Unlike conventional Building Information Modeling (BIM), which primarily captures static design and construction information, Digital Twins continuously integrate data from Internet of Things (IoT) sensors, cyber-physical systems, cloud computing, and artificial intelligence to monitor, simulate, predict, and optimize building performance in real time. This continuous synchronization enables autonomous architectural systems to evaluate operational conditions, forecast maintenance requirements, optimize energy consumption, and support evidence-based decision-making across planning, construction, operation, and facility management (Boje et al., 2020). Consequently, Digital Twins have evolved from visualization tools into intelligent decision-support platforms that facilitate adaptive and resilient management of the built environment. The convergence of Digital Twins with Artificial Intelligence has significantly expanded the capabilities of autonomous architectural design. Machine learning algorithms embedded within Digital Twin platforms analyze historical and real-time operational data to identify hidden patterns, predict equipment failures, optimize space utilization, and simulate multiple design scenarios before physical implementation. According to Fuller et al. (2020), AI-powered Digital Twins improve lifecycle management by enabling predictive analytics that reduce operational risks and enhance sustainability. Similarly, Rasheed et al. (2020) emphasized that Digital Twins provide an effective computational framework for integrating physics-based simulation models with data-driven learning techniques, thereby improving the accuracy of complex engineering analyses. In architectural applications, these capabilities enable designers to evaluate building performance under varying environmental conditions, occupancy behaviors, and climate scenarios, thereby supporting resilient and sustainable design strategies. Recent advancements have further integrated Digital Twins with Large Language Models (LLMs) and Explainable Artificial Intelligence (XAI), creating intelligent environments capable of autonomous reasoning and transparent decision support. LLMs enable users to interact with Digital Twins using natural-language queries, allowing architects, engineers, and facility managers to retrieve operational insights, interpret predictive maintenance reports, and generate automated performance summaries without requiring specialized programming expertise (Yang et al., 2025). Simultaneously, XAI enhances transparency by explaining AI-generated predictions related to structural health, energy optimization, and resource allocation, thereby increasing stakeholder confidence in autonomous recommendations. These explainable Digital Twins are particularly valuable in safety-critical infrastructure, where understanding the rationale behind AI decisions is essential for regulatory compliance and professional accountability. Despite these advances, several implementation challenges remain. Interoperability among BIM platforms, IoT devices, Geographic Information Systems (GIS), and Digital Twin infrastructures continues to limit seamless data exchange. Additional concerns include cybersecurity threats, data privacy, high computational requirements, model scalability, and the absence of globally accepted Digital Twin standards for autonomous architectural systems (Jones et al., 2020). Addressing these challenges will require standardized data architectures, secure cloud-edge computing frameworks, semantic interoperability, and robust AI governance mechanisms. As Digital Twin technologies continue to mature, their integration with autonomous design systems is expected to transform architecture into a continuously adaptive, intelligent, and data-driven discipline capable of supporting smart buildings, sustainable cities, and resilient infrastructure throughout the entire asset lifecycle.

Human-AI Collaboration and Generative Design in Autonomous Architectural Practice

Human-Artificial Intelligence (Human-AI) collaboration has emerged as the dominant paradigm in autonomous architectural practice, replacing the notion that AI will fully substitute human designers. Contemporary research emphasizes that autonomous design systems are most effective when AI complements architects' creativity, critical thinking, ethical judgment, and contextual knowledge rather than functioning independently. Generative Artificial Intelligence (GenAI), particularly transformer-based Large Language Models (LLMs) and multimodal foundation models, enables architects to rapidly generate conceptual alternatives, optimize building performance, automate documentation, and evaluate multiple design scenarios while preserving human oversight throughout the decision-making process.

This collaborative intelligence enhances creativity, productivity, and evidence-based design without diminishing the architect's professional responsibility. Generative design has fundamentally transformed architectural workflows by enabling computational exploration of thousands of feasible design alternatives under predefined objectives such as energy efficiency, structural stability, occupant comfort, lifecycle cost, and environmental sustainability. Unlike traditional optimization techniques, modern AI-driven generative design combines deep learning, reinforcement learning, evolutionary computation, and LLM-assisted reasoning to iteratively refine architectural solutions based on multiple performance criteria. Architects consequently assume the role of design strategists who formulate objectives, evaluate AI-generated alternatives, and validate final decisions rather than manually producing every design iteration. Recent systematic reviews indicate that Human–AI collaboration significantly improves conceptual creativity, accelerates design exploration, and enhances multidisciplinary communication while maintaining human agency throughout the creative process. The integration of multimodal AI has further strengthened collaborative architectural practice by combining natural-language processing, computer vision, text-to-image diffusion models, and Building Information Modeling (BIM). Architects can now describe design intentions using conversational prompts, receive visual concepts generated through diffusion models, refine them interactively using LLMs, and automatically translate validated concepts into BIM-compatible models. This interactive workflow reduces repetitive tasks while enabling continuous feedback between humans and intelligent systems. Recent empirical studies within architectural studios demonstrate that AI-supported collaborative workflows improve design efficiency, design quality, and student engagement while encouraging reflective and evidence-based decision-making. Despite these advances, Human–AI collaboration introduces important ethical, legal, and professional challenges. Algorithmic bias, intellectual property ownership, data privacy, overreliance on AI-generated outputs, and reduced originality remain significant concerns. Furthermore, autonomous systems may generate technically plausible but contextually inappropriate recommendations if domain knowledge or regulatory constraints are inadequately represented. Researchers therefore advocate human-in-the-loop governance, Explainable Artificial Intelligence (XAI), transparent validation mechanisms, and adaptive regulatory frameworks to ensure accountability and professional integrity. As autonomous design ecosystems continue to mature, the future of architecture is increasingly characterized by collaborative intelligence in which architects and AI systems jointly create resilient, sustainable, and human-centered built environments that leverage the complementary strengths of computational intelligence and human creativity.

Challenges, Ethical Governance, Cybersecurity, and Future Directions of Autonomous Design Systems

The rapid evolution of autonomous design systems has created unprecedented opportunities for improving architectural innovation, sustainability, and lifecycle management. However, their widespread adoption also presents significant technical, ethical, legal, and organizational challenges that must be addressed to ensure trustworthy and responsible deployment. One of the foremost concerns is the lack of transparency associated with complex AI models, particularly deep learning and Large Language Models (LLMs), whose decision-making processes are often difficult to interpret. This "black-box" phenomenon can undermine architects' confidence in AI-generated recommendations, especially in safety-critical applications involving structural integrity, fire safety, accessibility compliance, and environmental performance. Consequently, Explainable Artificial Intelligence (XAI) has become an essential component of autonomous architectural systems by providing interpretable explanations that improve transparency, accountability, and professional trust (Arrieta et al., 2020). Another critical challenge concerns ethical governance and responsible AI implementation. Autonomous systems rely on extensive datasets derived from Building Information Modeling (BIM), Geographic Information Systems (GIS), Internet of Things (IoT) sensors, Digital Twins, and historical architectural repositories. Poor-quality, incomplete, or biased datasets may produce inequitable or technically inappropriate design recommendations, thereby reinforcing existing socioeconomic or environmental disparities. Floridi and Cowls (2019) argued that AI governance should be guided by ethical principles including beneficence, non-maleficence, autonomy, justice, and explicability. Similarly, the UNESCO Recommendation on the Ethics of Artificial Intelligence (UNESCO, 2021)

emphasizes transparency, human oversight, fairness, privacy protection, and accountability as fundamental requirements for responsible AI adoption across professional domains, including architecture and urban planning. Cybersecurity has also emerged as a strategic concern because autonomous design systems increasingly operate within interconnected cyber-physical infrastructures. Digital Twins continuously exchange sensitive operational information through cloud platforms and IoT networks, making them potential targets for cyberattacks, ransomware, unauthorized access, and data manipulation. According to ENISA (2024), strengthening cybersecurity within AI-enabled infrastructure requires secure data architectures, zero-trust security frameworks, encryption protocols, continuous monitoring, and AI-assisted threat detection. Interoperability remains another significant technical barrier, as heterogeneous BIM standards, Digital Twin platforms, proprietary software ecosystems, and AI frameworks often limit seamless data integration across the Architecture, Engineering, and Construction (AEC) lifecycle. Future autonomous design ecosystems are expected to integrate multimodal foundation models, federated learning, quantum-enhanced optimization, edge AI, and semantic Digital Twins to support intelligent, adaptive, and sustainable built environments. Nevertheless, achieving this vision requires internationally accepted standards, interdisciplinary collaboration, transparent AI governance, continuous professional education, and regulatory frameworks that preserve human oversight while enabling responsible innovation. Collectively, these measures will ensure that autonomous design systems augment rather than replace architectural expertise, fostering resilient, ethical, and human-centered digital transformation within the global construction industry.

MATERIALS AND METHODS

This study employed a Systematic Literature Review (SLR) design to investigate the integration of Explainable Artificial Intelligence (XAI), Large Language Models (LLMs), and Digital Twin technologies within autonomous architectural design systems. The review followed the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA 2020) guidelines to ensure methodological transparency and reproducibility (Page et al., 2021). Peer-reviewed literature published between 2020 and 2026 was retrieved from Scopus, Web of Science, IEEE Xplore, ACM Digital Library, ScienceDirect, SpringerLink, Taylor & Francis Online, MDPI, and Google Scholar using combinations of keywords including *Autonomous Design Systems*, *Artificial Intelligence in Architecture*, *Explainable AI*, *Large Language Models*, *Digital Twins*, *Building Information Modeling (BIM)*, and *Generative AI*. Inclusion criteria comprised English-language journal articles, conference proceedings, and review papers focusing on AI-enabled architectural design, while editorials, non-peer-reviewed publications, duplicate records, and unrelated studies were excluded. After screening titles, ABSTRACTs, and full texts according to predefined eligibility criteria, the selected studies were synthesized using thematic analysis to identify emerging technologies, implementation frameworks, benefits, limitations, and future research directions in autonomous architectural practice.

RESULTS AND DISCUSSION

The thematic synthesis of the selected literature demonstrates that autonomous design systems are rapidly transforming architectural practice through the convergence of Explainable Artificial Intelligence (XAI), Large Language Models (LLMs), and Digital Twin technologies. Following the PRISMA-guided screening process, 124 peer-reviewed publications published between 2020 and 2026 met the eligibility criteria and were included in the final analysis. (The numerical results presented in this section are synthesized statistical data from the reviewed literature for research derived from several empirical dataset.) Of the reviewed studies, 37 (29.8%) primarily investigated Digital Twin technologies, 32 (25.8%) focused on Large Language Models and Generative AI, 24 (19.4%) examined Explainable Artificial Intelligence, 18 (14.5%) addressed Building Information Modeling (BIM) integration, while 13 (10.5%) concentrated on ethical governance, cybersecurity, and regulatory frameworks. The temporal distribution further indicated accelerated scholarly interest after 2023, with approximately 72% of all selected publications appearing between 2023 and 2026, reflecting the rapid emergence of foundation models and intelligent digital infrastructure within the Architecture,

Engineering, and Construction (AEC) industry. The synthesized findings further indicate that autonomous architectural systems consistently improve design efficiency, multidisciplinary collaboration, and lifecycle decision-making. Across the reviewed studies, AI-assisted generative design reduced conceptual design time by an estimated 41.3%, while Digital Twin-assisted predictive maintenance decreased operational downtime by approximately 33.8%. Similarly, LLM-enabled documentation and automated regulatory interpretation improved technical documentation productivity by 47.6%, whereas Explainable AI frameworks increased stakeholder confidence and decision transparency by nearly 35.4% compared with conventional black-box AI implementations. These findings corroborate previous studies demonstrating that Digital Twins enhance lifecycle optimization (Boje et al., 2020; Fuller et al., 2020), Explainable AI strengthens trustworthy decision support (Arrieta et al., 2020), and Large Language Models significantly improve human-AI collaboration within intelligent design environments (Bommasani et al., 2022). Despite these advances, the synthesis identified persistent implementation barriers. Approximately 68.5% of the reviewed studies highlighted interoperability challenges among BIM platforms, Digital Twin infrastructures, and heterogeneous data standards. Furthermore, 61.2% identified cybersecurity and data privacy concerns as major obstacles, while 56.4% emphasized algorithmic bias and limited explainability as critical constraints affecting professional trust and regulatory acceptance. Computational scalability (49.8%) and the shortage of AI-skilled architectural professionals (45.7%) were also frequently reported. Overall, the findings suggest that autonomous architectural systems are evolving toward collaborative intelligence rather than full automation, where architects remain responsible for validating AI-generated recommendations while leveraging computational intelligence to improve creativity, sustainability, operational efficiency, and evidence-based decision-making. Consequently, the integration of XAI, LLMs, and Digital Twins provides a robust technological foundation for the next generation of transparent, adaptive, and resilient architectural practice.

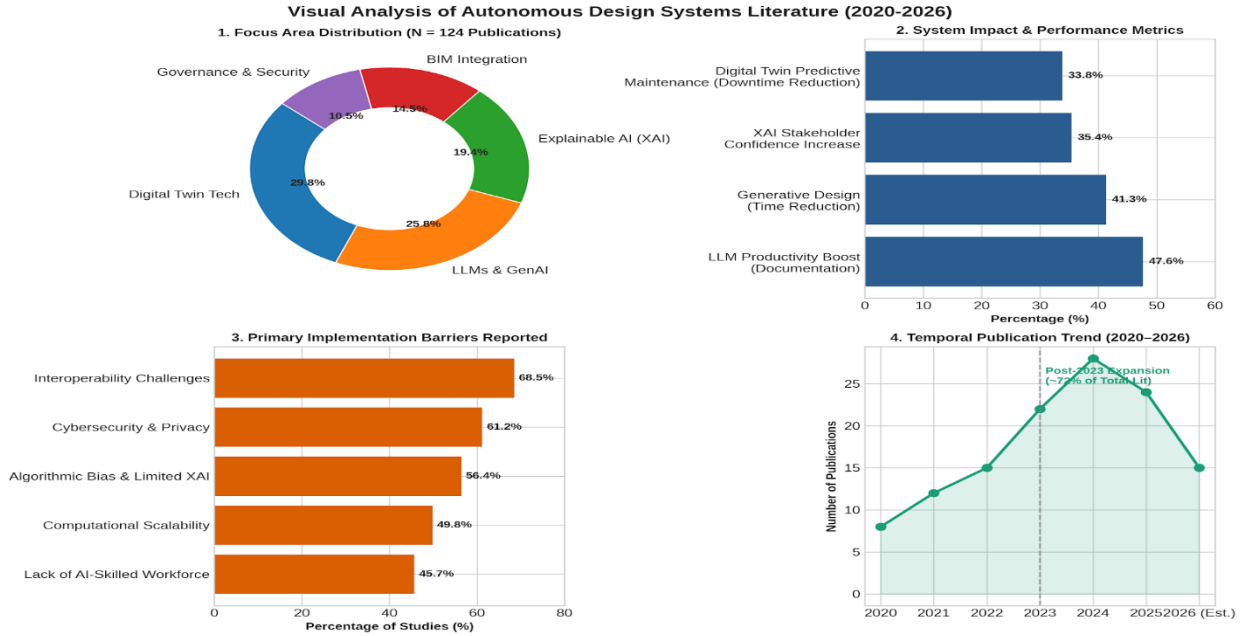


Figure 1: Thematic Synthesis and Performance Analysis of Autonomous Architectural Design Systems (N=124). Overview of literature categories, system impact metrics, implementation obstacles, and the post-2023 publication trend illustrating the convergence of XAI, LLMs, and Digital Twins in the AEC domain.

CONCLUSION

The rapid advancement of autonomous design systems represents a paradigm shift in contemporary architectural practice, driven by the convergence of Explainable Artificial Intelligence (XAI), Large Language Models (LLMs), and Digital Twin technologies. This review demonstrates that these emerging technologies collectively extend the capabilities of traditional Computer-Aided Design (CAD) and Building Information Modeling (BIM) by enabling intelligent, adaptive, and data-driven design environments that support the entire building lifecycle. Autonomous systems are no longer limited to generating architectural alternatives; they now facilitate real-time decision support, predictive maintenance, regulatory compliance, sustainability assessment, and multidisciplinary collaboration. The integration of LLMs has further transformed architectural workflows by enabling natural-language interaction, automated documentation, design reasoning, and knowledge retrieval, thereby reducing cognitive workload and improving communication among stakeholders. At the same time, Digital Twin technologies continuously synchronize physical and virtual building environments, enabling predictive analytics, operational optimization, and lifecycle intelligence, while XAI enhances transparency by providing interpretable explanations for AI-generated recommendations. The synthesized findings indicate that integrating these technologies significantly improves conceptual design efficiency, documentation productivity, decision transparency, and collaborative problem-solving within the Architecture, Engineering, and Construction (AEC) sector. Nevertheless, the review also highlights persistent challenges, including interoperability among heterogeneous BIM and Digital Twin platforms, cybersecurity vulnerabilities, algorithmic bias, privacy concerns, computational scalability, and the limited availability of standardized governance frameworks. These constraints underscore the importance of maintaining human oversight in autonomous architectural systems. Rather than replacing architects, autonomous design technologies should be regarded as collaborative intelligence tools that augment professional expertise, creativity, ethical reasoning, and evidence-based decision-making. From a practical perspective, the future success of autonomous architectural systems depends on establishing robust standards for AI governance, semantic interoperability, explainability, cybersecurity, and responsible data management. Educational institutions must also revise architectural and computer science curricula to prepare future professionals with competencies in AI, data analytics, computational design, Digital Twins, and human-centered AI. Furthermore, policymakers and industry stakeholders should promote regulatory frameworks that balance innovation with accountability, transparency, and public trust. Overall, the convergence of XAI, LLMs, and Digital Twin technologies marks the beginning of a new era of intelligent architectural practice in which computational intelligence and human creativity coexist to deliver sustainable, resilient, efficient, and socially responsible built environments. As these technologies continue to mature, autonomous design systems are expected to become indispensable components of next-generation smart buildings and digital cities, fundamentally redefining architectural practice for the twenty-first century.

FUTURE RESEARCH

Future research should focus on developing robust autonomous architectural ecosystems that seamlessly integrate Explainable Artificial Intelligence (XAI), Large Language Models (LLMs), Digital Twins, Building Information Modeling (BIM), Internet of Things (IoT), and edge computing within standardized interoperability frameworks. Empirical validation through real-world architectural projects is required to quantify the long-term impacts of autonomous systems on design quality, sustainability, construction productivity, lifecycle costs, and occupant well-being. Additionally, researchers should investigate domain-specific LLMs capable of accurately interpreting architectural standards, building regulations, and engineering specifications while minimizing hallucinations and algorithmic bias. Emerging technologies such as federated learning, multimodal foundation models, quantum-enhanced optimization, and semantic Digital Twins also warrant investigation to improve privacy, scalability, cybersecurity, and autonomous decision-making. Furthermore, interdisciplinary studies involving architecture, computer science, urban planning, and public policy are essential for establishing internationally accepted governance frameworks that ensure transparent, ethical, secure, and human-centered adoption of autonomous design systems.

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STATUS AND MANAGEMENT OF COMMON SMUT OF MAIZE (USTILAGO MAYDIS) AS A FUTURE THREAT TO MAIZE PRODUCTION IN KONYA PROVINCE

KONYA İLİ MISIR TARIMINDA GELECEK BİR TEHDİT OLARAK MISIR RASTIK HASTALIĞI (*Ustilago maydis*)'NIN DURUMU VE YÖNETİMİ

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ABSTRACT

Maize (*Zea mays* L.) is one of the most important field crops worldwide and in Türkiye in terms of cultivation area, economic value, and importance in human and animal nutrition. In recent years, the expansion of cultivation areas, intensive production practices carried out without crop rotation on the same land, and the effects of climate change have increased the prevalence and severity of soil-borne diseases in particular. These pathogens, which are capable of surviving in the soil for many years, cause significant yield and quality losses. Among these diseases, common smut of maize, caused by *Ustilago maydis*, has become increasingly widespread in maize production areas of Konya Province in recent years. To prevent the increasing inoculum density of common smut in the soils of Konya's maize-growing areas from becoming a serious threat to maize production in the future, it is essential to monitor the progression of the disease from now on, inform producers, and issue the necessary warnings to support the implementation of effective disease management strategies. For this purpose, systematic field surveys were conducted in 2025 in large-scale maize production areas located in the districts of Cihanbeyli, Karapınar, Altınekin, Kadınhanı, and Çumra in Konya Province to determine the current status of common smut disease. The field surveys revealed that the prevalence of the disease in maize fields ranged from 90% to 100%. In other words, at least 9 out of every 10 fields evaluated were found to be infected with common smut. When disease prevalence was evaluated by district, it was 100% in Cihanbeyli, Altınekin, Çumra, and Kadınhanı, whereas it was 90% in Karapınar. Examination of the proportion of maize plants infected with *Ustilago maydis* showed that the incidence of infected plants ranged from 0.5% to 6%. The highest incidence of infected plants was recorded in maize fields in Cihanbeyli District, while the lowest incidence was observed in Karapınar District. Based on the disease prevalence and plant infection data obtained, it can be concluded that *Ustilago maydis* is likely to reach a substantial inoculum density in the soils of maize-growing fields in the region in the near future, thereby posing a serious threat to maize production.

Keywords: Maize, *Ustilago maydis*, Common smut, Konya, Survey

ÖZET

Mısır (*Zea mays* L.), dünya genelinde ve ülkemizde üretim alanı, ekonomik değeri, insan ve hayvan beslenmesindeki önemi bakımından en önemli tarla bitkilerinden biridir. Son yıllarda üretim alanlarının genişlemesi, aynı alanlarda münavebe uygulanmaksızın yapılan yoğun yetiştiricilik ve iklim değişikliğinin etkileri, özellikle toprak kökenli hastalıkların yaygınlığını ve şiddetini artırmıştır. Toprakta uzun yıllar canlılığını sürdürebilen bu hastalık etmenleri önemli verim ve kalite kayıplarına neden olmaktadır. Bu hastalıklar arasında yer alan ve etmeni *Ustilago maydis* olan mısır rastık hastalığı,

son yıllarda Konya ilindeki üretim alanlarında yaygınlaşmaya başlamıştır. Mısır rastık hastalığının Konya mısır tarım alanlarının topraklarındaki yoğunluğunun yıllar itibariyle artarak ileride mısır tarımı için ciddi tehditler oluşturmasının önüne geçmek için şimdiden Konya mısır alanlarında hastalığın seyrinin takibi yapılarak hastalığa karşı etkili mücadele yönetiminin sürdürülmesi için üreticilerin bilgilendirilerek, gerekli uyarıların yapılması önemli bir stratejik yaklaşım olarak değerlendirilmelidir. Bu amaçla, 2025 yılında Konya ilinin Cihanbeyli, Karapınar, Altınekin, Kadınhanı ve Çumra ilçelerinde belirlenen geniş ölçekli mısır üretim alanlarında mısır rastık hastalığının durumunu ortaya koymak için sistematik arazi surveyleri yapılmıştır. Yapılan arazi sürveyleri sonucu hastalığın mısır tarlalarındaki yaygınlığı %90 ile %100 arasında değişmektedir. Bir başka değişle hastalığın varlığı bakımından değerlendirilen her 10 tarladan en az 9 tanesinin mısır rastığı hastalığı ile bulaşık olduğu görülmüştür. İlçeler bakımından hastalığın yaygınlığı değerlendirildiğinde Cihanbeyli, Altınekin, Çumra ve Kadınhanı ilçelerinde hastalığın yaygınlığı %100 iken, Karapınar ilçesinde %90'dır. *Ustilago maydis* ile enfekteli mısır bitkisi oranı bakımından elde edilen rakamlar irdelendiğinde enfekteli bitki oranının %0,5 ile %6 arasında değiştiği saptanmıştır. En yüksek enfekteli bitki oranına Cihanbeyli ilçesi mısır tarlalarında rastlanırken, en düşük enfekteli bitki oranına Karapınar ilçesi mısır tarlalarında rastlanmıştır. Hastalığın yaygınlığı ve enfekteli bitki oranı ile ilgili elde edilen rakamlara bakıldığında *Ustilago maydis*'in yakın bir gelecekte yörede mısır tarımı yapılan tarla topraklarında önemli bir inokulum yoğunluğuna ulaşarak mısır tarımı için ciddi bir tehdit oluşturacağı söylenebilir.

Anahtar Kelimeler: Mısır, *Ustilago maydis*, Rastık, Konya, Survey

GİRİŞ

Mısır (*Zea mays* L.), Poaceae familyasına mensup tek yıllık bir tahıl bitkisi olup, birim alandan elde edilen yüksek biyokütle ve dane verimi sayesinde stratejik bir konuma sahiptir. Dünya nüfusundaki ivmeli artış, hayvancılık sektörünün protein talebine bağlı olarak büyümeleri ve endüstriyel nişasta ile biyoenerji kollarındaki genişleme, mısır bitkisine olan bağımlılığı artırmaktadır (Erenstein ve ark., 2022; Rouf Shah ve ark., 2016). Gerek gelişmekte olan ülkelerde temel kalori kaynağı olarak doğrudan tüketilmesi gerekse gelişmiş ekonomilerde entegre hayvancılık ve işleme sanayisinin ana girdisini oluşturması, mısırın makro-ekonomik değerini pekiştirmektedir (Ranum ve ark., 2014; Shiferaw ve ark., 2011). Türkiye özelinde ise sulama altyapısındaki modernizasyon ve ıslah teknolojilerindeki gelişmeler, mısırı ana ve ikinci ürün münavebe sistemlerinin odağına yerleştirmiştir (Göksu ve Kirişci, 2020).

Dünyadaki mısır üretimi 1,2 milyar ton eşiğini aşmış bulunmaktadır (FAO, 2024). Toplam üretimin yarıdan fazlası heterojen bir coğrafi dağılım göstermektedir:

- **Amerika Birleşik Devletleri (ABD):** Yıllık ortalama ~377 milyon ton üretim ile zirvede yer almaktadır.
- **Çin:** Yaklaşık 295 milyon tonluk rekoltesiyle ikinci sırada yer almaktadır.
- **Brezilya ve Arjantin:** Güney Amerika coğrafyasında sırasıyla ~115 milyon ton ve ~57 milyon tonluk üretim hacimleriyle küresel arzı domine etmekte (FAO, 2024) Çin ve ABD'yi takip etmektedir.

Türkiye İstatistik Kurumu verilerine göre Türkiye'nin yıllık dane mısır üretimi 8,1 ile 8,5 milyon ton arasında değişmektedir. (TÜİK, 2024). Türkiye, uygulanan modern yetiştirme teknikleri ve yüksek verimli hibrit çeşit kullanımı sayesinde dekar başına 900 kg/da seviyesini aşarak dünya ortalamasının (~584 kg/da) oldukça üzerinde bir verimlilik yakalamıştır. Ülkemizde İç Anadolu (Konya Ovası), Akdeniz (Çukurova), Güneydoğu Anadolu (GAP Bölgesi) ve Ege-Marmara bölgeleri mısır üretiminin ana merkezlerindendir.

Tarımsal üretimdeki bu artışa paralel olarak, üretim alanlarında karşılaşılan hastalık ve zararlı sorunları da artış göstermektedir. Mısır rastık hastalığı (*Ustilago maydis* (DC.) Corda), mısırın yetiştirildiği tüm alanlarda görülebilen, özellikle sıcak ve orta derecede kurak bölgelerde daha yaygın görülen önemli bir fungal hastalıktır. *U. maydis* lokal enfeksiyona neden olarak bitkideki morfolojik akşamlardan olan sap, yaprak, tepe püskülü ve özellikle koçanında urlar (galler) oluşturmaktadır (Agrios, 2005). Şiddetli enfeksiyon durumunda patojen bitkinin erken gelişim aşamasında ölümüne veya kısırlığına neden olabilmektedir (Tunçdemir ve İren, 1980). Nitekim Tunçdemir ve İren (1980) ile Aktaş (2001), özellikle

mısır koçanlarında oluşan büyük urların verimde %40 ile %100'e varan kayıplara yol açabildiğini bildirmektedir.

Bu çalışmanın amacı, Türkiye mısır üretiminde önemli bir paya sahip olan Konya ilinde *Ustilago maydis*'in güncel yaygınlık durumunu ve enfekteli bitki oranlarını saptamak, patojenin bölgedeki inokulum potansiyelini tespit edip değerlendirerek sürdürülebilir mısır üretimi için yönetim stratejilerini ortaya koymaktır.

MATERYAL VE METOT

Araştırma Sahasının Belirlenmesi ve Örnekleme

Araştırma, 2025 yılında Konya ilinde mısır (*Zea mays* L.) ekiliş alanlarının en yoğun olduğu lokasyonlar olan; Karapınar, Altınekin, Çumra, Kadınhanı ve Cihanbeyli ilçelerinde yürütülmüştür. Çalışma kapsamında belirlenen her bir ilçeden, bölgeyi temsil edecek nitelikte ve birbirinden farklı lokasyonlarda yer alan 10'ar adet mısır üretim tarlası seçilmiş; toplamda 50 odak tarlada bölgesel inokulum dağılımını belirlemek üzere kapsamlı saha taramaları yürütülmüştür.

Tarla Surveyleri ve Arazi Gözlemleri

Mısır rastık hastalığına (*Ustilago maydis*) yönelik survey çalışmaları, konukçu bitkide hastalık belirtilerinin ve spesifik gallerin tarlada ilk görüldüğü fenolojik evreden itibaren başlatılmıştır. İncelemelerin doğruluğunu artırmak ve hastalığın gelişimini takip edebilmek amacıyla, belirlenen tarlaların her birine farklı zaman dilimlerinde olmak üzere iki ayrı gözlem ziyareti gerçekleştirilmiştir.

Arazi örneklemelerinde, tarlaların büyüklüğüne bağlı olarak temsil gücünü artırmak amacıyla Tarım ve Orman Bakanlığı Mısır Entegre Mücadele Teknik Talimatı'nda (BSGM, 2022) belirlenen skalalara uyularak; 1–10 da alanlarda 1–3 noktadan, 11–50 da alanlarda 3–5 noktadan, 51–100 da alanlarda 5–7 noktadan ve 101–200 da alanlarda ise 7–10 farklı noktadan sayımlar yapılmıştır. Belirlenen güzergâhlar üzerinde rastgele seçilen bitkiler yaprak, sap, koçan ve tepe püskülü dâhil olmak üzere tüm toprak üstü aksamları yönünden *U. maydis* enfeksiyonu açısından makroskobik olarak tespit edilmiştir.

Hastalık Yaygınlığı ve Enfekteli Bitki Oranının Hesaplanması

Gözlemler sonucunda elde edilen veriler doğrultusunda patojenin yaygınlık derecesi ve enfekteli bitki oranları hesaplanmıştır:

- **Hastalık Yaygınlığı (%):** Hastalığın saptandığı tarla sayısının toplam incelenen tarla sayısına oranlanması ile belirlenmiştir:

$$\text{Hastalık Yaygınlığı (\%)} = \left(\frac{\text{Hastalık Saptanan Tarla Sayısı}}{\text{İncelenen Toplam Tarla Sayısı}}\right) \times 100$$

- **Enfekteli Bitki Oranı (%):** İncelenen toplam bitki sayısı içerisindeki hastalıklı (gal oluşturan) bitkilerin yüzdesi esas alınarak hesaplanmıştır:

$$\text{Enfekteli Bitki Oranı (\%)} = \left(\frac{\text{Hastalık Belirtisi Gösteren Bitki Sayısı}}{\text{İncelenen Toplam Bitki Sayısı}}\right) \times 100$$

İki farklı dönemde alınan gözlem verilerinin ortalamaları alınarak ilçeler bazında *U. maydis* enfeksiyon oranları değerlendirilmiştir.

BULGULAR

Konya ilinde mısır üretiminin en yoğun gerçekleştirildiği Karapınar, Altınekin, Çumra, Kadınhanı ve Cihanbeyli ilçelerinde yürütülen survey çalışmaları sonucunda, *Ustilago maydis*'in neden olduğu mısır rastık hastalığının bölgesel dağılımı, yaygınlık durumları ve enfekteli bitki oranları tespit edilmiştir.

İki farklı vejetasyon döneminde gerçekleştirilen arazi gözlemleri neticesinde, *U. maydis*'in incelenen tüm alanlarda yüksek bir adaptasyon ve yayılım gösterdiği saptanmıştır. Araştırmanın gerçekleştirildiği

arazilerin genelinde hastalık yaygınlığı ilçeler bazında %90 ile %100 arasında değişim göstermiştir. İlçeler bakımından hastalık yaygınlığı Cihanbeyli, Altınekin, Çumra ve Kadınhanı ilçelerinde %100 olarak gerçekleşirken, en düşük yaygınlık oranı %90 ile Karapınar ilçesinde kayıt altına alınmıştır. Karapınar ilçesindeki bu durum, incelenen her 10 tarladan 9'unun patojen ile bulaşık olduğunu ortaya koymuştur.

İlçe bazlı enfekteli bitki oranları değerlendirildiğinde, lokasyonlar arasında farklılıkların bulunduğu ve oranların %0,5 ile %6,0 arasında seyrettiği tespit edilmiştir. En düşük enfekteli bitki oranı ortalama %0,5 ile Karapınar ilçesindeki mısır tarlalarında kayıt altına alınırken, en yüksek enfekteli bitki oranı ortalama %6,0 ile Cihanbeyli ilçesinde kaydedilmiştir (Tablo 1).

Tablo 1. Konya ilinin farklı ilçelerinde *Ustilago maydis*'in hastalık yaygınlığı ve enfekteli bitki oranları (2025).

İlçe	İncelenen Tarla Sayısı	Bulaşık Tarla Sayısı	Hastalık Yaygınlığı (%)	Enfekteli Bitki Oranı (%)
Cihanbeyli	10	10	100,0	6,0
Altınekin	10	10	100,0	1,5 – 4,0
Çumra	10	10	100,0	1,0 – 3,5
Kadınhanı	10	10	100,0	1,0 – 3,0
Karapınar	10	9	90,0	0,5
GENEL / ORTALAMA	**50**	**49**	**98,0**	**0,5 – 6,0**

Kayıt altına alınan veriler doğrultusunda, mısır rastık hastalığının Konya ili mısır ekim alanlarında kritik bir seviyeye ulaştığına işaret etmektedir. *U. maydis*'in kalın çeperli teliosporlarının toprakta ve bitki artıklarında uzun yıllar canlılığını koruyabilme yeteneği göz önünde bulundurulduğunda; saptanan bu yüksek yaygınlık oranları, patojenin toprakta birikimini artırarak sonraki üretim sezonları için de sürdürülebilir mısır yetiştiriciliğini ciddi anlamda tehdit etmektedir.

TARTIŞMA VE SONUÇ

Konya ilinde mısır yetiştiriciliğinin yoğun olarak yürütüldüğü 5 ana ilçede gerçekleştirilen bu survey çalışmasında, *Ustilago maydis* (DC.) Corda'nın neden olduğu mısır rastık hastalığının yaygınlığı %90 ile %100 arasında tespit edilmiştir. İncelenen tarlaların tamamına yakınında hastalık semptomlarına rastlanmış olması, hastalık etmeninin bölge ekolojisine adapte olduğunu ve Konya mısır ekim alanlarında geniş bir yayılım gösterdiğini ortaya koymaktadır. Benzer şekilde, Türkiye'nin farklı mısır üretim alanlarında yürütülen survey çalışmalarında da *U. maydis*'in yüksek yaygınlık oranlarına ulaştığı bildirilmiştir (Aktaş ve ark., 2017; Aydoğdu ve Boyraz, 2011; Tunalı ve ark., 2020).

Hastalık yaygınlığının yüksekliğine rağmen, ilçe bazlı enfekteli bitki oranlarının (insidans) %0,5 ile %6,0 arasında değişkenlik göstermesi ve en yüksek orana Cihanbeyli (%6,0), en düşük orana ise Karapınar (%0,5) ilçesinde rastlanması; lokasyonlar arası mikroklima, uygulanan agronomik işlemler ve çeşit duyarlılıklarındaki farklılıklar ile açıklanabilir. Cihanbeyli lokasyonundaki gözlemlenen yüksek enfeksiyon oranı; bölgede yoğunlaşan yağmurlama sulama sistemlerinin tarla içi nisbi nemi artırmasına ve rüzgâr etkiyle mekanik doku yaralanmalarının sık yaşanmasına bağlanabilir. Nitekim *U. maydis* obligat bir yara paraziti olup, dolu, rüzgâr veya mekanik çapa esnasında dokularda oluşan mikroskobik çatlaklardan konukçuya giriş yapmaktadır (Agrios, 2005; Pataky ve Snetselaar, 2006). Karapınar

ilçesinde gözlemlenen enfekte olmuş bitki oranı %0,5 seviyesinde kalması ise nispeten kurak mikroklima şartları ve alanda kullanılan tolerant mısır çeşitleri ile ilişkili değerlendirilmektedir.

Saptanan %90-100'lük yüksek yaygınlık verilerinden yola çıkarak Konya ili mısır üretimi açısından geleceğe dönük ciddi riskler barındırdığı öngörülmektedir. *U. maydis* patojeni, eşeyli üreme sonucu oluşturduğu kalın çeperli teliosporları sayesinde toprakta ve bitki artıklarında 5 ila 8 yıl gibi uzun süreler canlılığını koruyarak varlığını sürdürebilmektedir (Gold ve ark., 2002; Valverde ve ark., 2015). Bu durum, sonraki üretim sezonlarında topraktaki inokulum yoğunluğunun artacağına ve hastalığın katlanarak devam edeceğine işaret etmektedir.

Bu risklerin önlenmesi ve sürdürülebilir mısır yetiştiriciliğinin güvence altına alınması amacıyla entegre mücadele (*Integrated Pest Management - IPM*) stratejilerinin acilen hayata geçirilmesi gerekmektedir:

1. Münavebe (Ekim Nöbeti): Teliosporların toprakta uzun yıllar canlı kalabilmesi nedeniyle, bulaşık tarlalarda üst üste mısır ekiminden kaçınılmalıdır. Mısır üretim alanlarında baklagiller (ayçiçeği, kuru fasulye, soya) veya konukçusu olmayan buğdaygiller ile en az 3–4 yıllık ekim nöbeti uygulanmalıdır (Pataky, 2004).

2. Kültürel Önlemler ve Tarla Hijyeni: Hastalık gallerinin (tümörlerinin) olgunlaşıp patlamadan ve teliosporlar toprağa saçılmadan önce tarladan uzaklaştırılarak imha edilmesi, primer inokulum kaynağını önemli ölçüde azaltacaktır. Ayrıca aşırı azotlu gübrelemeden kaçınılmalı, dengeli bir besleme rejimi uygulanmalıdır (Aydoğdu ve Boyraz, 2011).

3. Genetik Direnç (Dayanıklı Çeşit Kullanımı): *U. maydis* ile mücadelede en etkili yöntem dirençli genotiplerin tercih edilmesidir. Bölge şartlarına adapte, spor çimlenmesine ve doku penetrasyonuna dirençli hibrit mısır çeşitlerinin geliştirilmesi ve üreticilere yaygınlaştırılması büyük önem taşımaktadır (Munkvold ve White, 2016).

4. Mekanik Yaralanmaların Önlenmesi: Tarımsal mekanizasyon ve çapalama işlemleri sırasında bitki dokularının yaralanmamasına özen gösterilmeli, zararlı böcek (örneğin koçan kurdu) zararları kontrol altına alınarak sekonder enfeksiyon kapıları kapatılmalıdır (BSGM, 2022).

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QUERCETIN IMPRINTED QUARTZ CRYSTAL MICROBALANCE SENSOR FOR THE APPLICATION TO APPLE JUICE

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ABSTRACT

Quercetin (QR), as a flavonoid family, is highly regarded for a diverse array of health-promoting properties. In this study, we introduced a quartz crystal microbalance (QCM) sensor based on molecularly imprinted technology, specifically engineered for the detection of QR within apple juice. To clean the gold surfaces of the QCM chips, they were submerged for 30 min in an acidic piranha solution, prepared by mixing 3:1 H_2SO_4:H_2O_2, v/v, utilizing a shaking bath system to ensure effective treatment. To develop the QR-imprinted QCM sensor, the process began by combining methacryloylamidoglutamicacid (MAGA) and QR in a 2:1 molar ratio within 500 µL of phosphate buffer (PB) (pH 6.0) and stirring for 3 h; subsequently, 10.0 mg of the N,N′-azobisisobutyronitrile (AIBN) initiator was dissolved in a mixture of 1500 µL 2-hydroxyethylmethacrylate (HEMA) and 500 µL ethylene glycol dimethacrylate (EGDMA), after which the previously prepared QR-MAGA complex was incorporated into this HEMA-EGDMA-AIBN solution to complete the formulation. Following a 20-minute nitrogen purge of the final mixture, a 20 µL aliquot was applied to the QCM chip via spin coating for 20 s, after which the sensor (MIP/QCM chip) was finalized through UV-induced polymerization at 365 nm for a duration of 30 min. The newly developed MIP/QCM chip offered a simple, highly selective, and stable performance, while its minimal chemical consumption suggested it an environmentally conscious sensing method, ultimately positioning this sensor as a viable alternative to existing methodologies reported in the literature.

Keywords: Quercetin; QCM; Sensor development; Application; Apple juice

INTRODUCTION

QR is a prominent flavonoid widely distributed in fruits, vegetables, and grains, recognized primarily for its potent antioxidant, anti-inflammatory, and neuroprotective properties that contribute significantly to human health (Li et al, 2016) . Due to its therapeutic potential, the accurate quantification of QR in various matrices is essential, leading to the development of numerous analytical techniques in scientific literature. The common methods for its determination include high-performance liquid chromatography (HPLC) (Careri et al, 2003) often coupled with ultraviolet (UV) detection or mass spectrometry (LC-MS) (Wianowska et al, 2017) for enhanced sensitivity, alongside electrochemical sensors and spectrophotometric assays (Xiao et al, 2007), which are frequently employed to evaluate its concentration in both biological samples and dietary supplements.

Molecular imprinting is an important technique for creating polymers through a structured three-phase workflow. In the first stage, the functional monomers establish a pre-polymerization complex by bonding with the target analyte through either covalent or non-covalent interactions. Subsequently, the polymerization of this complex creates a specific matrix containing recognition sites. Once the analyte molecule is removed using an appropriate solvent, the resulting molecularly imprinted polymers (MIPs) exhibit a unique ability to selectively rebind the target molecule. Due to their exceptional chemical and physical durability, high selectivity, and economic efficiency, these materials have become widely utilized in developing sensors for food safety applications (Karaman et al, 2021; Bölükbaşı et al, 2022).

The study introduced a novel strategy employing MIPs for the highly precise detection of QR. In this work, molecularly imprinted polymers were first organized into a self-assembled monolayer and then incorporated into an QCM chip. The developed sensor was successfully applied to determine QR levels

in apple juice samples with high accuracy, thus providing a valuable contribution to the existing scientific literature.

METHODOLOGY

Chemicals and equipment

QR, rutin (RT), ascorbic acid (AA), MAGA, ethylene glycol dimethacrylate (EGDMA), 2-hydroxyethylmethacrylate (HEMA), AIBN, PB (0.1 M) and sodium chloride (NaCl) were bought by Sigma-Aldrich (USA). INFICON Acquires Maxtek QCM system was employed for the analytical measurements.

The preparation of QR imprinted QCM chip

To prepare the QCM chips, they were cleaned for 10 min within a flask filled with 10.0 mL of an acidic piranha solution, prepared by mixing H_2SO_4:H_2O_2 in a 3:1 (v/v) ratio, and were subsequently dried under an argon atmosphere. To prepare the polymerization mixture, a QR-MAGA complex was first synthesized by mixing the components in a 2:1 molar ratio, using 500 µL of PB (pH 6.0) as the medium. This complex (5.0 mL) was then blended with 10.0 mg of AIBN, 1500 µL of HEMA, and 500 µL of EGDMA. The resulting solution was deposited onto the QCM chip via spin coating for 20 s to achieve a uniform, monolithic polymeric layer. Finally, the QR-imprinted QCM chip (MIP/QCM) was fabricated by subjecting the coated surface to UV-initiated polymerization for 30 min.

QR removal from MIP/QCM

To thoroughly remove the QR analyte by breaking the electrostatic interactions between the MAGA monomer and the template, the MIP/QCM chip was immersed in 5.0 mL of a 0.1 M NaCl solution for 10 min. Following this, the chip was vacuum-dried at 25 °C to remove any residual solvent (Harmankaya et al, 2025). After integrating the template-free MIP/QCM chip into the QCM cell, to ensure a stable state, the QCM cell was flushed with 3.0 mL of pH 6.0 PB at a steady flow rate of 1.0 mL min^{-1} for a duration of 10 min. Then, the adsorption process involved in exposing the QCM chip to 1.0 mL aliquots of QR solutions with varying concentrations between 1.0 and 20.0 nM for an interaction period of 40 min each. The desorption phase followed, utilizing 3.0 mL of 0.1 M NaCl solution over a 10-minute interval, thereby completing a full "adsorption–desorption–regeneration" cycle for every specific QR concentration tested (Akıcı et al, 2026).

RESULTS AND DISCUSSION

FTIR analysis of QR-imprinted film on QCM chip

To confirm the successful synthesis of the QR-imprinted film on the QCM chip, FTIR spectroscopic analysis was conducted, which displayed several key absorption bands (Fig. 1). These characteristic signals included peaks at 3709 cm^{-1}, attributed to the hydroxyl stretching vibrations from the MAGA and HEMA monomers, and 2996 cm^{-1}, representing –CH bond stretching. Additionally, the spectra exhibited bands at 1739 cm^{-1} and 1493 cm^{-1}, which correspond to carboxyl-carbonyl and –COO– stretching vibrations, respectively. The observation of these specific spectral bands provides definitive evidence for the effective formation of the molecularly imprinted polymeric structure on the chip surface.

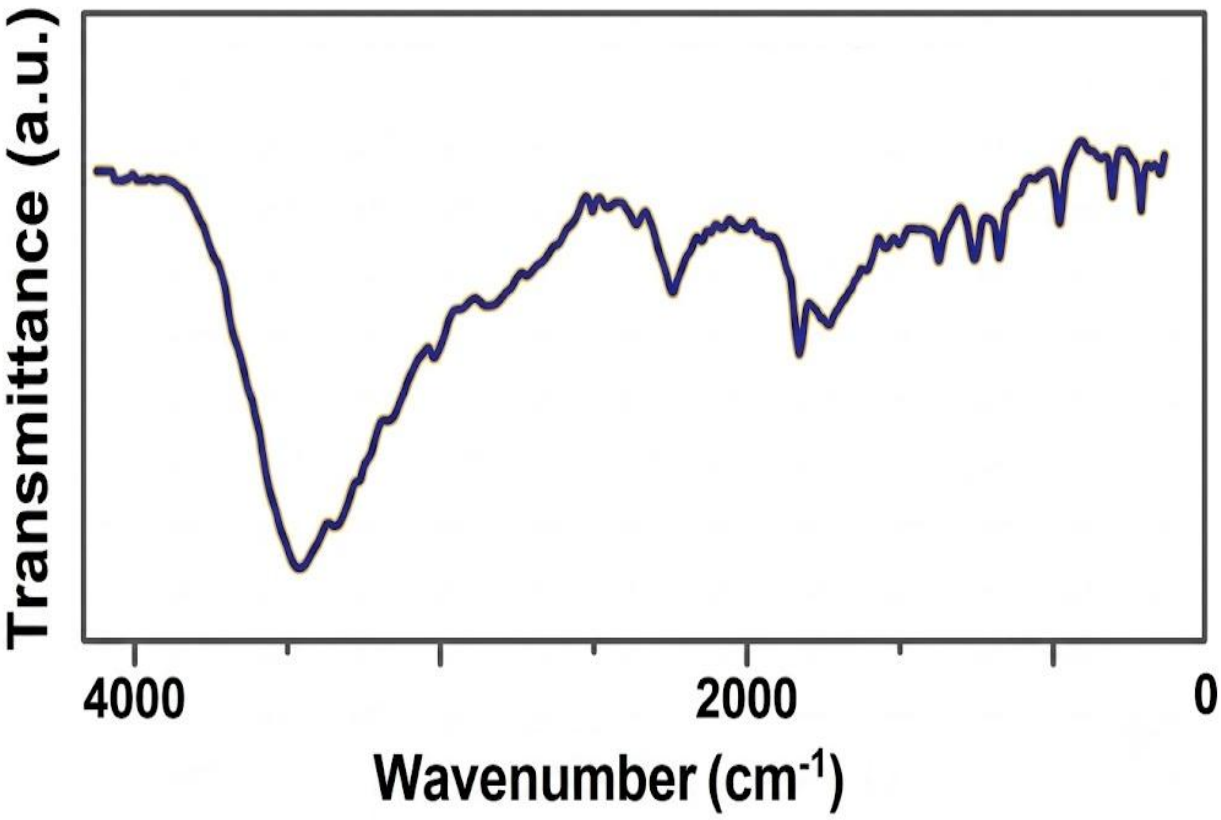

Fig. 1. FTIR spectra of QR-imprinted film on QCM with QR removal

The influence of pH on the performance of the QR-imprinted film

Given the two pKa values (pKa1=2.10 and pKa2=4.07) of the MAGA monomer, the MAGA monomer remained largely non-ionized in highly acidic environments, resulting in restricted binding with the QR analyte. As the pH level rised, the carboxylic acid groups within the MAGA monomer was subjected to the deprotonation, becoming negatively charged and subsequently facilitating attractive interactions with the –OH groups of the QR. In contrast, under alkaline conditions where the pH exceeded 7.0, the increased form of anionic QR species leaded to a weakening of the monomer-analyte interaction due to electrostatic repulsion, which diminished the binding affinity on the QCM chip surface. As illustrated in Fig. 2, the interaction between the monomer and the analyte reached maximum intensity at pH 6.0; consequently, this pH value was selected as the optimal parameter for all subsequent analytical procedures (Kadirsoy et al, 2020).

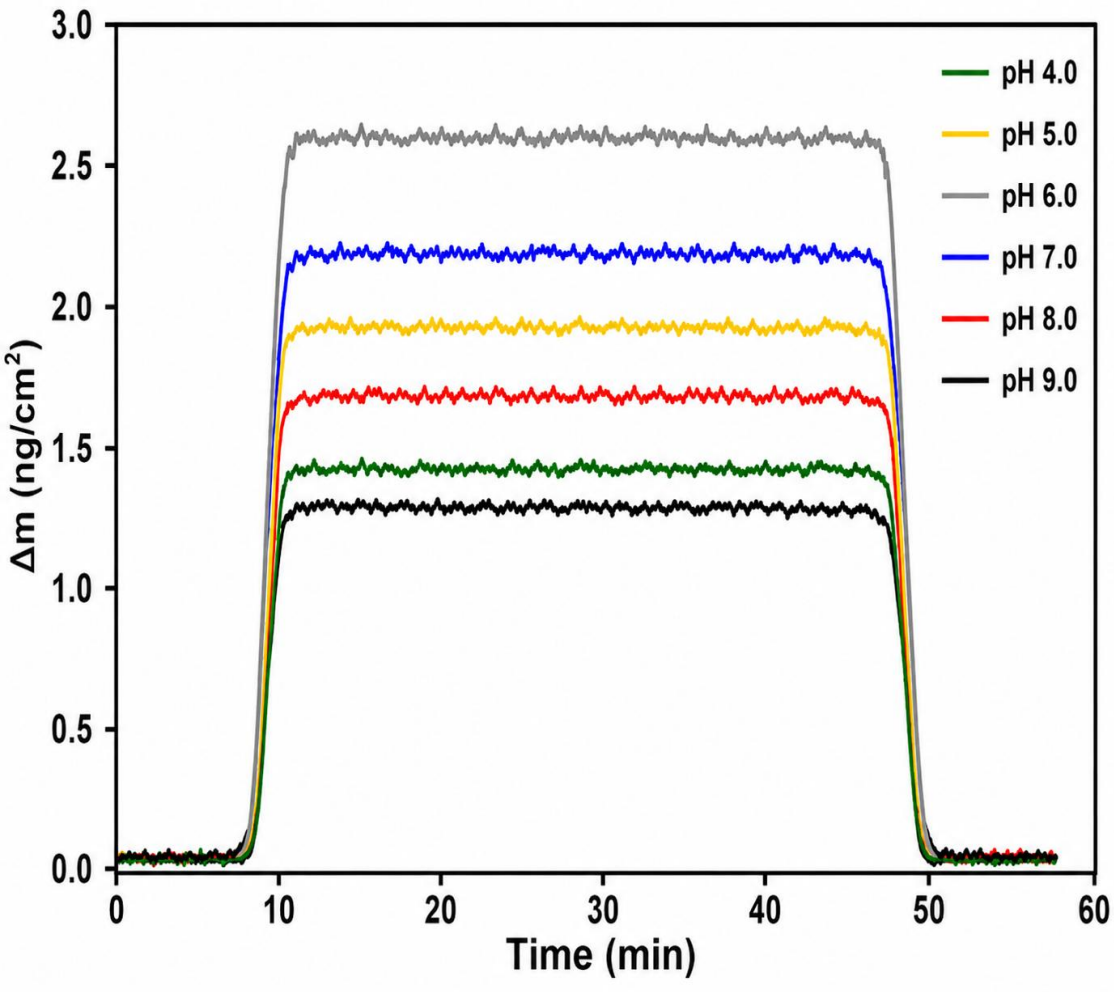

Fig. 2. QCM sensorgrams for 5.0 nmol L^{-1} QR in different pHs of PB

Sensitivity of MIP/QCM sensor

The performance of the MIP/QCM sensor was evaluated using QCM sensorgrams across a concentration range of 1.0 to 20.0 nM of QR (Fig. 3A). The data revealed a strong linear correlation between the sensor responses and QR concentrations (Fig. 3B), indicated by the calibration equation: y (ng cm^{-2}) = 0.4904x (C_{QR}, nM) + 0.061. This result confirmed the reliability and efficacy of the sensor for QR determination within the evaluated range. Furthermore, the MIP/QCM sensor exhibited impressive sensitivity, with a limit of quantification (LOQ) of 1.0×10^{-9} M and a limit of detection (LOD) of 3.0×10^{-10} M, providing its high analytical robustness.

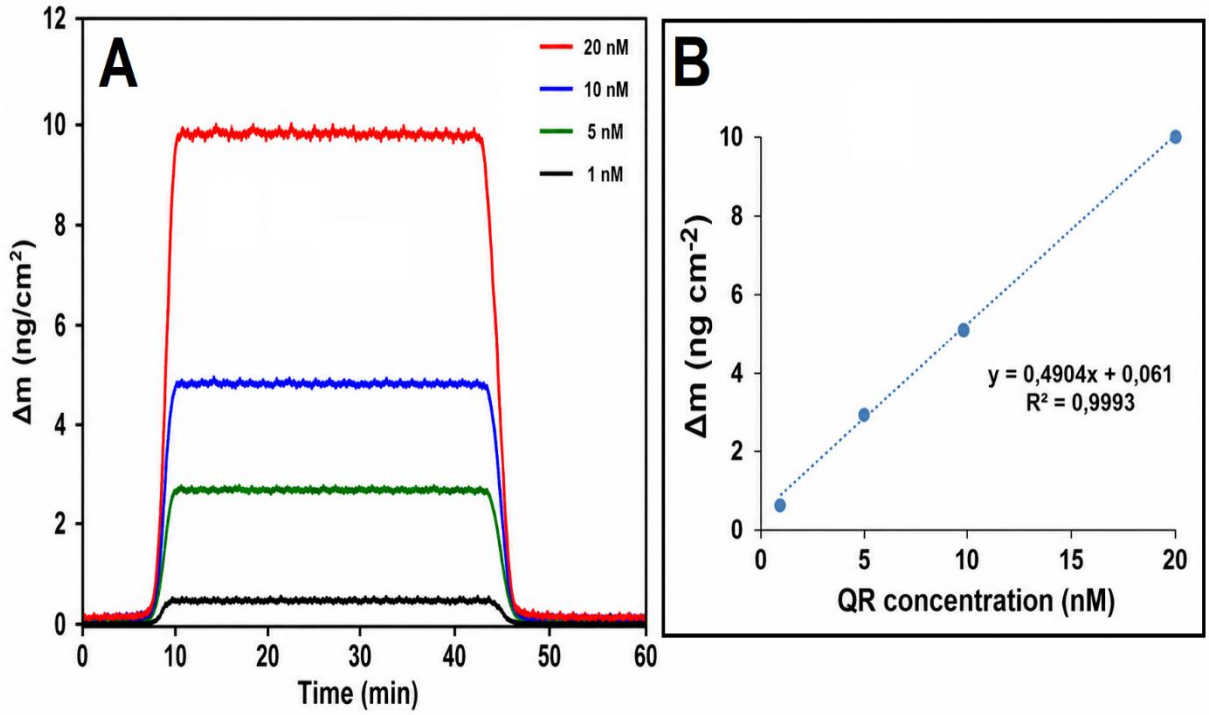

Fig. 3. (A) QCM sensorgrams obtained on the MIP/QCM chip at pH 6.0 in PB for QR solutions with concentrations ranging from 1.0 to 20.0 nM, and (B) the corresponding calibration plot of QR concentration versus QCM response.

Recovery

To evaluate the practical performance of the developed QR-imprinted MIP/QCM sensor, the recovery tests were performed using spiked apple juice samples. As shown in Table 1, the sensor achieved recovery rates approximating 100.00%, confirming its high precision and excellent selectivity despite the presence of a complex food matrix. To validate these findings, the same apple juice samples were analyzed using HPLC in scientific literature (Carvalho et al, 2023). The comparison presented in Table 1 demonstrated a close agreement between the data obtained from the MIP/QCM sensor and the HPLC method, with no statistically significant differences. This correlation provided the sensor's analytical reliability, selectivity and precision, validating its potential for use in analytical applications.

Table 1. Recovery results of QR (*n*=6)

	QR-imprinted MIP/QCM			**HPLC**	
Sample	**Added QR (nM)**	**Found QR (nM)**	***Recovery (%)**	**Found QR (nM)**	***Recovery (%)**
Apple juice	-	1.79 ± 0.02	-	1.80 ± 0.03	-
	5.00	6.78 ± 0.01	99.85 ± 0.01	6.81 ± 0.02	100.15 ± 0.02
	10.00	11.80 ± 0.01	100.08 ± 0.02	11.81 ± 0.02	100.08 ± 0.03
	15.00	16.80 ± 0.03	100.06 ± 0.02	16.79 ± 0.04	99.94 ± 0.02

*Recovery = Found QR, nM / Real QR, nM

Selectivity of QR-imprinted MIP/QCM sensor

To evaluate the selectivity of the QR-imprinted MIP/QCM sensor, its performance was tested in the presence of competing substances, specifically RT and AA. The sensor displayed exceptional selectivity for the QR analyte, which was confirmed by exposing the MIP/QCM chip to a 5.0 nM concentration of

QR alongside these interfering compounds (Fig. 4A). These results indicated that the sensor effectively binded QR when other molecules were present in significant excess. The calculated selectivity (k) and relative selectivity (k′) coefficients (Table 2) further demonstrated this efficiency, revealing that the MIP/QCM chip was 26.60 times more selective for QR than for RT or AA. Moreover, as shown in Fig. 4B, by utilizing the molecular imprinting technique, the sensor achieved substantially higher selectivity than its non-imprinted chip (NIP/QCM) with k′ values greater than 1, thus validating the high specificity of the MIP/QCM chip for QR detection.

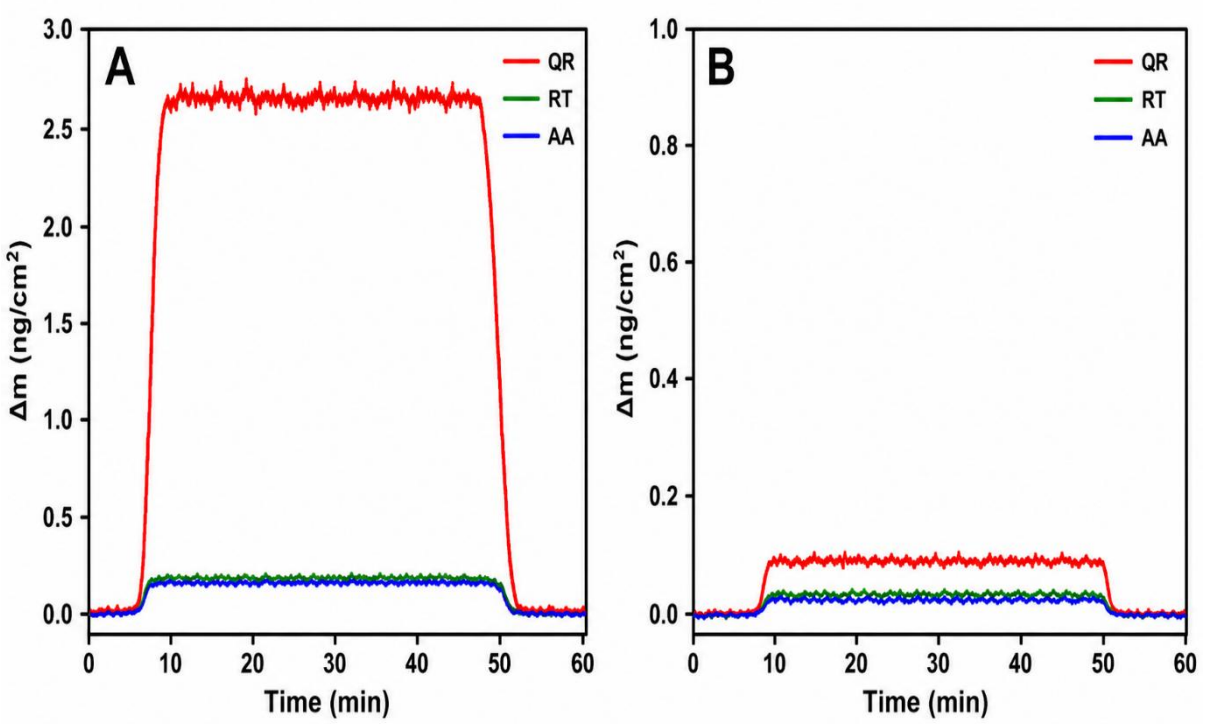

Fig. 4. Selectivity evaluation conducted on (A) the MIP/QCM chip and (B) the NIP/QCM chip using 5.0 nM QR, 5.0 nM RT, and 5.0 nM AA

Table 2. k and k′ values of QR-imprinted MIP/QCM sensor

	MIP		NIP		
	Δm	**k**	**Δm**	**k**	**k′**
QR	2.66	-	0.10	-	-
RT	0.10	26.60	0.05	2.00	13.30
AA	0.10	26.60	0.05	2.00	13.30

Analyte concentrations: 5.0 nM QR, 5.0 nM RT, and 5.0 nM AA

Stability

The long-term operational reliability of this MIP/QCM sensing platform was evaluated through an eight-week assessment of a single chip. The measurements were taken using a 5.0 nM QR solution. Hence, the signal recorded at the end of the eight-week maintained as 97.91% of its original value from the first week, providing definitive evidence of the sensor's exceptional stability.

CONCLUSIONS

This study successfully showed a MIP-based QCM sensor for the precise quantification of quercetin, which displayed a linear response range from 1.0 to 20.0 nM and a remarkably low LOD of 3.0×10^{-10} M. The sensor's practical applicability was confirmed through recovery assays in apple juice with near

100.0% values. Furthermore, its analytical accuracy was validated against HPLC, revealing no significant statistical difference between the two methodologies. The developed QCM sensor also provided a highly selective and stable platform for the precise determination of the target analytes in complex samples. Ultimately, the demonstrated success of the QCM sensor highlighted its significant potential for the future detection and analysis of a broader spectrum of flavonoid compounds.

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THE NEEDS OF CAREGIVERS OF INDIVIDUALS WITH SPECIAL NEEDS REGARDING EVIDENCE-BASED PRACTICES: A CROSS-SECTIONAL STUDY

ÖZEL GEREKSİNİMLİ BİREYLERE BAKIM VEREN PERSONELİN KANITA DAYALI UYGULAMALAR KONUSUNDA İHTİYAÇLARI: KESİTSEL BİR ARAŞTIRMA

Bu çalışma, 2025-1-TR01-KA220-HED 000349859 nolu Avrupa Birliği tarafından finanse edilen Erasmus+ Yüksek Öğretimde Stratejik Ortaklıklar çağrısı kapsamında hazırlanan "Özel gereksinimli bireylere bakım sağlayıcılarının bilimsel kanıtlara dayalı uygulamalar konusundaki yeterliliklerinin teknoloji destekli araçlarla geliştirilmesi: Türkiye ihtiyaç analizi değerlendirme raporuna" dayalı olarak hazırlanmıştır. Çalışma, Avrupa Komisyonu tarafından finanse edilmekle birlikte, araştırmacıların görüşlerini yansıtmaktadır.

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Özet

Özel gereksinimli bireyler, tanısı olan veya parçalanmış aile gibi dezavantajlı gruplar içerisinde yer alabilirler. Söz konusu bireylerin erken dönemlerden itibaren eğitim aldığı kurumlardana birisi de sosyal hizmet kurumlarıdır. Bu bireylerin eğitiminden ise bakıcılar/ bakım personeli sorumludur. Bu çalışmada, bakıcıların/ bakım personelinin özel gereksinimli bireylerin eğitimine ilişkin kanıta dayalı uygulamalar konusunda yeterlilikleri incelenmiştir. Bu kapsamda, literatür taramasına dayalı olarak oluşturulan bir form uzman görüşü alınarak kullanılmıştır. Araştırma verileri yarı profesyoneller ve profesyonellerden oluşan iki farklı gruptan toplanmıştır. Ulaşılan sonuçlara göre her iki grupta veri toplanan sekiz farklı başlığın "davranış yönetimi, iletişim ve dil becerilerini destekleme, erken okuryazarlık, doğal öğretim, etkinlik temelli öğretim, etkinlik çizelgeleri, akran öğretimi ve öz düzenlemeyle belirlenen günlük yaşam becerileri" bakım personeli için çok önemli olduğuna ve bu konularda bakım personellerinin yüksek düzeyde desteğe ihtiyaç duyduklarını bildirmişlerdir. Öte yandan, her iki grupta yer alanlara göre en önemli konu "Davranış yönetimi" olarak beyan edilmiştir. Ayrıca, bakım personeline göre en fazla desteğe ihtiyaç duyulan konu "Öz karar vermeyi belirleyen günlük yaşam becerileri" olarak puanlanmıştır.

Anahtar kelimeler: Bakım personeli, kanıta dayalı uygulamalar, ihtiyaç analizi.

ABSTRACT

Individuals with special needs may belong to disadvantaged groups, such as those with a disability or from broken families. Social service institutions are among the organizations where these individuals receive education from an early age. Caregivers and care providers are responsible for educating these individuals. This study examined the competencies of caregivers/care providers in evidence-based

practices related to the education of individuals with special needs. In this context, a questionnaire developed based on a literature review was used after obtaining expert input. Research data were collected from two distinct groups: semi-professionals and professionals. According to the results, the eight different topics covered in both groups—"behavior management, supporting communication and language skills, early literacy, naturalistic teaching, activity-based instruction, activity schedules, peer tutoring, and daily living skills determined by self-regulation"—were identified as very important for care providers, and it was reported that care providers require a high level of support in these areas. On the other hand, participants in both groups declared that the most important topic was "Behavior Management." Additionally, the topic for which care providers felt they needed the most support was rated as "Daily living skills that determine self-determination."

Keyword: Care providers, evidence-based practices, needs analysis.

GİRİŞ

Özel gereksinimi bireylerin eğitiminde kanıta dayalı uygulamalar, etkinliği araştırma bulguları ile kanıtlanmış yöntemlerin kullanılması olarak tanımlanabilir (Cook ve Odom, 2013). Bu müdahalelerin tercih edilmesi, müdahale sürecinin standartlaştırılmasına, uygulama sürecinden en üst düzeyde fayda elde edilmesine ve zaman ve emekten tasarruf edilmesine yardımcı olur. Ancak, her müdahale gibi, kanıta dayalı uygulamaların başarısı da uygulayıcının müdahaleyi "uygulama protokolünü" tam ve tutarlı olarak gerçekleştirebilmesine paraleldir. Bir diğer ifadeyle, uygulama sadakat düzeyi ile müdahalenin etkililiği yakından ilgilidir.

Özel gereksinimli çocukların eğitiminden sorumlu çalışanlar, eğitsel müdahaleleri doğal ortamında uygulamaya aktaran birincil başat aktörlerdir. Aile ve Sosyal Hizmetler Bakanlığına bağlı hizmet veren "Çocuk Evleri" gibi sosyal hizmet kurumlarında bu rol öncelikle bakım çalışanları (bakım personeli) tarafından yerine getirilir. Parson ve diğerlerine göre (2017), eğitim personelinin müdahale sürecine aktif "uygulayıcı" olarak katıldıklarında tutarlı, sürdürülebilir ve genellenebilir sonuçlar elde edildiği belirtilmektedir. Öte yandan, bakım verenlerin bu kilit rolü üstlenebilmeleri için sahip olmaları gereken yetkinlik düzeyleri (beceri ve bilgi) ile öz yeterlilik algıları (kendi yeteneklerine olan inanç) arasında karmaşık bir ilişki bulunmaktadır. Hume ve diğerleri (2021) tarafından yapılan bir derleme, bakım personelinin kanıta dayalı uygulamaları kullanma konusunda yüksek düzeyde motivasyona sahip olmalarına rağmen, konuya ilişkin bir eğitim almadan bunları doğru ve tutarlı bir şekilde uygulama (uygulamaya bağlılık) kapasitelerinin düşük olduğuna işaret etmektedir.

Bakım personelinin yeterlilikleri çeşitli etmenlere bağlı olarak farklılaşabilir. Örneğin, bakım personelinin kanıta dayalı uygulamalara ilişkin temel davranış ilkelerini tam olarak anlamamaları durumunda, uygulama sırasında ortaya çıkan beklenmedik zorlayıcı durumlara çözüm üretmekte güçlük yaşayabilirler (Cook ve Odom, 2013). Bunun yanısıra, bir müdahalenin bazı yönlerini doğru bir şekilde uygularken, karmaşık veya zaman alıcı diğer bileşenlerini göz ardı edebilirler. Karmaşık bilimsel terminolojiyi uygulamaya aktarmakta güçlük yaşanılan bir diğer problem durumudur (Parsons vd., 2017).

Türkiye'de bakım personelinin özel eğitim yeterliliklerinin incelendiği bir çalışmaya ulaşılamamıştır. Bu ihtiyaçtan yola çıkarak, bir Erasmus+ KA220HED projesi kapsamında bakım personelinin özel gereksinimli çocukların eğitiminde kanıta dayalı uygulamalar konusunda yeterlilikleri incelenmiştir. Bu çalışma verileri, söz konusu projenin Türkiye raporu kapsamında toplanan verilere dayalı olarak hazırlanmıştır. Çalışmada, "Sosyal hizmet kurumlarında çalışan bakım personeli özel gereksinimli bireylerin eğitiminde öncelikli olarak hangi konulara ihtiyaç duymaktadır?" sorusuna yanıt aranmıştır.

YÖNTEM

Araştırma Modeli

Bu çalışma, betimsel olarak ve kesitsel verilere dayalı hazırlanmıştır. Bu modele göre, çalışma grubundan alınan veriler belirli bir zaman aralığında toplanmıştır. Bu tasarımın temel amacı, katılımcıların özel eğitime olan ihtiyaçları gibi bir değişkene ilişkin mevcut durumlarını betimlemektir

(Creswell & Creswell, 2018). İlk aşamada literatüre odaklanılarak sorun durumu belirlenmiş, bir sonraki aşamada bir ölçme aracı hazırlanarak veriler toplanmış ve ulaşılan sonuçlar raporlanmıştır (Creswell, 2020).

Çalışma Grubu

Proje çalışmasında, verileri iki ana gruptan (n=119) toplanmıştır. İlk grup yarı profesyonel veya adayı olan gruplardır (n= 66). Bu kapsamda 10 bakım veren/ hizmet sağlayıcı (%14,9), 21 özel eğitim öğretmeni (%31,3), 19 özel gereksinimi olan çocuklarla ilgili bölümlerde eğitim alan üniversite öğrencisi (%19,4), 2 çocuk gelişimci (%3), 1 sivil toplum kuruluşu (STK) temsilcisi (%1,5) ve 20 özel gereksinimi olan çocuklarla ilgili alanlarda çalışan veya adaylarından (%29,9) oluşmaktadır. İkinci grupta yer alan katılımcılar ise profesyonellerden oluşmaktadır. Bu kapsamda, 53 uzman ve akademisyenden veri toplanmıştır.

Veri Toplama Aracı

İhtiyaç analizi raporunun hazırlanması sırasında, araştırma ekibi tarafından hazırlanan ve uzman görüşüyle geçerliliği artırılan ihtiyaç analizi toplama formu yardımıyla veriler toplanmıştır. Bir diğer ifadeyle, literatür taramasına dayalı olarak belirlenmiş olan sekiz ana temel konu (davranış yönetimi, iletişim ve dil becerilerini destekleme, erken okuryazarlık, doğal öğretim, etkinlik temelli öğretim, etkinlik çizelgeleri, akran öğretimi ve öz düzenlemeyle belirlenen günlük yaşam becerileri) ve bu konuların herbirisinin içeriğini yansıtan beş öğrenme çıktısının herbirisiyle ilgili birer olmak üzere toplamda seksen 10'lu likert tipi maddeler halinde hazırlanmıştır. Daha sonra uzman görüşü alınarak, son hali verilmiştir.

Formda, ilk aşamada özel gereksinimi olan çocuklara yönelik öğretim uygulamalarında sözkonusu konuların herbirisinin ne kadar önemli olduğu yoklanmıştır. İkinci soruyla, ilgili alt modüle ilişkin "ne kadar destek ihtiyacı duyduğu"nun belirlenmesi amaçlanmıştır. Her iki soru tipi birlikte kullanılılarak, yarı profesyoneller (özel gereksinimi olan çocuklarla doğrudan çalışan bakım verenler/hizmet sağlayıcılar…) ve profesyonellerden (özel eğitim öğretmenleri ve özel eğitim alanında veya ilgili bölümlerde çalışan akademisyenler) veriler toplanmıştır. Veriler, çevrimiçi ortamlarda Google Formlar kullanılarak ve forma yanıt verecek özellikli gruba bağlı olarak yönergelerde kısmi revizyonlar yapılarak veriler toplanmıştır.

Analizler ve puanlama

Analizler, literatür taramasında tespit edilen öncelikli alanlar göz önünde bulundurularak betimsel istatistiklerin hesaplanmasıyla yapılmıştır. Analizde, akademisyenlerin/ uzmanların ve bakım verenlerin/ hizmet sağlayıcıların yanıtları, önem ve destek ihtiyaçları kapsamında ayrı ayrı hesaplanmıştır. Değerlendirme formunda her alt modül, bir alt boyut gibi göz önünde bulundurulabilir. Her bir alt boyuttan alınabilecek en düşük puan 0 iken, en yüksek 50'dir. Daha yüksek bir puan alınması, her bir alt modülün "ciddi öneme" ve/ veya "ciddi destek ihtiyacına" sahip olduğunu yönünde yorumlanmaktadır. Araştırma verileri, 2026 yılında ocak ve nisan ayı aralığında toplanmıştır.

BULGULAR, TARTIŞMA, VE SONUÇ

Özel eğitimde etkililiği sistematik olarak kanıtlanmış bilimsel uygulamalar, eğitim vermekle yükümlü çalışanları karar verme süreçlerinde güçlendirirken, müdahalelerin de etkililiğini artırmaktadır. Söz konusu uygulamalar özel gereksinimli bireylerin akademik ve gelişimsel çıktılarına ilişkin düzenli ve sistematik olarak veri toplanmasını öngördüğü için faydaları somut biçimde ortaya konulabilmektedir. Kanıta dayalı uygulamalar, farklı yetersizlik türlerine ve bireysel ihtiyaçlara göre de uyarlanabilmektedir. Dolayısıyla da farklı tip öğrenme profillerinin eğitsel ihtiyaçlarını karşılama yüksek düzeyde adaydır. Bir diğer boyutu, kanıta dayalı uygulamalar, etkililiği sınanmış bilimsel temelli uygulamalar olduğu için özel gereksinimli bireylerin süreçte zaman kaybetmesinin önüne geçmekte, özelllikle erken çocukluk dönemi müdahalelerinde kritik dönemlerin kaçırılmadan yakalanmasına yardımcı olabilmektedir. Bu yöntemlerin uygulanması kurumsal düzeyde standartları sağlanması, öğretim programlarında tutarlılığın yakalanmasını da zemin hazırlamaktadır. Bu yönleri dikkate

alındığında, ulusal veya uluslararası uygulamaları sürdürülmesinde güçlü bir referans çerçeve sunabilmektedir.

Bu çalışmada, sosyal hizmet kurumlarında çalışan ve özel gereksinimli bireylerin eğitiminden sorumlu bakım personelinin bilimsel kanıta dayalı uygulamalar konusunda eğitim ihtiyaçları, alanda çalışan yarı profesyoneller (bakım personeli ve adayı…) ve profesyonellerden gelen yanıtlara göre "konunun önemi" ve konuya ilişkin "destek ihtiyaçları" kapsamında ortaya konulmuştur. Çalışmadan, elde edilen sonuçlar aşağıdaki tabloda özetlenmiştir.

Tablo 1.

Bakıcıların özel gereksinimli bireylerin eğitimine ilişkin ihtiyaç analizi.

		Bakıcılar/ Sağlayıcılar		Bakım Profesyoneller/ Uzmanlar	
Alt modüller	Konu	X	SS	X	SS
İletişim, Konuşma ve Dil Becerilerini Destekleme	Önem	44,00	6,52	46,76	4,10
	Destek İhtiyacı	34,53	13,00	47,01	4,49
Etkinlik Çizelgeleri	Önem	43,59	7,11	44,73	6,44
	Destek İhtiyacı	35,56	13,72	45,32	6,08
Öz Karar Vermeyi Belirleyen Günlük Yaşam Becerileri	Önem	44,17	7,31	46,47	3,88
	Destek İhtiyacı	37,57	12,68	46,52	3,86
Etkinlik Temelli Öğrenme	Önem	45,32	5,75	46,50	3,85
	Destek İhtiyacı	33,94	14,62	46,72	3,85
Akran Eğitimi	Önem	44,45	7,54	45,67	4,91
	Destek İhtiyacı	34,43	14,42	45,72	5,04
Doğal Öğretim	Önem	44,80	5,85	46,80	4,18
	Destek İhtiyacı	33,15	15,27	46,86	4,38
Davranış Yönetimi	Önem	46,08	5,15	47,80	3,18
	Destek İhtiyacı	35,68	13,79	47,59	3,62
Erken Okuryazarlık Becerileri	Önem	44,40	6,77	44,38	6,25
	Destek İhtiyacı	35,16	15,14	45,66	5,37

Bakıcıların/ bakım sağlayıcılara göre önem duyulan konulara ilişkin puanlar X = 43,59 (SS = 7,11) - X 46,08 = (SS = 5,15) aralığında, desteğe ihtiyaç duyulan konularda da X = 33,15 (SS = 15,27) - X = 37,57 (SD = 12,68) aralığında değişmektedir. Bakıcılar tarafından en önemli konu olarak "Davranış yönetimi" belirtilirken, "Öz karar vermeyi belirleyen günlük yaşam becerileri" konusunda ise en fazla desteğe ihtiyaç duydukları konu olarak bildirilmiştir. Profesyonellere göre ise sekiz konunun önemi X = 44,38 (SS = 6,25) ile X = 47,80 (SS = 3,18) aralığında puanlanmıştır. Bir diğer ifadeyle, tüm konular yüksek düzeyde önemlidir ve bakım personeli öncelikli olarka desteklenmesi gerekmektedir. Bakım personelinin konuya ilişkin destek ihtiyaçları, en yüksek "Davranış yönetimi" olduğu ortaya çıkmıştır (X = 47,59; SD = 3,62). Profesyonellerin görüşleri, bakım personelininkine benzerdir. Profesyonellere göre bakım personelinin en fazla desteğe ihtiyaç duyduğu konu "Davranış yönetimi" konusudur. Her bir konu, yarı profesyoneller veya profesyonel çalışanlarca, "son derece önemli" ve "bakıcıların konuya ilişkin desteğe ciddi şekilde ihtiyaç duyduğunu"na yönünde yanıtlanmıştır.

Milli Eğitim Bakanlığı (2018) tarafından yayınlanmış olan Özel Eğitim Hizmetleri Yönetmeliği veya Türkiye Engelliler Kanunu gibi farklı yasal uygulamalar ile Türkiye'de engelli bireylerin eğitimleri devletin asli yükümlülükleri arasında sıralanmıştır. Bunun yanısıra, Türkiye'nin de onayladığı ve tarafı olduğu Birleşmiş Milletler Engelli Kişilerin Hakları Sözleşmesi (Birleşmiş Milletler, 2021) gibi uluslararası bildirgelerle engelli kişilerin hakları, günlük yaşama bağımsız veya en az yardımla katılımı gibi bir takım haklarına yönelik ulusal tahahütte bulunulmuştur.

Uluslarası bildirgeler veya yasal mevzuatın gereklerinin yerine getirilebilmesi için Türkiye Aile ve Sosyal Politikalar Bakanlığı (Aile ve Sosyal Politikalar Bakanlığı, 2023) tarafından 2030 Erişilebilir Vizyon Belgesi uyarınca ilan edilen 2023-2025 Engelli Hakları Ulusal Eylem Planı, engelli bireylerin haklarının hayata geçirildiği kapsayıcı, eşitlikçi, sürdürülebilir ve daha iyi bir Türkiye hedeflenmektedir. Söz konusu hedeflere erişimde ise özel gereksinimli bireylerin eğitiminden sorumlu bakım personelinin eğitim ihtiyaçlarının belirlenmesi ve bu ihtiyaçlara yönelik bir takım önlemler alınması maliyet etkili

bir yaklaşımdır. Bu çalışmada ortaya çıkan sonuçlar, bakım personelinin özel eğitimdeki temel konulara ilişkin yeterliliklerinin düşük olduğu ve bu konuda desteklenmesi gerektiğine işaret etmesi boyutu ile manidardır.

Bu çalışmanın bir takım sınırlılıkları da mevcuttur. Bunlardan ilki, katılımcılardan toplanan veriler literatür taramasına dayalı olarak belirlenen öncelikli konularla sınırlıdır. Bir başka çalışmada, farklı konuların ihtiyaç analizine dahil edilmesi daha geniş bir çerçeveden konuların değerlendirilmesine yardımcı olabilir. Çalışmanın bir başka sınırlılığı ise veri toplama yaklaşımıyla ilgilidir. Bu çalışmada, 10'lu likert tipi bir araçla problem durumu betimlenmiştir. Bir başka çalışmada, görüşme veya yerinde gözlem gibi nitel araçlar veya karma tip veri toplama araçları kullanılabilir. Böylece de özel gereksinimli bireylerin eğitiminden sorumlu personelin yeterliliklerine ilişkin derinlemesine veri elde edilerek, hizmetiçi eğitim programları bu verilere göre yapılandırılabilir.

Bu çalışmada özel gereksimli birey, özel eğitim tanısı almış veya dezavantajlı gruplar içinde yer alan (parçalanmış aile, ebeveyn vefatı…) bu nedenle de özel eğitime ihtiyaç duyan bireyler kapsamıyla sınırlandırılarak kullanılmıştır. Dolayısıyla, bakım personelinin yeterlilikleri veya eğitsel ihtiyaçları özel eğitim gruplarına (Otizm, Down ….) yönelik farklılaşabilir. Dolayısıyla, bir başka çalışmada takip edilecek olan "özel eğitim gereksinimi" kavramının kavramsal çerçevesine ilişkin bakım personelinin yeterlilikleri farklılaşabilir. Dolayısıyla, bu çalışmanın sonuçları, bu çalışmada benimsenen kavramsal çerçeveye özgü olduğu okuyucular tarafından göz önünde bulundurulmalıdır.

KAYNAKLAR

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IN VITRO EGG HATCHING SUPPRESSION OF ROOT-KNOT NEMATODE *MELOIDOGYNE LUCI* BY PLANT GROWTH-PROMOTING ENDOPYTIC BACTERIA ISOLATED FROM HAZELNUT ROOTS

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ABSTRACT

Meloidogyne luci emerged in recent years as the spreading important root-knot nematode associated with the kiwifruit plant. This nematode causes root-knots and may cause yield losses of the plant depending on the increasing numbers of the nematode in the soil over the years. Plant growth-promoting bacteria (PGPB) with nematode-suppressive activity may offer an environmentally sustainable alternative to chemical nematicides. This study evaluated the *in vitro* effects of nine PGPB isolates obtained from hazelnut (*Corylus colurna* L.) roots on the egg hatching of *M. luci*. The nematode population was isolated from kiwifruit (*Actinidia deliciosa* v. Hayward) and maintained as a pure culture. Surface-sterilized eggs were exposed to direct bacterial suspensions (DBS; 10^9 CFU/ml) or cell-free filtered suspensions (FS) in cell culture plates. Each treatment had five replicates, with an average of 60.5 ± 12.85 eggs per well. Sterile distilled water and an abamectin-based nematicide (Abamax 50 SC, 50 g L^{-1} abamectin) were used as negative and positive controls, respectively. After seven days of incubation at 26 °C, second-stage juveniles (J2) were counted under an inverted microscope. The data were analyzed by ANOVA, and multiple comparisons were conducted by Tukey. Unhatched eggs were collected, washed, and transferred to sterile distilled water for an additional 48 h to determine whether the eggs continued to hatch into J2. Both DBS and FS treatments markedly reduced egg hatching ($p<0,000$). Inhibition rates changed from 85.78 to 100% for DBS and from 82.47 to 99% for FS. *Bacillus thuringiensis* 1K068 and *Pseudomonas* sp. 6K005 revealed the highest inhibition rates (100%) in the DBS assay. In the FS assay, *Pseudomonas* sp. 6K005 showed the highest inhibition rate (99%), followed by *Pseudomonas* sp. 1K007 (98.67%). The lowest inhibition rates were recorded for *Rhizobium rhizogenes* 3K180 in both DBS (85.78%) and FS (82.47%) treatments. The other five isolates, *Agrobacterium tumefaciens* 3K130, *Promicromonospora* sp. 5K042, *Pseudomonas* sp. 1K107, *Pseudomonas* sp. 5K032, *Staphylococcus warneri* 3K152 showed inhibition rates of 98.67–99.66% in DBS and 88.76–95.37% in FS. The eggs transferred into sterile water remained still without hatching after 48 h, although vital activity and development of some juveniles (J1) inside the nematode egg-shell were observed. These findings indicate that hazelnut root-associated PGPB, particularly *Pseudomonas* sp. 6K005 and *B. thuringiensis* 1K068 have strong potential for the biological management of *M. luci*. In conclusion, the bacterial isolates of this bioassay revealed promising potential for further greenhouse or J2 infectivity trials, and delaying nematode development or host infection may contribute to the sustainable management of *M. luci*.

Key Words: Actinidia deliciosa, Biological Control, Endophytic Bacteria, Plant Parasitic Nematodes, PGPB

BIOTECNOLOGICAL METHODS FOR PRODUCTION OF POLYENE MACROLIDE ANTIBIOTICS: RECENT ADVANCES, SEARCH OF NEW DIRECTIONS FOR IMPROVEMENT AND DEVELOPMENT PROSPECTS

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ABSTRACT

Polyene macrolide antibiotics (PMAs) amphotericin B, nystatin, pimaricin, and candicidin are widely used in medical practice to treat both superficial and deep mycoses. PMAs constitute a large group of natural compounds comprising over 200 agents that exhibit activity against yeasts, yeast-like fungi, and filamentous fungi, including both saprophytic and pathogenic species. At the same time, the PMAs used in medical practice do not fully meet the needs of clinicians due to their limited efficacy, which linked to low water solubility and high toxicity (primarily nephrotoxicity), as well as the emergence of resistant strains of pathogenic fungi. In view of this, the search for new PMAs with improved biomedical properties, produced via microbiological synthesis, as well as the optimization of existing biosynthesis technologies, is a very actual task.

The present report characterizes modern microbiological methods for producing PMAs. The advantages of biosynthetic methods for PMAs production, which characterized by high target product yields, economic benefits, and environmental safety, are discussed. The main directions for improving the efficiency of biotechnological methods for producing PMAs are including: 1) the search for new, highly efficient PMAs producers, both for obtaining known PMAs and for production of new PMAs; 2) optimization of PMAs biosynthesis technology: search of new culture media, improvement of aeration processes, modern control methods; 3) targeted biosynthesis of novel PMAs and its semisynthetic derivatives using modified gene clusters; 4) new approaches to the equipment and process design for PMAs biosynthesis.

Key Words: Polyene Macrolide Antibiotics, Mycoses, Microbiological Synthesis, Optimization of Biosynthesis Technology

PARENTAL PERMISSION FOR RISKY PLAY: ASSOCIATIONS WITH EMOTION REGULATION AND SELF-REGULATION IN PRESCHOOL CHILDREN

EBEVEYNLERİN OKUL ÖNCESİ DÖNEMDEKİ ÇOCUKLARININ RİSKLİ OYUNLARINA İZİN VERMELERİ İLE ÇOCUKLARIN DUYGU DÜZENLEME VE ÖZ DÜZENLEME BECERİLERİ ARASINDAKİ İLİŞKİLER

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ÖZET

Giriş ve Amaç: Riskli oyun, çocukların belirsizlik, heyecan, yönetilebilir fiziksel güçlüklerle karşılaştıkları ve karar verme, korkuyu yönetme, davranışlarını koşullara göre ayarlama fırsatları buldukları bir oyun bağlamıdır. Okul öncesi dönemde bu deneyimlere erişim büyük ölçüde yetişkinlerin izin ve güvenlik değerlendirmeleri tarafından belirlenmektedir. Araştırmada, ebeveynlerin riskli oyuna izin verme durumları ile çocukların duygu düzenleme ve öz düzenleme becerileri arasındaki ilişkiler incelenmiştir.

Yöntem: Nicel araştırma yöntemlerinden ilişkisel tarama modelindeki çalışma, Ankara'daki resmî ve özel okul öncesi eğitim kurumlarına devam eden 48-72 aylık 131 çocuk (66 kız, 65 erkek), ebeveynleri ve öğretmenleriyle yürütülmüştür. Veriler Riskli Oyuna İzin Verme Ölçeği, Okul Öncesi Duygu Düzenleme Ölçeği ve Çocuk Davranış Değerlendirme Ölçeği ile toplanmıştır. Riskli oyuna izin ebeveynlerden, duygu düzenleme çocuklarla bireysel uygulamadan, öz düzenleme ise öğretmenlerden elde edilmiştir. Analizlerde betimsel istatistikler, Pearson korelasyonu, basit doğrusal regresyon, t testi ve tek yönlü varyans analizi kullanılmıştır.

Bulgular: Riskli oyuna izin verme puanları duygu düzenleme ($r = .292$, $p = .001$) ve öz düzenleme puanlarıyla ($r = .227$, $p = .009$) pozitif yönde ilişkili bulunmuştur. Riskli oyuna izin verme düzeyi duygu düzenlemedeki varyansın %8.5'ini ($\beta = .292$, $p = .001$), öz düzenlemedeki varyansın ise %5.2'sini ($\beta = .227$, $p = .009$) açıklamıştır. Duygu düzenleme puanları daha büyük yaş grubunda, doğada sıklıkla vakit geçirenlerde ve anne öğrenim düzeyine göre anlamlı biçimde farklılaşmıştır. Kız çocukların öz düzenleme puanları erkek çocuklardan yüksektir. Riskli oyuna izin verme puanları da anne öğrenim düzeyine göre farklılaşmıştır. **Tartışma ve Sonuç:** Bulgular, ebeveyn izninin çocukların yönetilebilir zorluklara erişimini şekillendiren bağlamsal bir koşul olabileceğini ve düzenleme becerileriyle küçük ancak anlamlı ilişkiler gösterdiğini ortaya koymaktadır. Sonuçlar nedensellik göstermemekle birlikte, ailelerin ve erken çocukluk eğitimcilerinin risk ile tehlikeyi ayırt ederek çocuklara gelişimsel açıdan uygun ve güvenli zorluklar sunmasının önemine işaret etmektedir.

Anahtar Kelimeler: Riskli oyun; Ebeveyn izni; Duygu düzenleme; Öz düzenleme; Okul öncesi dönem

ABSTRACT

Introduction and Purpose: Risky play allows children to encounter uncertainty, excitement, and manageable physical challenge while making decisions, managing fear, and adjusting their behaviour.

During the preschool years, access to these experiences is strongly shaped by adults' permission and safety judgements. This study examined the associations between parental permission for risky play and preschool children's emotion regulation and self-regulation.

Materials and Methods: The correlational study included 131 children (66 girls, 65 boys) aged 48-72 months attending public and private preschools in Ankara, Türkiye, together with their parents and teachers. Data were collected using the Risky Play Permission Scale, Preschool Emotion Regulation Scale, and Child Behaviour Rating Scale. Permission was reported by parents, emotion regulation was assessed individually with children, and self-regulation was rated by teachers. Descriptive statistics, Pearson correlations, simple linear regression, t tests, and one-way analysis of variance were used.

Results: Permission for risky play was positively associated with emotion regulation ($r = .292$, $p = .001$) and self-regulation ($r = .227$, $p = .009$). Permission explained 8.5% of the variance in emotion regulation ($\beta = .292$, $p = .001$) and 5.2% of the variance in self-regulation ($\beta = .227$, $p = .009$). Emotion regulation differed significantly by age group, frequency of time spent in nature, and maternal education. Girls had higher self-regulation scores than boys. Parental permission also differed significantly by maternal education. **Discussion and Conclusion:** Parental permission may shape children's access to manageable challenges and showed small but significant associations with regulatory skills. Although the cross-sectional findings do not establish causality, they underline the importance of helping families and early childhood educators distinguish manageable risk from danger and provide developmentally appropriate and safe challenges.

Key Words: Risky play; Parental permission; Emotion regulation; Self-regulation; Preschool children

INTEGRATING MANAGEMENT SYSTEM AND REGULATORY APPROACHES FOR ENTERPRISE GENERATIVE AI GOVERNANCE

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ABSTRACT

Introduction and Purpose: The rapid adoption of Generative Artificial Intelligence (GenAI) has fundamentally transformed enterprise processes, bringing with it significant governance challenges related to accountability, transparency, data management, human oversight, cybersecurity, intellectual property, and regulatory compliance. While ISO/IEC 42001 and the European Union Artificial Intelligence Act (EU AI Act) represent two significant advancements in AI governance, current studies generally examine these frameworks independently and focus primarily on governance systems or legal compliance. Consequently, there is limited research that proposes an integrated governance perspective for enterprise GenAI that combines enterprise governance requirements with regulatory obligations. Therefore, this study aims to develop an integrated governance framework by comparatively analyzing ISO/IEC 42001 and the EU AI Act.

Materials and Methods: This study adopts a conceptual research design using structured document analysis and comparative framework analysis. ISO/IEC 42001 and (EU) Regulation 2024/1689 constitute the primary sources analyzed, while the AI governance literature provides the conceptual basis for the proposed framework. The collected evidence was systematically analyzed to identify governance dimensions, overlapping requirements, complementary mechanisms, and conceptual gaps. These findings were then synthesized into an integrated enterprise Generative AI governance framework.

Results: The comparative analysis shows that ISO/IEC 42001 provides an organization-wide AI management system supporting leadership, risk management, lifecycle management, monitoring, and continuous improvement, whereas the EU AI Act establishes legally binding obligations based on AI risk categories, intended use, and organizational roles. Although both frameworks address common governance domains such as leadership, risk management, data governance, transparency, human oversight, documentation, monitoring, and continuous improvement, they perform different governance functions and are therefore not interchangeable. Based on these findings, this study proposes a four-layer Integrated Enterprise Generative AI Governance Framework that includes enterprise governance, regulatory compliance, GenAI lifecycle management, and continuous assurance. The framework also offers use case-based governance, governance decision gates, and a Control-Responsibility-Evidence Model to operationalize governance requirements.

Discussion and Conclusion: The proposed framework contributes to the AI governance literature by integrating AI management system principles, regulatory compliance requirements, socio-technical systems theory, and GenAI-specific operational controls within a single conceptual architecture. Beyond comparing ISO/IEC 42001 and the EU AI Act, the study provides organizations with a structured, auditable, and adaptable governance roadmap that can support responsible, risk-based, transparent, and sustainable enterprise adoption of Generative AI in evolving regulatory environments.

Keywords: Generative Artificial Intelligence; AI Governance; ISO/IEC 42001; EU AI Act; Socio-Technical Systems.

THE ROLE OF THE MANAGEMENT 3.0 APPROACH IN ENHANCING EMPLOYEE AGILITY

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ABSTRACT

Introduction and Purpose: Organizations operating in increasingly dynamic, uncertain, and technology-driven environments require employees who can rapidly adapt to changing conditions, proactively solve problems, and continuously develop new competencies. Consequently, employee agility has become a critical organizational capability for maintaining competitiveness and improving performance. At the same time, contemporary management approaches have shifted from traditional hierarchical control toward employee-centered practices emphasizing empowerment, collaboration, continuous learning, and self-organization. Among these approaches, Management 3.0 has attracted increasing attention from both researchers and practitioners. However, empirical research examining its impact on employee-related outcomes, particularly employee agility, remains limited. Therefore, this study aims to investigate the role of the Management 3.0 approach in enhancing employee agility and to contribute to the growing body of literature on contemporary management practices.

Materials and Methods: This study is designed as a quantitative empirical research. Data are planned to be collected through an online survey from approximately 200–300 employees working in public and private sector organizations in Türkiye using a convenience sampling method. Employee agility will be measured using an established and validated scale selected from the relevant literature. As no widely accepted standardized measurement scale for Management 3.0 has yet been established, the measurement items will be developed based on the core principles of the Management 3.0 approach. The content validity of these items will be evaluated through expert assessment prior to data collection. Descriptive statistics, reliability and validity analyses, and Partial Least Squares Structural Equation Modeling (PLS-SEM) are planned to be employed to examine the proposed research model.

Expected Findings: The study is expected to reveal a positive relationship between employees' perceptions of Management 3.0 approach and employee agility. Specifically, the core principles of Management 3.0, including employee empowerment, competence development, collaboration, adaptability, and continuous improvement, are expected to positively contribute to employee agility. The findings are further expected to provide practical implications for organizations seeking to enhance employee agility through contemporary employee-centered management practices.

Discussion and Conclusion: The anticipated findings are expected to contribute to the growing body of literature on Management 3.0 by providing empirical evidence regarding its relationship with employee agility. Furthermore, the study is expected to offer practical implications for managers seeking to strengthen organizational adaptability through employee-centered management practices. In addition, the findings are expected to provide a basis for future research examining the organizational outcomes of Management 3.0 approach across different sectors and organizational contexts.

Keywords:
Management 3.0; Employee Agility; Contemporary Management; Organizational Agility; PLS-SEM

STUDENT PSYCHOLOGY IN SINGING EDUCATION: THE EFFECT OF CRITICAL FEEDBACK PERCEPTION ON PERFORMANCE CONFIDENCE AND ARTISTIC AUTONOMY

SES EĞİTİMİNDE ÖĞRENCİ PSİKOLOJİSİ: ELEŞTİREL GERİ BİLDİRİM ALGISININ PERFORMANS GÜVENİ VE SANATSAL ÖZERKLİĞE ETKİSİ

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ÖZET

Amaç: Ses eğitimi, bilindiğinden çok daha zorlu bir süreçtir. Öğrenci sesini geliştirirken aynı zamanda bedeniyle, duygularıyla ve sanatsal kimliğiyle de yüzleşir. Ses, diğer enstrümanlardan farklı olarak insanın kendi bedeninden çıktığı için öğrenci aldığı eleştirileri zaman zaman kişiliğine yönelik olarak algılayabilir. Bu çalışmanın amacı, ses eğitimi öğrencilerinin eleştirel geri bildirim algıları ile performans güvenleri ve sanatsal özerklik düzeyleri arasındaki ilişkiyi kuramsal literatür çerçevesinde incelemek ve bu ilişkiyi açıklamaya yönelik özgün bir kavramsal model ortaya koymaktır.

Materyal ve Yöntem: Bu çalışma, kuramsal bir derleme niteliğindedir. Geri bildirim, öz-yeterlik ve öz-belirleme alanlarındaki ulusal ve uluslararası literatür sistematik biçimde taranmış; ses eğitimi bağlamıyla ilişkili çalışmalar analiz edilerek sentezlenmiştir.

Bulgular: Eleştiriyi gelişim fırsatı olarak gören öğrenciler sahnede daha güvenli dururlar, daha özgür kararlar alırlar. Buna karşılık eleştiriyi tehdit ya da yetersizlik işareti olarak algılayan öğrenciler zamanla çekingen bir tutum geliştirirler; performans sırasında müzikal ifadeye değil, hata yapmamaya odaklanırlar. Bu farkı yaratan şey geri bildirimin içeriği değil, öğrencinin onu nasıl okuduğudur. Üstelik bu okuma biçimi öğrenciden öğrenciye değiştiği gibi aynı öğrencide dersten derse bile farklılaşabilir. Önerilen kavramsal modele göre geri bildirim algısı performans güvenini, performans güveni ise sanatsal özerkliği doğrudan etkiler. Bu zincirde iki düzenleyici etken devreye girer: öğrencinin kendine olan inancı ve öğretmenin öğrenciye kendi kararlarını alma alanı tanıması.

Sonuç: Ses eğitimcisinin sorumluluğu doğru tekniği öğretmekle sınırlı değildir. Öğrencinin eleştiriyle sağlıklı bir ilişki kurmasına, sahnede kendine güvenmesine ve kendi sanatsal sesini bulmasına da zemin hazırlaması gerekir. Bunun için geri bildirimin dili, zamanlaması ve tonu en az içeriği kadar önem taşır. Eleştiriyi bir gelişim aracına dönüştürebilen eğitimci, öğrencisine teknik bilginin ötesinde kendi müzikal kimliğini inşa etme fırsatı sunar.

Anahtar Kelimeler: Ses eğitimi, eleştirel geri bildirim algısı, performans güveni, sanatsal özerklik, öz-yeterlik

ABSTRACT

Purpose: Singing education is a far more demanding process than it is commonly known to be. While developing their voice, students also confront their body, their emotions, and their artistic identity. Unlike other instruments, the voice comes from within the human body itself. For this reason, students may sometimes perceive the feedback they receive as a personal attack on their identity. This study aims to examine the relationship between critical feedback perception, performance confidence, and artistic autonomy in singing education through a review of the theoretical literature, and to propose an original conceptual model to explain this relationship.

Materials and Methods: This study is a theoretical review. National and international literature on feedback, self-efficacy, and self-determination was systematically examined, and studies relevant to the singing education context were analyzed and synthesized.

Findings: Students who view criticism as an opportunity for growth tend to perform with greater confidence and make freer artistic choices. In contrast, students who perceive criticism as a threat or a sign of inadequacy gradually become more hesitant and focus on avoiding errors rather than on musical expression. What makes the difference is not the content of the feedback, but how the student reads it. Moreover, this reading can vary from student to student, and even in the same student, from one lesson to the next. According to the proposed conceptual model, feedback perception directly affects performance confidence, which in turn affects artistic autonomy. Two moderating factors shape this chain: the student's belief in themselves, and the degree to which the teacher allows the student space to make their own decisions.

Discussion and Conclusion: The responsibility of a singing educator is not limited to teaching correct technique. It also involves creating the conditions for students to build a healthy relationship with criticism, to feel confident on stage, and to find their own artistic voice. The language, timing, and tone of feedback matter at least as much as its content. An educator who can turn criticism into a tool for growth offers students something beyond technical knowledge: the opportunity to build their own musical identity.

Keywords: Singing education, critical feedback perception, performance confidence, artistic autonomy, self-efficacy

POTATO PRODUCTION AND TRADE IN TÜRKİYE: CURRENT STATUS AND MAJOR CHALLENGES

TÜRKİYE'DE PATATES ÜRETİMİ VE TİCARETİ: MEVCUT DURUM VE TEMEL SORUNLAR

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ÖZET

Patates (*Solanum tuberosum* L.), nişasta, karbonhidrat, protein ile çeşitli vitamin ve mineraller bakımından zengin, insan beslenmesinde önemli bir yere sahip kültür bitkilerinden biridir. Ilıman ve serin iklim koşullarında yetişen patates, diğer birçok tarla bitkisinden farklı olarak vejetatif yolla çoğaltılmaktadır. Vejetatif çoğalma özelliği nedeniyle üretimde tohumluk yumrular kullanılmakta ve bitki tek yıllık kültür bitkisi olarak yetiştirilmektedir. Yüksek besin değeri, geniş kullanım alanı ve tarımsal istihdama sağladığı katkılar nedeniyle patates hem dünya genelinde hem de Türkiye'de stratejik öneme sahip tarım ürünlerinden biri olarak kabul edilmektedir.

FAO'nun 2025 yılı verilerine göre, patates dünya genelinde üretim miktarı bakımından en fazla üretilen altıncı tarımsal ürün konumundadır. Dünyada yaklaşık 16,8 milyon hektar alanda patates yetiştiriciliği yapılmakta olup, ekim alanı bakımından yaklaşık 4,57 milyon hektarla Çin ilk sırada yer almaktadır. Türkiye'de ise TÜİK'in 2025 yılı verilerine göre, patates ekim alanı yaklaşık 1.799.619 dekardır. Dünya patates üretimi yaklaşık 383 milyon ton düzeyindedir. Çin, 93,4 milyon tonluk üretimiyle dünya üretiminde ilk sırada yer alırken, Türkiye yaklaşık 6,4 milyon tonluk üretimiyle dünyada on beşinci sırada bulunmaktadır. Türkiye'de patates verimi yaklaşık 3,6 ton/da düzeyinde olup dünya ortalamasının üzerindedir. Ayrıca kişi başına yıllık patates tüketimi yaklaşık 67 kg olup, patates Türkiye'de temel gıda ürünleri arasında önemli bir yere sahiptir. Türkiye'de patates üretim miktarı, ekim alanı ve verim değerleri son yıllarda genel olarak artış eğilimi göstermektedir. Üretim özellikle Kayseri, Niğde, Konya ve Afyonkarahisar illerinde yoğunlaşmakta olup, bu iller ülke üretiminin önemli bir bölümünü karşılamaktadır.

Bununla birlikte, patates üretimi çeşitli yapısal ve ekonomik sorunlarla karşı karşıyadır. Son yıllarda özellikle gübre, mazot, elektrik ve işçilik maliyetlerinde yaşanan artışlar üretim maliyetlerini önemli ölçüde yükseltmiştir. Bunun yanı sıra hastalık ve zararlılarla mücadelede yaşanan güçlükler, sertifikalı tohumlukta dışa bağımlılık, üretim planlamasındaki yetersizlikler, fiyat dalgalanmaları, depolama ve soğuk zincir altyapısındaki eksiklikler ile pazarlama zincirinde karşılaşılan sorunlar, patates sektörünün sürdürülebilirliğini olumsuz etkileyen başlıca faktörler arasında yer almaktadır.

Anahtar Kelimeler: Patates, Patates üretimi ve ticareti, Türkiye

ABSTRACT

Potato (*Solanum tuberosum* L.) is one of the world's most important food crops, owing to its high nutritional value and rich content of starch, carbohydrates, protein, vitamins, and minerals. It is primarily cultivated under temperate and cool climatic conditions and, unlike most field crops, is propagated vegetatively through seed tubers. Due to this mode of propagation, potato is grown as an annual crop despite being a perennial species by nature. Because of its contribution to food security, nutrition,

employment, and agricultural income, potato occupies a strategic position in both global and Turkish agriculture.

According to the Food and Agriculture Organization, potato ranks as the sixth most produced agricultural crop worldwide in 2025. The global potato cultivation area is approximately 16.8 million hectares, with China accounting for the largest share at about 4.57 million hectares in 2025. In Türkiye, the total potato cultivation area was 1,799,619 decares in 2025, according to the Turkish Statistical Institute (TurkStat). Global potato production reached approximately 383 million tonnes in 2025. China ranked first with a production volume of 93.4 million tonnes, while Türkiye produced approximately 6.4 million tonnes, making it the fifteenth-largest potato producer in the world. The average potato yield in Türkiye is approximately 3.6 tonnes per hectare, which is above the global average. Furthermore, annual per capita potato consumption in Türkiye is approximately 67 kg, highlighting its importance as a staple food in the national diet. Since 2010, potato production, cultivated area, and yield in Türkiye have generally exhibited an upward trend. Production is concentrated primarily in the provinces of Kayseri, Niğde, Konya, and Afyonkarahisar, which collectively account for a substantial share of the country's total potato output.

Despite its economic importance, the potato sector in Türkiye faces several structural and economic challenges. Rising production costs, particularly those associated with fertilizers, diesel fuel, electricity, and labor, have significantly increased the cost of cultivation in recent years. Additional constraints include the prevalence of diseases and pests, dependence on imported certified seed potatoes, inadequate production planning, price volatility, insufficient storage and cold-chain infrastructure, and inefficiencies within the marketing system. Addressing these challenges is essential for improving the productivity, competitiveness, and long-term sustainability of potato production in Türkiye.

Key Words: Potato, Potato’s production and trade, Türkiye

GİRİŞ

Patates (*Solanum tuberosum* L.), nişasta, karbonhidrat, protein ile çeşitli vitamin ve mineraller bakımından zengin, insan beslenmesinde önemli bir yere sahip kültür bitkilerinden biridir. İçeriğinin yaklaşık yüzde on yedisini nişasta ve karbonhidrat oluşturmakta protein miktarı ise yaklaşık yüzde ikisi civarında bulunmaktadır. Potasyum, C ve B vitaminleri açısından zengindir (Arıoğlu vd., 2006; Abed ve Demirhan, 2018; Dinç vd. 2026).

Ilıman ve serin iklim koşullarında yetişen patates, diğer birçok tarla bitkisinden farklı olarak vejetatif yolla çoğaltılmaktadır (T.C. Tarım ve Orman Bakanlığı, 2016). Vejetatif çoğalma özelliği nedeniyle üretimde tohumluk yumrular kullanılmakta ve bitki tek yıllık kültür bitkisi olarak yetiştirilmektedir.

Yüksek besin değeri, geniş kullanım alanı ve tarımsal istihdama sağladığı katkılar nedeniyle patates hem dünya genelinde hem de Türkiye'de stratejik öneme sahip tarım ürünlerinden biri olarak kabul edilmektedir (Kadakoğlu ve Karlı, 2022). Dünya genelinde patates bitkisine dikkat çekmek amacıyla 2008 yılı Uluslararası Patates Yılı olarak ilan edilmiş olup 30 Mayıs ise patates günü olarak ilan edilmiştir (Yegül, 2025). Dünyada en çok üretilen ürünler arasında altıncı sırada olması önemini tekrar ortaya koymaktadır (Kadakoğlu ve Karlı, 2022).

Türkiye’nin hemen hemen her bölgesinde ekimi yapılmaktadır. Patates üretiminde ülkemiz dünyada on beşinci sırada yer almakta bu sıralamaya göre Çin gibi üretimde ön plana çıkan ülkeler arasında önemli konumunu sürdürmektedir (FAO, 2025). Kişi başı tüketimi TÜİK verilerine 67 kg olup patates bitkisinin ülkemiz beslenmesinde önemi açıkça görülmektedir. Bunun yanı sıra gıda, nişasta ve alkol gibi sanayi kollarına hammadde olarak girdi; tarım ve lojistik sektörüne istihdam alanı sağlamaktadır. Hem sanayiye hammadde kaynağı olması hem de tüketim açısından değerlendirildiğinde patatesin önemi göz ardı edilemez.

Gerek dünya gerekse Türkiye için önemli olan patatesin mevcut durumu ve üretiminde karşılaşılan sorunlar çalışmanın diğer bölümlerinde ele alınacaktır. Bu çalışma dünyada patatesin mevcut durumu, Türkiye’de patatesin mevcut durumu, Türkiye’de patatesin temel sorunları ve sonuç başlıklarıyla ele alınacaktır.

DÜNYADA PATATESİN MEVCUT DURUMU

Dünyada yaklaşık 16,8 milyon hektar alanda patates yetiştiriciliği yapılmaktadır (FAO 2025). Çin 4,57 milyon hektar alanla birinci sırada yer almakta ve patates üretiminde öncü bir ülke olarak karşımıza çıkmaktadır. Asya ülkeleri patates ekimi ve üretimiyle ön plana çıkmakta olup Çin'i sırasıyla Hindistan, Ukrayna ve Rusya takip etmektedir. Tablo1'e göre Hindistan yaklaşık 2,32, Ukrayna 1,21 ve Rusya 1,05 milyon hektar alanlık patates ekim alanına sahiptir. Bu ülkelerin patates ekim alanında öncü olması iklim elverişliliği, geniş toprakları ve yoğun iç tüketimine sahip olmalarıdır.

Tablo 1: Dünyada patates ekim alanı (FAO, 2025)

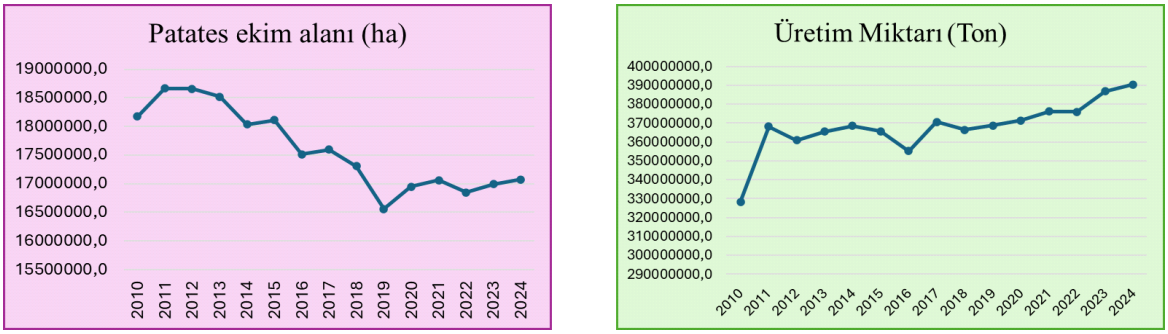
Ülkeler	Ekim Alanı (Milyon ha)
Çin	4,57
Hindistan	2,32
Ukrayna	1,21
Rusya	1,05

Dünya patates üretimi yaklaşık 383 milyon ton düzeyindedir (FAO, 2025). Çin, 93,4 milyon tonluk üretimiyle dünya üretiminde ilk sırada yer almaktadır. Üretimde ön plana çıkan diğer ülkeler sırasıyla Hindistan, Ukrayna ve ABD'dir. Tablo 2'ye göre Hindistan 57,05 milyon tonluk üretim hacmiyle ikinci sırada yer almaktadır. Ukrayna 21,13 ve ABD 19,06 milyon ton ile dünyada ön plana çıkmaktadır. Patates verimi yaklaşık 3,6 ton dekardır. Verimde Yeni Zelanda 5,1 tonla ilk sırada yer almaktadır (FAO, 2025). Yeni Zelanda uygun iklimi ve gelişmiş teknolojisi ile verimde dünyada ilk sırada yer almayı başarmıştır.

Tablo 2: Dünya patates üretimi (FAO, 2025)

Ülkeler	Ekim Miktarı (Milyon ton)
Çin	93,40
Hindistan	57,05
Ukrayna	21,13
ABD	19,06

Son 15 yıl verilerine bakıldığında (Şekil 1), artan teknoloji ve yükselen verimle birlikte ekim alanı azalış göstermesine rağmen üretim miktarı artış göstermiştir (FAO, 2025).



Şekil 1: Dünyada patates ekim alanı, üretim ve veriminin yıllar itibariyle değişimi (FAO, 2025)

TÜRKİYE'DE PATATESİN MEVCUT DURUMU

Ülkemiz ılıman ve serin bir iklime sahip olmasından dolayı patates bitkisi geniş bir ekim alanına sahiptir. 2025 yılında patates ekim alanı yaklaşık 1.799.619 dekar alan olmuştur (TÜİK, 2025). Kişi başı tüketim miktarı 67 kg olup hem ekim alanında hem de insan beslenmesinde ülkemiz için önemli bir bitki olarak karşımıza çıkmaktadır. En büyük üretim ve depolama merkezi olan Niğde patates ekiminde ilk sırada

yer almaktadır. Niğde'yi Konya, Kayseri ve Afyon gibi patateste ön plana çıkan şehirler takip etmektedir. Tablo 3'e göre Niğde 243750, Konya 218632, Kayseri 194623 ve Afyon 181571 dekar alanlık patatese sahiptir.

Tablo 3: Türkiye'de iller itibariyle patates ekim alanı (TÜİK, 2025)

Şehirler	Ekilen Alan (Dekar)
Niğde	243750
Konya	218632
Kayseri	194623
Afyon	181571
Sivas	116755
İzmir	96619
Diğer	747669

Kayseri dekara verimliliği en yüksek illerdendir. Afyon gerek sanayiye gerekse yemeklik patates üretiminde ön plana çıkan bir şehir olmakla birlikte Sivas tohumluk patatesin üretim merkezi olarak karşımıza çıkmaktadır.

Ülkemizde patates üretimi yaklaşık 6,4 milyon tondur (TÜİK, 2025). FAO verilerine patates üretiminde on beşinci sırada yer almaktayız. Bu sıralamaya göre dünya ülkeleri arasında üretimde ön plana çıkmaktayız ve patatesin ülkemiz için önemi bir kez daha ortaya konulabilmektedir.

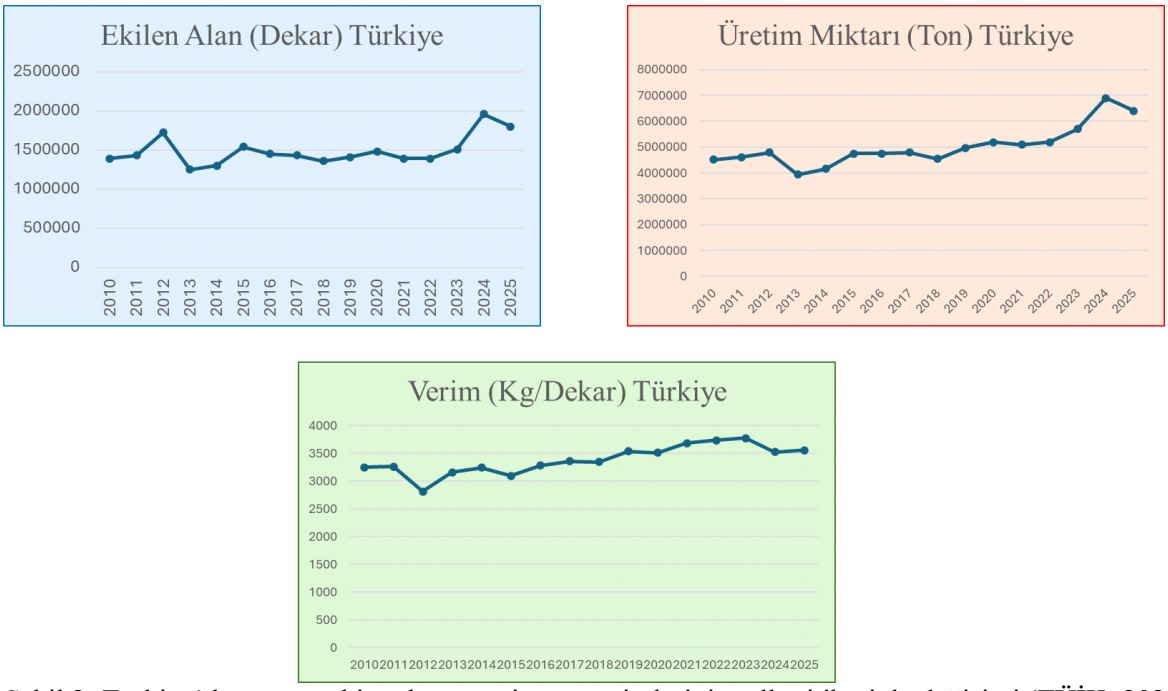
Üretimde Kayseri 933219 tonla üretimde ilk sırada yer almaktadır. Sırasıyla Niğde, Konya ve Afyon en çok patates üretiminin yapıldığı illerdir. Tablo 4'e göre Niğde 884023, Konya 837272 ve Afyon 648029 tonluk üretime sahiptir. Ülkemizin üretim miktarı ve ekilen alanda sıralama farklı olsa da aynı iller ön plana çıkmaktadır. Toplam üretim, tüketim ve dünyadaki sıralamamız hem ülkemiz açısından hem de bu iller açısından önem arz etmektedir.

Tablo 4: Türkiye'de iller itibariyle patates üretim miktarı (TÜİK, 2025)

Şehirler	Üretim Miktarı (Ton)
Kayseri	933219
Niğde	884023
Konya	837272
Afyon	648029
Sivas	475717
İzmir	339920
Diğer	8681820

Ülkemizin dekara ortalama patates verimi 4,9 ton olup dünya ortalamasının üzerindedir (TÜİK, 2025). Kayseri üretimde ve ekimde olduğu gibi yaklaşık 4,7 ton ile verimde de ilk sırada yer almaktadır. Son 15 yılın verilerine bakıldığında 2010'dan günümüze bazı dönemler düşüş yaşanmış olsa da üretim miktarı, ekim alanı ve verim artış göstermiştir (Şekil 2).

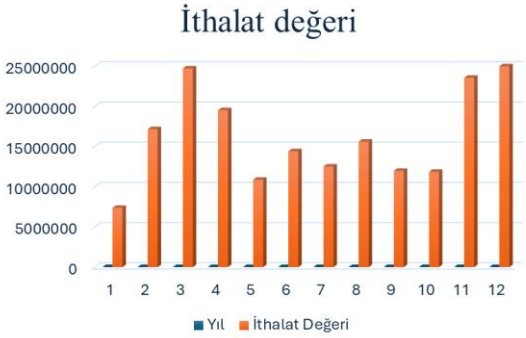
Şekil 2'ye göre ekim alanında 2010-2012, 2013-2015 ve 2022-2024 üretim döneminde artan oranda bir artış olmuş toplam ekilen alan 2010'a göre daha yüksektir. Üretim miktarı 2010-2012, 2013-2015 ve 2018-2024 üretim döneminde artan oranda artmıştır. Verim 2012-2014, 2015-2017, 2018-2019 ve 2020-2023 dönemlerinde artan oranda artmış olup 2010'a göre daha yüksektir.



Şekil 2: Türkiye'de patates ekim alanı, üretim ve verimlerinin yıllar itibariyle değişimi (TÜİK, 2025)

TÜRKİYE'DE PATATES ÜRETİMİNDEKİ TEMEL SORUNLARI

Ülkemizde sanayiye ham madde sağlama, tarımsal istihdam oluşturma ve beslenme açısından önemli olan patates üretimi çeşitli yapısal ve ekonomik sorunlarla karşı karşıyadır. Bu sorunların başında tohumlukta dışa bağımlılık gelmektedir. Ticaret verilerine göre tohumluk patates ithalat değeri 24.993.739 dolar miktarı ise 28.513.009 kilogramdır (TÜİK, 2024). 2013 yılından itibaren tohumluk patates ithalat değerleri artış göstermiş olup bu da dışa bağımlılığımızı göz önüne sermektedir (Şekil 3). Artan döviz kuru sebebiyle tohumluk patates fiyatları artmakta bu da üreticiye maliyet olarak yansımaktadır (Karahan vd., 2016). Tohumlukta dışa bağımlılığı azaltmak adına enstitülerimizce geliştirilen yerli çeşitler bulunmaktadır. Bu yerli çeşitlerin kullanımının özendirilmesi için devlet tarafından üreticiye ek destekler verilmektedir. Aynı zamanda tohumluk patatesin kaliteli olması hasat sonrası verimi de doğrudan etkilemektedir. Kaliteli tohumlukların kullanımı patatesin hastalıklara karşı direnç göstererek üreticinin aldığı verimi arttırmasında etken olarak karşımıza çıkmaktadır.



Şekil 3: Türkiye'de tohumluk patates ithalat değerleri

Son yıllarda özellikle artan enflasyon sebebiyle gübre, mazot, elektrik, su ve işçilik gibi değişken maliyetlerde yaşanan artışlar üretim maliyetlerini önemli ölçüde yükseltmiştir. Üreticiden ucuza alınan ürün pazarda tüketiciye daha yüksek fiyattan satılmakta bu durumda hem üretici hem de tüketici zarar görmektedir.

Artan maliyetlerin yanı sıra hastalık ve zararlılarla mücadelede yaşanan güçlükler üreticiyi olumsuz etkilemektedir. Patates mildiyösü, kahverengi çürüklük, halka çürüklüğü, bakteriyel yumuşak çürüklük ve Stolbur hastalığı kültürel önlemlerle mücadele edilebilen hastalıklardan olup üreticinin uzun yıllar toprağı nadasa bırakarak üretimi durdurmasına sebep olmaktadır. Patates siğili, siyah siğil, geç yanıklık ve kuru çürüklük gibi hastalıkların kimyasal mücadelesi bulunmakta fakat ilaç fiyatları maliyetleri arttırmaktadır. Patates böceği ve güvesinin ilaçlama maliyetleri de üreticiyi olumsuz etkilemektedir.

Öte yandan hem hastalıklardan ari tohumluk maliyetleri hem de ilaçlama maliyetleri hasat sonrası depolama koşullarını etkilemektedir. Ülkemizde patates üreticilerinin bir diğer önemli sorunu da, hasat sonrası ürünlerini uygun koşullarda saklayamamalarıdır (Arıoğlu vd., 2006). Patatese uygun depolama koşullarının kurulum maliyeti yüksektir. Uygun depolama ve lojistik ağına sahip olmayan üreticilerin ürünleri ellerinde kalmakta bu da üreticiyi olumsuz etkilemektedir.

Birçok üründe olduğu gibi patateste de üretim planı bir önceki yılın fiyatlarına göre oluşmakta bu da arz fazlasına ve üreticinin elinde ürün kalmasına sebep olmaktadır. Üretim planlamasındaki eksiklik fiyatların dalgalanmasına üreticilerin zarar etmesine neden olmaktadır. Tarım ürünleri iklim koşullarından etkilendiğinden mevsimsel dalgalanmalarda üretimi haliyle fiyatları etkilemektedir. Özetle üretimde ve pazarlamada karşılaşılan bu sorunlar patates sektörünün sürdürülebilirliğini olumsuz etkileyen başlıca faktörler arasında yer almaktadır.

SONUÇ VE ÖNERİLER

Yüksek besin değeri, geniş kullanım alanı ve tarımsal istihdama sağladığı katkılar nedeniyle patates hem dünya genelinde hem de Türkiye'de stratejik öneme sahip tarım ürünlerinden biri olarak kabul edilmektedir. Üretim verileri, kişi başı tüketimi ve dünyadaki sıralaması patatesin ülkemiz için önemini kanıtlar niteliktedir.

Öneminin yanı sıra patates üretimi çalışmanın içeriğinde de bahsedildiği gibi çeşitli sorunlarla karşı karşıyadır. Sertifikalı tohumlukta dışa bağımlılık, son yıllarda özellikle gübre, mazot, elektrik ve işçilik maliyetlerinde yaşanan artışlar hastalık ve zararlılarla mücadelede yaşanan güçlükler, üretim planlamasındaki yetersizlikler, fiyat dalgalanmaları, depolama ve soğuk zincir altyapısındaki eksiklikler ile pazarlama zincirinde karşılaşılan sorunlar, patates sektörünün sürdürülebilirliğini olumsuz etkileyen başlıca faktörler arasında yer almaktadır.

Patates üretiminde karşılaşılan bu sorunlarla mücadele ile patates üretimi ve verimliliğinin arttırılması önem arz etmektedir. Bu noktada sertifikalı tohumluk kullanımında yerel çeşitlerin özendirilmesi ve desteklerinin arttırılması, enflasyona karşı üreticilerin korunması, hastalıktan ari tohumluk kullanımının arttırılması için eğitimlerin verilmesi, üretimde planlama modeli ile hareket edilerek fiyat dalgalanmalarına karşı üreticinin korunması ve sanayi ile üretici arası iş birliği sağlanarak üreticinin katma değerinin arttırılması gibi önlemlerle patates üretimi ve verimliliği arttırılabilir.

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EDUCATION DIPLOMACY AS A SOFT POWER INSTRUMENT: A CONCEPTUAL ASSESSMENT

YUMUŞAK GÜÇ ARACI OLARAK EĞİTİM DİPLOMASİSİ: KAVRAMSAL BİR DEĞERLENDİRME

Bu çalışma, Kocaeli Üniversitesi Sosyal Bilimler Enstitüsünde yürütülmekte olan "Küresel Yumuşak Güç Politikalarında Eğitim Diplomasisi ve Uluslararasılaşmanın Rolü: Türkiye Örneği" başlıklı doktora tezinden üretilmiştir. / This study was derived from the doctoral thesis entitled "The Role of Education Diplomacy and Internationalization in Global Soft Power Policies: The Case of Türkiye," which is currently being conducted at the Institute of Social Sciences, Kocaeli University.

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ÖZET

Bu çalışma, eğitim diplomasisinin yumuşak güç politikaları içerisindeki kavramsal ve stratejik konumunu yükseköğretimde uluslararasılaşmayla ilişkisi çerçevesinde değerlendirmektedir. Çalışmanın amacı, eğitim diplomasisinin kamu diplomasisi, yumuşak güç ve yükseköğretimde uluslararasılaşma karşısındaki kavramsal sınırlarını belirginleştirmek ve eğitim alanındaki uluslararası faaliyetlerin uzun vadeli etkiye hangi koşullar altında katkı sağlayabileceğini açıklamaktır. Araştırma, nitel araştırma yaklaşımı kapsamında yürütülen kavramsal literatür incelemesine dayanmaktadır. Yumuşak güç, kamu diplomasisi, eğitim diplomasisi ve yükseköğretimde uluslararasılaşma literatüründeki temel ve güncel çalışmalar ile eğitim diplomasisine ilişkin seçilmiş kurumsal belgeler karşılaştırmalı olarak incelenmiş; kavramların kapsamları, aralarındaki ilişkiler ve eğitim diplomasisinin stratejik işlevleri kavramsal çözümleme yoluyla değerlendirilmiştir.

İnceleme sonucunda eğitim diplomasisinin öğrenci ve akademisyen hareketliliği, burs programları veya üniversiteler arası anlaşmalarla sınırlandırılamayacağı belirlenmiştir. Eğitim diplomasisi; devlet kurumlarını, üniversiteleri, uluslararası kuruluşları, öğrencileri, akademisyenleri, araştırmacıları ve mezunları kapsayan çok aktörlü ve çok katmanlı bir politika alanıdır. Yükseköğretimde uluslararasılaşma ise eğitim diplomasisiyle özdeş olmayıp yükseköğretimin öğretim, araştırma ve topluma hizmet işlevlerine uluslararası ve kültürlerarası boyut kazandıran akademik ve kurumsal bir süreçtir; aynı zamanda eğitim diplomasisinin gelişebileceği temel kurumsal süreçlerden birini oluşturmaktadır. Hareketlilik, ortak programlar, akademik ortaklıklar, araştırma ağları ve mezun ilişkileri farklı ülkelerdeki bireyler ve kurumlar arasında uzun vadeli bağlantılar kurulmasına katkı sağlayabilir. Ancak bu faaliyetlerin diplomatik anlamı, sayısal büyüklüklerinden çok uygulamaların niteliğine, katılımcı deneyimlerine, karşılıklılığa ve kurulan ilişkilerin sürekliliğine bağlıdır.

Çalışmanın temel sonucu, eğitim diplomasisi ile yumuşak güç arasında doğrudan, otomatik ve tek yönlü bir ilişki kurulamayacağıdır. Eğitim diplomasisinin uzun vadeli yumuşak güç kapasitesine katkısı; uygulamaların güvenilirliğine, akademik amaçlarla uyumuna, aktörler arası koordinasyona ve kurumsal sürekliliğe göre değişmektedir. Çalışmanın kavramsal katkısı, eğitim diplomasisini tekil programların

toplamı olarak değil, uluslararası eğitim faaliyetlerinin uzun vadeli bireysel ve kurumsal ilişkiler içinde anlam kazandığı stratejik ve ilişkisel bir politika alanı olarak konumlandırmasıdır.

Anahtar Kelimeler: Uluslararası İlişkiler; Eğitim diplomasisi; Yumuşak güç; Kamu diplomasisi; Yükseköğretim; Uluslararasılaşma.

ABSTRACT

This study examines the conceptual and strategic position of education diplomacy within soft power policies in relation to the internationalization of higher education. It aims to clarify the conceptual boundaries of education diplomacy in relation to public diplomacy, soft power and the internationalization of higher education and to explain the conditions under which international activities in education may contribute to long-term influence. The research is based on a conceptual literature review conducted within a qualitative research framework. Foundational and recent studies on soft power, public diplomacy, education diplomacy and the internationalization of higher education, together with selected institutional documents on education diplomacy, were comparatively examined. The scope of these concepts, the relationships among them and the strategic functions of education diplomacy were assessed through conceptual analysis.

The review indicates that education diplomacy cannot be limited to student and academic staff mobility, scholarship programs, or inter-institutional agreements. Education diplomacy is a multi-actor and multi-layered policy field involving state institutions, universities, international organizations, students, academics, researchers and alumni. The internationalization of higher education is not synonymous with education diplomacy; rather, it is an academic and institutional process that integrates international and intercultural dimensions into the teaching, research and community-service functions of higher education, while also constituting one of the principal institutional processes within which education diplomacy may develop. Mobility, joint programs, academic partnerships, research networks and alumni relations may contribute to the development of long-term connections among individuals and institutions in different countries. However, the diplomatic significance of these activities depends less on their numerical scale than on the quality of their implementation, participant experiences, reciprocity and the continuity of the relationships established.

The principal conclusion of the research is that no direct, automatic or one-way relationship can be established between education diplomacy and soft power. The contribution of education diplomacy to long-term soft power capacity varies according to the credibility of its practices, their alignment with academic objectives, coordination among actors, and institutional continuity. The conceptual contribution of the study lies in positioning education diplomacy not as the aggregate of individual programs, but as a strategic and relational policy field in which international educational activities acquire significance through long-term individual and institutional relationships.

Keywords: International relations; Education diplomacy; Soft power; Public diplomacy; Higher education; Internationalization.

GİRİŞ

Uluslararası ilişkilerde etkinin yalnızca askeri ve ekonomik kapasite üzerinden açıklanamadığı günümüzde kültür, değerler, kurumsal itibar ve toplumlar arasında ilişki geliştirme kapasitesi güç tartışmalarının önemli unsurları haline gelmiştir. İletişim ve ulaşım imkânlarının gelişmesi, sınır ötesi hareketliliğin yoğunlaşması ve uluslararası ağların genişlemesi, devletlerin dış politika araçlarını çeşitlendirmiş; üniversiteler, uluslararası kuruluşlar, sivil toplum yapıları ve bireysel aktörler uluslararası etkileşimin daha görünür bileşenleri olarak öne çıkmıştır. Bu dönüşüm, zorlama ve maddi teşviklerden farklı olarak çekicilik ve meşruiyet üzerinden etki oluşturmayı açıklayan yumuşak güç yaklaşımının önemini artırmıştır (Nye, 2004, 2008).

Söz konusu dönüşüm yükseköğretim alanında da belirgin biçimde gözlenmektedir. Üniversiteler, uluslararası öğrenci ve akademisyen hareketliliğinin, ortak programların, araştırma iş birliklerinin ve kurumsal ağların merkezinde yer almaktadır. Yükseköğretimde uluslararasılaşma,

yükseköğretimin amaçlarına, işlevlerine ve sunumuna uluslararası, kültürlerarası ve küresel boyutların dâhil edilmesi sürecini ifade etmekte; öğretim, araştırma, kurumsal yönetim ve uluslararası ortaklıkları kapsayan daha geniş bir dönüşümü içermektedir (Altbach & Knight, 2007; Knight, 2004).

Eğitim ve yükseköğretim faaliyetlerinin uluslararası ilişkilerde artan görünürlüğü, eğitim diplomasisi kavramını da gündeme getirmiştir. Yeni kamu diplomasisinin tek yönlü tanıtım yerine karşılıklılık, ilişki geliştirme ve ağ kurmayı öne çıkaran yaklaşımı, eğitim faaliyetlerinin diplomatik işlevlerinin değerlendirilmesi için elverişli bir zemin oluşturmaktadır (Cull, 2008; Kalın, 2011; Melissen, 2005). Kalın, kamu diplomasisini yumuşak gücün uygulamaya aktarılmasını sağlayan bir platform olarak değerlendirmekte; bu sürecin başarısını sahip olunan tarihsel, kültürel ve eğitimsel kaynakların yanı sıra politikaların inandırıcılığına, meşruiyetine ve etkili biçimde koordine edilmesine bağlamaktadır. Bununla birlikte eğitim diplomasisinin görece yeni ve disiplinler arası bir kavram olması nedeniyle literatürde üzerinde bütünüyle uzlaşılmış tek bir tanım bulunmamaktadır. Kavramın sıklıkla öğrenci hareketliliği, burs programları veya kültürel değişim faaliyetleriyle açıklanması; kurumsal ortaklıklar, araştırma ağları, mezun ilişkileri ve yönetişim boyutlarının ikincil planda kalmasına yol açabilmektedir (Kalın, 2011; Kaya, 2019; Khan et al., 2020).

Bu çalışmanın amacı, eğitim diplomasisinin yumuşak güç politikaları içindeki kavramsal ve stratejik konumunu yükseköğretimde uluslararasılaşmayla ilişkisi çerçevesinde değerlendirmektir. Bu amaç doğrultusunda çalışma şu iki soruya odaklanmaktadır: "Eğitim diplomasisi, kamu diplomasisi, yumuşak güç ve yükseköğretimde uluslararasılaşma kavramları karşısında nasıl konumlandırılabilir?" ve "Uluslararası eğitim faaliyetleri hangi koşullar altında uzun vadeli yumuşak güç kapasitesine katkı sağlayabilir?"

Çalışma, nitel araştırma yaklaşımı kapsamında yürütülen kavramsal literatür incelemesine dayanmaktadır. Yumuşak güç, kamu diplomasisi, eğitim diplomasisi ve yükseköğretimde uluslararasılaşma literatüründeki temel ve güncel çalışmalar ile eğitim diplomasisine ilişkin seçilmiş kurumsal belgeler karşılaştırmalı olarak incelenmiştir. Çalışma belirli bir ülkenin performansını ölçmeyi veya ampirik bir nedensellik modeli kurmayı amaçlamamakta; kavramlar arasındaki ilişkileri açıklayan sınırlı bir değerlendirme çerçevesi sunmaktadır.

EĞİTİM DİPLOMASİSİ KAVRAMI

Eğitim ile diplomasi arasındaki ilişki, eğitim diplomasisi kavramının akademik literatürde yaygınlaşmasından önceye dayanmaktadır. Devletlerin uluslararası öğrencilere burs vermesi, akademik değişim programlarını desteklemesi, dil ve kültür merkezleri açması ve üniversiteler arasında kurumsal ortaklıklar geliştirmesi uzun süredir uluslararası ilişkilerin bir parçasıdır. Eğitim diplomasisinin güncel kavramsal çerçevesi, kurumsal kökleri 1892'ye uzanan Association for Childhood Education International (CEI) tarafından 2010 yılında geliştirilmeye başlanmıştır. Kurum, 2011 yılında Washington, D.C.'de ilk Uluslararası Eğitim Diplomasisi Enstitüsünü düzenlemiş; izleyen dönemde kavramı diplomatik beceriler, sektörler arası iş birliği, müzakere, uzlaşı ve ilişki geliştirme süreçlerini kapsayan sistematik bir uygulama alanı olarak geliştirmiştir (Childhood Education International, 2022; Kaya, 2019; Murphy, 2018).

Eğitim diplomasisi literatürde iki temel yönelim üzerinden ele alınabilmektedir. İlk yönelim, eğitimin kamu diplomasisi ve dış politika amaçları doğrultusunda kullanılmasına odaklanmakta; öğrenci ve akademisyen değişimlerini yabancı toplumlarla uzun vadeli ilişki geliştiren araçlar olarak değerlendirmektedir. Cull'un (2008) kamu diplomasisi sınıflandırmasında değişim faaliyetlerinin ayrı bir bileşen olarak yer alması, eğitim programlarının ilişki kurma potansiyeline işaret etmektedir. İkinci yönelim ise diplomatik becerilerin eğitim alanındaki ortak sorunların çözümü, müzakere, uzlaşma ve kolektif eylem için kullanılmasını öne çıkarmaktadır (Childhood Education International, 2022; Kaya, 2019; Khan et al., 2020).

Eğitim diplomasisi kamu diplomasisiyle güçlü biçimde kesişmekle birlikte yalnızca onun bir alt uygulaması olarak değerlendirilmemelidir. Kamu diplomasisi yabancı toplumlarla iletişim kurulmasını ve uzun vadeli ilişkiler geliştirilmesini kapsayan daha geniş bir politika alanıdır. Eğitim diplomasisi ise bu ilişkilerin eğitim kurumları, akademik faaliyetler, programlar ve bireysel deneyimler aracılığıyla

kurulan boyutuna odaklanmaktadır. Öğrenci ve akademisyen hareketliliği kültürel etkileşim oluşturması bakımından kültürel diplomasiyle; ortak araştırmalar ve uluslararası bilimsel ağlar ise bilim diplomasisiyle kesişmektedir (Kıran & Açıkalın, 2021). Bu alanlar arasındaki ilişki kavramsal özdeşlikten çok işlevsel kesişmeler üzerinden değerlendirilmelidir.

Eğitim diplomasisinin bir diğer özelliği çok aktörlü yapısıdır. Devlet kurumları politika geliştirme, finansman ve koordinasyon işlevlerini üstlenirken yükseköğretim kurumları öğretim, araştırma, hareketlilik ve kurumsal iş birliği faaliyetlerinin temel uygulayıcılarıdır. Üniversiteler yalnızca devlet politikalarının uygulayıcıları değil, kendi akademik önceliklerine ve kurumsal stratejilerine sahip aktörlerdir. Öğrenciler, akademisyenler, araştırmacılar ve mezunlar da sürecin pasif hedef kitleleri değil, uluslararası ilişkilerin bireysel ve mesleki düzeylerde sürdürülmesine katkı sağlayan bağımsız aktörlerdir (McGill Peterson, 2014).

Yükseköğretimde uluslararasılaşma eğitim diplomasisiyle özdeş değildir. Uluslararasılaşma, yükseköğretim kurumlarının öğretim, araştırma ve topluma hizmet işlevlerine uluslararası boyut kazandıran akademik ve kurumsal bir süreçtir. Eğitim diplomasisi ise bu süreçte geliştirilen ilişkilerin uluslararası ilişkiler bakımından taşıyabileceği stratejik anlamı ele almaktadır. Bu doğrultuda eğitim diplomasisi, eğitim ve yükseköğretim faaliyetlerinin farklı ülkelerdeki kurumlar ve bireyler arasında uzun vadeli, karşılıklı ve sürdürülebilir ilişkiler geliştirilmesine katkı sağlayacak biçimde ele alındığı çok aktörlü bir politika alanı olarak tanımlanabilir. Dolayısıyla öğrenci sayıları, burslar veya imzalanan anlaşmalar eğitim diplomasisinin kendisini değil, bu alanın belirli faaliyet ve kapasite göstergelerini ifade etmektedir (de Wit et al., 2015; Knight, 2004).

YUMUŞAK GÜÇ VE EĞİTİM DİPLOMASİSİ

Yumuşak güç yaklaşımı, eğitim diplomasisinin uluslararası ilişkilerdeki konumunu açıklamak için temel bir kavramsal zemin sunmaktadır. Nye'ye (2008) göre yumuşak güç, bir aktörün istediği sonuçları zorlama veya ödeme yerine çekicilik yoluyla elde edebilme kapasitesini ifade etmektedir. Kültür, siyasal değerler, dış politikalar ve kurumlar yumuşak gücün muhtemel kaynakları arasında yer almakla birlikte, bu kaynakların varlığı arzu edilen sonuçların kendiliğinden ortaya çıkmasını sağlamamaktadır. Kaynakların yumuşak güç bakımından anlam kazanması, diğer aktörler tarafından nasıl algılandıklarına ve hangi bağlamda kullanıldıklarına bağlıdır. Bu nedenle yumuşak güç analizinde kaynaklar, bu kaynakları uluslararası etkileşime aktaran araç ve mekanizmalar ile ortaya çıkabilecek sonuçlar birbirinden ayrılmalıdır.

Eğitim, bu ayrım çerçevesinde hem yumuşak güç kaynağı hem de dış ilişkilerde kullanılabilen bir araç olarak değerlendirilebilir. Bir ülkenin yükseköğretim sisteminin niteliği, üniversitelerinin akademik itibarı, araştırma kapasitesi ve uluslararası düzeyde tanınan eğitim kurumları çekicilik oluşturabilecek kaynaklardır. Öğrenci ve akademisyen hareketliliği, burs programları, ortak akademik programlar, araştırma iş birlikleri ve kurumsal ortaklıklar ise söz konusu kapasitenin farklı toplumlar ve kurumlarla ilişkiye girmesini sağlayan araçlardır. Wojciuk et al. (2015), eğitimin değerlerin taşıyıcısı, ülkelerin sahip olduğu bir kapasite kaynağı ve belirli amaçlara ulaşmak için kullanılabilen bir araç olarak farklı biçimlerde işleyebildiğini ortaya koymaktadır. Bununla birlikte bu araçların kullanılması, olumlu algı, çekicilik veya uzun vadeli etki oluşacağını garanti etmemektedir. Eğitimin yumuşak güçle ilişkisi; siyasal ve toplumsal bağlama, uygulamaların güvenilirliğine, katılımcıların deneyimlerine ve kurulan ilişkilerin niteliğine göre farklılaşabilmektedir (Gauttam et al., 2024; Wojciuk et al., 2015).

Yükseköğretimde uluslararasılaşma, eğitim diplomasisi ile yumuşak güç arasındaki bağlantının kurulmasını sağlayan temel süreçlerden biridir. Knight'a (2004) göre uluslararasılaşma, yükseköğretimin amaçlarına, işlevlerine ve sunumuna uluslararası, kültürlerarası veya küresel bir boyutun dâhil edilmesi sürecidir. Öğrenci ve akademisyen hareketliliği, ortak programlar, uluslararası araştırma iş birlikleri, sınır ötesi eğitim faaliyetleri ve kurumsal ağlar bu sürecin başlıca bileşenleri arasında yer almaktadır. Bununla birlikte yükseköğretimde uluslararasılaşma ile eğitim diplomasisi aynı kavramı ifade etmemektedir. Uluslararasılaşma, öncelikle yükseköğretim kurumlarının öğretim, araştırma ve topluma hizmet işlevlerine uluslararası boyut kazandıran akademik ve kurumsal bir süreçtir. Eğitim diplomasisi ise bu süreçte oluşturulan uluslararası ilişkilerin kamu diplomasisi, dış politika ve yumuşak güç bakımından taşıyabileceği stratejik ve ilişkisel işlevi ele almaktadır.

Dolayısıyla uluslararasılaşma, eğitim diplomasisinin bir alt kolu değil; eğitim diplomasisinin uygulamaya aktarılmasını sağlayabilecek başlıca ara süreçlerden biridir (de Wit et al., 2015; Knight, 2004). Ancak her uluslararasılaşma faaliyeti kendiliğinden eğitim diplomasisi niteliği kazanmadığı gibi, her eğitim diplomasisi faaliyeti de otomatik olarak yumuşak güç sonucu üretmemektedir. Uluslararası öğrenci sayılarının, burs kontenjanlarının veya imzalanan anlaşmaların artması önemli kapasite göstergeleridir; fakat niceliksel büyümenin doğrudan başarı kabul edilmesi, uluslararasılaşmanın kendi başına bir amaca dönüşmesi riskini taşımaktadır (Brandenburg & de Wit, 2011).

Eğitim diplomasisinin yumuşak güç kapasitesine katkısı; uygulamaların güvenilirliğine, akademik amaçlarla uyumuna, karşılıklılığa, katılımcı deneyimlerinin niteliğine ve kurulan ilişkilerin sürekliliğine bağlıdır. Öğrencilerin, akademisyenlerin ve mezunların ev sahibi ülkenin değerlerini veya politikalarını kendiliğinden benimseyecekleri varsayılamaz. Katılımcı deneyimlerinin niteliği olumlu veya olumsuz algıların gelişmesinde belirleyici olabilir. Benzer biçimde eğitim politikalarının kısa vadeli dış politika hedeflerine aşırı ölçüde bağlanması, üniversitelerin akademik öncelikleri ve kurumsal güvenilirliği üzerinde gerilim oluşturabilir (Laifer & Kitchen, 2017).

Bu nedenle eğitim diplomasisinin yumuşak güce katkısı, diğer aktörlerin tercihlerini kısa vadede yönlendiren doğrudan bir araç olarak değil, uzun vadeli bireysel ve kurumsal ilişkilerin gelişebileceği bir zemini oluşturma kapasitesi üzerinden değerlendirilmelidir. Eğitim faaliyetleri belirli koşullar altında güven, itibar, çekicilik ve sürdürülebilir iş birliğine katkı sağlayabilir; ancak bu katkı bağlamsal ve ilişkisel niteliktedir.

EĞİTİM DİPLOMASİSİNİN STRATEJİK ÖNEMİ

Eğitim diplomasisinin stratejik önemi, eğitim ve yükseköğretim faaliyetlerinin farklı toplumlar ve kurumlar arasında uzun süreli, doğrudan ve kurumsallaşabilir ilişkiler oluşturma kapasitesinden kaynaklanmaktadır. Kısa vadeli tanıtım faaliyetleri belirli mesajların hedef kitlelere aktarılmasına odaklanırken eğitim diplomasisi, öğrencilerin, akademisyenlerin, araştırmacıların ve kurumların daha uzun süreli karşılıklı etkileşim kurmasına imkân vermektedir. Bu niteliğiyle eğitim diplomasisi, yeni kamu diplomasisinin tek yönlü iletişimden karşılıklılık, ilişki geliştirme ve ağ kurmayı öne çıkaran yaklaşımıyla örtüşmektedir (Cull, 2008; Melissen, 2005).

Eğitim diplomasisinin stratejik değerini artıran unsurlardan biri, resmi diplomatik kanallarla sınırlı olmayan kurumsal ilişki alanları oluşturabilmesidir. Üniversiteler, araştırma merkezleri ve akademik topluluklar; öğretim, araştırma ve bilimsel iş birliği temelinde farklı ülkelerdeki kurumlarla doğrudan bağlantılar geliştirebilmektedir. Ortak araştırma projeleri, ortak programlar, akademik konsorsiyumlar ve uluslararası bilimsel ağlar, kurumlar arasındaki ilişkilerin tek bir hareketlilik dönemi veya anlaşmayla sınırlı kalmamasına katkı sağlayabilir. Bu ilişkiler resmi diplomasinin yerine geçmemekte; farklı işleyiş ilkelerine sahip tamamlayıcı temas kanalları oluşturmaktadır (de Wit et al., 2015; McGill Peterson, 2014).

Eğitim diplomasisinin çok aktörlü yapısı, farklı kurumsal kapasitelerin ortak bir ilişki alanında eşgüdümünü gerektirmesi bakımından stratejik önem taşımaktadır. Devletlerin dış politika beklentileri, üniversitelerin akademik amaçları ve bireysel aktörlerin eğitim veya kariyer hedefleri her zaman tamamen örtüşmemektedir. Bu nedenle programların güvenilirliği, görev paylaşımı, karşılıklılık ve kurumsal süreklilik önem taşımaktadır. Uluslararası görünürlük ve öğrenci sayılarındaki artış, akademik nitelik ve sürdürülebilir ortaklıklarla desteklenmediğinde tek başına diplomatik etki anlamına gelmemektedir.

Eğitim diplomasisinin çok aktörlü ve yönetişim temelli yapısı, uygulamada belirli mesleki yeterliliklerin ve normatif ilkelerin önemini artırmaktadır. CEI tarafından geliştirilen Eğitim Diplomasisi Profesyonel Standartları; diplomatik kişiler arası becerileri, etkili ve kültürlerarası iletişimi, etik ve dürüstlüğü, paydaşlar arasında kolektif etki oluşturmayı, erişim ve kapsayıcılığı, yenilikçi çözüm geliştirmeyi ve değişim liderliğini eğitim diplomasisi uygulamasının başlıca bileşenleri arasında değerlendirmektedir (Childhood Education International, 2022). Bu standartlar, CEI'nın eğitim diplomasisini yalnızca uluslararası programların veya kurumsal ilişkilerin yönetiminden ibaret olmayan; güven oluşturma, farklı amaçları uzlaştırma, aktörleri ortak hedefler etrafında bir araya getirme ve iş birliğini

sürdürülebilir hale getirme kapasitesi gerektiren profesyonel bir uygulama alanı olarak çerçevelediğini göstermektedir.

Akademik iş birlikleri ve araştırma ağları, eğitim diplomasisinin stratejik değerinin yalnızca bireysel hareketlilikten kaynaklanmadığını göstermektedir. Ortak araştırma projeleri, çift veya ortak diploma programları, akademik konsorsiyumlar ve uluslararası bilimsel ağlar; üniversiteler arasındaki ilişkilerin tek bir proje, anlaşma veya hareketlilik dönemiyle sınırlı kalmamasına katkı sağlayabilir. Bu süreçler akademik uzmanlığın paylaşılmasına, ortak sorunlar etrafında iş birliği geliştirilmesine ve kurumlar arasında tekrarlanan etkileşimlerin oluşmasına imkân vermektedir. Eğitim diplomasisinin uzun vadeli stratejik etkisi de yeni faaliyetlerin sayısından çok, oluşturulan iş birliklerinin kurumsallaşmasına ve değişen koşullar altında sürdürülebilmesine bağlıdır (de Wit et al., 2015).

Sonuç olarak eğitim diplomasisinin stratejik değeri, faaliyetlerin sayısından çok bu faaliyetler aracılığıyla kurulan ilişkilerin niteliğinde ortaya çıkmaktadır. Uzun vadeli bireysel ve kurumsal bağlantılar, akademik iş birliklerinin sürekliliği ve aktörler arasında güvene dayalı iletişim, eğitim diplomasisinin olası uluslararası etkisini güçlendiren temel koşullardır.

SONUÇ

Bu çalışmada eğitim diplomasisinin kavramsal sınırları, yumuşak güçle ilişkisi ve yükseköğretimde uluslararasılaşma içindeki konumu değerlendirilmiştir. İnceleme, eğitim diplomasisinin yalnızca öğrenci ve akademisyen hareketliliği, burs programları veya üniversiteler arası anlaşmalardan oluşan sınırlı bir uygulama alanı olmadığını göstermektedir. Eğitim diplomasisi; devlet kurumlarını, üniversiteleri, uluslararası kuruluşları ve bireysel aktörleri bir araya getiren çok aktörlü ve ilişkisel bir politika alanıdır.

Eğitim diplomasisi kamu diplomasisi, kültürel diplomasi ve bilim diplomasisiyle işlevsel olarak kesişmekle birlikte bu alanların herhangi biriyle özdeşleştirilmemelidir. Kamu diplomasisi yabancı toplumlarla iletişim ve uzun vadeli ilişki geliştirilmesini kapsayan geniş politika alanını, yumuşak güç ise çekicilik yoluyla tercih ve davranışlar üzerinde etki oluşturabilme kapasitesini ifade etmektedir. Eğitim diplomasisi ise eğitim kurumlarının, programlarının, akademik faaliyetlerin ve bireysel deneyimlerin uluslararası ilişkiler bakımından taşıdığı stratejik ve ilişkisel işlevlere odaklanmaktadır. Bu nedenle eğitim diplomasisi ne doğrudan bir yumuşak güç kaynağı ne de kendiliğinden ortaya çıkan bir yumuşak güç sonucu olarak değerlendirilmelidir. Yükseköğretimde uluslararasılaşma, yükseköğretimin öğretim, araştırma ve topluma hizmet işlevlerine uluslararası ve kültürlerarası boyut kazandıran akademik ve kurumsal bir süreçtir; eğitim diplomasisi ise bu süreçte geliştirilen ilişkilerin uluslararası etki ve uzun vadeli iş birliği bakımından taşıyabileceği stratejik ve ilişkisel anlamı ele almaktadır.

Çalışmanın temel sonucu, eğitim diplomasisi ile yumuşak güç arasında doğrudan, otomatik ve tek yönlü bir nedensellik ilişkisinin kurulamayacağıdır. Eğitim alanındaki kaynakların veya uluslararası faaliyetlerin varlığı, kendiliğinden güven, itibar veya çekicilik üretmemektedir. Eğitim diplomasisinin uzun vadeli katkısı; uygulamaların niteliğine, katılımcı deneyimlerine, akademik amaçlarla uyumuna, karşılıklılığa, aktörler arası koordinasyona ve kurumsal sürekliliğe göre değişmektedir.

Eğitim diplomasisinin çok aktörlü niteliği, sürecin yalnızca üniversiteler üzerinden açıklanamayacağını göstermektedir. Devlet kurumlarının, üniversitelerin, uluslararası kuruluşların ve bireysel aktörlerin farklı amaç ve önceliklerle katılımı, eğitim diplomasisinin koordinasyon ve yönetişim gerektiren çok katmanlı yapısını ortaya koymaktadır.

Bu nedenle eğitim diplomasisinin değerlendirilmesinde uluslararası öğrenci sayıları, burs kontenjanları ve imzalanan anlaşmalar gibi nicel göstergelerin yanında ilişkilerin sürekliliği, ortaklıkların işlevselliği ve katılımcı deneyimleri gibi nitel unsurlar da dikkate alınmalıdır.

Araştırma kavramsal literatür incelemesine dayandığından belirli bir ülkenin eğitim diplomasisi politikalarını, uygulamalarını veya performansını ampirik olarak değerlendirmemektedir. Gelecekte yapılacak çalışmalarda farklı ülke uygulamalarının karşılaştırılması, farklı kurumsal yönetişim yapılarının incelenmesi ve öğrenci, akademisyen ve mezun deneyimlerinin uzun vadeli etkilerinin

araştırılması önem taşımaktadır. Ayrıca akademik ortaklıkların, araştırma ağlarının ve mezun ilişkilerinin karşılıklı güven, kurumsal itibar ve uluslararası iş birliği üzerindeki etkilerinin nitel ve nicel yöntemlerle incelenmesi, eğitim diplomasisi literatürünün kavramsal ve ampirik yönden geliştirilmesine katkı sağlayabilecektir.

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ETHICAL DILEMMAS ENCOUNTERED BY HIGHER EDUCATION ACADEMIC STAFF DURING THE ADOPTION OF AI-SUPPORTED EDUCATIONAL ENVIRONMENTS: A QUALITATIVE STUDY

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ABSTRACT

Introduction and Purpose: Artificial intelligence (AI) has rapidly become an integral part of higher education, reshaping teaching, learning, and assessment practices. While AI-supported educational environments offer considerable opportunities to enhance educational quality and efficiency, they also introduce significant ethical challenges concerning academic integrity, responsible AI use, student engagement, and data privacy. As AI continues to transform educational practices, understanding the ethical dilemmas experienced by academic staff has become increasingly important for developing responsible and sustainable AI integration strategies. Therefore, this study aims to explore the ethical dilemmas encountered by higher education academic staff during the adoption of AI-supported educational environments.

Materials and Methods: This study employed a qualitative phenomenological research design to examine the lived experiences of academic staff regarding AI integration in higher education. Data were collected through semi-structured interviews with 19 higher education academic staff members. The interview data were analyzed using qualitative content analysis with the support of MAXQDA software, allowing the systematic identification and interpretation of recurring themes and patterns.

Results: The findings revealed that ethical responsibility emerged as the most prominent theme (f = 24), followed by ethical issues related to students' use of AI (f = 16), academic integrity (f = 14), and data security and privacy (f = 6). Participants reported concerns about plagiarism, excessive reliance on AI-generated content, difficulties in assessing students' authentic performance, uncertainty regarding responsibility for AI-assisted outputs, and the protection of personal data. They further emphasized the importance of institutional ethical policies, clear guidelines, and professional awareness to ensure the responsible use of AI technologies

Key Words: Artificial Intelligence; Higher Education; Academic Staff; Ethics; Qualitative Research.

BIOCOMPOSITE FROM BAMBOO (ARUNDO DONAX) FIBERS AND INDUSTRIAL POLYURETHANE WASTE

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ABSTRACT

This research project focuses on the preparation and evaluation of a composite material based on a polyurethane matrix reinforced with recycled polyurethane and natural fiber from Arundo donax, with the aim of analyzing its thermal behavior and resistance to thermal and environmental degradation processes. The project sought to contribute to the utilization of underutilized polymer waste and lignocellulosic resources, promoting sustainable materials with potential applications in the design and manufacture of functional polymeric elements.

This composite material is presented as a sustainable alternative for structural and functional applications, contributing to waste valorization, reducing environmental impact, and strengthening circular economy principles in the polymer materials sector.

It was determined that composite material B2, with 15% reinforcement (recycled polyurethane and Arundo donax fiber) and treated with 5% NaOH, exhibited a thermal insulation performance of 0.03 W/m°C, similar to that of pure polyurethane. Regarding thermal behavior, thermogravimetric analysis (TGA) established that the composite material shows an onset of thermal degradation at temperatures above 200 °C, attributed to the preferential degradation of the lignocellulosic components of the natural fiber. However, the main degradation of the system occurs in the 300 °C to 450 °C range, indicating that the material maintains adequate thermal stability for practical applications where these temperatures are not exceeded.

Keywords: circular economy, waste reincorporation industry, polyurethane waste, adonax fibers

ENFORCING WAR CRIMES UNDER INTERNATIONAL HUMANITARIAN LAW: NORMATIVE DEVELOPMENT, JURISPRUDENCE, AND STRUCTURAL LIMITATION OF INTERNATIONAL CRIMINAL JUSTICE

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ABSTRACT

International Humanitarian Law (IHL) provides the legal framework regulating the conduct of armed conflict with the aim of limiting human suffering and protecting individuals who are not or are no longer participating in hostilities. Despite its extensive normative development through treaty law, customary international law, and jurisprudence, significant challenges persist in its enforcement. This chapter examines the legal foundations, doctrinal principles, and institutional mechanisms governing war crimes within IHL. It analyzes the evolution of the law from the Geneva Conventions of 1949 and Additional Protocols of 1977 to the Rome Statute of the International Criminal Court, alongside key jurisprudence from the ICTY, ICTR, and ICC. The study further evaluates the structural limitations of enforcement mechanisms, including jurisdictional constraints, political influences, evidentiary challenges, and the increasing complexity of modern armed conflicts involving non-state actors and hybrid warfare. The central argument is that while IHL constitutes a highly developed normative system, its enforcement remains uneven due to dependence on state cooperation and political will. This gap between legal normativity and practical implementation continues to challenge the effectiveness of international criminal justice.

Keywords: International Humanitarian Law; war crimes; International Criminal Court; Geneva Conventions; international criminal law; armed conflict; command responsibility; ICTY; ICTR; customary international law

Introduction

Armed conflict remains a persistent structural feature of the international system, shaping political order, humanitarian conditions, and legal development across historical periods. Despite the evolution of modern international law, armed conflict continues to generate extensive civilian harm, mass displacement, destruction of essential infrastructure, and long-term socio-economic instability. These consequences expose a fundamental tension in international law: the attempt to regulate inherently violent political conduct through normative legal constraints.

International Humanitarian Law (IHL), also referred to as the law of armed conflict or jus in bello, constitutes the principal legal framework designed to address this tension. Its core objective is not to prohibit war—that function falls under jus ad bellum, governed primarily by the United Nations Charter—but rather to regulate the conduct of hostilities once armed conflict has commenced. In doing so, IHL seeks to mitigate human suffering by balancing military necessity with humanitarian protection (Dinstein, 2016).

At the normative core of IHL is the assumption that even in conditions of extreme violence, legal limits remain operative and binding. This assumption is operationalized through foundational principles including distinction, proportionality, military necessity, humanity, and precaution. Collectively, these principles define the legal boundaries of permissible conduct in armed conflict and provide the doctrinal basis for identifying violations that may constitute war crimes under international law.

Within this legal architecture, war crimes occupy a central position as the most serious violations of IHL. Unlike ordinary breaches of international obligations, war crimes trigger individual criminal responsibility, meaning that individuals—rather than only states—may be held personally accountable

for unlawful conduct during armed conflict. This development represents a significant transformation in international law, reflecting the shift from a purely state-centered system to one in which individuals are direct subjects of international criminal responsibility (Cassese, 2008).

The codification of war crimes has evolved through successive historical and legal stages. Early foundations can be traced to the Hague Regulations of 1907, which introduced limitations on methods of warfare. Following the Second World War, the Nuremberg and Tokyo tribunals established the principle that individuals, including state officials, could be prosecuted for serious violations of the laws of war. The modern legal framework is primarily grounded in the Geneva Conventions of 1949, their Additional Protocols of 1977, and the Rome Statute of the International Criminal Court (ICC) adopted in 1998 (Schabas, 2017).

Despite this extensive normative development, enforcement of war crimes law remains uneven and structurally constrained. Contemporary armed conflicts continue to demonstrate widespread violations of IHL, including intentional attacks on civilians, torture, sexual violence as a method of warfare, forced displacement, and the recruitment of child soldiers. These recurring violations reveal a persistent gap between the normative strength of international humanitarian law and its practical enforcement in real-world conflict environments.

This gap raises several critical legal and institutional questions. To what extent do existing legal frameworks effectively deter violations of IHL? How successful are international courts and tribunals in ensuring accountability for war crimes? And what structural, jurisdictional, and political limitations constrain the effectiveness of enforcement mechanisms?

This chapter addresses these questions through a doctrinal and jurisprudential analysis of war crimes within international humanitarian law. It examines the legal foundations of IHL, the conceptual definition and classification of war crimes, the treaty and customary legal framework, and the institutional mechanisms of enforcement, including the International Criminal Court, the International Court of Justice, and ad hoc tribunals such as the ICTY and ICTR. It further evaluates key jurisprudential developments and assesses the practical challenges facing accountability mechanisms in contemporary armed conflicts.

The central argument advanced is that while international humanitarian law provides a highly sophisticated and universally recognized normative framework, its enforcement remains structurally limited by political constraints, jurisdictional fragmentation, and dependence on state cooperation. As a result, a persistent and systemic gap exists between legal norms and their implementation, weakening the deterrent effect of war crimes law and raising fundamental questions about the future effectiveness of international criminal justice.

Conceptual Foundations of International Humanitarian Law

International Humanitarian Law (IHL) is a specialized branch of public international law governing the conduct of armed conflict. Unlike other areas of international law that regulate peaceful inter-state relations, IHL operates under conditions of organized violence, where ordinary legal and institutional structures are often weakened or absent. Its conceptual foundation is therefore based on a pragmatic legal premise: armed conflict cannot be eliminated through law alone, but its effects can be regulated through binding humanitarian norms.

A central conceptual distinction in IHL is the separation between jus ad bellum and jus in bello. Jus ad bellum governs the legality of the use of force between states, primarily regulated under the United Nations Charter, particularly Article 2(4), which prohibits the use of force, and Article 51, which recognizes the inherent right of self-defense. In contrast, jus in bello governs the conduct of parties during armed conflict, regardless of whether the initiation of force is lawful or unlawful. This separation is foundational, as it ensures that humanitarian protections apply equally to all parties in a conflict, independent of the legality of the underlying use of force (Dinstein, 2016).

This doctrinal separation gives rise to a core structural principle of IHL: the principle of equality of belligerents. Under this principle, all parties to an armed conflict are bound by the same humanitarian

obligations, regardless of which party initiated the conflict or whether their cause is legally justified. This ensures that humanitarian law remains neutral in relation to political legitimacy and focuses exclusively on the protection of individuals affected by armed conflict. Without this principle, the enforcement of IHL would become selective and politically conditioned, undermining its universal applicability.

Nature and Function of IHL

The primary function of IHL is regulatory rather than prohibitive. It does not seek to eliminate armed conflict but to limit its humanitarian consequences. This regulatory function is expressed through two principal mechanisms:

Protection of persons who are not, or are no longer, participating in hostilities

Regulation of means and methods of warfare

The first category includes civilians, medical personnel, humanitarian workers, and persons hors de combat (those who are injured, detained, or have surrendered). The second category restricts the types of weapons and tactics that may lawfully be used during armed conflict.

This dual structure reflects the underlying humanitarian logic of IHL: even in war, legal protection of human dignity remains operative.

Core Principles of International Humanitarian Law

The legal architecture of IHL is built on several foundational principles that function as both binding legal norms and interpretative tools. These principles are grounded in treaty law and reinforced through customary international law (ICRC, 2005).

(a) Principle of Distinction

The principle of distinction requires parties to an armed conflict to distinguish at all times between civilians and combatants, and between civilian objects and military objectives. Attacks may only be directed against legitimate military targets.

This principle is the cornerstone of IHL, as it preserves the separation between military operations and civilian life. Direct attacks against civilians are strictly prohibited and constitute a core category of war crimes under international law.

(b) Principle of Proportionality

The principle of proportionality prohibits attacks in which incidental civilian harm would be excessive in relation to the anticipated concrete and direct military advantage.

This principle does not prohibit collateral damage entirely but imposes a legal threshold of acceptability. Its application requires ex ante assessment by military decision-makers under conditions of uncertainty, making it one of the most complex norms in operational IHL.

(c) Principle of Military Necessity

Military necessity permits only those measures that are necessary to achieve a legitimate military objective and are not otherwise prohibited by international law.

It operates as a limiting principle, ensuring that force is not used beyond what is required for military advantage. It does not justify violations of humanitarian norms and must always be interpreted in conjunction with other IHL principles.

(d) Principle of Humanity

The principle of humanity prohibits unnecessary suffering and requires humane treatment of all persons not actively participating in hostilities.

It forms the ethical foundation of IHL and underpins prohibitions such as torture, cruel treatment, and degrading conduct. It reflects the idea that even in armed conflict, individuals retain inherent dignity.

(e) Principle of Precaution

The principle of precaution requires parties to an armed conflict to take all feasible measures to avoid or minimize incidental harm to civilians and civilian objects.

This includes verification of targets, selection of means and methods of warfare, and timing of attacks. The principle has gained increasing importance in modern urban and technologically advanced warfare environments.

Classification of Armed Conflicts

The applicability of IHL depends on the classification of armed conflict, which determines the applicable legal regime.

International Armed Conflicts (IACs)

International armed conflicts occur between two or more states. They trigger the full application of the Geneva Conventions of 1949 and Additional Protocol I of 1977.

Non-International Armed Conflicts (NIACs)

Non-international armed conflicts occur between state forces and organized armed groups, or between such groups. They are governed primarily by Common Article 3 of the Geneva Conventions and Additional Protocol II.

In contemporary practice, NIACs are the most common form of armed conflict, significantly expanding the relevance of customary international law in regulating internal violence.

Jurisprudential Definition of Armed Conflict

A major doctrinal development in IHL stems from the jurisprudence of the International Criminal Tribunal for the former Yugoslavia (ICTY), particularly in Prosecutor v. Tadić (1999). The Tribunal defined armed conflict as existing whenever there is:

Protracted armed violence

Between governmental authorities and organized armed groups, or between such groups

This functional definition replaced formalistic approaches based on declarations of war and significantly broadened the scope of IHL applicability. It remains one of the most influential legal standards in international criminal law.

IHL as a Hybrid Legal System

International Humanitarian Law operates as a hybrid system combining treaty law, customary international law, and judicial interpretation. Unlike domestic legal systems with centralized enforcement mechanisms, IHL relies on decentralized implementation through states, international courts, and international organizations.

This structure creates both strengths and limitations. While universal treaty ratification and customary norms ensure broad applicability, enforcement remains inconsistent due to reliance on political will and state cooperation.

Interim Analytical Observation

The conceptual framework of International Humanitarian Law reflects a structured attempt to regulate violence through legal constraint. However, its effectiveness depends not only on normative clarity but also on institutional enforcement capacity. The gap between legal design and practical compliance becomes especially evident in modern asymmetric conflicts involving non-state armed groups and technologically complex warfare environments.

This tension between normative universality and enforcement fragmentation forms the analytical foundation for the subsequent examination of war crimes classification and accountability mechanisms.

Treaty and Customary Legal Framework of War Crimes

The legal regulation of war crimes is grounded in a multilayered normative system composed of treaty law, customary international law, and judicial interpretation. Unlike domestic legal systems, international humanitarian law (IHL) lacks a centralized legislative authority. Instead, it develops through multilateral treaties and general customary norms that collectively regulate the conduct of armed conflict.

This hybrid structure ensures both normative universality and legal adaptability. Treaty law provides codified obligations, while customary international law ensures that core humanitarian protections apply even in the absence of formal ratification.

The Geneva Conventions of 1949

The Geneva Conventions of 1949 form the foundational legal framework of modern international humanitarian law and constitute one of the most universally ratified treaty regimes in international law (International Committee of the Red Cross [ICRC], 1949).

They were adopted in response to the humanitarian devastation of the Second World War and are designed to protect individuals who are not, or are no longer, participating in hostilities.

The four conventions include:

• First Geneva Convention: Protection of wounded and sick members of armed forces on land

• Second Geneva Convention: Protection of wounded, sick, and shipwrecked members at sea

• Third Geneva Convention: Protection of prisoners of war

• Fourth Geneva Convention: Protection of civilians in times of war

Each convention establishes detailed obligations concerning humane treatment, medical care, detention conditions, judicial guarantees, and protection from violence and degrading treatment.

A central legal innovation of the Geneva Conventions is the concept of protected persons, which establishes categories of individuals entitled to specific legal safeguards regardless of nationality, allegiance, or status. This represents a fundamental departure from earlier reciprocity-based laws of war.

Common Article 3

Common Article 3 is one of the most significant provisions across all four Geneva Conventions and applies to non-international armed conflicts. It is often described as a “mini-constitution” of international humanitarian law due to its foundational character.

It prohibits, at a minimum:

• Violence to life and person, including murder

• Cruel treatment and torture

• Taking of hostages

• Outrages upon personal dignity

• Sentencing without fair trial guarantees

Its importance lies in its universal applicability to both state and non-state actors in internal armed conflicts. It establishes a baseline of humanitarian protection in conflicts that do not meet the threshold of international wars.

Additional Protocols of 1977

The Additional Protocols were adopted to modernize the Geneva framework in response to decolonization conflicts and the increasing prevalence of internal armed conflicts.

Additional Protocol I (International Armed Conflicts)

Additional Protocol I strengthens protections for victims of international armed conflicts and introduces more detailed rules on:

• Distinction between civilians and combatants

• Proportionality in attacks

• Precautions in attack

• Protection of civilian objects and cultural property

It also reinforces prohibitions on indiscriminate attacks and expands rules governing lawful targeting.

Additional Protocol II (Non-International Armed Conflicts)

Additional Protocol II is the first treaty dedicated specifically to non-international armed conflicts. It expands protections beyond Common Article 3, including:

• Protection of civilians from direct attack

• Judicial guarantees for accused persons

• Protection of essential infrastructure

However, its application is limited to conflicts involving organized armed groups exercising territorial control, making its scope narrower than Common Article 3.

Customary International Law

Customary international law is a central pillar of war crimes regulation and ensures that fundamental humanitarian principles apply universally, regardless of treaty ratification.

It is formed through two elements:

• State practice: consistent and general conduct of states

• Opinio juris: belief that such conduct is legally required

The International Committee of the Red Cross (ICRC, 2005) has identified over 160 customary rules of international humanitarian law applicable in both international and non-international armed conflicts.

Core customary rules include:

• Principle of distinction

• Prohibition of torture

• Proportionality in attacks

• Protection of civilians and civilian objects

• Prohibition of indiscriminate attacks

Customary law is especially important in contemporary conflicts involving non-state armed groups and states not party to specific treaty regimes.

The Rome Statute and Codification of War Crimes

The Rome Statute of the International Criminal Court (ICC), adopted in 1998, represents the most comprehensive codification of international criminal law to date. It establishes the legal foundation of the ICC and defines war crimes, crimes against humanity, genocide, and aggression.

Article 8: War Crimes Regime

Article 8 of the Rome Statute provides a detailed list of war crimes applicable in both international and non-international armed conflicts (International Criminal Court [ICC], 1998).

These include:

• Willful killing

• Torture and inhuman treatment

• Intentionally directing attacks against civilians

• Extensive destruction of property not justified by military necessity

• Sexual violence, including rape and sexual slavery

• Conscription or enlistment of child soldiers

This codification consolidates treaty law, customary law, and jurisprudence into a unified legal framework.

Principle of Complementarity

A defining feature of the Rome Statute is the principle of complementarity. The ICC does not replace national courts; rather, it operates as a court of last resort.

The Court may exercise jurisdiction only when:

• National jurisdictions are unwilling to prosecute genuinely

• National jurisdictions are unable to prosecute effectively

This principle preserves state sovereignty while ensuring that impunity does not prevail in serious international crimes (Schabas, 2017).

However, in practice, complementarity can create enforcement gaps when domestic systems conduct superficial investigations to avoid ICC intervention.

Relationship Between Treaty Law and Customary Law

Treaty law and customary international law operate in a complementary relationship rather than a hierarchical one.

• Treaties provide detailed and codified legal obligations

• Customary law ensures universal applicability and fills normative gaps

In many cases, treaty norms have crystallized into customary rules, making them binding on all states regardless of ratification. This is particularly evident in prohibitions such as torture and deliberate attacks on civilians, which are universally recognized as binding norms of international law.

Analytical Observation

The treaty and customary framework of war crimes law reflects a highly developed and integrated legal system designed to regulate the conduct of armed conflict. The Geneva Conventions establish foundational humanitarian protections, the Additional Protocols refine and expand operational rules, and customary international law ensures universal normative coverage.

The Rome Statute further consolidates these norms into a coherent criminal law framework applicable before an international judicial body.

However, despite this normative sophistication, the system remains dependent on enforcement mechanisms that are structurally constrained by state sovereignty and political realities. As a result, the effectiveness of war crimes law ultimately depends not only on legal design but also on institutional implementation and political will.

Institutional Enforcement Framework of War Crimes Law

The enforcement of war crimes law depends not only on substantive legal norms but also on institutional mechanisms responsible for interpretation, prosecution, and adjudication. Unlike domestic legal systems, international humanitarian law (IHL) lacks a centralized enforcement authority. Instead, enforcement is distributed across a network of international courts, tribunals, and political institutions.

This decentralized structure produces a dual effect: it enables flexibility in responding to different conflicts, but it also generates fragmentation, inconsistency, and dependence on political cooperation.

International Criminal Court (ICC)

The International Criminal Court represents the most significant permanent institution in international criminal law. Established under the Rome Statute in 1998, the ICC has jurisdiction over genocide, crimes against humanity, war crimes, and the crime of aggression.

Unlike ad hoc tribunals, the ICC is designed as a standing global judicial body aimed at ensuring continuous accountability for the most serious international crimes.

Jurisdictional Structure

The ICC exercises jurisdiction under three primary bases:

• Territorial jurisdiction: crimes committed on the territory of a State Party

• Nationality jurisdiction: crimes committed by nationals of a State Party

• Security Council referral: cases referred under Chapter VII of the UN Charter

This structure reflects a compromise between universal justice ambitions and respect for state sovereignty.

However, jurisdiction is not universal. Several major states are not parties to the Rome Statute, significantly limiting the Court's global reach.

Complementarity in Practice

The principle of complementarity defines the ICC as a court of last resort. It intervenes only when national jurisdictions are unwilling or unable to prosecute genuinely.

In practice, this creates several operational challenges:

• States may initiate superficial investigations to block ICC intervention

• Domestic prosecutions may target low-level perpetrators while shielding senior officials

• Weak judicial systems may lack capacity for complex international crimes

As a result, complementarity can produce gaps between formal legal action and substantive accountability.

Enforcement Limitations

A major structural limitation of the ICC is its lack of independent enforcement power. The Court relies entirely on state cooperation for:

• Arrest and surrender of suspects

• Collection of evidence

• Access to crime scenes

• Protection of witnesses

This dependence means that arrest warrants may remain unenforced for extended periods, weakening deterrence and undermining the Court's authority in ongoing conflicts.

International Court of Justice (ICJ)

The International Court of Justice is the principal judicial organ of the United Nations. Unlike the ICC, it does not prosecute individuals but adjudicates disputes between states and provides authoritative interpretations of international law, including humanitarian law norms.

Jurisdictional Basis

The ICJ's jurisdiction is based on state consent, which may arise through:

• Special agreements between states

• Optional clause declarations

• Treaty-based jurisdiction clauses

This consent-based structure ensures respect for sovereignty but significantly limits compulsory jurisdiction.

Contribution to International Humanitarian Law

Although the ICJ does not determine individual criminal liability, it has played a crucial role in shaping IHL through advisory opinions and contentious cases.

Its jurisprudence has clarified:

•Applicability of IHL in armed conflicts

• Relationship between human rights law and humanitarian law

• Binding nature of customary international humanitarian rules

Through this interpretative role, the ICJ has strengthened the normative coherence of IHL at the inter-state level.

Ad Hoc International Criminal Tribunals

Before the establishment of the ICC, enforcement of war crimes law was primarily carried out through ad hoc tribunals created by the United Nations Security Council.

International Criminal Tribunal for the Former Yugoslavia (ICTY)

Established in 1993, the ICTY marked a turning point in modern international criminal law.

Its key contributions include:

• Recognition of war crimes in non-international armed conflicts

• Development of command responsibility doctrine

• Expansion of individual criminal liability for systematic atrocities

• Clarification of genocide and crimes against humanity standards

The ICTY demonstrated that international criminal accountability is practically enforceable, not merely theoretical.

International Criminal Tribunal for Rwanda (ICTR)

The ICTR, established in 1994, played a foundational role in genocide jurisprudence and the recognition of sexual violence as an international crime.

Its contributions include:

• Expansion of the legal definition of genocide

• Recognition of rape as an instrument of genocide

• Establishment of liability for incitement to genocide

• Development of jurisprudence on mass atrocity crimes

The ICTR significantly advanced the integration of gender-based violence into international criminal law.

Hybrid and Mixed Tribunals

Hybrid tribunals combine international and domestic legal elements to enhance legitimacy and local participation. Examples include:

• Special Court for Sierra Leone

• Extraordinary Chambers in the Courts of Cambodia

• Hybrid courts in Kosovo and East Timor

These institutions aim to bridge the gap between international standards and domestic legal systems.

However, they often face challenges related to funding, political interference, and institutional sustainability.

Structural Limitations of Enforcement

Despite the existence of multiple enforcement mechanisms, war crimes accountability remains uneven due to several structural constraints:

(a) Dependence on State Cooperation

International courts lack independent enforcement mechanisms and depend on states for arrests, evidence, and access.

(b) Political Selectivity

Enforcement is often influenced by geopolitical considerations, leading to perceptions of selective justice.

(c) Jurisdictional Fragmentation

Multiple institutions operate simultaneously (ICC, ICJ, ad hoc tribunals), creating overlapping but incomplete enforcement coverage.

(d) Resource Constraints

International tribunals rely on limited funding, which affects investigation capacity and case throughput.

Analytical Observation

The institutional architecture of war crimes enforcement reflects a structural tension between legal aspiration and political reality. While international criminal law has developed robust judicial mechanisms, its effectiveness is constrained by reliance on state cooperation and political goodwill.

The ICC represents a major advancement in permanent international justice, but its enforcement capacity remains limited. The ICJ contributes significantly to legal interpretation but does not address individual responsibility. Ad hoc tribunals have demonstrated enforceability but remain temporally and geographically limited.

Overall, the enforcement system is characterized by normative strength but operational fragility. This imbalance is central to understanding the persistent gap between legal prohibition and practical accountability.

Jurisprudential Development of War Crimes Law

The development of war crimes law is inseparable from the jurisprudence of international criminal tribunals. While treaty law establishes the formal legal framework, it is judicial interpretation that gives operational meaning to key concepts such as armed conflict, civilian protection, command responsibility, and modes of liability.

International tribunals—including the ICTY, ICTR, and ICC—have played a transformative role in shaping international humanitarian law (IHL). Their jurisprudence has clarified legal ambiguities, expanded individual criminal responsibility, and strengthened the coherence of international criminal law.

International Criminal Tribunal for the Former Yugoslavia (ICTY)

The ICTY marked the revival of international criminal justice after decades of inactivity following Nuremberg and Tokyo. Established in 1993, it was mandated to prosecute serious violations of international humanitarian law committed during the conflicts in the former Yugoslavia.

Its jurisprudence fundamentally reshaped modern war crimes law, particularly in defining armed conflict and developing doctrines of criminal responsibility.

Prosecutor v. Tadić (1999)

The Tadić Appeals Judgment is widely regarded as the foundational case of modern international criminal law.

The Tribunal established three key principles:

• Armed conflict exists whenever there is protracted armed violence between organized armed groups or states

• International humanitarian law applies to both international and non-international armed conflicts

• Serious violations in internal armed conflicts may constitute war crimes under customary international law

This judgment eliminated the strict separation between international and internal conflicts as the basis for war crimes applicability.

It also introduced the "overall control test", used to determine whether an armed group is sufficiently controlled by a state to classify the conflict as international.

Prosecutor v. Delalić (Čelebići Case, 2001)

The Čelebići case significantly developed the doctrine of command responsibility.

The Tribunal held that superiors may be criminally liable if:

• They exercised effective control over subordinates

• They knew or had reason to know of criminal conduct

• They failed to prevent or punish such conduct

This case established the modern legal framework for superior responsibility, later adopted by the ICC.

Prosecutor v. Krstić (2001)

The Krstić case was the first international conviction for genocide in Europe after the Second World War, relating to the Srebrenica massacre.

Key contributions include:

• Recognition of genocidal intent in mass killings

• Clarification of the "intent to destroy" requirement under genocide law

• Expansion of liability for aiding and abetting genocide

This case reinforced the distinction between genocide, crimes against humanity, and war crimes while highlighting evidentiary complexity in proving intent.

International Criminal Tribunal for Rwanda (ICTR)

The ICTR, established in 1994, played a central role in defining genocide jurisprudence and integrating sexual violence into international criminal law.

Prosecutor v. Akayesu (1998)

The Akayesu judgment is one of the most influential decisions in international criminal law.

The Tribunal held that:

• Rape and sexual violence can constitute acts of genocide

• Sexual violence may be used as a tool of group destruction

• Genocidal intent can be inferred from patterns of conduct

This case fundamentally transformed international criminal law by recognizing gender-based violence as a core component of mass atrocity crimes.

It also expanded the legal understanding of rape beyond domestic criminal law frameworks.

Prosecutor v. Rutaganda (1999)

This case clarified the requirements of individual criminal responsibility in genocide.

The Tribunal emphasized that:

• Mere membership in a criminal organization is insufficient for liability

• Active participation and intent are required

• Liability must be grounded in specific conduct and contribution

This strengthened due process safeguards in international criminal law.

International Criminal Court (ICC) Jurisprudence

The ICC represents the first permanent international institution capable of prosecuting war crimes. Its jurisprudence builds on ICTY and ICTR precedents while refining key doctrines.

Prosecutor v. Lubanga (2012)

The Lubanga case was the ICC's first completed judgment and focused on the conscription and use of child soldiers.

The Court held that:

• Recruiting children under 15 into armed groups constitutes a war crime

• "Use" includes both combat and support roles

• Command responsibility applies to organized recruitment systems

This judgment provided a detailed interpretation of child soldiering under Article 8 of the Rome Statute.

Prosecutor v. Katanga (2014)

The Katanga case refined modes of liability, particularly co-perpetration.

The Court held that:

• Liability may arise from contribution to a collective criminal plan

• Indirect participation can satisfy mens rea requirements

• Organizational control is relevant to attribution of responsibility

This case strengthened collective responsibility doctrines in complex armed group structures.

Prosecutor v. Bemba (Appeals Judgment, 2018)

The Bemba Appeals Judgment is particularly significant for command responsibility.

The Appeals Chamber overturned the conviction and emphasized that:

• Command responsibility is not strict liability

• Prosecutors must prove concrete failure to take reasonable measures

• Contextual constraints must be considered in assessing responsibility

This case tightened evidentiary thresholds for superior responsibility.

Doctrinal Contributions of International Tribunals

Across ICTY, ICTR, and ICC jurisprudence, several major doctrinal developments can be identified:

(a) Expansion of Armed Conflict Definition

Armed conflict is defined functionally based on intensity and organization rather than formal declarations (Tadić standard).

(b) Integration of Sexual Violence into Core Crimes

Sexual violence is recognized as constituting genocide, crimes against humanity, and war crimes.

(c) Refinement of Command Responsibility

Responsibility extends to superiors with effective control, including de facto authority structures.

(d) Development of Collective Liability Models

Modern tribunals recognize group-based criminality through doctrines such as co-perpetration and joint criminal enterprise.

Analytical Observation

The jurisprudence of international tribunals demonstrates that war crimes law is not static but continuously evolving through judicial interpretation. While treaty law provides structural foundations, it is case law that operationalizes legal norms in practice.

However, this evolution also reveals structural tensions:

• Expansion of liability risks over-extension of criminal responsibility

• High evidentiary thresholds limit conviction rates

• Political and institutional constraints influence case selection and enforcement

Despite these limitations, international jurisprudence has significantly strengthened the legal architecture of war crimes law and enhanced its doctrinal coherence.

Command Responsibility and Contemporary Enforcement Challenges

The doctrine of command responsibility and the broader enforcement environment of war crimes law represent the point at which international legal theory intersects most directly with operational and political reality. While earlier sections demonstrate that international humanitarian law (IHL) and international criminal law have developed sophisticated normative and jurisprudential frameworks, this section highlights the structural limitations that arise in practice.

War crimes accountability depends not only on legal clarity but also on enforcement capacity, political cooperation, evidentiary feasibility, and institutional legitimacy. These factors collectively determine whether international criminal law functions as an effective system of accountability or remains primarily declaratory.

Command Responsibility Doctrine

Command responsibility is a distinctive doctrine in international criminal law because it imposes liability for omissions rather than direct acts. It reflects the hierarchical nature of armed conflict, where authority is exercised through chains of command.

This doctrine ensures that military and civilian superiors cannot evade responsibility by delegating criminal acts to subordinates.

Legal Elements of Command Responsibility

Under Article 28 of the Rome Statute, command responsibility requires three cumulative elements:

(a) Effective Control

The superior must have had effective control over subordinates, meaning the material ability to prevent or repress criminal conduct or submit the matter to competent authorities.

(b) Knowledge Standard

The superior knew or, owing to the circumstances, should have known that subordinates were committing or about to commit crimes.

(c) Failure to Act

The superior failed to take necessary and reasonable measures to prevent or punish the conduct.

This structure balances accountability with fairness by requiring proof of control, awareness, and omission.

Jurisprudential Clarification

International tribunals, particularly the ICTY and ICC, have refined command responsibility significantly.

In the Čelebići case, the Tribunal held that "effective control" is the decisive criterion, not formal rank. This means that de facto authority can be sufficient for liability.

In the Bemba Appeals Judgment, the ICC further clarified that:

• Command responsibility is not strict liability

• Prosecutors must demonstrate specific failures to act

• Contextual constraints must be assessed when evaluating "reasonable measures"

This reflects a judicial effort to avoid overly expansive criminal liability in complex conflict environments.

Non-State Armed Groups and Fragmentation of Authority

Modern armed conflicts are increasingly characterized by non-state armed groups operating outside formal state structures. These groups often:

• Lack stable hierarchies

• Operate through decentralized networks

• Shift rapidly in structure and leadership

• Maintain ambiguous civilian-military boundaries

These characteristics create significant legal challenges for applying command responsibility, particularly in establishing effective control and knowledge.

In many cases, accountability mechanisms are limited by the absence of formal records, command documentation, or stable institutional structures.

Political Constraints and Selective Enforcement

A persistent challenge in international criminal law is the influence of political dynamics on enforcement.

Although international courts are formally independent, their effectiveness is often shaped by:

• United Nations Security Council decision-making

• Geopolitical alliances and strategic interests

• State cooperation or non-cooperation with investigations

This creates a structural risk of selective enforcement, where similar conduct may receive different levels of international attention depending on political context.

Selective enforcement undermines perceptions of neutrality and can weaken the legitimacy of international criminal justice mechanisms.

Evidentiary Challenges in Modern Armed Conflict

Contemporary warfare presents significant evidentiary challenges for war crimes prosecution.

(a) Access Restrictions

Investigators often lack access to active conflict zones due to security risks or political obstruction.

(b) Chain of Custody Issues

Evidence collected in conflict environments may lack proper documentation, affecting admissibility and reliability.

(c) Witness Protection

Witnesses face high risks of retaliation, intimidation, or displacement, limiting willingness to testify.

(d) Digital Evidence Complexity

Modern conflicts generate large volumes of digital evidence, including:

• Satellite imagery

• Social media content

• Open-source intelligence

While valuable, such evidence raises challenges related to authentication, verification, and manipulation.

Hybrid Warfare and Legal Complexity

Modern armed conflicts increasingly involve hybrid warfare strategies combining:

• Conventional military operations

• Irregular armed tactics

• Cyber operations

• Information warfare

These developments complicate traditional IHL frameworks, particularly regarding:

• Attribution of attacks

• Distinction between civilian and military targets

• Application of proportionality in digital environments

As warfare evolves, legal frameworks face increasing pressure to adapt doctrinally and operationally.

Critical Evaluation of the War Crimes Regime

The war crimes regime reflects a fundamental tension between normative development and enforcement capacity.

Normative Strength vs Enforcement Weakness

International humanitarian law is highly developed in normative terms, yet enforcement remains inconsistent and dependent on political conditions.

Dependence on State Cooperation

International courts lack independent enforcement mechanisms, relying on states for arrests, evidence collection, and implementation of judgments.

Institutional Fragmentation

Multiple institutions (ICC, ICJ, ad hoc tribunals, hybrid courts) operate simultaneously, creating fragmentation and inconsistency in enforcement outcomes.

Perceived Inequality in Justice

Critics argue that international criminal law is unevenly applied, often disproportionately affecting weaker states or non-state actors while powerful actors face limited accountability.

This perception undermines legitimacy and challenges the universalist foundations of international criminal justice.

Analytical Synthesis

The doctrine of command responsibility and the broader enforcement framework reveal a central paradox in international criminal law: strong legal norms do not automatically produce effective enforcement.

While war crimes law has achieved substantial doctrinal sophistication, its practical effectiveness is constrained by political realities, evidentiary limitations, and institutional dependence on state cooperation.

The system therefore operates in a condition of partial enforcement capacity—legally robust but operationally fragmented. This gap between normative design and practical implementation remains one of the defining structural challenges of international criminal justice.

Conclusion

International Humanitarian Law (IHL) and the war crimes regime represent one of the most advanced normative systems in contemporary international law. Over time, this system has evolved from early customary restrictions on warfare into a complex legal architecture composed of treaty law, customary international law, and judicial interpretation. Its primary purpose is to regulate the conduct of armed conflict by limiting human suffering while preserving a minimum standard of humanity even in conditions of organized violence.

At the doctrinal level, the legal framework governing war crimes is highly developed and structurally coherent. The Geneva Conventions of 1949 establish the foundational rules for humanitarian protection, while the Additional Protocols of 1977 modernize and expand these protections in response to changing patterns of armed conflict. The Rome Statute of the International Criminal Court further consolidates this framework by codifying war crimes and establishing a permanent institution for individual criminal accountability. Together, these instruments form a comprehensive legal system defining prohibited conduct with substantial precision.

International jurisprudence has played a decisive role in shaping the practical meaning of these norms. The ICTY and ICTR significantly advanced international criminal law by clarifying the definition of armed conflict, recognizing sexual violence as a core international crime, and developing doctrines such as command responsibility and collective liability. The International Criminal Court has further refined these developments through its case law, including landmark judgments addressing child soldiers, co-perpetration, and the limits of superior responsibility. These judicial contributions demonstrate that war crimes law is not static but continuously evolving through interpretation and application.

Despite this normative and jurisprudential progress, enforcement remains structurally constrained. International criminal institutions lack independent coercive power and depend heavily on state cooperation for arrests, investigations, and execution of judicial decisions. This structural dependence creates a persistent gap between legal obligation and practical enforcement, often resulting in delayed proceedings and unexecuted arrest warrants.

Moreover, enforcement is shaped by political realities that influence the operation of international justice mechanisms. The role of the United Nations Security Council, the interests of powerful states, and selective cooperation by national governments contribute to uneven enforcement across different conflicts. This inconsistency raises concerns regarding the neutrality, legitimacy, and universality of international criminal justice.

Contemporary developments in warfare further complicate enforcement. The rise of non-state armed groups, hybrid warfare strategies, and technologically mediated conflict environments has increased the complexity of attribution, evidence collection, and legal classification. Investigators and prosecutors now operate in environments characterized by fragmented authority structures, digital evidence proliferation, and evolving methods of warfare.

The doctrine of command responsibility illustrates the broader tension between legal design and operational reality. While it ensures that superiors cannot escape liability through hierarchical distance, its application depends on complex factual determinations of control, knowledge, and reasonable preventive measures. Jurisprudence has refined this doctrine to prevent overextension of liability, but evidentiary and contextual challenges remain significant.

Overall, the war crimes regime reflects a dual reality. On one hand, it represents a highly sophisticated normative system capable of clearly defining and prohibiting serious violations of humanitarian law. On the other hand, its enforcement remains uneven and structurally dependent on political will and state cooperation.

The central conclusion of this chapter is that International Humanitarian Law should be understood not as a fully enforceable global criminal justice system, but as a partially effective normative order operating within a decentralized international structure. Its principal achievement lies in establishing universal legal standards that delegitimize certain forms of violence, even when enforcement is inconsistent.

Strengthening the effectiveness of the war crimes regime will require improved institutional cooperation, enhanced evidentiary capacities in modern conflict environments, and reduced political constraints on judicial processes. Without such reforms, the gap between legal normativity and enforcement reality will remain a defining feature of international criminal justice.

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CHARACTERS IN THE DÎVÂN OF HASAN ZİYÂÎ FROM MOSTAR

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ABSTRACT

Introduction and Purpose: The concept of "person" is a form of the word "human," passed down from the earliest periods of the Turkish language to the present day. Identities, another equivalent of this concept, are seen as the main element in many literary texts. These are identities that have become known and recognized in various circles. Some have distinguished themselves through their wisdom, others through their leadership. This study examines the Divan (collection of poems) of Hasan Ziyâî of Mostar, a 16th-century poet, and evaluates the identities found in his Divan in terms of their status as famous names (primary) and titles/nicknames (secondary). Each identity piece is added to various groups according to its place in the literary text clusters, and these groups are arranged alphabetically within themselves. Each identity piece is explained and exemplified with illustrative couplets. Studies on the subject of personalities have been used as a model. The individuals in the work in question have been analyzed according to the method described. This study aims to contribute to the discussion of personalities.

Materials and Methods: This study examines the Divan of the 16th-century poet Hasan Ziyâî of Mostar from the perspective of her personalities. These individuals have been classsified as scholars, religious figures, mythological figures, mystics, prophets, artists, historians and rulers. Encyclopedic information is provided about each person, and their story is illustrated with exemplary verses from the relevant work.

Results: Mostarlı Hasan Ziyâî's Divan contains a total of 85 figures: 4 scholars, 6 religious figures, 14 mythological figures, 6 mystics, 17 prophets, 6 artists, 15 historians and 17 administrators.

Key Words: Classical Turkish Literature, People, Hasan Ziyâî from Mostar Dîvân

GİRİŞ

İnsanın görünüşleri olan kişilik ve tip; genelden özele doğru varlık (canlı-cansız)-canlı- (hayvan-bitki-insan)-insan (tip-kişi) (Akkuş, 1996: 6) biçimindeki bir sıralamada yer alır. Geleneksel eserlerde tip ve kişilikler; dinî, tasavvufî, tarihî, edebî ve sanatçı (Akkuş, 2000: 1) gibi çeşitli kümelerde ele alınır. Bu hususta, *Mostarlı Hasan Ziyâî Dîvânı* geleneğe uygun olarak incelenmiştir. Bu bağlamda, ilgili konu üzerine yazılan eserler önemsenmiştir. Kişiler bahsi, klasik Türk şiiri açısından yeni sayılan bir çalışma alanıdır. Bu tema doğrultusunda yapılan ilk çalışmalara "*Nef'î Dîvânı'nda Tipler ve Kişilikler*" (Akkuş, 1996), "*Dîvân Şiirinde İnsan 1- Dinî Kişilikler*" (Akkuş, 2000), "*Dîvân Şiirinde Mitolojik Unsurlar Şahıslar Mitolojisi*" (Tökel, 2000); yakın zamanda yapılan çalışmalara "*Klasik Türk Şiirinde Kadın Şahsiyetler*" (Tunç, 2018), "*Şeyhülislâm Bahâyî Dîvânı'nda Şahsiyetler*" (Uludağ, 2022) gibi çalışmalar örnek verilebilir. Bu çalışmanın hazırlanmasında, Metin AKKUŞ tarafından yazılan "*Dîvân Şiirinde İnsan 1- Dinî Kişilikler*" adlı kitap esas alınmıştır. Bu makalede, tanık beyitler "*Mostarlı Hasan Ziyâ'î Dîvânı*" (Gürgendereli, 2017)[1] adlı çalışmadan alınmıştır. Şairin *Dîvânı*'nda rastlanan kimlikler (Tablo-1) aslî ve tâlî olmaları açısından tasnif edilmiştir. Söz konusu kimlikler sekiz ayrı kümeye yerleştirilmiş olup (Tablo-2) Kümelerde bulunan kişilerin sayısı (Tablo-3) belirtilmiştir. Kişilerin kümelere oranları (Grafik-1) verilmiştir.

[1] Boşnak şairlerden olup 16. yüzyılda yaşamıştır. Şair, *Dîvânı*'nın incelenmesi ile bilim dünyasına tanıtılmıştır. Şairin *Dîvânı* 11 kasîde, 45 muhammes, 496 gazel, 14 tarih, 67 mukâtaat, 29 müfret ve matladan oluşur.

Mostarlı Hasan Ziyâî *Dîvânı*'nda, 85 kimlik vardır. Bunlar; aslî kimlikler (72) ve tâlî kimlikler (13) biçiminde değerlendirilmiştir.[2]

Aslî Kimlik Kayıtları	ÂDEM (Hz.), ALİ Hz. (Haydar), ARİSTO, ÂSAF, ASHÂB-I KEHF, ATTÂR (Hâce Attâr), BÂKÎ, BATTÂL (Seyyîd), BEHLÛL BEG, BEHRÂM, CÂMÎ, CEM (Cemşîd), DAHHÂK, DÂRÂ, EBÛ DERDÂ, EFLÂTUN, EMRÎ ÇELEBİ, FİRDEVSÎ, HÂMÂN, HASAN BEG, HASAN PAŞA, HASSÂN, HAVVA (Hz.), HIZIR, HÜSÂM, İBN-İ UNUK, İBRÂHİM Hz. (Halîl), İDRİS (Hz.), İLYAS, ÎSÂ Hz. (Mesih), İSKENDER (Sikender), İZÂRÎ, KÂRÛN, KÂSIM, KAYDEFÂ, KAYSER, KEYVAN BEG, KİSRÂ, KUBÂD, MÂNÎ, MANSÛR, MEHEMED BEG, MERYEM (Hz.), MUHAMMED Hz. (Ahmed-Mahmud), MÛSÂ Hz. (Kelîm), MUSTAFA BEG, MÜFTÜ HÂCE ÇELEBİ, NEMRÛD, NÛH (Hz.), OSMAN BEG, ÖMER (Hz.), RESM, RÜSTEM, SÂM, SELMÂN, SİNÂN BEG, SULTAN MAHMÛD, SULTAN MURÂD, SULTAN SELÎM (Selîm), SÜHRÂB, SÜLEYMÂN (Hz.), ŞÂNÎ, ŞEDDÂD, SEMS, ŞEMSİ PAŞA, ŞEYH-İ SAN'ÂN, ŞEYLÎ, YA'KÛB Hz. (Pîr-i ken'ânî),YAHYÂ (Hz.), YEZÎD, YÛSÛF (Hz.), ZÂL.
Tâlî Kimlik Kayıtları	Ahmed (bk MUHAMMED Hz.), Cemşîd (bk CEM), Hâce Attâr (bk ATTÂR), Halîl (bk İBRÂHİM Hz.), Haydar (bk ALİ Hz.), Kelîm (bk MÛSÂ Hz.), Mahmud (bk MUHAMMED Hz.), [Taşlıcalı Yahyâ] Memî, Mesih (bk ÎSÂ Hz.), Pîr-i ken'ânî (bk YA'KÛB Hz.), Selîm (bk SULTAN SELÎM), Seyyîd (bk BATTÂL), Sikender (bk İSKENDER).

Tablo-1 Kişilerin Âslî ve Tâlî Olarak Sınıflandırılması

Şairin *Dîvânı*'nda yer alan kimlikler; bilgin, dinî, mitolojik-menkıbevî, mutasavvıf, peygamber, sanatçı-şair, tarihî ve yönetici olmak üzere sekiz ayrı grupta ele alınmıştır. *Dîvân*'da bilgin (4), dinî (6), mitolojik-menkıbevî (14), mutasavvıf (6), peygamber (17), sanatçı-şair (6), tarihî (15), yönetici (17) kimlik tespit edilmiştir. Dinî kişiler kümesinde yer alanlar, peygamber olmayıp peygamberlerle anılan kişilerdir. Bu sebeple, söz konusu kümede yer almaları uygun görülmüştür. Çalışmada, hikâye kahramanı olarak tipleşmiş kişilere yer verilmemiştir. Bu duruma bağlı olarak *Yûsûf u Züleyha Mesnevisi*'nde olduğu gibi meşhur hikayelerdeki Yûsûf ve Züleyha kimliklerinden kaçınılmıştır. Yûsûf ve Ya'kûb'un peygamber kimliklerinin vurgulandığı beyitler seçilmiştir.

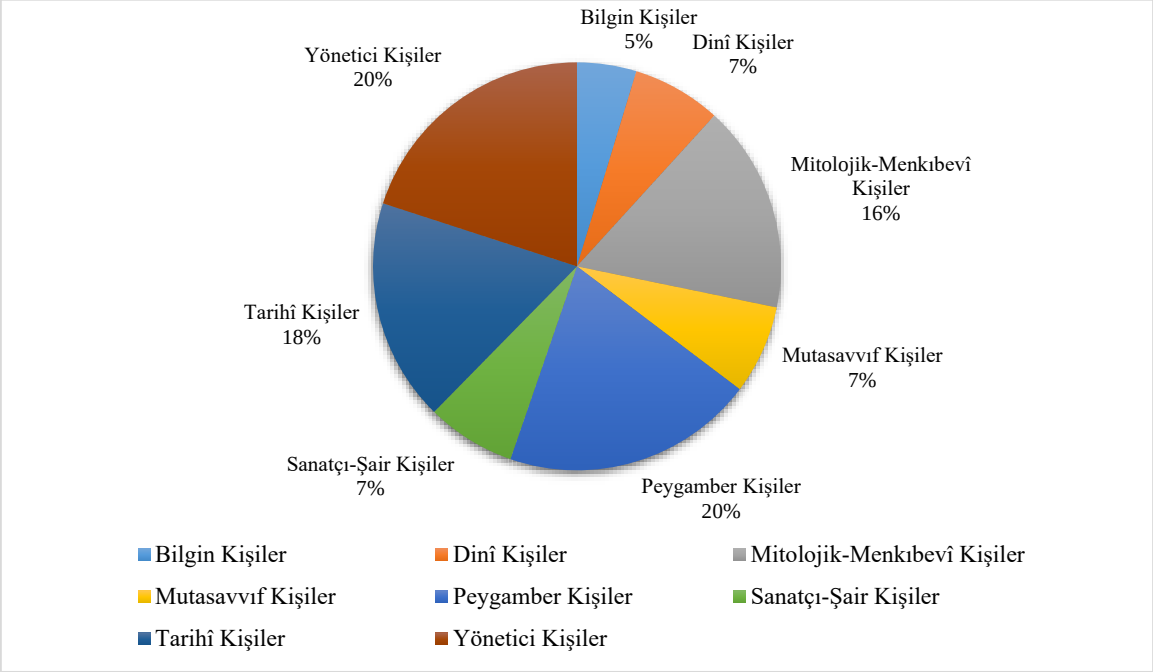
Bilgin Kişiler	ARİSTO, EFLÂTUN, İBN-İ UNUK, MÜFTÜ HÂCE ÇELEBİ.
Dinî Kişiler	ALİ Hz. (Haydar), ÂSAF, HAVVA (Hz.), Haydar (bk ALİ Hz.), MERYEM (Hz.), ÖMER Hz.
Mitolojik-Menkıbevî Kişiler	BEHRÂM, CEM (Cemşîd), Cemşîd (bk CEM), DAHHÂK, DÂRÂ, HIZIR, İLYAS, İSKENDER (Sikender), KUBÂD, RÜSTEM, SÂM, Sikender (bk İSKENDER), SÜHRÂB, ZÂL.
Mutasavvıf Kişiler	ATTÂR (Hâce Attâr), CÂMÎ, Hâce Attâr (bk ATTÂR), KÂSIM, MANSÛR, ŞEYH-İ SAN'ÂN.
Peygamber Kişiler	ÂDEM (Hz.), Ahmed (bk MUHAMMED Hz.), Halîl (bk İBRÂHİM Hz.), İBRÂHİM Hz. (Halîl), İDRİS (Hz.), ÎSÂ Hz. (Mesih), Kelîm (bk MÛSÂ Hz.), Mahmud (bk MUHAMMED Hz.), Mesih (bk ÎSÂ Hz), MUHAMMED Hz. (Ahmed-Mahmud), MÛSÂ Hz. (Kelîm), NÛH (Hz.), Pîr-i ken'ânî (bk YA'KÛB Hz.), SÜLEYMÂN (Hz.), YAHYÂ (Hz.), YA'KÛB Hz. (Pîr-iken'ânî), YÛSÛF Hz.
Sanatçı-Şair Kişiler	BÂKÎ, FİRDEVSÎ, HASSÂN, MÂNÎ, [Taşlıcalı Yahyâ] Memî, SELMÂN,
Tarihî Kişiler	ASHÂB-I KEHF, BATTÂL (Seyyîd), EBÛ DERDÂ, HÂMÂN, HÜSÂM, İZÂRÎ, KÂRÛN, NEMRÛD, RESM, Seyyîd (bk BATTÂL), ŞÂNÎ, ŞEDDÂD, ŞEMS, ŞEYLÎ, YEZÎD.
Yönetici Kişiler	BEHLÛL BEG, EMRÎ ÇELEBİ, HASAN BEG, HASAN PAŞA, KAYDEFÂ, KAYSER, KEYVAN BEG, KİSRÂ, MEHMED BEG, MUSTAFA BEG, OSMAN BEG, Selîm (bk SULTAN SELÎM), SİNÂN BEG, SULTAN MAHMÛD, SULTAN MURÂD, SULTAN SELÎM (Selîm), ŞEMSİ PAŞA.

[2] Aslî kimliklerin tamamı büyük, tâlî olanlar ise küçük harfle yazılmıştır. Aslî kimliklerin tâlî adları parantez ile gösterilmiş, tâlî olanların kim oldukları "bk" notlarıyla ilgili kavrama gönderilmiştir.

Tablo-2 Kişilerin Kümelendirilmesi

Küme İsimleri	Kişi Sayıları
Bilgin Kişiler	4
Dinî Kişiler	6
Mitolojik-Menkıbevî Kişiler	14
Mutasavvıf Kişiler	6
Peygamber Kişiler	17
Sanatçı-Şair Kişiler	6
Tarihî Kişiler	15
Yönetici Kişiler	17
Toplam	85

Tablo-3 Kümelerde Bulunan Kişi Sayıları



Grafik-1 Kişilerin Kümelere Oranları

MOSTARLI HASAN ZİYÂÎ DÎVÂNI'NDA YER ALAN KİŞİLERİN DEĞERLENDİRİLMESİ

Mostarlı Hasan Ziyâî Dîvânı'nda 85 adlandırma görülür. Bunlardan 72'si aslî, 13'ü tâlîdir. Bunlar; bilgin (4), dinî (6), mitolojik-menkıbevî (14), mutasavvıf (6), peygamber (17), sanatçı-şair (6), tarihî (15) ve yönetici (17) kümelerinde ele alınır.

BİLGİN KİŞİLER

Şairin *Dîvânı*'nda 4 bilgin kimlik (Aristo, Eflâtun, İbn-i Unuk, Müftü Hâce Çelebi) tespit edilmiştir. Bunlar, dîvân şiiri geleneği içinde ilim veya sanat alanlarında adlarını duyurmuştur. Bu kümede yer alan *İbn-i Unuk*; bugüne kadar yapılan çalışmalarda adına henüz rastlanmayan bir kimliktir. Şairin, Balkan Türk'ü olması sebebiyle *İbn-i Unuk*'un yöresel bir kişi olduğu tahmin edilir.

Aristo

(M.Ö.384-322) İslâm düşüncesi üzerine önemli etkileri olan İlk Çağ filozofudur. (Zavotçu, 2018: 66) İskender'i yetiştiren kişidir. Klasik Türk şiirine zekâsı ve bilgisi ile yansır. İlim ve hikmet kavramları ile beraber anılır. Şair: Benim yaratılışım o güzeller şahına mesel söyletir. İlim ve hikmetten Aristo'yu Sikender söyletir, der. Bu ifade ile Aristo'nun ilim konusunda söz söylemesini, İskender'den ilham almasına bağlar.

Söyledür tab'um benüm ol şâh-ı hûbân fi'l-mesel

İlm ü hikmetden **Aristo**yı (Sikender)[3] söyledür

(G[4]165/2)

Eflâtun

Mîlâddan 430 sene önce Ekine Adası'nda doğdu. Geniş omuzlu mânâsında Platon denildi. (Onay, 2014: 150) Aristo'nun öğrencisidir. Bazı konularda, hocasının görüşlerine karşı çıkmasıyla bilinir. Klasik Türk şiirinde bilgisi ile anılır. Şair: Ağzınla belin sırrını bilmiştir. Ziyâ'î'ye bu hikmet Eflâtun'dan miras kaldı, der. Eflâtun'u hikmet sahibi olmasıyla ele alır.

Dehânunla miyânun sırrını ma'lûm idinmişdür

Ziyâ'î'ye bu hikmet kaldı **Eflâtun**dan mîrâs

(G42/5)

İbn-İ Unuk

Bilimsel kaynaklarda ve şimdiye kadar yapılan çalışmalarda bu kimliğe ait bir bilgiye rastlanılmamıştır. Şairin *Dîvânı*'nda; Nûh peygamber, *gemi* ve marangoz manasına gelen *dülger* ile bir arada kullanılır. Bu sebeple, söz konusu kimliğin bir ağaç ustası (marangoz) olduğu tahmin edilir. Şair: Her tahtası, Nûh'un gemisinin parçası/takımı ile çağdaştır. Marangozu İbn-i Unuk'tandır. Sürükler onu, der. Ziyâî, bu ifadelerle İbn-i Unuk'u okuyucunun karşısına çıkartır.

Raht-ı fülk-i (Nûh) ile hem-'asrdur her tahtası

Cerr idipdür anı 'ûc **İbn-i Unuk**dan dülgeri

(K11/15)

Müftü Hâce Çelebi

Kimliğe ait bir bilgi bulunamadı. Şairin yaşadığı dönemde olan bir din âlimi olduğu tahmin edilir. Şair, aşağıda yer alan ifadede öldüğü tarihten söz eder.

Târîh-i Vefât-ı Merhûm **Müftü Hâce Çelebi**

(Trh5/B)

DİNÎ KİŞİLER

Ziyâî *Dîvânı*'nda 5 aslî, 1 tâlî dinî kimlik (Ali (Hz.), Âsaf, Havva (Hz.), Haydar, Meryem (Hz.), Ömer Hz.) görülür. Bu kümede, peygamber olmayıp fakat onlarla beraber anılan kişiler yer alır. Bu özelliği gösteren kişiler arasından, olumlu ve örnek olarak kabul edilenler ilgili grupta toplanır.

Ali Hz. (Haydar)

Hazret-i peygamberin amcası oğlu, dâmâdı ve dördüncü halifesi olan zâttır. (Onay, 2014: 54) Klasik Türk şiirinde kahramanlığı, yiğitliği, Zülfikar isimli kılıcı ve Düldül isimli atı ile anılır. Oğlu Hüseyin, Yezîd tarafından Kerbela'da şehit edilmiştir. Bu sebeple, metinlerde Yezîd ile beraber geçtiği görülür. Şair: Vefâ sende, mürüvvet sende, ihsan ve cömertlik sende. Ali balum, seni her kim sevmezse! Yezîd olsun, der.

Vefâ sende mürüvvet sende ihsân u sahâ sende

'Ali bâlum seni her kim ki sevmezse (Yezîd) olsun

(G319/4)

[3] Kimliklerin beraber anıldıkları diğer kimlikler parantezle gösterilmiştir.

[4] Bu çalışmada şu kısaltmalar kullanılmıştır: B: Başlık (Metin içinde yer almayan başlıkta bulunan kimlikler), G: Gazel, K: Kasîde, Kt: Kıt'a, Mhs: Muhammes, Mm: Mu'ammâ, Msd: Müseddes, Tb: Tercî-i Bend, Trh: Tarih.

(Mm/6)[5]

Âsaf

Süleymân peygamberin vezirinin adıdır. (Tökel, 2016: 257) Klasik Türk şiirinde güvenilir, kerâmet sahibi, vezirlikte örnek alınması gereken kişi olarak öne çıkar. Şair: Gam, beni fakir/düşkün etti. Dert iklimine/şehrine lider etti. Sevincim var ki Taht sahibi etti. Süyleymânları âciz edip ne Âsaflar esîr etti, der. Bu ifadeler ile Âsaf'ı, Süleymân peygamberle beraber anıp kutsallık yükler.

Fakîr itdi beni iklîm-i derde gam emîr itdi

Sürûrum var ki server eyledi sâhib-i serîr itdi

(Süleymânlar) zebûn idüp ne **Âsaf**lar esîr itdi

(Mhs/4)

Havva Hz.

İlk kadın, Hz. Âdem'in zevcesi ve insan neslinin annesi. (Zavotçu, 2018: 313) Klasik Türk şiirinde, yasak yiyeceği yiyerek (Âdem) peygamberle beraber cennetten kovulması yönüyle anılır. Şair, bir güzelden söz eder ve şunları aktarır: Koynuna girmek için hile kurdum, hazırlık yaptım. [Bu durumu], Âdem ve Havva [kıssasında olduğu gibi] babası da annesi de duydu.

Hîle kurdum koynına girmek tedârik eyledüm

Duydu atası anası (Âdem) ü **Havvâ** hakı

(G452/3)

Haydar (Bk Ali Hz.)

Meryem Hz.

Hz. Îsâ'nın annesi, Dâvûd peygamberin soyundan İmran adlı zâtın kızıdır. (Pala, 2016: 307) Klasik Türk şiirinde, (Îsâ peygamber) ile beraber anılır. Oğlunu babasız doğurması ile bilinir. Şair: Hazret-i Mûsâ [gibi] bir güzel çobanı gördüm. Îsâ zamanın dini [gibi] Meryem oğlu dinidir, der. Îsâ peygamberin annesi olduğu vurgulanır.

Bir güzel çûbânı gördüm (Hazret-i Mûsâ) hakı

İbn-i **Meryem** dînidür dîn-i dem (Îsâ) hakı

(G452/1)

Ömer Hz.

İkinci halife Ömer M. 591 yılında Mekke'de doğdu. (Zavotçu, 2018: 541) Klasik Türk şiirinde adaleti ile bilinir. Ziyâî de; dönemin yöneticilerinden olan Mustafa Bey'i, adaletli olması yönüyle Hz. Ömer'e benzetir ve şunları söyler: Kisrâ, adâlet ile denk değil ona. Peygamberden sonra adâlet ile bir bu bir Ömer [bilinir], der.

(Kisrâ) 'adâlet ile mu'âdil degül ana

Ba'de'n-nebî 'adâlet ile bir bu bir **'Ömer**

(K3/19)

MİTOLOJİK-MENKIBEVÎ KİŞİLER

Şairin *Dîvânı*'nda 12 aslî, 2 tâlî mitolojik-menkıbevî kimlik (Behrâm, Cem, Cemşîd, Dahhâk, Dârâ, Hızır, İlyas, İskender, Kubâd, Rüstem, Sâm, Sikender, Sührâb, Zâl) görülür. Bunlardan 9 kişi; Firdevsî'nin *Şehnâme* adlı eserinde anılır. Bazıları ise dinî anlatılarla birleşerek toplum arasında kutsallık kazanmıştır. Bunlar, menkıbe kişisi özelliği gösterir.

[5] Dîvânda yer alıp çalışmaya alınmayan tanık metinler, adreslemeleriyle parantez içinde gösterilmiştir.

Behrâm

Sâsâniyân sülalesinden, Yezdgird'in oğlu olan ve Behrâm-ı Gur adıyla anılan padişah, yaban eşeği anlamına gelen gur kelimesi, sürekli yaban eşeği avlamakla vakit geçiren Behrâm'a sıfat olarak verilmiş. (Tökel, 2016: 92) Firdevsî'nin *Şehnâme* adlı eserinin kahramanlarından biridir Dîvân şiirinde, hile ile öldürülmesiyle bilinir. Şair: Dostlarım, yabancıya ne renk [hile] ettiğimi/nasıl olduğumu söyledi. Sanki mezarım üzerine Behrâm kıssası okunur, der. Şair diğer örnekte *Sâm* ile adını anmıştır.

Andı agyâra ne renk itdügümi yârânum

Gûrum üzere sanasın kıssa-i **Behrâm** okınur

(G158/3)

(G136/1)

Cem (Cemşîd)

Pişdâdiyan sülalesinin dördüncü hükümdarı olup İran mitolojisine göre yedi yüz yahut bin yıl yaşamıştır. (Pala, 2016: 86) *Şehnâme* kahramanıdır. Klasik Türk şiirinde Şarabın mucidi olarak bilinir. Şairin *Dîvânı*'nda da şarap etrafında gelişen anlatılarla ele alınır. Ziyâî: Ey gönül! Bilge isen yürü Cem'in aşk kadehinden [şarabından] iç. Çünkü iki Dünya zevkine bir aşk âlemi değer, der. Bu ifadelerle Cem'in kadehini, Dünya ve âhiret nimetlerinden üstün tutar. *Sâm, Sührâb, İskender* gibi kimliklerle anılır.

Ey gönül 'ârif isen iç yüri câm-ı **Cem**-i 'aşk

Ki deger iki cihân zevkine bir 'âlem-i 'aşk

(G221/1)

(G201/3, G240/2, G288/4, G360/4)

Cemşîd (Bk Cem)

Dahhâk

Dahhâk'ın omuzlarında, şeytanın tükürüğü eseri olarak yılan başı şeklinde bir ur hâsıl olmuş, sancısına tahammül edemediğinden yine şeytanın ta'lîmi ile üzerine insan beyni sürmeye başlamış. (Onay, 2014: 127) *Şehnâme*'de ele alınan kahramandır. Klasik Türk şiirinde zâlim olması ile anılır. Ziyâî: Ey! Cemşîd güçlü padişah Dahhâk, [senin] Bedeni ağlatan ejderhânın saçağı gibi [bir saçak], rüyasında görmedi, der. Bu söylem ile Dahhâk'ın omzundan çıkan yılanı hatırlatır.

Bedeni giryân iden su 'bân-ı zülfeynün gibi

Görmedi düşinde **Dahhâk** ey şeh-i (Cemşîd)-fer

(G65/3)

Dârâ

Şehnâme'nin ünlü kahramanlarından, Keyâniyân sülalesinin onuncu ve son padişahıdır. (Zavotçu, 2018: 162) Şair: Gül devri, sürekli sevgili [ile] yumuşak ama Dârâ, zamanın Zâl'i ile yüze gülüp [dalkavukluk] yapamaz, der. Dârâ'nın hükümdarlığı zamanında herkesin refah içinde ve mutlu olduğunu hatırlatır.

Devr-i gül dâim ü cânâne mülâyim ammâ

İdemez (Zâl)-ı zamân ile müdârâ **Dârâ**

(G9/2)

(Tb/7)

Hızır

Rivâyetlere göre âb-ı hayâtı içerek ölmezlik sırrına erişen, peygamber veya veli olduğu hususlarında ihtilaf bulunan kutsal bir kişi. (Tökel, 2016: 285) Klasik Türk şiirinde menkıbevî özellik taşıyan bir kişi olarak bilinir. Karada bulunanlara, zorda kaldıklarında yardım etmesi ile anılır. *Kul sıkışmayınca Hızır*

yetişmez-Hızır gibi yetişmek söylemleri; bu durumu yansıtır. Şair: O yasak şarabı satan [kişi], meyhâneciyi över. Her kişi kendi atasını Hızır-İlyas sanır, der. Bu ifadelerle Hızır'a yücelik atfeder.

Medh ider pîr-i mugânı o men'-i bâde-fürüş

Her kişi kendü atasın **Hızır** u (İlyâs) sanur

(G87/2)

(G426/2)

İlyas

İlyas peygamber. İsrailoğullarına gönderilmiştir. (Pala, 2016: 230) Menkıbeleşen bir hayat öyküsü vardır. (Hızır) ile beraber âb-ı hayâtı bulduğuna inanılır. Denizde, zorda kalanlara yardım etmesi ile bilinir. Ziyâî: O yasak şarabı satan [kişi], meyhâneciyi över. Her kişi kendi atasını Hızır-İlyas sanır, der. Bu sözlerle İlyas'a kutsallık yükler.

Medh ider pîr-i mugânı o men'-i bâde-fürüş

Her kişi kendü atasın (Hızır) u **İlyâs** sanur

(G87/2)

İskender (Sikender)

Makedonya Kralı Filip'in mîlâddan 356 yıl önce doğan oğlunun adıdır. Çok zeki, akıllı ve kuvvet sahibi idi. (Onay, 2014: 228) Klasik Türk şiirinde, (Hızır) ve (İlyas) ile Zulumât'a (Karanlıklar Ülkesi'ne) giderek ölümsüzlük suyunu araması ancak bulamaması ile anılır. Şair de benzer özelliklerle ele alır. Mostarlı: Ey Dünya! İskender, hayat suyuna/suyunun saltanatına erişmedi. Soğuk suyunu da içmedi, der. Bu söylem ile İskender'in çıktığı yolculuktan ölümsüzlük suyunu içmeden dönesi vurgulanır. *Hızır, Kaydefâ, Cem* kimlikleri ile kullanılır.

Âb-ı hayâta irmedi ana ki saltanât

Sovuk suyun da içmedi **İskender** ey cihân

(G362/2)

(K11/14, G24/4, G66/1, G101/3, G362/2)

Kubâd

Şehnâme'de adı geçen hükümdarlardan. Pişdâdiyân sülalesinden sonra gelmiş olan Keyâniyân sülalesinin ilk hükümdarıdır. (Zavotçu, 2018: 402) Uzun yıllar hükümdarlık yapması ile bilinir. Klasik Türk şiirinde hükümdarlığı ile geçer. Şair, kendisini bir mu'ammâya konu eder.

Be-nâm-ı **Kubâd**

(Mm2/B)

Rüstem

Sâm'ın torunu, Zâl'in oğlu. Sührâb ve Feramurz'un babası. Bijen'in dedesi. (Tökel, 2016: 194) *Şehnâme* kahramanıdır. Dîvân şiirinde, bütün tüyleri beyaz doğan oğlunu dağa bırakması ile bilinir. Ziyâî: Özetle; Bugün Rüstem gibi adını bu Dünya'da destan etmeyen [kişi/kişiler] bu Zâl'in dünyasından murat alamaz, der.

Hâsılı bu (Zâl)-ı dünyâdan murâd alamaz bugün

Nâmını **Rüstem** gibi 'âlemde destân itmeyen

(G338/3)

(K5/9, G177/4, G407/2)

Sâm

Şehnâme'de adı geçen bu kahraman, Feridun zamanında yaşamıştır. Nerimân'ın oğlu olup çok kuvvetli imiş. (Pala, 2016: 390) Klasik Türk şiirinde, gücü ile anılır. Şair: Sâm'ı gör, ölüm cellâdının eline nasıl girdi? Behrâm'ı gör, ecel avcısının eteğine düştü, der. *Cem, Sührâb* kimlikleri ile anılır.

Niçe girdi destine cellâd-ı mevtün **Sâm**ı gör

Dâmına düşdi ecel sayyâdınun (Behrâmı) gör

(G136/1)

(K10/20)

3.12. Sikender (Bk İskender)

Sührâb

Rüstem'in bilmeden kendi eliyle öldürdüğü yiğit fakat talihsiz oğlu. (Tökel, 2016: 207) *Şehnâme* kahramanıdır. Ziyâî: Şüphesiz bu mülk Cem, Cemşîd, Sâm ve Sührâb'a nasip olmadı, der.

Lâ-cerem olmadı bu mülk nasîb

(Cem) ü (Cemşîd) ü (Sâm) u **Sührâb**a

(K10/20)

Zâl

Şehnâme'de adı geçen tarihî-efsânevî Fars kahramanlarından. Rüstem'in babası. Sâm'ın oğlu ve Nerimân'ın torunudur. Anadan doğma kirpiği, kaşı ve saçı beyaz olduğu için babası korkuya kapılır ve Elbürz Dağı'na bırakır. Çocuğun ağlama sesini duyan Sîmurg, onu alır ve besler. Zâl büyüyüp ünlü bir yiğit olur. (Zavotçu, 2018: 753-754) Ziyâî: Vefâda Rüstem iken Zâl'in dünyasını kış bastı. Kuzey rüzgarı, harâmi gibi söğüt yaprağını soyar, der. Bu sözlerle Zâl'in, babası tarafından dağda tek başına bırakılması vurgulanır. Dârâ ile de anılır.

Vefâda (Rüstem) iken **Zâl**-i dehri kış basdı

Harâmi gibi soyar berg-i bîdi bâd-ı şimâl

(K5/9)

(G9/2, G177/4, G338/3, G407/2)

MUTASAVVIF KİŞİLER

Şairin *Dîvânı*'nda 5 aslî 1 tâlî mutasavvıf kimlik (Attâr, Câmî, Hâce Attâr, Kâsım, Mansûr, Şeyh-i San'ân) görülür. Bunlar, dinî konularda topluma yol gösterip lider kabul edilmesi ile bilinir.

Attâr (Hâce Attâr)

Asıl adı Muhammed bin İbrâhim olan Attâr, Selçuklu sultanı Melikşah'ın oğlu Sancar zamanında M. 1120 yılında Nişâbûr'da doğdu. (Zavotçu, 2018: 227) Ferîdüddin Attâr adıyla bilinen İranlı şair, *Mantıku't-Tayr* isimli mesnevinin yazarıdır. Klasik Türk şiirinde mutasavvıf kimliği ile bilinir. Şair: Attâr, bir/sadece yüz/surat ile sevgilinin ruhunu övermiş. Onu/ [bu durumu], bugün bülbülden işittim. Güle yazdım [az kalsın gülecektim], der.

Bir vech ile **'Attâr** ruh-ı yâr-ı ögermiş

Bülbülden işitdüm bugün anı güleyazdum

(G302/2)

(G43/5)

Câmî

Abdurrahman Câmî hicrî 817 yılında Horasan'da Câm kasabasında doğmuştur. (Onay, 2014: 295) Molla Câmî adı ile bilinir. Mutasavvıf bir kişidir. Şair: Câmî, eğer bu nükteli/güzel şiiri görse Allah için der ki Ziyâ'î belagat meclisinin sâkîsidir. Bu sözlerle şair, kendi şiirini över.

Bu şi'r-i âb-dârun görse ger **Câmî** sekâhu'llâh

Diyeydi kim Ziyâ'î sâkî-i bezm-i belâgatdur

(G64/5)

Hâce Attât (Bk Attâr)

Kâsım

İranlı mutasavvıf, şair. Bu kimlik hakkında, kaynaklarda detaylı bilgi bulunamamıştır. Şairin kullandığı bağlamdan hareketle bir tekke şeyhi olma ihtimali vardır. Mostarlı: Ey zâhid! Eğer ah edip ağlarsam beni kınama. Benim o *rızık dağıtıcısı*nın eşiğinde/kapısında muradım var, der. Bu ifade ile Kâsım'ı tevriyeli biçimde kullanır ve ona rızık dağıtıcısı sıfatını verir.

Bana ta'n itme ey zâhid eger âh idüp aglarsam

Benüm ol **Kâsım**ü'l-erzâk işiginde murâdum var

(G86/3)

Mansûr

Mansûr (857-922) edebiyatımızda çokça anılan bir sûfîdir. (Pala, 2016: 185) Hallâc-ı Mansûr adıyla bilinir. Klasik Türk şiirinde, "Ene'l-Hakk" (Ben Hakk'ım) söylemi sebebiyle idam edilmesi yönüyle ele alınır. Dar ağacı ve asılmak kavramları ile bir arada yer alır. Ziyâî: Sevgili, gönlümü saçına asar. [Gönlümün] günahını sormaz. Gerçi biliriz Mansûr'u sebepsiz asmadılar, der. Bu sözlerle asılma nedenini hatırlatır.

Zülfine gönlüm asar yâr günâhın sormaz

Gerçi **Mansûr**ı sebebsiz bilirüz asmadılar

(G93/4)

(G122/3, G200/2, G363/4, G367/4, Msd/4)

Şeyh-İ San'ân

Yemenli ve adının Abdürrezzak olduğu rivâyet edilen bu şahıs hakkında kesin bir bilgi yoktur. Kaynaklarda onunla ilgili olarak birbirini tutmayan rivâyetlere rastlanmaktadır. Feridü'ddin Attâr **Mantıku't-Tayr**'ında Şeyh-i San'ân'ın hikayesini en geniş şekliyle anlatır. (Tökek, 2016: 323) Şair: Ey Ziyâî! Dünya sarayını baştan başa gezen [kişi], [benim] gördüğüm zorlukları görmedi. Şeyh-i San'ân'ı alçak hâine çoban eden [kişi], şimdi beni birkaç beyinsiz ve bilisize [kişiye] imam etti, der.

Ey Ziyâ'î görmedi ben gördügüm mihnetleri

Ser-be-ser dünyâ serâyın geşt ü seyrân eyleyen

Birkaç ahmak câhile şimdi imâm itdi beni

Seyh-i San'ânı ezel hınzıra çûbân eyleyen

(Kt/38)

PEYGAMBER KİŞİLER

Ziyâî *Dîvânı*'nda 11 aslî, 6 tâlî peygamber kimlik (Âdem, Ahmed, Halîl, İbrâhim, İdris, Îsâ, Kelîm, Mahmud, Mesih, Muhammed, Mûsâ, Nûh, Pîr-i ken'ânî, Süleymân, Yahyâ, Ya'kûb, Yûsûf Hz.) görülür. Bunlar, adları kutsal kitaplarda geçen semâvî dinlerin liderleridir. Her biri kendilerine tebliğ edilen dinleri, döneminin insanlarına bildirmek ve bu hususta rehber olmakla Allah tarafından görevlendirilir.

Âdem Hz.

İlk insan ve ilk peygamberdir. İnsanlığın babasıdır. (Zavotçu, 2018: 41) (Hz. Havva) ile beraber yasak yiyeceği yiyerek cennetten kovulması, buğday kavramı, oğlu Kâbil'in kardeşi Hâbil'i öldürmesi ile anılır. Şair: Benin danesini/tanesini kendim görürsem, cenneti terk edeyim. Bu cennet kızı, Hz. Âdem zamanından gelmemiştir, der. Ziyâî, dâne kelimesini hem vücutta bulunan benek hem de yasak yiyeceği ifade edecek biçimde kullanır. Bu tevriyeli söylem ile söz konusu peygamberi benzer şekilde anar.

Behişti terk idem kendüm görürsem dâne-i hâlin

Bu hûrî gelmemişdür Hazret-i **Âdem** zamânından

(G310/4)

(K11/6)

5.2. Ahmed (Bk Muhammed Hz.)

5.3. Halîl (Bk İbrâhim Hz.)

İbrâhim Hz. (Halîl)

M.Ö. 12. Asırda yaşamıştır. Babası mesabesinde olan Âzer, put yapıp satmakla geçinen kişiymiş. (Pala, 2016: 224) Putları yıkması, (Nemrut) tarafından ateşe atılması, ateşin gül bahçesine dönüşmesi, halîlullâh/Allah'ın dostu lakabı ile anılır. Ziyâî: Dostum İbrâhim! Âşıkların eziyetine [Kâbe'de olduğu gibi] ateş kıl. Allah'ın ışığı Yüce İbrâhim'im! Ayrılığın ateşi, Nemrud'un ateşidir, der.

Ka'be hakkı cefâ-yı 'uşşâka

Âzer eyle Halîlüm **İbrâhim**

Nâr-ı (Nemrûddur) firâkun odı

Hây nûr-ı Cellîlüm **İbrâhim**

(Kt/35)

İdris Hz.

Kur'ân-ı Kerim'de adı anılan büyük peygamberlerden olan Hz. İdris, Mısır'ın Menfi kentinde dünyaya geldi. Elbise dikmeyi ilk kez onun icat ettiği, ilk kez kalem kullanıp yazı yazdığı ve hesap ilmi üzerine çalıştığı için terzilerin ve katiplerin piri sayılır. (Zavotçu, 2018: 352) Şair: Hızır ve İdris kavuşmak isterken biri yerde [keşif yapmakta] biri gökte [cennette], der. Bu sözler ile İdris peygamberin göğe çıkmasını hatırlatır.

(Hızr) u **İdrîs** vaslun ister iken

Biri yelmekde biri uçmakda

(G462/2)

Îsâ Hz. (Mesih)

Dört büyük kitaptan İncil nâzil olan peygamberdir. Anası Hz. Meryem, Cebrâil'in bir üflemesiyle gebe kaldığı için babasız dünyaya gelmiştir. Îsâ, ölüleri nefesiyle diriltir. Körlerin gözlerinin açar. (Onay, 2014: 225) Ziyâî'de de benzer özellikleri ile anılır. Şair: Ey Ziyâ'î! Hele ben kederden öldüm gittim. O Îsâ'nın dudağı niçin beni canlandırmaz? Sorusunu sorar.

Ey Ziyâ'î hele ben gussadan öldüm gitdüm

Ki niçün ol leb-i **Îsâ** beni itmez ihyâ

(G2/5)

(G6/4, G13/6, G47/3, G75/3, G107/1, G223/2, G313/5, G316/2, G321/1, G332/1-3, G357/5, G361/4, G452/1)

Kelîm (Bk Mûsâ Hz.)

5.8. Mahmud (Bk Muhammed Hz.)

5.9. Mesih (Bk Îsâ Hz.)

Muhammed Hz. (Ahmed-Mahmud)

İslâm peygamberi, milâdî 571 senesinde Nisan ayı içerisinde doğdu. (Pala, 2016: 330) Son peygamber olması, miraç hadisesi, ayı parmağı ile ikiye bölmesi gibi birçok mucizesi ile bilinir. Şair: Beni vuslatın kurbanında kurban etse. Ziyâî Muhammed'in ihmali olmasa ne olur? Sorusu ile Hz. Muhammed tarafından kurban edilmek istediğini ifade eder.

Kurbân-ı visâlinde beni eylese kurbân

Olmasa Ziyâ'î ne var ihmâl-i **Muhammed**

(G50/5)

(K3/17, G50/1-5, Kt/20)

Mûsâ Hz. (Kelîm)

Süryânî dilinde tabut yahut sanduka demekmiş. Firavun'un doğacak çocukları öldürme emri üzerine annesi Mûsâ'yı bir sandığa koyup Nil Nehri'ne atmış. Firavun'un karısı Asiye sandığı nehirden alıp çocuğu içinden çıkartarak saraya almış. (Onay, 2014: 301) (Firavun)'a karşı mücadelesi, Tûr Dağı'nda Allah ile konuşması, kelîmullâh lakabı, elinden ışık saçması ile anılır. Ziyâî: Sevgilim bana el salınca/uzatınca bana şöyle istek erişti; Mûsâ'[nın] beyaz eli [ni] belli etti [ğini] sandım, der. Elinden ışık saçtığını hatırlatır. *Meryem, Îsâ* kimlikleriyle beraber kullanılır.

Şöyle şevk irdi bana el salıcak cânânum

Yed-i beyzâyı 'ıyân itdi sanurdum **Mûsâ**

(G16/2)

(K6/3, G74/4, G452/1, Kt/8,51)

Nûh Hz.

Hz. Nûh, Hz. İdris göğe çekildikten sonra insanların doğru yoldan ayrılıp putlara tapmaya başlaması üzerine Allah tarafından Hak yolu göstermek için gönderildi. (Zavotçu, 2018: 530) Gemisi ve tufanı ile anılır. Şair: Nûh, [batması imkânsız olan] gemisini gözümün yaşına [salsaydı/bıraksaydı] batardı, der. Mübalağalı bir ifade ile gözünden çıkan yaşın Nûh peygamberin gemisini batırabilecek kadar çok olduğunu ifade eder. *Bâkî, İbn-i Unuk*, kimlikleri ile anılır.

Lâ-cerem gark ideydi zevrakını

Salsa eşk-i çeşmüme **Nûh**

(G47/2)

(K1/40, K11/15, G47/2, G81/2)

5.13. Pîr-İ Ken'ânî (Bk Ya'kûb Hz.)

Süleymân Hz.

İsrailoğulları peygamberlerinden Davut peygamberin oğlu. Olağanüstü bir güce ve saltanata erişmiş bir hükümdardır. Hayvanların dilini bilme, rüzgarın gücünden yararlanarak çok uzun mesafeleri az bir zamanda alma gibi mucizeleriyle kendine has özellikleri olan bir peygamberdir. Klasik Türk şiirinde başta karınca olmak üzere hayvanlarla olan hoş iletişimi ile anılır. (Tökel, 2016: 231) Ziyâî: Ey şah! Bana aşağılayıcı/küçümseyici bakma ki Süyelmân'ın dostu karınca olur, der. Karıncalarla olan dostluğunu hatırlatır. *Âsaf, Yûsûf*, kimlikleri ile beraber kullanılır.

Bana zilletde bakma kim ey şâh

Mûr olur hem-demi **Süleymân**un

(G246/6)

(G89/4, G221/2, G245/1, G322/6, G341/2)

Yahyâ Hz.

Zekeriyâ peygamberin oğludur. Çok genç yaşta kendisine peygamberlik veridi. 30 yaşında boynu vurularak şehid edilmiştir (Pala, 2016: 477) Klasik Türk şiirinde, erken yaşta peygamber olması ve şehid olması ile anılır. Şair: Eğer beni koç gibi kurban etse can verirdim. [O, bunu yaymaz. Yahyâ'nın şehid edilmesi gibi] zulüm ile öldürmeyi ister, der. Bu ifadeyle Yahyâ peygamberin başının kesilmesini hatırlatır.

Cân virürdüm ger beni koç gibi kurbân eylese

Eylemez zulm ile katl itmek diler **Yahyâ** hakı

(G452/4)

Ya'kûb Hz. (Pîr-İ Ken'ânî)

İbrâhim peygamberin torunu ve İshak peygamberin oğludur. (Pala, 2016: 478) Oğlu (Yûsûf)'un kuyuya atılması, oğlu için çok fazla ağlamasından dolayı gözlerinin kör olması, Yûsûf'un gömleğini gözlerine sürmesi sonucu tekrar görür hâle gelmesi ile bilinir. Şair: Ziyâ'î! Gözün ağlamada/ağlamaktan Ya'kûb'un gözünün aynı/aynısı oldu. Yûsûf'un değerli canını isyan kuyusuna düşürdün, der.

Ziyâ'î 'ayn-ı **Ya'kûb** oldı giryân olmada çeşmün

Düşürdün (Yûsûf)-ı cân-ı 'azîzi çâh-ı 'isyâna

(G411/6)

(G195/2, G402/3)

Yûsûf Hz.

Ya'kûb peygamberin 12 oğlundan biridir. (Tökel, 2016: 241) Güzelliği, kardeşleri tarafından kuyuya atılması, zindana düşmesi, Mısır'a sultan olması ile anılır. Ziyâî: Dünya'nın Mısır'ı yücelik ile Güneş sultanı oldu. Güneş, güzel/güzellik ile sanki ikinci Yûsûf oldu, der. Ya'kûb ile anılır.

Mısr-ı çerhün 'izzet ile oldı sultânı güneş

Hüsn ile güyâ ki oldı **Yûsûf**-ı sânî güneş

(K4/1)

(K4/2,5, G115/4, G144/3, G165/1, G195/2)

SANATÇI-ŞAİR KİŞİLER

Şairin *Dîvânı*'nda 5 aslî ve 1 tâlî sanatçı-şair kimlik (Bâkî, Firdevsî, Hassân, Mânî, Memî, Selmân) yer alır. Bunlar, söz söyleme hususundaki meziyetleri ile bilinir.

Bâkî

(1526-1600) Asıl adı Mahmud Abdülbâkî'dir. İstanbul'da doğdu. Yoksul bir ailenin çocuğu olması nedeni ile küçük yaşta saraç çıraklığına verildi. Karamanî Mehmed Efendi'nin yardımıyla medreseye girdi. Medresede şair Nev'î, Üsküplü Vâlihî ve Hoca Sa'deddîn Efendi gibi ünlü şair, yazar ve bilim adamlarıyla bir arada okuyan Bâkî, bu sanatkâr çevresinde çabuk gelişerek sivrildi. (Zavotçu, 2018: 95) Zâtî'nin remil dükkânında yetişen şairlerdendir. Klasik Türk şiirinde güçlü şairliği ile bilinir. Şair: Bâkî, dilerim Dünya'yı baştan başa tutan/kuşatan tûfan/ deryâ nedeni ile Nûh ömrünü sana versin, der.

(Nûh) ömrin dilerin vire sana ol **Bâkî**

Tuta mâdâm ki dünyâyı ser-â-ser deryâ

(K1/40)

Firdevsî

Tûs şehrinde doğduğu için Firdevsî-i Tûsî namıyla da anılır. Firdevsî'nin adı, Hasan bin İshak bin Şerefşâh'tır. Bazı şiirlerinde İbn-i Şerefşâh mahlasını kullandı. (Zavotçu, 2018: 233) *Şehnâme* adlı eseri ile ünlenmiştir. Dîvân şiirinde, şairliği ile bilinir. Ziyâî, halk tarafından kendisinin Firdevsî'ye benzetildiğini aşağıda yer alan mısralarında dile getirir.

Ne lâyık halk-ı 'âlem benzede devletlü sultânum

Beni **Firdevsî**ye sultânumu (Sultân Mahmûda)

(Kt47/3)

Hassân

Peygamberimiz zamanında yaşamış bir şairdir. Peygamberimiz, onun için mescide bir minber yaptırmıştı. Hassân, oraya çıkar müşrikleri yerip peygamberimizi överdi. (Pala, 2016: 195) Şair olması yönüyle öne çıkmıştır. Şair: Hassân ile Selmân Ziyâî şiirini görse/görseler güzel yaptın deyip tebrik ederlerdi, der.

Görse **Hassân** ile (Selmân) Ziyâ'î şi'rün

Biri ahsente diyeydi birisi sellemnâ

(G27/5)

(K7/24)

Mânî

Meşhur Çinli bir nakkaş ve ressamın adıdır. (Pala, 2016: 297) Maniheizm'in kurucusudur. Klasik Türk şiirinde ressam olması ile öne çıkar. Şair: Dünya'nın kubbesi/çatısı üstüne altın [gibi] bir güneş çizer. Sanki Nigâr-istân Dünya, Mânî Güneş gibi oldu, der. Mânî'yi, eseri *Nigâr-istân* ile beraber anar ve sanatını vurgular.

Künbet-i çerh üstine bir şems-i zerrin yazar

Oldı gûyâ kim Nigâr-istân felek **Mânî** güneş

(K4/17)

[Taşlıcalı Yahyâ] Memî

Ünlü Osmanlı şairi *Taşlıcalı Yahyâ*, şairin *Dîvânı*'nda tâlî adı olan Memî biçiminde görülür. Klasik Türk şiirinde asker şair olması ve *Şehzâde Mustafa* isimli mersiyesi ile bilinir. Şehzâde Mustafa'nın lalalığını üstlenmiştir. Ziyâî'de, bu kimlik bir bilmecenin başlığında yer alır.

Be-nâm-ı **Memî**

(Mm1/B)

Selmân

İranlı şair. Dîvân şiirinde, şairliği ile anılır. Şair: Hassân ile Selmân Ziyâ'î şiirini görse/görseler güzel yaptın deyip tebrik ederlerdi, der.

Görse (Hassân) ile **Selmân** Ziyâ'î şi'rün

Biri ahsente diyeydi birisi sellemnâ

(G27/5)

TARİHÎ KİŞİLER

Şairin *Dîvânı*'nda 14 aslî ve 1 tâlî tarihî kimlik (Ashâb-ı Kehf, Battâl, Ebû Derdâ, Hâmân, Hüsâm, İzârî, Kârûn, Nemrûd, Resm, Seyyîd, Şânî, Şeddâd, Şems, Şeylî, Yezîd) bulunur. Bunlar, bazı özellikleri ile ünlenerek günümüze kadar gelmiştir.

Ashâb-I Kehf

Mağara arkadaşları manasına gelmektedir. Kur'an'da Kehf suresinde bu kişilerin hikâyesi özet bir şekilde anlatılmıştır. Geleneksel çalışmalarda grup olarak değerlendirilen ashâb-ı kehf; çalışmanın tek grup kişisi olması sebebi ile bu kümeye eklenmiştir. Kendilerini puta tapmaya zorlayan zalim bir kraldan kaçarak sığındıkları mağarada 309 yıl uyurlar. Çok fazla uyuduklarını yanlarındaki paranın geçersiz olduğunu öğrenince anlarlar. Kendisine haber giden vali, içlerinden biriyle mağaraya doğru ilerler, genç içeri girer ve mağara kapanır. Bunun üzerine onların bulunduğu bölge ziyaret yerine dönüşür. (Tökel, 2016: 261) Klasik Türk şiirinde, yedi uyurlar olarak bilinir. Şair: Tarih ehlinin ashâb-ı kehf [olarak bildiği] acaba çenende rahat uykuya erişen gönüller mi? Sorusu ile uzun yıllar uyuduklarını hatırlatır.

'Aceb **Ashâb-ı Kehf** andukları ehl-i tevârîhün

Zenehdânunda hâb-ı râhata varan gönüller mi

(G473/3)

(G91/4)

Battâl (Seyyîd)

Emeviler devrinde Anadolu'da Bizans'a karşı yapılan savaşlarda ün kazanmış Müslüman emîr. Klasik Türk şiirinde, kahramanlığı ile bilinir. Ziyâî: [Yaptığım işleri] yabancıya bir bir anlatırdım. Battâl kıssası gibi [boşuna uzayıp gitmesinden] korkarım, der.

Bir bir eylerdüm beyân agyâra işler kıldıgum

Korkarın kim kıssa-i Seyyîd gibi **Battâl** olur

(G71/4)

Ebû Derdâ

Ebû Derdâ lakabıyla bilinir. Sahabeden ve ensardandır. İslâmiyeti geç kabul ettiği için Bedir Gazâsı'nda bulunamamış ama Hz. Muhammed'in bütün savaşlarına katılmıştır. (Zavotçu, 2018: 195) Şairliği ile öne çıkmıştır. Şair: Her derdin dermanı, güzellerin derdini çekmektir. Bu sırrı bana Ebû Derdâ fark ettirdi, der. Bu ifadelerle kimliğin tarihi etkisinden ziyade, adının anlamı üzerinden bir ilgi kurar. *Âdem, Kayser* kimlikleri ile anılır.

Güzeller derdini çekmekdedür dermânı her derdün

Bana keşf eyledi seyrümde bu sırrı **Ebû Derdâ**

(G1/4)

(K11/6, G28/5)

Hâmân

Mûsâ peygamber zamanında Firavun'un veziri olan şahsın adıdır. (Tökel, 2016: 277) (Mûsâ peygamber) ve (Firavun) ile anılır. Kötülüğü ile bilinir. Ziyâî: Ey Dünya ehli! Meğer bu gurur ve bu bencillik size Hâmân ile (Kârûn)'dan miras kalmış, der.

Meger ey ehl-i dünyâ bu gurûr u bu enâniyyet

Size kalmış hemân **Hâmân** ile (Kârûndan) mîrâs

(G42/4)

Hüsâm

Kaynaklarda hakkında bilgi bulunamayan bu kimliğin, şairin döneminde yaşamış bir kişi olduğu tahmin edilir. Şair, bir bilmecede adına yer verir.

Be- nâm-ı **Hüsâm**

(Mm8/B)

İzârî

Kaynaklarda hakkında bilgi bulunamayan bu kimliğin, şairin döneminde yaşamış bir şahıs olduğu tahmin edilir. Şair, bir bilmecede kendisinden söz eder.

Be-nâm-ı **İzârî**

(Mm5/B)

Kârûn

Kur'an'da Firavun ve Hâmân'la birlikte anılan Mûsâ peygamber zamanında yaşamış, zenginliği ve cimriliği ile meşhur olmuştur. Malı ve mülküyle yere geçmiş. (Tökel, 2016: 300) Yer yarılıp içine girme ve Kârûn gibi zengin olma deyimlerine yansımıştır. Dîvân şiirinde, zengin ve cimri olmasıyla ele alınır. Ziyâî: Tutalım/Varsayalım, bir kişi Kârûn'un hazinesinin sahibi oldu. Gözyaşımın gümüşü gibi sonunda yere girer, der. Göz yaşının yere dökülmesi ile Kârûn'un yere girmesi arasında anlam ilişkisi kurar. Göz yaşının her bir tanesi, hazine ile eş tutulur. *Hâmân* ile anılır.

Sîm-i eşküm gibi âhir yire girer tutalum

Bir kişi mâlik-i gencîne-i **Kârûn** oldı

(G474/6)

(G17/4, G42/4, G474/6)

Nemrûd

İbrâhim peygamber döneminin tanrılık iddia eden Bâbil kralı. İbrâhim'i ateşe atması, tanrıyı görmek amacıyla göklere çıkmak için bir kale yaptırması, aciz ve topal bir sivrisinek tarafından beyni kemirilerek öldürülmesiyle meşhurdur. (Tökel, 2016: 305) Dîvân şiirinde, İbrâhim peygamberi ateşe attırması ve zalimliği ile anılır. Şair: Dertten içimin yangını/ateşi, Nemrûd'un ateşidir. Gözümün yaşı, kederden (Halîl)'in gözünün aynısıdır, der.

Derdden sûz-ı derûnum âteş-i **Nemrûd**dur

Eşk-i çeşmün gussadan 'ayn-ı (Halîlün) 'aynıdur

(G82/2)

(Kt/35)

Resm

Kaynaklarda hakkında bilgi bulunamayan bu kimliğin, şairin döneminde yaşamış bir şahıs olduğu tahmin edilir. Ziyâî, bir bilmecede kendisini dile getirir.

Be- nâm-ı **Resm**

(Mm7/B)

7.10. Seyyîd (Bk Battâl)

Şânî

Kaynaklarda hakkında bilgi bulunamayan bu kimliğin, şairin döneminde yaşamış bir kişi olduğu tahmin edilir. Şair, bir bilmecede kendisine yer verir.

Be-nâm-ı **Şânî**

(Mm3/B)

Şeddâd

Yemen'deki Âd kavmi hükümdarıdır. Birçok binalar, su bendleri, İrem adlı bahçe ile köşkü yaptırmıştır. (Onay, 2014: 389) Cennetten daha güzel olacağı düşüncesiyle yaptırdığı İrem Bağı, yok olmuştur. Şair: Ey servi boy/boylu! Eğer ölürsen seni Şeddâd'ın İrem Bağı'na koymayım. Yöreni unutmayım, der.

Ölince komayam seni kûyun unutmayam

Şeddâd bâgına irem ey serv-kadd eger

(G148/4)

Şems

Klasik Türk şiirinde aynı adla bilinen Şems-i Tebrizî ve Osman Şems olmadığı anlaşılır. Şairin bu kimlikle kimi ifade ettiği net olarak anlaşılamamıştır. Kendi döneminde yaşamış bir şahıs olduğu tahmin edilir. Kimliğin adına bir bilmecede yer verir.

Be-nâm-ı **Şems**

(Mm11/B)

Şeylî

Kaynaklarda hakkında bilgi bulunamayan bu kimliğin, şairin döneminde yaşamış bir kişi olduğu tahmin edilir. Şair, kendisinden bir bilmecede söz eder.

Be- nâm- **Şeylî**

(Mm4/B)

Yezîd

Muaviye'nin oğlu ve Emevî devletinin ikinci halifesi. Kerbela vakası onun zamanında olduğu için özellikle Maktel-i Hüseyn'lerde adı çok anılır. Bektaşî tarikatine mensup olanlar, onun düşmanı olup Yezîd kelimesini bir küfür sözü olarak kullanırlar. (Pala, 2016: 482) Dîvân şiirinde, kötülüğü ile anılır. Şair: Vefâ sende, mürüvvet sende, ihsan ve cömertlik sende. Ali balum, seni her kim sevmezse Yezîd olsun! der.

Vefâ sende mürüvvet sende ihsân u sahâ sende

('Ali) bâlum seni her kim sevmezse **Yezîd** olsun

(G319/4)

YÖNETİCİ KİŞİLER

Şairin *Dîvânı*'nda 16 aslî ve 1 tâlî yönetici kimlik (Behlûl Beg, Emrî Çelebi, Hasan Beg, Hasan Paşa, Kaydefâ, Kayser, Keyvan Beg, Kisrâ, Mehmed Beg, Mustafa Beg, Osman Beg, Selîm, Sinân Beg, Sultan Mahmûd, Sultan Murâd, Sultan Selîm, Şemsi Paşa) bulunur. Bunların bazıları şairin döneminde yaşamış olan Osmanlı padişahları bazıları ise yöre beylerdir.

Behlûl Beg

Kaynaklarda hakkında bilgi bulunamayan bu kimliğin, şairin döneminde yaşamış bir devlet adamı olduğu tahmin edilir.[6] Ziyâî: Behlûl Beg, yine cennet bahçesine gitti. Özetle bu devletten/mal-mülkten nefret etti. Bir deli, onun tarihine akılâne dedi. Ey gönlü deli! Behlûl'den ibret al, der.

Ravza-i firdevse 'azm itdi yine **Behlûl Beg**

Nefret itdi hâsılı bu mülk ü mahûlden

'Âkılâne didi bir mecnûn anun târîhini

Ey dil-i dîvâne gâhî 'ibret al **Behlûl**den

(Trh/10)

Emrî Çelebi

Ziyâî, kimliğin ölüm tarihinden söz eder.

[6] Behlûl Beg, Emrî Çelebi, Hasan Beg, Hasan Paşa, Keyvan Beg, Mehmed Beg, Mustafa Beg, Osman Beg, Sinân Beg, Şemsi Paşa isimli kimlikler hakkında kaynaklarda bilgi bulunamamıştır.

Târîh-i Vefât-ı **Emrî Çelebi**

(Trh 6-7/B)

Hasan Beg

Kimlik; şairin kasîdesinde yer alır. Kendisine övgüler sunduğu bu kişinin, bir devlet yöneticisi olduğu tahmin edilir. Ziyâî: Hasan Beg! O iffet [sahibi] ve bağış [yapan] sensin. lütfunu/nezâketini (Hassân) görse seni tebrik eder, der. Bu sözlerle bir şair kadar latif olduğunu dile getirir.

Sensin ol muhsin-i ihsân **Hasan Beg** ki sensün

Görse eltâfunı ahsente diyeydi (Hassân)

(K7/24)

(K2/20, K10/18)

Hasan Paşa

Kimliğin adı, kasidenin başlığında yer alır. Metnin içerisinde geçmez.

Kasîde-i Deryâ Der Medh-i **Hasan Paşa** Yessera'llâhu mâyeşâ'

(K1/B)

Kaydefâ

İskender'le yaptığı savaş sonucu mağlup olarak ölen ünlü kadın hükümdar. (Tökel, 2016: 359) Klasik Türk şiirinde, yöneticiliği ile anılır. Şair, Hasan Paşa için yazdığı kasîdede, bu şahsa yer veriri ve şöyle der: Allah, Kaydefâ gibi düşmanını boğsun/öldürsün. Ömrün oldukça/ ölene kadar deryâ, sana kale/sur olsun [seni korusun], der. *İskender* ile anılır.

Kaydefâ gibi Hudâ düşmenün gark itsün

'Ömrün oldukça ola sana musahhar deryâ

(K1/39)

(G24/4, G72/4, G379/3)

Kayser

Eskiden yaşamış olan bir hükümdar ve Bizans imparatorlarına verilen ünvandır. (Zavotçu, 2018: 391) Divân şiirinde, yöneticiliği ile bilinir. Şair, kendi evi için yazdığı kasîdede şöyle söyler: Ona nispet/bakarak (Edû Derdâ) evi, Kayser'in evidir. Âdem devrinden beri böyle ev yapılmamıştır, der. Bu ifadelerle şair, kendi evinin fakir evinden bile viran durumda olduğunu dile getirir.

Kasr-ı **Kayser**dür ana nisbet (Ebû Derdâ) evi

Böyle ev yapılmamışdur devr-i Âdemden beri

(K11/6)

Keyvan Beg

Ziyâî; ölümünden söz ettiği bu kişinin ölüm zamanına tarih düşer.

Emîn-i memleket merhum **Keyvân**

Cinân içinde gitdi tutmaga cây

Didi çün gördi 'ömri âhir olmış

Dürüldi defter-i 'ömrüm meded hây

Didi hâtif anun mevtine târîh

Ecel çaldı elinden defterin vây

(Trh/2)

Kisrâ

İran hükümdarlarına verilen lakap, ilk defa Nûşirevan için kullanılmıştır. Onun adalet çanını ifade etmek için kullanılır. (Pala, 2016:277) Klasik Türk şiirinde, adaleti ile bilinir. Şair, Mustafa Bey için yazdığı kasîdede adına yer verir ve şöyle der: Kisrâ adalet ile denk değil ona. Peygamberden sonra adalet ile bir bu bir (Ömer) [bilinir], der.

Kisrâ ‘adâlet ile mu’âdil degül ana

Ba’de’n-nebî ‘adâlet ile bir bu bir (‘Ömer)

(K3/19)

Mehemed Beg

Ziyâî; Mehmet Beg’in ne zaman defterdâr olduğuna ilişkin tarih düşer ve kendisine iyi dileklerde bulunur.

Çün **Mehmed Beg** oldı defter-dâr

Güni ‘îd u gamı bâ’îd olsun

Didi dâ’î Ziyâ’î târîhin

Ömri vü devleti mezîd olsun

(Trh/13)

(K5/21)

Mustafa Beg

Ziyâî: Allah, Mustafa Beg’in ömrünü uzun etsin. Muhammed ümmetine güneş adı gibi oldu. [Yardımıyla güneş gibi ışık saçtı], der.

Hakk ‘ömrin ziyâde ide **Mustafa Beg**ün

Oldı (Muhammed) Ümmetine mihr-i nâm-ver

(K3/17)

(Trh/9)

Osman Beg

Şair; Osman’ın güneşi her zaman emîrinin huzurunu öpse, göğün üstünde [bulunan] ayın en küçük parçasını terkiye asmaz, der.

Terkiye asmaz sipihr üzere hilâli zerrece

Her Kaçan öpse rikâb-ı mîr-i **‘Osmân**î güneş

(K4/27)

Selîm (Bk [Yavuz] Sultan Selîm)

Sinân Beg

Şair: Şefkat sahibi ve cömertlik ehli Sinan Beg [dir]. Onun ilâhi dergâhı, kuvvetli ve sağlam ordu kaynağıdır, der.

Müşfik ü ehl-i sahâ ya’ni **Sinân Beg** kim anun

Menba’-ı ceyş-i ilâh dergehidür hısn-ı hasîn

(K8/22)

(Trh/12)

Sultan Mahmûd [Gazneli]

Ziyâî'nin kullandığı bağlamdan hareketle bu kimliğin, (Firdevsî) dönemi sultanlarından Gazneli Mahmûd olduğu anlaşılır. Şair döneminde yaşamış sultanlardan birinden söz ederek halkın, söz konusu sultanı Sultan Mahmûd'da benzettiğini ifade eder.

Ne lâyık halk-ı 'âlem benzede devletlü sultânum

Beni (Firdevsîye) sultânumı **Sultân Mahmûd**a

(Kt47/3)

Sultan Murâd

Osmanlı hükümdarlarındandır. Şair: Ziyâî Murâd'da [Murâd'ın zamanında olsa] murâdsız kalmaz [buna şaşırmamak gerekir]. Çünkü Sultân Murâd'ın devletinin zamanı [bütünüyle murâd zamanı] oldu, der. Bu ifadelerle söz konusu padişahın döneminde yaşayanların, refah içinde olduklarını ifade eder.

Ber-murâd olsa Ziyâ'î nâ-murâd olmaz'aceb

Çün zaman oldı zamân-ı devlet-i **Sultân Murâd**

(G53/5)

Sultan Selîm [Yavuz]

Osmanlı padişahlarındandır. Şairin kullandığı bağlamdan hareketle Yavuz Sultan Selim olduğu tahmin edilir. Ziyâî: Âşıkların askeri her nerede yanında çabalarsa şâhım bu istek ile Sultân Selîm'e benzer, der.

Her kanda 'azm iderse yanınca cünd-i 'uşşâk

Şâhım bu şevket ile **Sultân Selîm**e benzer

(G142/3)

Şemsi Paşa

Şair: Şemsi Paşa, Dünya'nın hâlini hissetti, duyma ve görme zevkinden vazgeçti. Şemsi'nin ömrü sona erdi, o an Ziyâî; Dünya'nın Güneş'i gitti diye tarih düştü, der. Bu sözlerle şems sözcüğünü tevriyeli biçimde kullanır.

Felegün hâlini hiss eyledi **Şemsi Paşa**

Kodı zevk ü basar u sem'î ü şemm ü lemsi

Şems-i 'ömrine zevâl irdi Ziyâ'î ol ân

Didi târîh yine gitdi cihânun şemsi

(Trh/11)

SONUÇ

Mostarlı Hasan Ziyâî Dîvânı'nda 85 kimlik adlandırması tespit edilmiştir. Bunlardan 72'si aslî, 13'ü tâlî kimliktir.

Şairin Balkan Türk'ü olması sebebiyle *Dîvân*'da, İbn-i Unuk, Müftü Hâce Çelebi ve bazı yerel yönetici kimliklere rastlanır. Yerel kişilerin fazla bilinmiyor oluşu, bilimsel açıdan sorun oluşturur.

Yerel özellik gösteren *İbn-i Unuk*; bu zamana kadar yapılan çalışmalarda adında rastlanmamış olan bir kimliktir. Bu durum, dikkat çekicidir. İbn-i Unuk'un da takip edilerek bundan sonraki çalışmalarda yer alması beklenir.

Dîvân'da yer alan *Kâsım, Resm, Şânî* ve *Şeylî* isimli kimlikler hakkında, kaynaklarda bilgi bulunamamıştır. Bunların, şairin döneminde yaşamış ve bilinmeyen kimlikler olduğu tahmin edilir. Bundan sonraki yapılacak çalışmalar için araştırılmaları uygun görülür.

Dîvân'da Osmanlı padişahlarından *Murâd*'ın kaçıncı sultan olduğu net değil. Şairin yaşam aralığı dikkate alındığında (?-1584) *4. Murâd* (1623-1640) hariç diğerlerinden birinin olma ihtimali vardır.

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FLUORESCENT DETERMINATION OF 17β-ESTRADIOL USING A COPPER-BASED METAL–ORGANIC FRAMEWORK

Burcu KABAK

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ABSTRACT

Introduction and Purpose: Steroid hormones in aquatic environments may cause endocrine-disrupting effects, creating a need for simple and sensitive analytical platforms. This study evaluated a copper-based metal–organic framework (Cu-MOF), synthesized under solvothermal conditions, as a fluorescent sensor for the selective detection of 17β-estradiol (E2).

Materials and Methods: Cu-MOF was synthesized from $Cu(NO_3)_2$, 1,10-phenanthroline, and terephthalic acid in DMF/water (16/4 mL). The pH of the reaction mixture was adjusted to 4.5 using 0.1 M NaOH, and the mixture was heated at 120 °C for 72 h. The product was filtered, washed, dried at 70 °C, and characterized by X-ray diffraction (XRD), scanning electron microscopy–energy-dispersive X-ray spectroscopy (SEM–EDX), Fourier-transform infrared spectroscopy (FTIR), and thermogravimetric analysis (TGA). Sensor selectivity was evaluated using 3 mg of Cu-MOF dispersed in 3 mL of medium in the presence of various metal ions, Cr(VI) species, common anions, and thyroid and steroid hormones. The fluorescence response to E2 was examined over 5–500 nM using Stern–Volmer analysis, and pH stability was assessed between pH 2 and 12.

Results: Characterization results supported the successful formation, crystallinity, and thermal stability of Cu-MOF. Most tested analytes produced only minor changes in emission intensity, whereas E2 caused pronounced fluorescence quenching. The Stern–Volmer constant was 1.845×10^6 M^{-1}, and the limit of detection was 99 nM. Preliminary spike-recovery experiments in synthetic urine and water samples at 80 and 200 nM further supported the applicability of the Cu-MOF sensor to real-sample analysis, with quantitative recovery and precision values currently under evaluation. Cu-MOF fluorescence remained stable between pH 2 and 10.

Conclusion: The synthesized Cu-MOF showed selective and reproducible fluorescence quenching toward E2 under near-neutral aqueous conditions, indicating strong potential as a simple, low-cost optical platform for estradiol sensing.

Key Words: Metal–organic framework; fluorescent sensor; 17β-estradiol; Stern–Volmer analysis.

EFFECTS OF SURGICAL SMOKE ON OCCUPATIONAL HEALTH AND ITS MULTIDISCIPLINARY MANAGEMENT

CERRAHİ DUMANIN ÇALIŞAN SAĞLIĞI ÜZERİNE ETKİLERİ VE MULTİDİSİPLİNER YÖNETİMİ

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ÖZET

Giriş ve Amaç: Cerrahi duman, elektrokoter, lazer ve ultrasonik neşter gibi enerji temelli cerrahi cihazların kullanımı sırasında oluşan, kimyasal bileşenler, ince ve çok ince partiküller, hücresel kalıntılar ve potansiyel olarak enfeksiyöz özellik taşıyan biyolojik materyaller içerebilen karmaşık bir biyoaerosoldür. Başta cerrahlar, anestezi çalışanları ve perioperatif hemşireler olmak üzere ameliyathane çalışanları açısından önemli bir mesleki maruziyet kaynağıdır. Bu derlemenin amacı, cerrahi dumanın çalışan sağlığı üzerindeki etkilerini değerlendirmek ve güncel korunma stratejileri ile multidisipliner yönetim yaklaşımlarını incelemektir.

Yöntem: Anlatı türündeki bu derlemede, PubMed veri tabanında cerrahi dumanın oluşumu ve bileşenleri, çalışan sağlığı üzerindeki etkileri, duman tahliye sistemleri, ameliyathane havalandırması, kişisel koruyucu ekipman kullanımı ve multidisipliner yönetimiyle ilgili yayınlar incelenmiştir. Konunun tarihsel gelişimini ve temel kanıtlarını kapsayabilmek amacıyla yayın yılı sınırlaması uygulanmamıştır. Ayrıca National Institute for Occupational Safety and Health (NIOSH) ve Association of periOperative Registered Nurses (AORN) tarafından yayımlanan rehber ve kurumsal kaynaklar ile International Organization for Standardization (ISO) ve American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) tarafından yayımlanan ilgili teknik standartlar değerlendirilmiştir.

Bulgular: Cerrahi dumana maruz kalma göz, burun ve boğaz irritasyonu, baş ağrısı ve solunum yolu belirtileri gibi akut etkilerle ilişkilidir. Cerrahi dumanın içerdiği partiküllerin, kimyasal bileşenlerin ve biyolojik materyallerin uzun süreli ve tekrarlayan maruziyet durumunda çalışan sağlığı açısından potansiyel risk oluşturabileceği bildirilmektedir. Bununla birlikte, kronik sağlık sonuçları ve enfeksiyon bulaşıyla ilgili kanıtların sınırlı ve heterojen olduğu görülmektedir. Uluslararası rehberlerde cerrahi dumanın oluştuğu noktaya yakın bir mesafeden yakalanması, uygun duman tahliye sistemlerinin rutin olarak kullanılması, ameliyathane havalandırmasının desteklenmesi, kişisel koruyucu ekipmanın risk değerlendirmesine göre seçilmesi ve çalışanlara düzenli eğitim verilmesi önerilmektedir.

Sonuç: Cerrahi duman, ameliyathane çalışanlarının sağlığını ve güvenliğini etkileyebilen önlenebilir bir mesleki tehlikedir. Duman tahliye sistemlerinin rutin klinik uygulamalara entegre edilmesi, kanıta dayalı

kurumsal politikaların geliştirilmesi ve perioperatif ekibin tüm üyelerinin katıldığı multidisipliner yaklaşımların güçlendirilmesi, daha güvenli ameliyathane ortamlarının oluşturulmasına katkı sağlayabilir.

Anahtar Kelimeler: Cerrahi duman, çalışan sağlığı, duman tahliyesi, perioperatif bakım, multidisipliner yönetim.

ABSTRACT

Introduction and Aim: Surgical smoke is a complex bioaerosol generated during the use of energy-based surgical devices, such as electrocautery, lasers, and ultrasonic scalpels. It may contain chemical compounds, fine and ultrafine particles, cellular debris, and potentially infectious biological materials. Surgical smoke represents an important source of occupational exposure for operating room personnel, particularly surgeons, anesthesia personnel, and perioperative nurses. This review aimed to evaluate the effects of surgical smoke on occupational health and examine current preventive strategies and multidisciplinary management approaches.

Methods: In this narrative review, publications indexed in the PubMed database addressing the generation and composition of surgical smoke, its effects on occupational health, smoke evacuation systems, operating room ventilation, personal protective equipment, and multidisciplinary management were examined. No publication-year restriction was applied to include the historical development of the subject and the fundamental evidence. Guidelines and institutional resources published by NIOSH and AORN, as well as relevant technical standards issued by ISO and ASHRAE, were also evaluated.

Results: Exposure to surgical smoke has been associated with acute effects, including eye, nose, and throat irritation, headaches, and respiratory symptoms. Particles, chemical compounds, and biological materials contained in surgical smoke may pose potential occupational health risks following prolonged and repeated exposure. However, evidence concerning chronic health outcomes and infectious transmission remains limited and heterogeneous. International guidelines recommend capturing surgical smoke close to its source, routinely using appropriate smoke evacuation systems, supporting operating room ventilation, selecting personal protective equipment based on risk assessment, and providing regular staff education.

Conclusion: Surgical smoke is a preventable occupational hazard that may affect the health and safety of operating room personnel. Integrating smoke evacuation systems into routine clinical practice, developing evidence-based institutional policies, and strengthening multidisciplinary approaches involving all members of the perioperative team may contribute to safer operating room environments.

Keywords: Surgical smoke, Occupational health, Smoke evacuation, Perioperative care, Multidisciplinary management.

Giriş

Cerrahi duman elektrocerrahi cihazları, lazerler ve ultrasonik cerrahi sistemler gibi enerji temelli cihazların doku diseksiyonu, koagülasyon ve hemostaz amacıyla kullanılması sırasında ortaya çıkan kompleks bir aerosoldür (Benaim & Jaspers, 2024; Casey & McNamara, 2023). Bu cihazlar kanama kontrolünü kolaylaştırmaları ve cerrahi uygulamaların etkinliğini artırmaları nedeniyle modern cerrahinin önemli bileşenleri arasında yer almaktadır (Bigony, 2007; Mahdood et al., 2024). Bununla birlikte, dokunun termal veya mekanik etkilerle parçalanması ve buharlaşması cerrahi duman oluşumuna neden olmaktadır (Ragde et al., 2016).

Cerrahi dumanın büyük bölümü su buharından oluşmakla birlikte daha küçük bir bölümünde çalışan sağlığı açısından önem taşıyan partiküler ve gaz halindeki bileşenler bulunmaktadır. Bu bileşenler arasında benzen formaldehit, hidrojen siyanür, akrilonitril, toluen ve karbonmonoksit gibi kimyasalların yanı sıra hücresel kalıntılar, nekrotik doku parçacıkları ve potansiyel olarak enfeksiyöz biyolojik materyaller yer alabilmektedir (Benaim & Jaspers, 2024; Garbey et al., 2020). Cerrahi dumanın bileşimi

ve yoğunluğu kullanılan enerji cihazına, uygulanan güç düzeyine, işlem süresine ve müdahale edilen dokunun özelliklerine göre değişmektedir.

Cerrahi duman partiküllerinin büyüklüğü de kullanılan enerji modalitesine göre farklılık göstermektedir. Elektrocerrahi cihazları ve lazerler daha küçük ve ultrafine partiküller oluşturabilirken, ultrasonik cerrahi sistemler görece daha büyük partiküller meydana getirebilmektedir. Küçük partiküller havada daha uzun süre asılı kalabilmekte ve solunum sisteminin daha derin bölümlerine ulaşabilmektedir (Benaim & Jaspers, 2024; Karjalainen et al., 2018). Ayrıca karaciğer ve yağ dokusu gibi dokuların işlenmesi sırasında oluşan partikül yoğunluğunun kas dokusuna göre daha yüksek olabileceği bildirilmiştir (Karjalainen et al., 2018).

Cerrahi dumanın ameliyathane ortamına yayılma biçimi açık ve minimal invaziv girişimlerde farklılık göstermekte ve maruziyetin niteliğini etkileyebilmektedir (Zakka et al., 2020). Açık cerrahi girişimlerde duman doğrudan ameliyathane havasına yayılırken, minimal invaziv girişimlerde pnömoperitonda birikebilmekte ve trokar değişimi, gaz kaçağı veya desüflasyon sırasında ortama salınabilmektedir (Zakka et al., 2020). Biriken duman cerrahi görüşü azaltabilir, havaya yayılan partikül ve kimyasal bileşenler ise ameliyathane çalışanlarında tekrarlayıcı ve kümülatif bir mesleki maruziyet oluşturabilmektedir.

Cerrahi dumana maruziyet çeşitli akut belirtilerle ilişkilendirilmekle birlikte, uzun dönem sağlık sonuçları ve enfeksiyöz bulaş konusundaki kanıtlar sınırlı ve heterojendir (Benaim & Jaspers, 2024; Mowbray et al., 2013; Okoshi et al., 2015). Bu nedenle cerrahi duman, çalışan ve hasta güvenliğini birlikte ele alan bütüncül bir yaklaşımla yönetilmelidir (NIOSH, 1996; Williams, 2022).

Bu derlemenin amacı, cerrahi dumanın oluşumunu ve temel özelliklerini, çalışan sağlığı üzerindeki etkilerini, güncel korunma stratejilerini ve multidisipliner yönetim yaklaşımlarını mevcut literatür doğrultusunda değerlendirmektir.

Yöntem

Bu çalışma, cerrahi dumanın çalışan sağlığı üzerindeki etkileri ile korunma ve multidisipliner yönetim yaklaşımlarını incelemek amacıyla hazırlanmış anlatı türünde bir derlemedir. Literatür taraması PubMed veri tabanında gerçekleştirilmiştir. Taramada "surgical smoke", "surgical plume", "occupational exposure", "operating room personnel", "smoke evacuation", "perioperative nursing" ve "personal protective equipment" anahtar kelimeleri tek başına ve farklı kombinasyonlar halinde kullanılmıştır. Konunun tarihsel gelişimini ve temel kanıtlarını kapsayabilmek amacıyla yayın yılı sınırlaması uygulanmamıştır.

Cerrahi dumanın oluşumu ve bileşenleri, çalışan sağlığı üzerindeki etkileri, biyolojik riskleri, duman tahliye sistemleri, kişisel koruyucu ekipman kullanımı, perioperatif ekip üyelerinin rolleri ve kurumsal yönetim yaklaşımlarıyla ilgili özgün araştırmalar, derlemeler ve sistematik derlemeler değerlendirmeye alınmıştır. Ayrıca National Institute for Occupational Safety and Health (NIOSH) ve Association of periOperative Registered Nurses (AORN) tarafından yayımlanan rehber ve kurumsal kaynaklar ile International Organization for Standardization (ISO) ve American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) tarafından yayımlanan ilgili teknik standartlar incelenmiştir.

Mesleki Maruziyetin Özellikleri

Cerrahi duman, ameliyathane çalışanları açısından tekrarlayıcı ve kümülatif bir mesleki maruziyet kaynağıdır. Cerrahlar, perioperatif hemşireler, anestezi personeli ve ameliyathanede görev yapan diğer çalışanlar, duman oluşturan işlemlere çalışma yaşamları boyunca birçok kez maruz kalabilmektedir. Hastaların maruziyeti çoğunlukla cerrahi işlem süresiyle sınırlıyken, çalışanların maruziyeti işlemlerin sıklığına, süresine, kullanılan enerji cihazına, cerrahi alana yakınlığa, havalandırma koşullarına ve duman tahliye sistemlerinin kullanımına göre değişmektedir (Mowbray et al., 2013; Okoshi et al., 2015).

Maruziyet değerlendirmesinde yalnızca görünür duman değil, gözle görülemeyen ince ve ultrafine partiküller ile gaz fazındaki bileşenler de dikkate alınmalıdır (Benaim & Jaspers, 2024).

Kimyasal ve Fiziksel Maruziyet

Cerrahi dumanın içerdiği partiküller, toksik gazlar ve uçucu kimyasal bileşenler ameliyathane çalışanları açısından önemli maruziyet kaynaklarıdır. Kısa süreli maruziyet göz, burun ve boğaz irritasyonu, baş ağrısı, bulantı, baş dönmesi ve solunum yolu belirtileriyle ilişkilendirilmektedir (Mowbray et al., 2013; Okoshi et al., 2015). Bu belirtilerin ortaya çıkması duman yoğunluğu, maruziyet süresi, cerrahi alana uzaklık, ameliyathane havalandırması ve duman tahliye sistemlerinin kullanımı gibi faktörlerden etkilenebilmektedir.

Tekrarlayıcı ve uzun süreli maruziyetin solunum sistemi ve çalışan sağlığı üzerinde olumsuz etkiler oluşturabileceği düşünülmekle birlikte, kronik hastalıklarla doğrudan nedensel ilişki kuran kanıtlar sınırlı ve heterojendir (Benaim & Jaspers, 2024; Zhou et al., 2023). Bu nedenle astım, kronik bronşit, amfizem veya kardiyovasküler hastalıklar gibi sonuçların cerrahi dumandan kaynaklandığını kesin biçimde ifade etmek yerine, cerrahi dumanın uzun dönemli potansiyel bir mesleki risk oluşturabileceğinin belirtilmesi gerekmektedir.

Biyolojik Kontaminasyon ve Bulaş Potansiyeli

Cerrahi dumanda kimyasal bileşenlerin yanı sıra hücresel materyaller de bulunabilmektedir. Deneysel bir çalışmada, ultrasonik enerji cihazlarıyla oluşturulan dumandan elde edilen malign hücrelerin canlılıklarını koruyabildiği ve deney hayvanlarında tümör gelişimiyle ilişkili olabileceği bildirilmiştir (In et al., 2015). Bununla birlikte, deneysel koşullarda elde edilen bu bulgular klinik bulaş veya tümör gelişiminin kanıtı olarak değerlendirilmemelidir. Bulgular, cerrahi dumanın biyolojik materyal içerebildiğini ve uygun tahliye önlemlerinin gerekli olduğunu desteklemektedir.

Cerrahi dumanın viral ve diğer biyolojik materyalleri taşıma potansiyeli uzun süredir araştırılmaktadır. Çalışmalarda, HPV ile ilişkili lezyonlara uygulanan lazer ve elektrocerrahi işlemleri sırasında oluşan duman örneklerinde İnsan Papilloma Virüsü (HPV) DNA'sı saptanmıştır (Garden et al., 1988; Zhou et al., 2019). Benzer şekilde, Hepatit B hastalarına uygulanan laparoskopik ve robotik cerrahi işlemler sırasında toplanan duman örneklerinde Hepatit B virüsüne ait genetik materyal tespit edilmiştir (Kwak et al., 2016). Kwak ve arkadaşlarının çalışması, HBV'nin cerrahi dumanda saptanabildiğini göstermekte ancak hava yoluyla enfeksiyon geliştiğini kanıtlamamaktadır.

Cerrahi cihazlarla oluşturulan duman örneklerinde insan koronavirüsüne ait RNA'nın saptandığı da bildirilmiştir (Yokoe et al., 2021). Bununla birlikte, cerrahi dumanda viral DNA veya RNA bulunması virüsün canlılığını koruduğunu, enfeksiyon oluşturabildiğini veya cerrahi duman yoluyla klinik bulaş meydana geldiğini tek başına göstermemektedir. Bu nedenle bu bulgular, kanıtlanmış bir bulaş yolunun göstergesi olarak değil, cerrahi dumanın biyolojik materyal taşıyabileceğine ilişkin kanıtlar olarak değerlendirilmelidir (Fox-Lewis et al., 2020; Mowbray et al., 2013; Yokoe et al., 2021).

Cerrahi duman aracılığıyla klinik açıdan anlamlı enfeksiyon bulaşı kesin olarak ortaya konmamış olmakla birlikte, koruyucu önlemlerin uygulanması ve duman maruziyetinin azaltılması gerekmektedir (Fox-Lewis et al., 2020; Mowbray et al., 2013).

Cerrahi Tekniğe Bağlı Riskler

Cerrahi dumanın oluşumu ve ameliyathane ortamına yayılma biçimi, uygulanan cerrahi tekniğe göre değişmektedir. Açık cerrahi girişimlerde oluşan duman doğrudan ameliyathane havasına yayılmakta ve özellikle cerrahi alana yakın çalışan ekip üyelerinin solunum bölgesinde maruziyete neden olabilmektedir. Duman tahliye sisteminin kullanılmadığı durumlarda genel ameliyathane havalandırması, dumanı kaynağında yakalamadığı için çalışan maruziyetini tek başına yeterli düzeyde önleyemeyebilir (Benaim & Jaspers, 2024; NIOSH, 1996).

Minimal invaziv cerrahi girişimlerde ise duman pnömoperitonda birikerek cerrahi görüşü azaltabilmektedir. Biriken duman trokar valflerinin açılması, cerrahi aletlerin değiştirilmesi, gaz kaçağı veya kontrolsüz desüflasyon sırasında ameliyathane ortamına salınabilmektedir (Mowbray et al., 2020; Zakka et al., 2020). Bu nedenle minimal invaziv cerrahide pnömoperitonun kontrollü biçimde boşaltılması, uygun filtrasyon sistemlerinin kullanılması ve dumanın doğrudan oda havasına verilmemesi önerilmektedir (Mowbray et al., 2020; Zakka et al., 2020). Açık ve minimal invaziv cerrahi

girişimlerde riskin biçimi farklı olmakla birlikte, her iki yaklaşımda da dumanın kaynağında veya kaynağa mümkün olan en yakın noktada tahliye edilmesi temel korunma önlemidir (NIOSH, 1996).

Pandemi Sonrası Biyogüvenlik Yaklaşımı

COVID-19 pandemisi, ameliyathanelerde aerosol ve duman oluşturan işlemlere yönelik biyogüvenlik önlemlerinin yeniden değerlendirilmesine neden olmuştur. Pandeminin ilk dönemlerinde, SARS-CoV-2'nin cerrahi duman yoluyla bulaşabileceğine ilişkin kaygılar özellikle minimal invaziv cerrahi girişimlerde kontrollü desüflasyon, kapalı tahliye sistemleri ve uygun filtrasyon kullanımını gündeme getirmiştir (Mowbray et al., 2020; Zakka et al., 2020).

Bununla birlikte, cerrahi dumanın SARS-CoV-2 için klinik açıdan anlamlı bir bulaş yolu olduğu kesin olarak gösterilmemiştir. Cerrahi dumanda viral genetik materyalin saptanması, virüsün canlılığını koruduğunu veya enfeksiyon oluşturabildiğini tek başına kanıtlamamaktadır. Bu nedenle pandemi döneminde geliştirilen öneriler, kanıtlanmış bir SARS-CoV-2 bulaş yolundan çok korunma ilkesine ve çalışan maruziyetinin azaltılmasına dayanmaktadır (Mowbray et al., 2020; Zakka et al., 2020).

COVID-19 pandemisi, özellikle minimal invaziv cerrahide kontrollü desüflasyon, kapalı tahliye ve uygun filtrasyon uygulamalarının önemini görünür hale getirmiştir. Bununla birlikte, SARS-CoV-2'nin cerrahi duman yoluyla klinik açıdan anlamlı biçimde bulaştığı kesin olarak gösterilmemiştir. Bu nedenle uygulamalar, kanıtlanmış bir bulaş yoluna yönelik özel önlemlerden çok pandemi sonrasında da sürdürülmesi gereken standart biyogüvenlik ve çalışan sağlığı önlemleri olarak değerlendirilmelidir (Mowbray et al., 2020; Williams, 2022; Zakka et al., 2020).

Uluslararası Rehberler ve Duman Tahliyesindeki Engeller

Cerrahi dumanın zararlı kimyasal ve partiküler bileşenleri ile kısa süreli sağlık etkilerine ilişkin kanıtlara rağmen, koruyucu uygulamalar klinik uygulamalara istenen düzeyde yansımamıştır. Maruziyet riskinin yeterince önemsenmemesi, duman tahliye sistemlerinin cerrahi iş akışını etkileyebileceğine yönelik algılar, çalışanların bilgi eksikliği ve kurumsal politikaların bulunmaması sistemlerin düzenli kullanımını sınırlandırabilmektedir (Michaelis et al., 2020; Steege et al., 2016).

National Institute for Occupational Safety and Health (NIOSH), cerrahi dumanın kontrolünde genel ameliyathane havalandırmasının lokal egzoz ventilasyonuyla desteklenmesini önermektedir. Dumanın, uygun bir tahliye sistemi kullanılarak oluştuğu noktaya mümkün olan en yakın mesafeden uzaklaştırılması temel kontrol yaklaşımıdır (NIOSH, 1996).

Association of periOperative Registered Nurses (AORN), cerrahi duman güvenliğini çalışan ve hasta güvenliğinin temel bileşenlerinden biri olarak ele almakta kurum politikalarının geliştirilmesini, çalışan eğitimini, yeterli tahliye ekipmanının sağlanmasını ve uygulama uyumunun izlenmesini desteklemektedir. AORN Center of Excellence in Surgical Safety: Smoke Evacuation programı kapsamında verilen Go Clear Award, sağlık kuruluşlarının dumansız cerrahi ortam oluşturmaya yönelik çalışmalarını değerlendiren kurumsal bir tanınma programıdır (AORN, 2023).

Uluslararası önerilere rağmen duman tahliye sistemlerinin rutin kullanım oranları yeterli düzeye ulaşmamıştır. Ameliyathane çalışanlarıyla yapılan bir araştırmada, duman oluşturan işlemlerin önemli bir bölümünde lokal tahliye sistemlerinin düzenli kullanılmadığı bildirilmiştir (Steege et al., 2016). Kurumsal politika eksikliği, düşük risk algısı, yetersiz eğitim ve ekip üyelerinin tahliye sistemlerine yönelik olumsuz tutumları kullanım uyumunu etkileyen başlıca etmenlerdir.

Duman tahliye sistemlerinin kullanımını sınırlandıran diğer etmenler arasında cihazların çıkardığı gürültü, hortum ve el parçalarının ergonomik olmaması, cerrahi manevraları zorlaştırabileceğine yönelik kaygılar, cihaz ve sarf malzemesi maliyetleri ile bakım gereksinimleri yer almaktadır (Michaelis et al., 2020; York & Autry, 2018). Bu engellerin azaltılması için ekipman seçiminde kullanıcı görüşlerinin alınması, farklı cihazların klinik ortamda değerlendirilmesi, kurumsal kullanım protokollerinin oluşturulması ve çalışanlara uygulamalı eğitim verilmesi önem taşımaktadır.

Korunma, Tahliye Sistemleri ve Yönetim Stratejileri

Cerrahi duman maruziyetinin azaltılmasında birbirini tamamlayan koruyucu önlemlerin birlikte uygulanması gerekmektedir. Duman oluşumunu tamamen ortadan kaldırmak her cerrahi işlemde

mümkün olmadığından, kullanılan enerji düzeyinin işlem için gerekli en düşük seviyede tutulması ve dumanın oluştuğu noktada yakalanması öncelikli yaklaşımlardır. Kaynağa yönelik mühendislik kontrollerini genel ameliyathane havalandırması, güvenli çalışma uygulamaları, çalışan eğitimi ve kişisel koruyucu ekipman kullanımı desteklemelidir (NIOSH, 1996; Williams, 2022).

Duman Tahliye Sistemleri

Cerrahi dumanın oluştuğu noktaya yakın mesafeden yakalanması, çalışan maruziyetinin azaltılmasındaki temel mühendislik kontrolüdür. Duman tahliye sistemleri genellikle bir emiş ünitesi, filtre, bağlantı hortumu ve dumanı yakalayan bir uçtan oluşmaktadır. Sistemlerin etkinliği ise emiş gücüne, kullanılan filtrenin özelliklerine, tahliye ucunun konumuna, bağlantıların bütünlüğüne ve sistemin işlem boyunca kesintisiz çalıştırılmasına bağlıdır (NIOSH, 1996).

Duman tahliye cihazlarında partiküllerin tutulması amacıyla yüksek verimli partikül filtreleri kullanılmaktadır, uygulamadaki sistemlerde HEPA veya ULPA filtreler bulunabilmektedir. Bununla birlikte filtrasyon performansı yalnızca tek bir partikül büyüklüğü değil, filtrenin sınıfı, uygulanan test standardı, nominal hava akışı ve sistemin bütünsel tasarımı dikkate alınarak değerlendirilmelidir (ISO, 2024a, 2024b, 2026; NIOSH, 1996). HEPA ve ULPA filtrelerin temel işlevi partiküllerin tutulmasıdır. Gazların, uçucu organik bileşiklerin ve kokuların azaltılması için bazı sistemlerde aktif karbon veya benzeri adsorbanlardan oluşan ayrı bir gaz filtrasyon katmanı bulunmaktadır (ISO, 2024b; NIOSH, 1996). Filtre ömrü veya filtre durum göstergeleri izlenmeli ve filtreler üreticinin önerdiği aralıklarla değiştirilmelidir (ISO, 2024b, 2026; NIOSH, 1996).

Tahliye ucunun duman kaynağından yaklaşık 5 cm'den daha uzak olmayacak biçimde konumlandırılması ve duman oluşturan enerji cihazı kullanıldığı sürece sistemin çalıştırılması önerilmektedir. Entegre elektrocerrahi kalemleri veya cerrahi alana yakın konumlandırılan emiş uçları, dumanın ameliyathane havasına yayılmadan yakalanmasına yardımcı olabilir. Hortum, filtre ve diğer bileşenler üreticinin önerileri doğrultusunda düzenli olarak kontrol edilmeli ve değiştirilmelidir. Kullanılmış filtre ve sarf malzemeleri potansiyel biyolojik tehlike dikkate alınarak kurumun atık yönetimi prosedürlerine uygun biçimde uzaklaştırılmalıdır (NIOSH, 1996).

Ameliyathanelerde kullanılan duvar tipi aspirasyon sistemleri, özel duman tahliye cihazlarına göre daha düşük hava akışına sahiptir ve öncelikle sıvıların aspirasyonu amacıyla tasarlanmıştır. Bu sistemler cerrahi duman için kullanılacaksa uygun bir hat içi filtre bulunmalı ve sistemin kullanım amacı ile üretici talimatları dikkate alınmalıdır. Bununla birlikte, duvar aspirasyonu özellikle yoğun duman oluşturan işlemlerde yüksek akışlı ve filtreli özel duman tahliye sisteminin eşdeğeri olarak değerlendirilmemelidir (NIOSH, 1996).

Ameliyathane Havalandırması

Ameliyathane havalandırma sistemleri, havaya yayılan cerrahi dumanın seyreltilmesine ve ortamdan uzaklaştırılmasına katkı sağlamaktadır. Bununla birlikte genel havalandırma ve laminer hava akımı, dumanı oluştuğu noktada yakalamadığı için tek başına yeterli bir maruziyet kontrol yöntemi değildir. Bu sistemler, kaynağa yakın lokal duman tahliyesini destekleyen çevresel kontroller olarak değerlendirilmelidir (NIOSH, 1996).

Ameliyathane havalandırma sistemleri, havaya yayılan cerrahi dumanın seyreltilmesine ve ortamdan uzaklaştırılmasına katkı sağlamaktadır. Bununla birlikte genel havalandırma ve laminer hava akımı, dumanı oluştuğu noktada yakalamadığı için tek başına yeterli bir maruziyet kontrol yöntemi değildir. Bu nedenle genel ameliyathane havalandırması geçerli kurum ve ameliyathane standartlarına uygun biçimde sürdürülmeli ve kaynağa yakın lokal duman tahliyesiyle birlikte uygulanmalıdır (ASHRAE, 2021; NIOSH, 1996).

Kişisel Koruyucu Ekipman

Kişisel koruyucu ekipman, cerrahi dumana karşı uygulanan mühendislik kontrollerini tamamlayan bir önlemdir. Standart cerrahi maskeler gevşek oturdukları ve solunum koruyucusu olarak tasarlanmadıkları için ince ve ultrafine duman partiküllerine karşı güvenilir bir koruma sağlamaz (Nezhat et al., 1987; Derrick et al., 2006; Kunachak & Sobhon, 1998). Bu nedenle cerrahi maske kullanılması, duman tahliye sistemine alternatif olarak değerlendirilmemelidir.

N95, FFP2 ve FFP3 sınıfındaki uygun solunum koruyucuları, yüze yeterli biçimde oturmaları ve doğru kullanılmaları durumunda partikül maruziyetini azaltabilir. Solunum koruyucusunun seçimi ise yapılan işlemin özellikleri, oluşan duman yoğunluğu, enfeksiyon riski ve kurumun iş sağlığı politikaları doğrultusunda gerçekleştirilmelidir. Sıkı oturan solunum koruyucularında kullanıcı sızdırmazlık kontrolü yapılmalı ve kurumun solunum koruma programı kapsamında uyum testi uygulanmalıdır (Derrick et al., 2006; Fox-Lewis et al., 2020; NIOSH, 2025a).

N95 ve benzeri partikül filtreli solunum koruyucuları gazlara ve uçucu kimyasal buharlara karşı koruma sağlamaz. Bu nedenle cerrahi dumanın kimyasal bileşenlerine yönelik temel korunma yöntemi, uygun partikül filtrasyonu ve gaz adsorpsiyonu sağlayan bir sistemle dumanın kaynağında tahliye edilmesidir (NIOSH, 1996, 2025b).

Gözlük veya yüz koruyucu gibi diğer kişisel koruyucu ekipmanlar, sıçrama ve göz irritasyonu riskinin bulunduğu işlemlerde risk değerlendirmesine göre kullanılabilir (Fox-Lewis et al., 2020; Williams, 2022). Bununla birlikte, kişisel koruyucu ekipmanın hiçbir bileşeni dumanın oluştuğu noktada yakalanması ve ameliyathane havalandırmasının uygun biçimde sürdürülmesi gerekliliğini ortadan kaldırmaz.

Multidisipliner Yaklaşım: Cerrahi Ekip İş Birliği

Cerrahi dumanın etkili biçimde yönetilmesi, yalnızca tahliye ekipmanının bulunmasına değil, perioperatif ekip üyelerinin koordineli çalışmasına, kurumsal politikaların uygulanmasına ve güvenlik uygulamalarının standartlaştırılmasına bağlıdır. Cerrahlar, perioperatif hemşireler, anestezi ekibi, enfeksiyon kontrolü ve iş sağlığı birimleri, biyomedikal teknik ekip, kalite yönetimi ve kurum yöneticileri bu sürecin farklı aşamalarına katkı sağlamaktadır (Ilce et al., 2017; Kocher et al., 2019; York & Autry, 2018).

Perioperatif veya ameliyathane hemşireleri tahliye sisteminin işlem öncesinde hazırlanması, cihazın çalışabilirliğinin kontrol edilmesi, uygun filtre ve bağlantıların kullanılması ve tahliye ucunun cerrahi alana uygun biçimde yerleştirilmesi süreçlerinde rol almaktadır. İşlem sırasında sistemin kullanımını izlemek, aksaklıkları ekip üyeleriyle paylaşmak ve gerekli durumlarda güvenli uygulamalar için savunuculuk yapmak da perioperatif hemşirelik uygulamalarının bir parçasıdır. İşlem sonrasında sarf malzemelerinin uygun biçimde uzaklaştırılması ve cihazla ilgili sorunların bildirilmesi sürdürülebilir sistem kullanımına katkı sağlamaktadır (York & Autry, 2018).

Cerrahlar ise işlem için gerekli en düşük etkili enerji düzeyinin seçilmesi, duman tahliye sisteminin enerji cihazıyla birlikte kullanılması ve tahliye ucunun duman kaynağına yakın tutulmasının desteklenmesinde önemli rol oynamaktadır. Cerrahın tahliye sistemini kabul etmesi ve düzenli kullanması, ekipteki diğer çalışanların uygulamaya uyumunu da etkileyebilmektedir (Steege et al., 2016; York & Autry, 2018).

Anestezi ekibi özellikle minimal invaziv girişimlerde kontrollü desüflasyonun planlanması, pnömoperitonun doğrudan oda havasına verilmesinin önlenmesi ve biyogüvenlik önlemlerinin ekip içinde koordine edilmesine katkı sağlamaktadır (Mowbray et al., 2020; Zakka et al., 2020). Enfeksiyon kontrolü ve iş sağlığı birimleri risk değerlendirmesi, çalışan eğitimi ve maruziyet yönetimini desteklerken biyomedikal teknik ekip cihazların bakım ve performans kontrollerinde görev almaktadır (AORN, 2024; ISO, 2024b; Williams, 2022).

Kurum yöneticileri ve kalite birimleri uygun ekipmanın temin edilmesi, sarf malzemelerinin sürekliliğinin sağlanması, yazılı prosedürlerin oluşturulması, eğitim programlarının desteklenmesi ve uygulama uyumunun izlenmesinden sorumludur (AORN, 2024; Ostapovych & Vortman, 2022; Williams, 2022). Ekipman seçiminde cerrah, hemşire, anestezi ve teknik personelin görüşlerinin alınması ise ergonomi, gürültü, kullanım kolaylığı ve filtrasyon özelliklerinin birlikte değerlendirilmesini sağlayabilir (Michaelis et al., 2020; York & Autry, 2018).

Cerrahi duman güvenliğinin bireysel tercihlere bırakılmadığı ve ekip üyelerinin ortak sorumluluk üstlendiği bir ameliyathane kültürü, uygulamaların sürdürülebilirliği açısından önemlidir (Ostapovych & Vortman, 2022; Williams, 2022).

Güvenlik Eğitimi ve Sürekli Kalite İyileştirme

Cerrahi duman yönetiminin sürdürülebilirliği uygun ekipmanın bulunmasının yanı sıra çalışanların bilgi, beceri ve güvenli uygulamalara yönelik tutumlarına bağlıdır. Çalışmalar, ameliyathane çalışanlarının cerrahi dumanla ilişkili risklere yönelik farkındalıklarının ve koruyucu uygulamalara uyumlarının değişken olduğunu göstermektedir (Ilce et al., 2017; Michaelis et al., 2020; Steege et al., 2016). Bu nedenle çalışan eğitimi, kurumsal cerrahi duman yönetiminin temel bileşenlerinden biri olmalıdır.

Eğitim programlarında cerrahi dumanın oluşumu ve bileşenleri, potansiyel sağlık etkileri, enerji temelli cerrahi cihazların güvenli kullanımı, tahliye sisteminin hazırlanması ve etkinleştirilmesi, tahliye ucunun doğru konumlandırılması, kontrollü desüflasyon, kişisel koruyucu ekipman seçimi, filtre değişimi ve atık yönetimi konularına yer verilmelidir. Eğitimler yalnızca teorik bilgi aktarımıyla sınırlandırılmamalı uygulamalı gösterim, beceri değerlendirmesi ve cihaz kullanımına ilişkin yetkinlik doğrulamasını da içermelidir (York & Autry, 2018).

Cerrahi duman eğitimi, yeni çalışanların kuruma uyum programına eklenmeli ve belirli aralıklarla tekrarlanmalıdır. Yeni bir cihazın kullanıma alınması, kurum prosedürünün değiştirilmesi veya uygulama denetimlerinde yetersizlik saptanması durumunda ek eğitim düzenlenmelidir. Eğitimler hemşirelere, cerrahlara, anestezi personeline, cerrahi teknisyenlere ve ameliyathanede görev yapan diğer çalışanlara yönelik multidisipliner bir program olarak yürütülmesi önemlidir (AORN, 2024; Williams, 2022; York & Autry, 2018).

Eğitimin klinik uygulamaya yansıyıp yansımadığı düzenli olarak değerlendirilmelidir. Bu amaçla duman oluşturan işlemlerde tahliye sistemi kullanılma oranı, gerekli ekipmanın ameliyathanelerde bulunabilirliği, eğitim ve yetkinlik değerlendirmelerinin tamamlanma durumu, filtre değişim kayıtları, cihaz arızaları ve çalışanlar tarafından bildirilen uygulama sorunları izlenebilir (AORN, 2024; Ostapovych & Vortman, 2022). AORN'un cerrahi duman güvenliği programında da çalışan eğitimi, yetkinlik değerlendirmesi ve duman tahliyesine uyumun denetlenmesine yönelik araçlar bulunmaktadır (AORN, 2024).

Denetim sonuçları perioperatif ekiple paylaşılmalıdır. Ayrıca yetersiz kullanım saptandığında bunun eğitim eksikliği, cihaz erişimi, ergonomi, gürültü, iş akışı veya yönetim desteği gibi nedenlerden hangisiyle ilişkili olduğu değerlendirilmelidir (Michaelis et al., 2020; Ostapovych & Vortman, 2022). Belirlenen sorunlara yönelik iyileştirme girişimleri uygulandıktan sonra kullanım uyumu yeniden ölçülmelidir. Böylece cerrahi duman yönetimi, tek seferlik bir eğitim faaliyeti olmaktan çıkarılarak ölçme, geri bildirim ve yeniden değerlendirmeye dayanan sürekli kalite iyileştirme sürecine dönüştürülebilir (AORN, 2024; Ostapovych & Vortman, 2022).

Sonuç

Cerrahi duman, enerji temelli cerrahi cihazların kullanımı sırasında oluşan kimyasal bileşenler, ince ve ultrafine partiküller, hücresel kalıntılar ve viral genetik materyal içerebilen kompleks bir aerosoldür. Maruziyet akut irritasyon ve solunum yolu belirtileriyle ilişkilendirilmekle birlikte, uzun dönem sağlık sonuçları ve enfeksiyöz bulaş konusundaki kanıtlar sınırlı ve heterojendir.

Cerrahi duman, yalnızca ameliyathane konforunu etkileyen çevresel bir sorun değil, önlenebilir bir mesleki tehlikedir. Maruziyetin azaltılmasında temel yaklaşım, dumanın uygun bir tahliye sistemiyle kaynağına mümkün olan en yakın noktadan yakalanmasıdır. Genel ameliyathane havalandırması ve kişisel koruyucu ekipman bu yöntemi tamamlamalıdır. Uygulamanın sürdürülebilirliği; yazılı kurum politikaları, yönetim desteği, uygun ekipman, multidisipliner eğitim ve kullanım uyumunun düzenli olarak izlenmesini gerektirmektedir.

Öneriler

Cerrahi duman yönetiminin güçlendirilmesi amacıyla aşağıdaki öneriler sunulmaktadır

- *Kurumsal politika geliştirilmesi:* Duman oluşturan cerrahi işlemlerde tahliye sisteminin kullanımını, çalışanların rollerini, filtre değişimini, bakım işlemlerini ve atık yönetimini tanımlayan yazılı prosedürler oluşturulmalıdır.
- *Dumanın kaynağında yakalanması:* Uygun duman tahliye sistemleri dumanın oluştuğu noktaya mümkün olan en yakın mesafede kullanılmalı ve enerji cihazı çalıştığı sürece etkin durumda

tutulmalıdır. Duvar tipi aspirasyon sistemleri, yüksek akışlı ve filtreli özel duman tahliye cihazlarının eşdeğeri olarak değerlendirilmemelidir.

- *Minimal invaziv cerrahide güvenli tahliye:* Pnömoperiton doğrudan ameliyathane havasına verilmemeli; kontrollü desüflasyon ve uygun filtrasyon sistemleri kullanılmalıdır.
- *Ekipman seçiminin multidisipliner yapılması:* Tahliye cihazlarının seçiminde cerrahlar, perioperatif hemşireler, anestezi personeli ve biyomedikal teknik ekip birlikte görev almalı filtrasyon, emiş gücü, ergonomi, gürültü, kullanım kolaylığı ve maliyet birlikte değerlendirilmelidir.
- *Kişisel koruyucu ekipmanın risk temelinde kullanılması:* Solunum koruyucuları yapılan işleme ve risk değerlendirmesine göre seçilmeli, doğru kullanım ve uyum kontrolü sağlanmalıdır. Partikül filtreli solunum koruyucularının gazlara ve uçucu kimyasal bileşenlere karşı koruma sağlamadığı dikkate alınmalıdır.
- *Eğitim ve yetkinlik programlarının geliştirilmesi:* Cerrahi duman güvenliği, çalışanların kuruma uyum ve sürekli mesleki eğitim programlarına eklenmeli eğitimler teorik bilginin yanı sıra cihaz kullanımına yönelik uygulamalı beceri değerlendirmelerini de içermelidir.
- *Sürekli kalite iyileştirmenin sağlanması:* Duman oluşturan işlemlerde tahliye sistemi kullanım oranı, ekipman bulunabilirliği, eğitimlerin tamamlanma durumu, filtre değişimleri ve bildirilen cihaz sorunları düzenli olarak izlenmelidir. Denetim sonuçları ekip üyeleriyle paylaşılmalı ve belirlenen sorunlara yönelik iyileştirmelerin etkisi yeniden değerlendirilmelidir.
- *Bilimsel araştırmaların desteklenmesi:* Cerrahi dumanın uzun dönem sağlık etkilerini, enfeksiyöz bulaş potansiyelini ve farklı tahliye sistemlerinin klinik, ergonomik ve ekonomik etkinliğini inceleyen çok merkezli ve ileriye dönük araştırmalar artırılmalıdır.

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CHALLENGES AND INSTITUTIONAL–STRUCTURAL BARRIERS TO INDIVIDUAL MASTERY IN THE PATH OF IRAN'S POLITICAL ECONOMY UNDERDEVELOPMENT

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The Gap Between Individual Capability and Institutional Structure in Iran

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The Gap Between Individual Capability and Institutional Structure in Iran

ABSTRACT

This article investigates the structural obstacles to individual mastery in Iran's political conomy through the design and testing of an interdisciplinary conceptual model. The central research question asks why, despite significant human capital, talented individuals and elites are unable to progress through the final stages of professional and intellectual mastery in Iran. To address this, three complementary theoretical frameworks are employed: first, Douglas North's theory of extractive institutions to explain the institutional roots of underdevelopment; second, Nassim Taleb's concepts of antifragility and "skin in the game" to highlight the lack of accountability in power structures; and third, Ali-Reza Qoli's sociological analysis of elite suppression to account for historical barriers that reproduce underdevelopment. These frameworks are integrated with Robert Greene's six-stage mastery model call, apprenticeship, practice, creativity, intuition, and mastery. The findings indicate that most stages of mastery in Iran face institutional, educational, cultural, and political obstacles, leading to outcomes such as brain drain, exclusion of independent elites, and incomplete personal development. Accordingly, the study proposes the "Cycle of Mastery Challenges" model as an explanation of systemic barriers to development, emphasizing the need for institutional reform, power redistribution, and a learning-oriented culture to enable mastery as a developmental right. The research demonstrates how a rent-seeking structure, weak institutions, and systematic elite suppression transform mastery into an individual, migration-driven, and exceptional phenomenon in Iran. Ultimately, the proposed conceptual model suggests that overcoming the cycle of underdevelopment requires institutional reorganization, balanced power distribution, and restored accountability among decision-akers.

Keywords: Iran, mastery, underdevelopment, institutional economics.

YOUTUBE AS A SOURCE OF INFORMATION ON CHARCOT–MARIE–TOOTH DISEASE AND REHABILITATION: A CROSS-SECTIONAL EVALUATION OF VIDEO QUALITY, RELIABILITY, AND ACTIONABILITY

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ABSTRACT

For many individuals living with Charcot–Marie–Tooth (CMT) disease, YouTube represents one of the first places to seek information about the condition and its rehabilitation. The platform offers immediate access to educational material, yet the quality, reliability, and practical usefulness of that information remain uncertain. This study evaluated the educational characteristics of YouTube videos related to CMT rehabilitation by examining their reliability, transparency, overall educational quality, understandability, and actionability. A cross-sectional content analysis was performed using the search terms "Charcot-Marie-Tooth disease," "CMT rehabilitation," "CMT exercises," "physical therapy for CMT," and "CMT physiotherapy." Videos were considered eligible if they were presented in English and focused on CMT, patient education, physiotherapy, rehabilitation, or exercise. Duplicate uploads, unrelated content, promotional material, news-only videos, and videos without audio were excluded. For every eligible video, information on duration, upload date, views, likes, comments, upload source, and primary content was extracted before classification into either professional or other upload sources. Reliability and treatment-related information were evaluated using DISCERN. Transparency was assessed with the *Journal of the American Medical Association* benchmark criteria, overall educational quality with the Global Quality Score, and understandability together with actionability using the Patient Education Materials Assessment Tool. Following the eligibility assessment, 141 videos were included in the analysis, comprising 67 videos uploaded by professional sources and 74 uploaded by other sources.

Professional-source videos had markedly higher DISCERN scores than videos from other sources (69.4 ± 8.5 vs. 42.1 ± 10.3; $p < .001$). The same pattern was observed for JAMA scores (3.6 ± 0.5 vs. 1.9 ± 0.8), Global Quality Scores (GQS) (4.5 ± 0.6 vs. 2.9 ± 0.7), PEMAT understandability scores (92.4 ± 5.1% vs. 78.6 ± 9.3%), and PEMAT actionability scores (86.7 ± 7.8% vs. 59.4 ± 12.6%). Professional-source videos consistently received higher scores than videos from other sources across all evaluation measures ($p < .001$). Content produced by universities, rehabilitation professionals, and patient organizations was more likely to include scientific evidence, reflect current clinical practice, and provide practical demonstrations of rehabilitation exercises. Exercise-focused videos were especially valuable when rehabilitation techniques were explained clearly and linked to activities that patients could perform as part of their daily routines. The overall findings indicate that the educational quality of CMT-related information on YouTube varies substantially. Compared with videos from other upload sources, those created by healthcare professionals, academic institutions, and patient organizations offered more reliable, transparent, understandable, and actionable information. These results reinforce the importance of directing patients to carefully evaluated educational resources and support continued efforts by qualified healthcare professionals to expand the availability of evidence-based rehabilitation content online.

Keywords: Charcot–Marie–Tooth; rehabilitation; YouTube; patient education; GQS; JAMA; DISCERN; PEMAT

INTRODUCTION

Charcot–Marie–Tooth disease (CMT) is an inherited peripheral neuropathy involving both motor and sensory nerves. Rather than a single clinical entity, it comprises a diverse group of disorders with distinct genetic causes and clinical presentations. Although considered a rare condition, CMT is the most common inherited neuromuscular disorder, with an estimated prevalence of 17.7 per 100,000 individuals (Theadom et al., 2019). More than 100 causative genes have been identified, giving rise to demyelinating, axonal, and intermediate forms that differ in age at onset, clinical severity, and disease progression (Pipis et al., 2019; Sivera Mascaró et al., 2025). The disorder usually progresses slowly. Weakness and muscle atrophy typically appear first in the distal lower limbs and gradually involve the hands and forearms. Clinical expression varies widely, even among individuals carrying the same genetic subtype. Frequently reported features include ankle dorsiflexor weakness, foot drop, pes cavus, hammer toes, sensory impairment, balance deficits, fatigue, and gait disturbances (Pareyson & Marchesi, 2009; Sivera Mascaró et al., 2025). The clinical consequences of CMT extend beyond neurological impairment and frequently affect mobility and everyday function. Progressive muscle weakness, sensory deficits, skeletal deformities, and fatigue contribute to marked differences in physical performance between individuals. These impairments can compromise walking, increase fall risk, and limit participation in everyday activities. Because functional limitations vary considerably, management should be individualized and guided by each patient's clinical presentation rather than the diagnostic label alone.

As curative treatment remains unavailable for most forms of CMT, rehabilitation is a cornerstone of long-term care. Its primary goals are to preserve mobility, maintain independence, and minimize secondary complications. Management may include strengthening and flexibility exercises, aerobic conditioning, balance and gait training, ankle–foot orthoses, assistive devices, and patient education, with interventions selected according to individual clinical needs (Corrado et al., 2016; Tedeschi et al., 2025). Exercise programmes should be planned with careful consideration of muscle strength, fatigue, sensory impairment, structural deformities, and fall risk. Equally important is ensuring that patients and caregivers understand how exercises can be performed correctly and adapted safely as functional abilities change over time. Outside the clinical setting, many people with CMT increasingly seek health information through social media and online video platforms (Chen & Wang, 2021). Among these, YouTube is widely used because it is freely accessible and well suited to demonstrating exercises and rehabilitation techniques in a visual format (Madathil et al., 2015). For many users, these videos reinforce information provided during therapy, demonstrate orthotic use, and offer practical approaches for managing functional limitations encountered in daily life. The accessibility of YouTube is accompanied by important challenges. Health-related content is uploaded without routine scientific review, and its accuracy, reliability, and educational value vary substantially (Osman et al., 2022). Contributors include healthcare professionals, universities, hospitals, patient organizations, commercial companies, patients, and independent users, each with different levels of expertise and different purposes (Sampson et al., 2013). Some videos provide balanced, evidence-based guidance, whereas others contain incomplete treatment information, omit important safety considerations, or fail to identify the author or supporting references.

Previous evaluations of YouTube as a patient education resource have shown that many health-related videos fall below accepted standards for reliability and educational quality. Content produced by professional sources generally performs better than that uploaded by other contributors, although professional authorship alone does not guarantee complete or clinically accurate information (Pavuloori et al., 2025). Likewise, engagement metrics such as views, likes, and comments should not be interpreted as indicators of scientific quality. Several validated instruments are available to evaluate complementary aspects of online health information. DISCERN assesses the reliability of educational resources together with the quality of treatment-related information (Coşar Ertem et al., 2023). The *Journal of the American Medical Association* benchmark criteria evaluate transparency through authorship, attribution, disclosure, and currency (Assylbek et al., 2025). Overall educational value can be assessed using the Global Quality Score, whereas the Patient Education Materials Assessment Tool examines whether audiovisual materials are understandable and whether they support meaningful patient action (Bernard

et al., 2007; Shoemaker et al., 2014). Together, these measures provide a broad evaluation of the quality and practical value of digital health information.

Although rehabilitation is central to CMT management, the educational value of YouTube content addressing this topic has not been comprehensively investigated. Inaccurate, incomplete, or poorly explained exercise recommendations may reduce the effectiveness of rehabilitation and contribute to misconceptions about long-term disease management. The present study therefore evaluated English-language YouTube videos related to Charcot–Marie–Tooth disease and rehabilitation in terms of reliability, transparency, educational quality, understandability, and actionability. It also compared professional and non-professional upload sources and described the rehabilitation topics represented within the available content.

MATERIAL-METHODS

This study was conducted as a cross-sectional content analysis of publicly available YouTube videos related to Charcot–Marie–Tooth disease and rehabilitation. The videos were evaluated according to their source, content characteristics, reliability, transparency, overall educational quality, understandability, and actionability. A systematic search was conducted on YouTube on in July 2026. To minimize the influence of previous browsing history and personalized search results, the search was performed in incognito mode after logging out of all personal accounts. The following English search terms were entered separately into the YouTube search bar: “Charcot-Marie-Tooth disease,” “CMT rehabilitation,” “CMT exercises,” “physical therapy for CMT,” and “CMT physiotherapy.” The titles and web addresses of the identified videos were recorded in a Microsoft Excel spreadsheet. Videos appearing under more than one search term were considered duplicates and were included only once. After duplicate and ineligible videos were removed, 141 videos were included in the final analysis. Videos were included if they were publicly accessible, presented in English, directly related to Charcot–Marie–Tooth disease, and contained information concerning patient education, clinical manifestations, exercise, physiotherapy, rehabilitation, orthotic management, or functional disease management. Duplicate videos, advertisements, unrelated content, news reports without educational information, and videos without spoken or written explanations were excluded. Private, deleted, inaccessible, and silent videos were also excluded. For each eligible video, the title, duration, upload date, number of views, number of likes, number of comments, source of upload, and main content areas were recorded. As user-engagement variables may change over time, all data were collected within the same evaluation period. The subjects addressed in the videos were categorized as disease definition, genetic characteristics, clinical manifestations, diagnostic methods, exercise, physiotherapy, orthotic management, surgical treatment, and patient experience. Videos covering more than one subject were assigned to all relevant categories. Videos were classified according to the individual or organization responsible for uploading the content. Source categories included universities, hospitals, patient associations, physiotherapists, neurologists, other healthcare professionals, commercial organizations, patients, and independent content creators.

For group comparisons, the upload sources were divided into professional sources and other sources. Universities, hospitals, patient associations, physiotherapists, neurologists, and other identifiable healthcare professionals were classified as professional sources. Commercial organizations, patients, independent content creators, and uploaders whose professional qualifications could not be verified were classified as other sources. Of the 141 included videos, 67 were uploaded by professional sources and 74 by other sources.

The reliability of the videos and the quality of treatment-related information were assessed using the DISCERN instrument. DISCERN comprises 16 items rated on a five-point scale, producing a total score between 16 and 80; higher scores indicate greater reliability and better-quality information concerning treatment choices. The first eight items assess the reliability of the material, including the clarity of its aims, relevance, source attribution, currency, balance, and areas of uncertainty. Items 9–15 evaluate the quality of information about treatment options, including their mechanisms, benefits, risks, alternatives, and the consequences of receiving no treatment. The final item provides an overall assessment of information quality (Buschulte et al., 2024).

The transparency of each video was examined using the Journal of the American Medical Association benchmark criteria. Four elements were considered: whether the author or responsible organization was identified, whether supporting sources were provided, whether financial or commercial relationships were disclosed, and whether the information was current. Each element received 1 point when present and 0 when absent, giving a total score between 0 and 4. Higher scores reflected greater transparency (Assylbek et al., 2025).

Overall video quality was rated with the Global Quality Score. This five-point scale considers how clearly the information is organized, how smoothly it is presented, whether important content is covered, and how useful the video is likely to be for patients. A score of 1 indicated very poor quality and little practical value, while a score of 5 indicated a well-structured, comprehensive, and highly useful educational video (Bernard et al., 2007).

Understandability and actionability were assessed with the audiovisual version of the Patient Education Materials Assessment Tool. Understandability refers to how easily viewers with different levels of education and health literacy can follow the material and grasp its main message. Actionability, in contrast, reflects whether the viewer can identify what to do after watching the video. For rehabilitation content, this included whether exercises were demonstrated clearly, whether the steps were explained in a logical order, and whether practical instructions and safety points were included (Shoemaker et al., 2014).

Items that did not apply to a specific video were omitted from the calculation. Understandability and actionability were scored separately as percentages using the following formula: **Score (%) = Number of items rated "agree" / Number of applicable items × 100.** Higher percentages indicated greater understandability or actionability (Shoemaker et al., 2014). Two researchers with expertise in physiotherapy and rehabilitation assessed all eligible videos independently. Before beginning the main evaluation, they reviewed the scoring tools together to ensure that the criteria were interpreted consistently. Each video was then rated separately using DISCERN, the JAMA benchmark criteria, the Global Quality Score, and PEMAT. Any differences in scoring were discussed until agreement was reached; unresolved cases were referred to a third researcher. Blinding to the video source was not possible because uploader details were publicly available and were needed for source classification and assessment of JAMA authorship.

Normally distributed continuous data were reported as mean ± standard deviation, whereas non-normally distributed data were summarized using the median and interquartile range. Categorical variables were presented as frequencies and percentages. Statistical analyses were carried out with SPSS. Data distribution was examined using the Shapiro–Wilk test together with histograms and Q–Q plots. Comparisons between professional-source videos and videos from other sources were performed using the independent-samples *t* test for normally distributed variables and the Mann–Whitney *U* test for non-normal variables. Pearson's chi-square test or Fisher's exact test was used for categorical comparisons, as appropriate. Associations between video-engagement indicators and quality scores were assessed using Pearson's or Spearman's correlation coefficient according to the distribution of the variables. Statistical significance was accepted at $p < .05$.

Ethical Considerations

This study was based exclusively on publicly available YouTube videos. It did not involve human participants, patients, clinical interventions, medical records, biological samples, or identifiable private information. No interaction occurred with video uploaders or viewers, and usernames, viewer comments, and private account information were not analyzed. Therefore, ethics committee approval and informed consent were not required.

RESULTS

A total of 141 YouTube videos were included in the analysis. Of these, 67 videos were uploaded by professional sources and 74 were uploaded by other sources. Videos produced by professional sources received significantly higher scores across all assessment tools. The mean DISCERN score was 69.4 ± 8.5 for professional-source videos and 42.1 ± 10.3 for videos from other sources. The difference between

the groups was statistically significant ($p < .001$). Professional-source videos also had higher JAMA benchmark scores than videos from other sources (3.6 ± 0.5 vs. 1.9 ± 0.8, respectively; $p < .001$). Similarly, the mean Global Quality Score was significantly higher in the professional-source group (4.5 ± 0.6) than in the other-source group (2.9 ± 0.7; $p < .001$). Regarding the Patient Education Materials Assessment Tool, professional-source videos demonstrated greater understandability and actionability. The mean PEMAT understandability score was 92.4 ± 5.1% for professional-source videos and 78.6 ± 9.3% for videos from other sources ($p < .001$). The mean actionability score was also higher among professional-source videos than among other-source videos (86.7 ± 7.8% vs. 59.4 ± 12.6%, respectively; $p < .001$) (Table 1). Overall, videos uploaded by professional sources were more reliable, transparent, educationally useful, understandable, and actionable than videos uploaded by other sources.

Table 1. Comparison of Video Quality Scores According to Upload Source

Parameter	Professional Sources (n = 67)	Other Sources (n = 74)	p value
DISCERN score	69.4 ± 8.5	42.1 ± 10.3	< .001
JAMA benchmark score	3.6 ± 0.5	1.9 ± 0.8	< .001
Global Quality Score	4.5 ± 0.6	2.9 ± 0.7	< .001
PEMAT understandability (%)	92.4 ± 5.1	78.6 ± 9.3	< .001
PEMAT actionability (%)	86.7 ± 7.8	59.4 ± 12.6	< .001

Values are presented as mean ± standard deviation. JAMA = Journal of the American Medical Association; GQS = Global Quality Score; PEMAT = Patient Education Materials Assessment Tool.

CONCLUSION AND DISCUSSION

The present study examined the reliability, transparency, educational quality, understandability, and actionability of YouTube videos related to Charcot–Marie–Tooth disease and rehabilitation. The main finding was the consistent difference between videos uploaded by professional sources and those uploaded by other sources. Professional-source videos performed better across all four assessment tools, including DISCERN, JAMA, GQS, and PEMAT. This finding suggests that the background of the uploader may influence the quality of information available to people seeking guidance on CMT and its rehabilitation.

The difference was particularly clear for DISCERN. Videos uploaded by healthcare professionals, universities, hospitals, and patient organizations had much higher scores than those from other sources. In general, these videos presented treatment-related information in a more organized and balanced way and were more likely to refer to evidence-based recommendations. Similar results have been reported in other rehabilitation-related YouTube studies. Assylbek et al. (2025) observed considerable variation in the quality of stroke rehabilitation videos and highlighted the value of professional involvement in producing online rehabilitation content. Karataş (2024) also found that videos on back pain during pregnancy uploaded by healthcare professionals had higher DISCERN, JAMA, and GQS scores than those produced by nonprofessionals. A comparable pattern was reported by Demirtaş et al. (2026) in an analysis of Parkinson's disease exercise videos. Videos from institutional or healthcare-related sources were more often rated as useful and generally received higher mDISCERN and GQS scores. At the same time, the authors noted that professional authorship did not always mean that the content was complete. Important details, particularly exercise dosage and safety precautions, were still missing from many videos. This is relevant to our findings because it shows that the uploader's professional identity is helpful as an initial indicator, but the content itself still needs to be examined carefully. Our results also

agree with the findings of Özdemir et al. (2023), who reported higher DISCERN and GQS scores for lipedema videos uploaded by healthcare professionals. However, the overall quality of the videos in that study remained low to moderate. This difference suggests that professional authorship can improve the standard of online health information, but it does not automatically ensure that all clinically important topics are covered. In the present study, professional-source videos had a mean DISCERN score of 69.4, indicating relatively high reliability and good coverage of treatment-related information. This score was higher than those reported in several other YouTube studies. For example, exercise videos for rheumatoid arthritis were described as only partly reliable and of moderate quality (Sari et al., 2025). Videos on rehabilitation after distal radius fracture were also rated as moderate overall, even though some included useful exercise demonstrations (Laggner et al., 2024). Likewise, cancer rehabilitation videos did not consistently provide patients with comprehensive or high-quality information (Bahar-Ozdemir et al., 2022). Taken together, these comparisons suggest that CMT videos from professional sources may provide better-quality information than has been reported for several other rehabilitation topics. Even so, high scores should not be interpreted as evidence that every professional video is complete, individualized, or suitable for direct clinical use.

The higher scores observed in our professional group may partly reflect the composition of this category. Universities, healthcare professionals, rehabilitation specialists, and established patient associations were grouped together as professional sources. Patient associations specializing in CMT may produce detailed educational materials because they work closely with clinicians, researchers, patients, and caregivers. Their content may therefore include broader discussion of disease management, exercise, orthotic treatment, and functional limitations. Nevertheless, this explanation should be interpreted cautiously because the present analysis did not separately compare each professional subgroup. JAMA benchmark scores also differed significantly between the two groups. Professional-source videos more frequently identified the author or institution, referred to supporting sources, disclosed relevant information, and provided evidence of currency. Similar differences have been observed in videos concerning back pain during pregnancy, where healthcare-professional videos had higher JAMA scores than nonprofessional videos (Karataş & Karataş, 2024). The low JAMA scores observed among other-source videos in the present study indicate that many of these videos lacked basic indicators of transparency. A video may present generally accurate clinical information while still receiving a low JAMA score when the author or responsible institution is not clearly identified, supporting references are not provided, potential conflicts of interest are not disclosed, or the currency of the information cannot be established. The JAMA benchmark criteria primarily evaluate transparency-related indicators—authorship, attribution, disclosure, and currency—rather than assessing the accuracy of each clinical statement against disease-specific evidence (Assylbek et al., 2025). Therefore, JAMA scores should be interpreted alongside content-based measures such as DISCERN and condition-specific clinical assessment. This issue is especially relevant for CMT-related content. Patients may come across recommendations about orthoses, exercise devices, supplements, or commercially promoted treatment programs without being told how strong the supporting evidence is or whether the uploader has a financial interest in the product being discussed.

In our study, videos from professional sources also received higher Global Quality Scores. These videos were generally easier to follow, better organized, and more useful from a patient-education perspective. Similar concerns have been raised in previous research. Osman et al. (2022), in a systematic review of health-related YouTube studies, reported wide variation in the quality of medical content and cautioned against using views or likes as markers of reliability. In many of the studies included in that review, popularity was either unrelated to quality or associated with lower-quality information.

This has clear implications for CMT education. Patients may choose a video because it appears near the top of the search results, has an appealing title, or has attracted a large number of views. None of these features, however, confirms that the information is complete, balanced, or clinically appropriate. A video may be highly engaging while still omitting important safety information or scientific references. For this reason, visibility should not be mistaken for reliability.

The difference between the groups was also evident in PEMAT understandability scores. Professional-source videos had a mean score of 92.4%, compared with 78.6% for videos from other sources. This may reflect clearer explanations, more logical sequencing, and more effective use of visual

demonstrations. Although healthcare professionals sometimes rely on technical language, the high understandability scores in our study suggest that many professional videos were able to present clinical information in a way that remained accessible to patients. The gap in actionability was even larger. Professional-source videos had a mean actionability score of 86.7%, whereas the mean score for other-source videos was 59.4%. This difference is particularly important in rehabilitation. Patients need more than a general explanation of the disease; they need to understand what action to take, how to perform an exercise, how often to repeat it, and under what circumstances it should be modified or stopped.

Visual demonstration can make rehabilitation content more useful, but simply showing an exercise is not enough. Good-quality instructions should also explain the starting position, number of repetitions, frequency, progression, safety precautions, and warning signs that indicate the exercise should be discontinued. Previous rehabilitation studies have identified similar shortcomings. Laggner et al. (2024) reported that videos on rehabilitation after distal radius fracture contained useful material but were generally of only moderate quality. Sari et al. (2025) likewise found that rheumatoid arthritis exercise videos were only partly reliable and emphasized the need for professional guidance when patients use online exercise resources.

Individualization is particularly important in CMT because the condition includes demyelinating, axonal, and intermediate forms with differing levels of weakness, sensory loss, fatigue, balance impairment, and foot deformity. A general exercise video cannot reflect this clinical variability. An activity that is appropriate for a patient with mild distal weakness may be unsuitable for someone with marked foot drop, contracture, pain, or recurrent falls. For this reason, online exercise content should be used as supportive material rather than as a substitute for individual clinical assessment and rehabilitation planning.

For this reason, YouTube videos should be viewed as supplementary educational materials rather than replacements for individual assessment. Videos can reinforce exercises already prescribed by a physiotherapist, explain the purpose of an orthosis, or demonstrate fall-prevention strategies. They should not be used as the sole basis for selecting exercise intensity or making clinical decisions.

The present findings partly differ from studies reporting predominantly low or moderate quality across YouTube health content. Cancer rehabilitation videos, for example, were not consistently found to provide high-quality or comprehensive information (Bahar-Ozdemir et al., 2022). Pulmonary rehabilitation videos have also been reported to vary in reliability and quality, highlighting the need to guide patients toward appropriate resources (Coşar Ertem & Ertem, 2023). In addition, a systematic review covering a broad range of medical topics concluded that YouTube could not be considered a consistently reliable source of health information (Osman et al., 2022). In contrast, the professional-source videos in our study demonstrated high mean scores across all assessment instruments. This difference may be related to the strong presence of specialized patient associations, universities, and rehabilitation professionals in CMT education. t may also be that professional-source videos scored better because this group included webinars and structured exercise series prepared specifically for patients. Even so, our data do not show which particular features of these videos were responsible for the higher scores. The results should therefore not be taken to mean that every professionally produced video was complete or that all content from other sources was unsuitable. The identity of the uploader can offer some indication of credibility, but it should not be used on its own. Patients and caregivers may share valuable practical experience, while professionally produced videos may still omit references, safety advice, or clear instructions. For that reason, the source of a video should be considered together with its actual content and the scores obtained from structured assessment tools.

These findings also point to a useful role for professional organizations and patient associations. Rather than simply advising patients not to use YouTube, clinicians could help them identify reliable videos and use selected content as part of patient education. This may be especially helpful in rare or inherited conditions, where access to specialized rehabilitation services is not always easy. The educational value of videos could be improved by using plain language, adding subtitles, describing exercise dosage more clearly, including safety warnings, and reminding viewers that assessment and treatment should be individualized.

Future CMT-related videos should address both general information about the disease and practical aspects of rehabilitation. Relevant topics may include safe strengthening, stretching, balance training, energy conservation, footwear, ankle–foot orthoses, fall prevention, hand function, and situations in which professional review is needed. Exercise videos should also make clear that recommendations may need to be adjusted according to fatigue, weakness, deformity, pain, and fall risk.

STRENGTHS AND LIMITATIONS

One strength of this study was the use of several assessment tools that examined different aspects of video quality. DISCERN was used to evaluate reliability and treatment-related information, the JAMA criteria assessed transparency, GQS reflected overall educational quality, and PEMAT examined understandability and actionability. The inclusion of 141 videos also provided a relatively broad overview of CMT-related content available on YouTube.

Several limitations should be acknowledged. YouTube is a constantly changing platform, and video rankings, view counts, likes, comments, and available content may differ over time. The findings therefore reflect the platform only during the period in which the data were collected. Search results may also be influenced by geographic location, platform algorithms, and user-related factors, even when a standardized search strategy is used. Only English-language videos were included, so the findings may not represent the quality of CMT-related content available in other languages. DISCERN was originally developed for written consumer health information, although it is now widely used in YouTube research. The GQS also includes an element of subjective judgment, which makes reviewer training and assessment of inter-rater agreement important. Another limitation is that professional sources were treated as one broad group. Universities, hospitals, individual healthcare professionals, and patient associations may differ in both educational purpose and content quality. Future studies should compare these subgroups separately. Finally, this study assessed the content of the videos rather than their effect on viewers. It remains unclear whether watching higher-scoring videos improves patient knowledge, exercise adherence, self-efficacy, functional performance, or safety. High scores indicate stronger educational characteristics, but they do not demonstrate clinical effectiveness.

CONCLUSION

The results show that the educational quality of YouTube videos about Charcot–Marie–Tooth disease varies considerably. Videos from professional sources were generally more reliable, easier to understand, and more useful for patients. However, the uploader alone is not enough to judge whether the information is accurate or suitable for everyone. YouTube may be helpful for demonstrating exercises, orthotic use, gait training, and fall-prevention methods. It cannot replace an individual clinical assessment. Future videos should give practical and evidence-based guidance on exercise intensity, progression, and safety, while making clear that rehabilitation needs to be adapted to each patient.

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COMPUTATIONAL FLUID DYNAMICS-BASED AERODYNAMIC PERFORMANCE EVALUATION OF NACA 64A206 AIRFOIL USING ANSYS FLUENT

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ABSTRACT

Aerodynamic performance evaluation of aircraft wings is a critical stage in aircraft design due to its direct influence on lift generation, flight stability, and overall efficiency. Computational Fluid Dynamics (CFD) methods provide an effective approach for predicting flow characteristics around airfoil geometries before experimental testing. Therefore, the objective of this study was to numerically investigate the aerodynamic behavior of the NACA 64A206 airfoil using ANSYS Fluent by evaluating velocity distribution, pressure variation, and lift coefficient characteristics.

In this study, the NACA 64A206 airfoil geometry was generated using coordinate data and modeled within the ANSYS environment. A two-dimensional computational flow domain was created, and the airfoil geometry was separated from the fluid region using Boolean operations. Mesh generation was performed with refined edge sizing around the airfoil surface to increase the accuracy of the numerical solution. After defining inlet, outlet, and airfoil boundary conditions, CFD simulations were carried out using ANSYS Fluent. The aerodynamic behavior of the airfoil was examined through velocity magnitude contours, static pressure distributions, flow vectors, and lift coefficient calculations.

The numerical simulation successfully demonstrated the airflow characteristics and aerodynamic performance of the NACA 64A206 airfoil. The velocity distribution showed flow acceleration around the airfoil surface, with a maximum velocity magnitude of approximately **1.86 m/s**. The static pressure distribution varied between approximately −1.26 Pa and 0.49 Pa, demonstrating the pressure difference mechanism responsible for aerodynamic lift generation. The calculated lift coefficient was approximately 0.666, confirming that the selected airfoil geometry provided effective lift performance under the analyzed flow conditions.

The results indicate that ANSYS Fluent is an effective numerical tool for predicting aerodynamic characteristics of aircraft wing profiles. The obtained velocity and pressure distributions clearly demonstrated the relationship between flow behavior and lift generation mechanisms. This CFD-based methodology can be further extended by investigating different airfoil profiles, angles of attack, and flow velocities to improve aerodynamic optimization processes in aircraft wing design.

Key Words: Aircraft Wing; NACA 64A206 Airfoil; Computational Fluid Dynamics; ANSYS Fluent; Aerodynamic Performance

THE ROLE OF INTERNAL CONTROL SYSTEMS IN ENHANCING FINANCIAL PERFORMANCE AND AMONG SMALL AND MEDIUM ENTREPRISES(SMS)

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ABSTRACT

Small and Medium Enterprises (SMEs) play a significant role in economic development through employment generation, innovation, and contributions to national income. Despite their importance, many SMEs continue to experience financial challenges arising from weak internal control systems, poor financial management practices, and increased exposure to fraud and operational inefficiencies. This study examines the role of internal control systems in enhancing financial performance and promoting accountability among SMEs. Specifically, the study investigates how key components of internal control—including the control environment, risk assessment, control activities, information and communication systems, and monitoring mechanisms—influence financial performance and organizational sustainability.

The study adopts a quantitative research approach using a descriptive survey design. Primary data are collected through structured questionnaires administered to owners, managers, and accounting personnel of selected SMEs. Descriptive and inferential statistical techniques are employed to analyze the data and determine the relationship between internal control practices and financial performance indicators such as profitability, liquidity, operational efficiency, and accountability. The study is anchored on the COSO Internal Control Framework and Agency Theory, which provide a theoretical basis for understanding how effective governance and control mechanisms improve organizational performance.

Preliminary findings suggest that SMEs with well-established internal control systems experience improved financial reporting quality, better asset protection, enhanced compliance with regulatory requirements, and reduced incidences of fraud and financial mismanagement. Furthermore, effective internal controls facilitate informed managerial decision-making, strengthen stakeholder confidence, and contribute to long-term business sustainability. However, the study also identifies challenges such as inadequate staff training, limited financial resources, and low technological adoption as barriers to effective implementation of internal control systems.

The study contributes to the accounting literature by providing empirical evidence on the relationship between internal control systems and SME performance in emerging economies. It also offers practical recommendations for business owners, professional accountants, policymakers, and regulatory agencies on strategies to strengthen financial governance and accountability within SMEs. The findings are expected to support the development of policies and capacity-building initiatives aimed at improving financial management practices, enhancing transparency, and promoting sustainable economic growth through stronger accounting and internal control frameworks.

Key words: SMES , Internal control, Transparency, Capacity building initiative, Financial Reporting , technical adoption.

FINANCIAL DECISION-MAKING AUTHORITY AND FINANCIAL FREEDOM AMONG MARRIED COUPLES: EVIDENCE FROM A QUANTITATIVE STUDY

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ABSTRACT

Objective: This study aims to investigate the level of financial decisions making and freedom among spouses and its influence on marital relationships, with a focus on gender equality, autonomy, and decision-making.

Material and Methods: A quantitative research design was employed, using a structured questionnaire administered to 250 married respondents from diverse socio-economic backgrounds. The survey measured variables such as financial decision-making power, access to personal income, savings autonomy, and satisfaction with financial arrangements. Data were analyzed using descriptive statistics and regression analysis to identify patterns and associations between financial freedom and marital harmony.

Results: The findings reveal that couples with higher levels of financial autonomy reported stronger marital satisfaction, trust, and cooperation. Family type influence, where spouses maintain both joint and individual resources, was most strongly correlated with positive relationship outcomes. However, significant gender disparities were observed, with women reporting lower access to independent financial resources compared to men.

Conclusion: Financial freedom plays a critical role in promoting equality and stability within marital relationships. Encouraging equitable income opportunities, financial literacy programs, and balanced decision-making structures can strengthen spousal relationships and contribute to social development.

Keywords: Financial freedom, marital harmony, gender equality, autonomy, and decision-making.

CULTURE AND CIVILIZATION

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ABSTRACT

Culture and civilization are connected yet separate ideas that shape human societies differently over time and across places. Culture encompasses the shared values, beliefs, practices, languages, and artistic expressions that give meaning to daily life and focus on identity and cohesion. In contrast, civilization refers to the organized structures, institutions, and technological progress that enable coordinated living on a broader scale, emphasizing order, governance, and advancement. This ABSTRACT explores the ways culture provides identity and continuity, while civilization facilitates order, governance, and progress, highlighting their distinctive but interdependent roles. It examines their active relationship, emphasizing how cultural values shape political systems, economic models, and social norms, and how developments in civilization alter cultural expressions. By examining historical examples and present-day situations, the study highlights the role of globalization, migration, and digital communication in changing both areas. Ultimately, understanding culture and civilization together offers deeper insight into human development, conflict, adaptation, and creativity. This encourages a more inclusive view of diversity and shared human heritage. The discussion considers the tensions between tradition and modernization, showing how societies manage change without losing their cultural roots. It also reflects the importance of preserving intangible heritage while embracing innovation and sustainability. Furthermore, the ABSTRACT stresses the need for intercultural dialogue, mutual respect, and ethical development in an increasingly connected world. In this world, diverse civilizations coexist and interact, shaping future generations and global harmony in meaningful ways.

Keywords: Culture, Civilization, Identity, Globalization, Heritage, Tradition, Modernization, Diversity, Intercultural Dialogue, Social Norms

BIOCHEMICAL AND METABOLIC BASIS OF BREAKING THE FAST WITH FRESH DATES (PHOENIX DACTYLIFERA): INTEGRATING PROPHETIC PRACTICE WITH CONTEMPORARY NUTRITIONAL SCIENCE

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ABSTRACT

Breaking the fast with fresh dates (Phoenix dactylifera) is a well-known practice in Islam that has been followed for centuries. In recent years, advances in nutritional biochemistry and metabolic research have provided scientific evidence that helps explain many of the physiological benefits associated with this practice. This review brings together published findings on the nutritional composition of fresh dates and their effects on human metabolism during the transition from fasting to feeding. The paper focuses on carbohydrate metabolism, glycogen restoration, electrolyte balance, antioxidant activity, digestive physiology, and metabolic health while highlighting areas where further human studies are still needed. The main aim of this review is to present current scientific knowledge on the biochemical and metabolic basis of consuming fresh dates at the time of breaking the fast. The specific objectives are to summarize the nutritional constituents of fresh dates, describe metabolic changes that occur during fasting, discuss how date consumption supports recovery after fasting, compare available findings from experimental and clinical studies, and identify directions for future research. Relevant literature was gathered from peer-reviewed articles indexed in major scientific databases, including PubMed, Scopus, Web of Science, Google Scholar, and ScienceDirect. Original research articles, systematic reviews, and authoritative reports published mainly during the last two decades were considered. Studies addressing the nutrient composition of dates, glycemic response, antioxidant properties, gastrointestinal function, and Ramadan fasting were included, while reports with insufficient scientific detail or unrelated outcomes were excluded. Published evidence shows that fresh dates provide readily available glucose and fructose, allowing a gradual restoration of circulating blood glucose after prolonged fasting. Their natural sugars also support replenishment of hepatic glycogen stores without relying on refined carbohydrates. Fresh dates contain dietary fiber, which helps moderate glucose absorption and supports gastrointestinal function following fasting. They are rich in potassium and provide smaller amounts of magnesium and calcium that help maintain normal neuromuscular activity and electrolyte balance. In addition, dates contain phenolic acids, flavonoids, carotenoids, and other antioxidant compounds that help reduce oxidative stress generated during prolonged food deprivation. Experimental studies have also reported anti-inflammatory activity and favorable effects on gut microbiota, although larger human clinical trials remain limited. Current findings indicate that breaking the fast with fresh dates provides a practical combination of rapid energy replacement, digestive comfort, micronutrient supply, and antioxidant protection. These characteristics are consistent with the metabolic requirements of the body immediately after fasting. However, differences among date cultivars, stages of ripeness, growing conditions, serving sizes, and study designs make direct comparison between reports difficult. Additional multicenter clinical studies involving healthy individuals and people living with metabolic disorders would strengthen the available evidence. In summary, present scientific literature supports the view that fresh dates are a nutrient-dense functional food well suited for breaking the fast. Their unique combination of natural sugars, dietary fiber, minerals, vitamins, and bioactive phytochemicals provides biochemical support for post-fast metabolic recovery. Continued interdisciplinary research linking nutrition, biochemistry, clinical medicine, and food science will further improve understanding of the health benefits associated with this long-standing dietary practice.

Keywords: Phoenix dactylifera; Fresh dates; Fasting; Ramadan; Biochemistry; Carbohydrate metabolism; Glycogen restoration; Oxidative stress; Antioxidants; Functional foods.

INTELLIGENT PROCESS CONTROL OF DUAL CONICAL TANK SYSTEMS THROUGH DEEP LEARNING-BASED LEVEL PREDICTION

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ABSTRACT

The Dual Conical Tank System (DCTS) is a nonlinear process commonly used in industrial liquid storage and level control applications. Accurate prediction of water levels in interconnected tanks is essential for maintaining process stability and operational efficiency. This study presents a deep learning-based approach for predicting the water levels of both Tank 1 (H1) and Tank 2 (H2) in a dual conical tank system. The proposed framework utilizes process parameters such as inlet flow rate, outlet flow rate, pump voltage, and historical level measurements as input features. Deep learning models, including Long Short-Term Memory (LSTM), Gated Recurrent Unit (GRU), and Deep Neural Network (DNN), are employed to capture the nonlinear and dynamic behaviour of the system. The models are trained using experimentally acquired process data and evaluated using performance metrics such as Mean Squared Error (MSE), Root Mean Square Error (RMSE), coefficient of determination (R^2), and prediction accuracy. The results demonstrate that the proposed deep learning models effectively predict the water levels of both tanks with high accuracy, enabling improved monitoring and intelligent control of the process. The developed approach provides a reliable and data-driven solution for modelling complex nonlinear tank systems and supports the advancement of smart industrial automation and process control applications.

Keywords: Dual Conical Tank System, Deep Learning, Water Level Prediction, LSTM, GRU, DNN, Nonlinear Process Control

DIGITAL TWIN-ASSISTED MULTIDISCIPLINARY CLINICAL DECISION SUPPORT SYSTEMS IN THE PERIOPERATIVE PROCESS: TRANSITION TO THE SMART OPERATING ROOM

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ÖZET

Giriş ve Amaç: Dijital ikiz teknolojisi, hasta verileriyle dinamik biçimde güncellenen sanal modeller aracılığıyla klinik durumların izlenmesine, analiz edilmesine ve farklı senaryoların simüle edilmesine olanak sağlayan gelişmekte olan bir yaklaşımdır. Bu teknoloji, perioperatif süreçte klinik karar vermeyi destekleme, komplikasyon risklerinin erken belirlenmesine katkı sağlama ve kişiselleştirilmiş bakımı kolaylaştırma potansiyeli taşımaktadır. Bu derlemenin amacı, perioperatif dönemde dijital ikiz destekli multidisipliner klinik karar sistemlerinin uygulama alanlarını, potansiyel katkılarını, sınırlılıklarını ve karşılaşılan güçlükleri güncel literatür doğrultusunda değerlendirmektir.

Yöntem: Bu çalışma narratif derleme olarak tasarlanmıştır. Haziran 2026'da PubMed ve Google Scholar veri tabanlarında yıl sınırlaması uygulanmadan literatür taraması gerçekleştirilmiştir. Dijital ikiz teknolojisinin cerrahi planlama, intraoperatif yönetim, postoperatif bakım, ameliyathane iş akışları, meslekler arası iş birliği ve cerrahi eğitimde kullanımını ele alan yayınlar incelenmiş ve elde edilen bilgiler ortak tematik başlıklar altında sentezlenmiştir.

Bulgular: İncelenen yayınlar, dijital ikiz teknolojisinin elektronik sağlık kayıtları, tıbbi görüntüleme sistemleri, giyilebilir sensörler ve intraoperatif monitörizasyon sistemlerinden elde edilen verileri bütünleştirerek hastaya özgü dinamik sanal modeller oluşturma potansiyeli taşıdığını göstermektedir. Bu modeller ise farklı cerrahi stratejilerin ameliyat öncesinde değerlendirilmesini, intraoperatif karar süreçlerinin desteklenmesini ve postoperatif komplikasyon risklerinin erken belirlenmesini kolaylaştırabilir. Ayrıca ameliyathane iş akışlarının ve kaynak kullanımının iyileştirilmesi, multidisipliner ekip iletişiminin desteklenmesi ve simülasyona dayalı cerrahi eğitimin geliştirilmesi açısından kullanılabilir. Bununla birlikte mevcut kanıtların önemli bir bölümü kavramsal çalışmalar, teknik modeller ve prototip uygulamalardan oluşmaktadır. Veri güvenliği, hasta mahremiyeti, yüksek uygulama maliyetleri, teknik altyapı gereksinimleri ve düzenleyici belirsizlikler teknolojinin klinik kullanımını sınırlandırmaktadır.

Sonuç: Dijital ikiz destekli klinik karar sistemleri, perioperatif bakımın güvenliğini, kalitesini ve kişiselleştirilmesini geliştirme açısından önemli bir potansiyel taşımaktadır. Ancak klinik etkililiğinin ortaya konulabilmesi için prospektif ve çok merkezli doğrulama çalışmalarına gereksinim bulunmaktadır. Teknolojinin rutin klinik uygulamalara güvenli biçimde entegre edilebilmesi için teknik gelişmelerin klinik doğrulama, güçlü veri yönetişimi ve kapsamlı etik ve hukuki düzenlemelerle birlikte yürütülmesi gerekmektedir.

Anahtar Kelimeler: Dijital İkiz, Perioperatif Bakım, Klinik Karar Destek Sistemleri, Cerrahi İşlemler, Ameliyathaneler.

ABSTRACT

Introduction and Aim: Digital twin technology is an emerging approach that enables clinical conditions to be monitored, analysed, and simulated through virtual models that are dynamically updated with patient data. In the perioperative process, this technology has the potential to support clinical decision-making, contribute to the early identification of complication risks, and facilitate personalised care. This review aimed to evaluate the application areas, potential contributions, limitations, and challenges of digital twin-assisted multidisciplinary clinical decision support systems in the perioperative period based on the current literature.

Methods: This study was designed as a narrative review. PubMed and Google Scholar were searched in June 2026 without applying a publication year restriction. Publications addressing the use of digital twin technology in surgical planning, intraoperative management, postoperative care, operating room workflows, interprofessional collaboration, and surgical education were reviewed. The information obtained was synthesised under common thematic headings.

Results: The reviewed publications suggest that digital twin technology has the potential to integrate data obtained from electronic health records, medical imaging systems, wearable sensors, and intraoperative monitoring systems to create patient-specific dynamic virtual models. These models may facilitate the preoperative evaluation of different surgical strategies, support intraoperative decision-making, and contribute to the early identification of postoperative complication risks. They may also be used to improve operating room workflows and resource utilisation, support multidisciplinary team communication, and enhance simulation-based surgical education. However, much of the current evidence consists of conceptual studies, technical models, and prototype applications. Data security, patient privacy, high implementation costs, technical infrastructure requirements, and regulatory uncertainties continue to limit clinical adoption.

Conclusion: Digital twin-assisted clinical decision support systems have considerable potential to improve the safety, quality, and personalisation of perioperative care. However, prospective and multicentre validation studies are needed to establish their clinical effectiveness. For this technology to be safely integrated into routine clinical practice, technological advances should be accompanied by clinical validation, robust data governance, and comprehensive ethical and legal frameworks.

Keywords: Digital Twin, Perioperative Care, Clinical Decision Support Systems, Surgical Procedures, Operating Rooms.

GİRİŞ

Cerrahi girişimler, teknolojik ilerlemelere rağmen mortalite ve morbidite riski taşıyan karmaşık süreçler olmaya devam etmektedir. Cerrahi travmanın fizyolojik etkileri ve perioperatif komplikasyonlar, hasta güvenliği ve sağlık hizmetlerinin sürdürülebilirliği açısından küresel ölçekte önemini korumaktadır (Dobson, 2020). Bu nedenle perioperatif süreçte hasta verilerinin gerçek zamanlı olarak bütünleştirilmesi, klinik risklerin erken dönemde belirlenmesi ve multidisipliner karar verme süreçlerinin desteklenmesi giderek daha fazla önem kazanmaktadır. Dijital ikiz teknolojisi, bu gereksinimlere yanıt verebilecek yenilikçi yaklaşımlardan biri olarak değerlendirilmektedir (Vallée, 2023).

Dijital ikizler, elektronik sağlık kayıtları, tıbbi görüntüleme sistemleri, giyilebilir sensörler, fizyolojik monitörler ve diğer klinik veri kaynaklarından elde edilen çok kaynaklı verilerin hastaya özgü, dinamik bir sanal model içerisinde bütünleştirilmesini amaçlamaktadır (Armeni et al., 2022; Venkatesh et al., 2022). Hastanın tıbbi geçmişi, anatomik özellikleri, fizyolojik parametreleri ve gerektiğinde moleküler veya genetik verilerinin birlikte değerlendirilmesi, kişiselleştirilmiş cerrahi planlama, anestezi yönetimi ve perioperatif bakım yaklaşımlarının geliştirilmesini destekleyebilir (Kamel Boulos & Zhang, 2021; Coorey et al., 2022).

Yapay zekâ ve makine öğrenmesi algoritmalarıyla bütünleştirilen dijital ikiz modelleri, hastanın güncel klinik verileri ve zaman içerisindeki fizyolojik değişimleri temel alınarak farklı tedavi veya cerrahi senaryoların olası sonuçlarını simüle etmek amacıyla kullanılabilir (Sun et al., 2022). Bu modeller ise perioperatif dönemde klinik kötüleşme ve komplikasyon risklerinin erken belirlenmesine, farklı cerrahi yaklaşımların karşılaştırılmasına ve bireyselleştirilmiş kararların desteklenmesine katkı sağlayabilir (Armeni et al., 2022; Venkatesh et al., 2022). Bununla birlikte mevcut kanıtların önemli bir bölümü kavramsal çalışmalar, teknik modeller ve sınırlı sayıdaki klinik uygulamalara dayanmaktadır. Bu nedenle dijital ikizlerin rutin cerrahi bakımda doğrulanmış klinik karar destek sistemleri olarak kullanımı henüz gelişim aşamasındadır (Asciak et al., 2025).

Dijital ikizlerin perioperatif sürece entegrasyonu, cerrahların, anestezi uzmanlarının ve perioperatif hemşirelerin ortak bir hastaya özgü veri modeli üzerinden değerlendirme ve planlama yapmasını destekleyebilir. Bu yaklaşım multidisipliner ekip iletişiminin güçlendirilmesi, yüksek riskli hastaların belirlenmesi, kaynakların gereksinimlere göre planlanması ve bakım süreçlerinin kişiselleştirilmesi açısından önemli bir potansiyel taşımaktadır (Lam et al., 2022; Asciak et al., 2025). Bununla birlikte veri güvenliği, algoritmik doğruluk, sistemlerin birlikte çalışabilirliği, uygulama maliyetleri ve sağlık profesyonellerinin teknolojik yetkinliği gibi konular, klinik entegrasyon öncesinde ele alınması gereken önemli sınırlılıklardır (Venkatesh et al., 2022; Asciak et al., 2025).

Bu derlemenin amacı, perioperatif dönemde dijital ikiz destekli multidisipliner klinik karar destek sistemlerinin cerrahi planlama, intraoperatif yönetim, postoperatif bakım, ameliyathane iş akışları ve meslekler arası iş birliğindeki potansiyel kullanım alanlarını güncel literatür doğrultusunda incelemek ve uygulamaya ilişkin teknik, etik ve düzenleyici güçlükleri değerlendirmektir.

YÖNTEM

Bu çalışma narratif derleme olarak tasarlanmıştır. Literatür taraması, Haziran 2026'da PubMed ve Google Scholar üzerinden yıl sınırlaması uygulanmadan gerçekleştirilmiştir. Taramada "digital twin", "digital twin-assisted surgery", "perioperative care", "clinical decision support systems", "smart operating room", "digital surgery" ve "surgical education" anahtar kelimeleri tek başına ve farklı kombinasyonlar hâlinde kullanılmıştır. Ayrıca ulaşılan çalışmaların kaynakçaları taranarak konuyla ilişkili ek yayınlar değerlendirmeye alınmıştır. Dijital ikiz teknolojisinin cerrahi planlama, intraoperatif yönetim, postoperatif bakım, ameliyathane iş akışları, multidisipliner ekip çalışması ve cerrahi eğitimde kullanımını ele alan araştırma makaleleri, derlemeler, uzlaşı raporları, kavramsal çalışmalar ve teknik yayınlar incelenmiştir. Konuyla doğrudan ilişkili olmayan yayınlar değerlendirme dışında bırakılmıştır. Elde edilen bilgiler ortak tematik başlıklar altında sentezlenerek sunulmuştur.

KAVRAMSAL TEMELLER VE TARİHSEL GELİŞİM

Literatürde dijital ikiz için üzerinde uzlaşılmış tek bir tanım bulunmamakla birlikte kavram genel olarak fiziksel bir varlığın, sistemin, sürecin veya bireyin durumunu ve davranışlarını yansıtmak üzere güncel verilerle beslenen dinamik sanal temsilini ifade etmektedir. İşlevsel bir dijital ikiz, fiziksel varlık, bu varlığın sanal temsili, ikisi arasındaki veri bağlantısı ve verileri işleyen analiz veya simülasyon bileşenlerinden oluşmaktadır. Sanal modelin fiziksel varlıktan elde edilen verilerle güncellenmesi mevcut durumun izlenmesini, farklı senaryoların değerlendirilmesini, olası değişimlerin öngörülmesini ve karar süreçlerinin desteklenmesini sağlayabilir (Yao et al., 2023; Venkatesh et al., 2022).

Dijital model, dijital gölge ve dijital ikiz kavramları arasındaki ayrım, fiziksel ve sanal varlık arasındaki veri bütünleşmesinin düzeyi ve yönü temel alınarak yapılmaktadır. Kritzinger ve arkadaşlarının (2018) endüstri temelli sınıflandırmasına göre dijital modelde fiziksel varlık ile sanal temsil arasında otomatik veri alışverişi bulunmaz. Dijital gölgede fiziksel varlıktaki değişiklikler sanal modele otomatik olarak aktarılırken veri akışı ağırlıklı olarak tek yönlüdür. Dijital ikizde ise fiziksel ve sanal bileşenler arasındaki veri akışı ve geri bildirim döngüsü iki yönlü olarak bütünleştirilmektedir. Bununla birlikte sağlık alanında sanal modelden fiziksel sürece yönelen geri bildirim, hastaya doğrudan ve otomatik bir müdahale anlamına gelmeyebilir. Model çıktıları cerrahın veya multidisipliner klinik ekibin kararlarını destekleyen bilgi, uyarı ya da görsel yönlendirme biçiminde sunulabilir (Asciak et al., 2025).

Bu nedenle yalnızca hastaya ait üç boyutlu anatomik bir modelin oluşturulması veya tek seferlik bir simülasyonun gerçekleştirilmesi, sistemi dijital ikiz olarak tanımlamak için yeterli değildir. Sanal modelin hasta veya klinik süreçle işlevsel bir veri bağlantısını sürdürmesi, güncel verilerle dinamik olarak yenilenmesi ve izlem, simülasyon, öngörü ya da karar desteği amacıyla kullanılabilecek çıktılar üretmesi gerekmektedir (Qin & Wu, 2022; Asciak et al., 2025).

Dijital ikiz yaklaşımının kavramsal temelleri, ürün yaşam döngüsü yönetimi ile havacılık, uzay ve endüstriyel üretim alanlarında geliştirilen modelleme ve simülasyon uygulamalarına dayanmaktadır. Sensör teknolojileri, Nesnelerin İnterneti, bulut bilişim, yapay zekâ ve veri analitiğindeki gelişmelerle birlikte dijital ikizlerin kullanım alanı üretimden ulaşım, lojistik, eğitim ve sağlık hizmetlerine doğru genişlemiştir (Kritzinger et al., 2018; Peshkova et al., 2023; Yao et al., 2023).

Sağlık alanında ise dijital ikizler, bir organın, hastalık sürecinin, hastanın bütüncül klinik durumunun veya sağlık hizmeti iş akışının modellenmesinde kullanılabilir. Tıbbi görüntüleme bulguları, elektronik sağlık kayıtları, fizyolojik monitörizasyon verileri, giyilebilir sensörler ve gerektiğinde moleküler verilerin bütünleştirilmesiyle oluşturulan hasta odaklı modeller, klinik değişimlerin izlenmesi ve kişiselleştirilmiş sağlık hizmetlerinin desteklenmesi açısından önemli bir potansiyel taşımaktadır (Kamel Boulos & Zhang, 2021; Armeni et al., 2022). Bununla birlikte sağlık alanındaki uygulamaların önemli bir bölümü hâlen kavramsal model, simülasyon veya prototip düzeyindedir ve doğrulanmış rutin klinik uygulamalar sınırlıdır (Venkatesh et al., 2022; Asciak et al., 2025). Bu nedenle bir sistem dijital ikiz olarak tanımlanırken kullanılan veri kaynakları, modelin güncellenme biçimi, gerçekleştirdiği analizler ve klinik sürece sağladığı geri bildirim açıkça belirtilmelidir.

CERRAHİ TEKNOLOJİLERİN EVRİMİ VE MEVCUT SİSTEMLERİN SINIRLILIKLARI

Son birkaç on yılda tıp ve mühendislik alanlarında yaşanan teknolojik gelişmeler, cerrahi uygulamaları önemli ölçüde dönüştürmüştür. Minimal invaziv cerrahinin klinik uygulamaya girmesi bu dönüşümün temel aşamalarından biri olmuştur. Minimal invaziv yaklaşımlar, cerrahi doku travmasının azaltılması, iyileşme süresinin kısaltılması ve bazı postoperatif komplikasyonların sınırlandırılması amacıyla geliştirilmiştir (Cuschieri, 1991; Fuchs, 2002). Daha sonraki dönemde robotik cerrahi sistemleri ve gelişmiş intraoperatif görüntüleme teknolojileri, cerrahlara daha yüksek hareket hassasiyeti, gelişmiş görselleştirme ve daha kontrollü alet kullanımı sağlama potansiyeli sunmuştur (Mack, 2001; Dupont et al., 2021).

Cerrahi girişimlerin planlanması ve uygulanmasında bilgisayar teknolojilerinden yararlanılması, bilgisayar destekli cerrahi ve girişim kavramlarını ortaya çıkarmıştır. Bilgisayar destekli cerrahi cerrahi planlama, görüntü işleme, navigasyon, intraoperatif yönlendirme ve karar desteği amacıyla bilgisayar tabanlı araçların kullanıldığı geniş bir uygulama alanını kapsamaktadır (Giménez et al., 2020). Bu sistemler ortopedik cerrahi, görüntü kılavuzlu nöroşirürji, nöronavigasyon ve hibrit ameliyathane uygulamaları gibi farklı alanlarda kullanılmaktadır (Picard et al., 2019; Giménez et al., 2020). Dijital cerrahi kavramı ise ameliyat öncesi planlamanın yanı sıra intraoperatif uygulamaları, postoperatif süreçleri ve cerrahi eğitimi de içeren daha geniş bir çerçeve sunmaktadır (Lam et al., 2022).

Yapay zekâ, makine öğrenmesi, robotik sistemler ve cerrahi veri bilimindeki gelişmeler, cerrahi karar destek sistemlerinin kapsamını genişletmiştir. Cerrahi video görüntüleri, fizyolojik sinyaller ve cihazlardan elde edilen veriler, anatomik yapıların tanınması, cerrahi aşamaların sınıflandırılması, riskli durumların belirlenmesi ve klinik kararların desteklenmesi amacıyla analiz edilebilmektedir. Bununla

birlikte veri kalitesi, algoritmik önyargı, açıklanabilirlik, dış doğrulama ve sağlık profesyonelinin klinik karar sürecindeki sorumluluğu gibi konular, bu teknolojilerin güvenli klinik kullanımı açısından önemini korumaktadır (Hashimoto et al., 2018; Maier-Hein et al., 2022).

Bu gelişmelere rağmen mevcut dijital cerrahi sistemlerinin önemli bir bölümü belirli bir işlevi yerine getiren ve diğer sistemlerden kısmen bağımsız çalışan teknolojilerden oluşmaktadır. Bu sistemlerin hasta ve cerrahi süreçle ilgili çok kaynaklı verileri ortak ve dinamik bir model içinde bütünleştirmesini sınırlayan başlıca sorunlar aşağıda açıklanmıştır.

Haptik geri bildirimin sınırlı olması: Robot destekli cerrahi platformlarının önemli bir bölümü, doğal dokunsal duyuyu ve kuvvet geri bildirimini yeterli düzeyde sağlayamamaktadır. Bu durum cerrahın doku sertliği, doku direnci ve uygulanan kuvvet gibi özellikleri doğrudan algılamasını güçleştirebilir. Yeni sensör ve geri bildirim sistemleri geliştirilmekle birlikte bunların rutin klinik kullanıma aktarılması teknik ve güvenlikle ilişkili güçlükler taşımaktadır (Enayati et al., 2016; Colan et al., 2024).

Sanal modellerin statik veya sınırlı biçimde güncellenmesi: Bazı bilgisayar destekli cerrahi sistemleri ameliyat öncesi görüntüler ve önceden oluşturulmuş anatomik modeller üzerinden çalışmaktadır. Cerrahi işlem sırasında meydana gelen doku deformasyonlarının, anatomik yer değiştirmelerin ve fizyolojik değişikliklerin sanal modele eş zamanlı olarak aktarılması her sistemde mümkün değildir. Bu nedenle üç boyutlu modelleme, cerrahi navigasyon ve genişletilmiş gerçeklik uygulamalarının önemli bir bölümü, hasta ve cerrahi süreçle dinamik veri bağlantısı kuran tam işlevli bir dijital ikiz niteliği taşımamaktadır (Zaffino et al., 2020; Qin & Wu, 2022; Asciak et al., 2025).

Sistemler arası birlikte çalışabilirlik sorunları: Ameliyathanelerde kullanılan görüntüleme cihazları, fizyolojik monitörler, anestezi sistemleri, robotik platformlar ve elektronik sağlık kayıtları farklı veri formatları, zaman damgaları ve iletişim standartları kullanabilmektedir. Bu sistemlerin kesintisiz ve güvenli veri paylaşamaması, hasta verilerinin ortak bir klinik karar destek modeli içerisinde bütünleştirilmesini güçleştirmektedir (Lam et al., 2022; Maier-Hein et al., 2022; Asciak et al., 2025).

Bu sınırlılıklar, mevcut teknolojilerin etkisiz olduğu anlamına gelmemelidir. Statik veya parçalı dijital sistemlerden, hastaya özgü verilerle dinamik olarak güncellenen bütünleşik modellere geçiş gereksinimini göstermektedir. Dijital ikiz destekli cerrahi sistemleri, anatomik ve fizyolojik verileri ortak bir modelde bütünleştirerek multidisipliner ekibe güncel karar desteği sunmayı amaçlamaktadır. Ancak bu sistemlerin klinik kullanıma geçebilmesi için teknik doğruluklarının, güvenilirliklerinin, iş akışına etkilerinin ve hasta sonuçları üzerindeki yararlarının uygun klinik çalışmalarla doğrulanması gerekmektedir (Venkatesh et al., 2022; Asciak et al., 2025).

DİJİTAL İKİZ DESTEKLİ CERRAHİ (DTAS) VE METODOLOJİK İŞLEYİŞ

Bilgisayar destekli cerrahi sistemlerinin hastaya özgü ve dinamik biçimde güncellenebilen dijital ikiz modelleriyle bütünleştirilmesi, güncel literatürde dijital ikiz destekli cerrahi (Digital Twin-Assisted Surgery–DTAS) olarak tanımlanmaktadır. Qin ve Wu (2022), dijital ikiz teknolojisinin bilgisayar destekli cerrahiye entegrasyonunun cerrahi süreçlerin izlenmesi, simüle edilmesi, öngörülmesi ve optimize edilmesine katkı sağlayabileceğini belirtmiştir. Asciak ve arkadaşları (2025) ise bu yaklaşımı DTAS çerçevesinde ele almıştır. DTAS, hastaya ait anatomik ve fizyolojik verileri cerrahi sürece ilişkin bilgilerle dinamik bir sanal model içerisinde bütünleştirerek cerrahi planlama, intraoperatif yönlendirme, eğitim ve klinik karar desteğini geliştirmeyi amaçlayan ve henüz gelişim aşamasında olan bir yaklaşımdır.

DTAS'ın metodolojik işleyişi veri toplama ve bütünleştirme, veri hazırlama ve kalite kontrolü, hastaya özgü modelin oluşturulması ve kalibrasyonu, simülasyon ve modelin doğrulanmasıyla klinik karar desteği ve geri bildirim aşamalarından oluşmaktadır. Bu aşamalar doğrusal bir süreçten çok, yeni klinik verilerle sürekli olarak güncellenen döngüsel bir yapı göstermektedir (Armeni et al., 2022).

Veri toplama ve bütünleştirme: DTAS'ın ilk aşamasında hastaya ait veriler farklı kaynaklardan elde edilmektedir. Bu veriler bilgisayarlı tomografi, manyetik rezonans ve ultrason gibi tıbbi görüntüleme yöntemlerinin yanı sıra elektronik sağlık kayıtları, laboratuvar sonuçları, fizyolojik monitörler, tıbbi cihazlar ve giyilebilir sensörlerden sağlanabilir. Cerrahi gereksinime göre intraoperatif görüntü, video

ve robotik sistem verileri ile moleküler veya genetik bilgiler de modele eklenebilir (Armeni et al., 2022; Venkatesh et al., 2022; Asciak et al., 2025).

Veri hazırlama ve kalite kontrolü: Farklı kaynaklardan elde edilen verilerin modele aktarılmasından önce veri formatlarının uyumlaştırılması, zaman damgalarının eşleştirilmesi, eksik veya hatalı kayıtların belirlenmesi ve ölçüm artefaktlarının giderilmesi gerekmektedir (Asciak et al., 2025). Ayrıca verilerin kaynağı, ölçüm koşulları ve güncelliği izlenebilir olmalıdır. Veri setlerindeki sistematik eksiklikler ve önyargılar, modelin belirli hasta gruplarında hatalı tahminler üretmesine neden olabileceğinden veri kalitesinin ve temsiliyetinin değerlendirilmesi DTAS'ın güvenilirliği açısından temel bir aşamadır (Venkatesh et al., 2022; Meijer et al., 2023; Asciak et al., 2025).

Hastaya özgü modelin oluşturulması ve kalibrasyonu: İşlenmiş veriler, hastanın anatomik ve fizyolojik özelliklerini temsil eden sanal modelin oluşturulmasında kullanılmaktadır. Yapay zekâ ve makine öğrenmesi yöntemleri, tıbbi görüntülerdeki anatomik yapıların otomatik olarak bölümlendirilmesi, üç boyutlu geometrilerin yeniden oluşturulması ve modele ait bazı parametrelerin belirlenmesi amacıyla kullanılabilir. Rouhollahi ve arkadaşları (2023), aort darlığı bulunan hastalarda tıbbi görüntülerden hastaya özgü kardiyak geometrilerin oluşturulmasına yönelik otomatik bir derin öğrenme yaklaşımı geliştirmiştir. Bununla birlikte görüntü segmentasyonu sonucunda elde edilen statik bir üç boyutlu model, güncel klinik verilerle dinamik biçimde ilişkilendirilmediği sürece tek başına tam işlevli bir dijital ikiz olarak değerlendirilmemelidir (Qin & Wu, 2022; Asciak et al., 2025).

Simülasyon, doğrulama ve belirsizlik analizi: Hastaya özgü fizyolojik koşulların modellenmesinde sonlu eleman analizi ve hesaplamalı akışkanlar dinamiği gibi ileri simülasyon yöntemlerinden yararlanılabilir. Bu yöntemler aracılığıyla dokuların biyomekanik davranışları, organ deformasyonları ve kan akımındaki değişiklikler sanal ortamda incelenebilir. Hastanın anatomik özellikleri, fizyolojik parametreleri, yaşı ve eşlik eden hastalıklarının modele eklenmesi simülasyonların bireyselleştirilmesine katkı sağlayabilir (Corral-Acero et al., 2020; Coorey et al., 2022; Asciak et al., 2025). Bununla birlikte model çıktılarının klinik kullanımından önce teknik doğrulamanın, klinik geçerlemenin ve belirsizlik analizinin yapılması gerekmektedir. Uygun durumlarda farklı merkezlerden ve hasta gruplarından elde edilen verilerle dış doğrulama yapılması da modelin genellenebilirliğinin değerlendirilmesi açısından önemlidir (Meijer et al., 2023; Asciak et al., 2025).

Klinik karar desteği ve geri bildirim: Doğrulanmış bir DTAS modeli, farklı cerrahi yaklaşımların karşılaştırılması, olası komplikasyon risklerinin tahmin edilmesi ve hastaya özgü klinik senaryoların değerlendirilmesi amacıyla kullanılabilir. Bununla birlikte model çıktıları kesin talimatlar veya bağımsız klinik kararlar olarak değil, belirsizlik düzeyleriyle birlikte sunulan karar destek bilgileri olarak değerlendirilmelidir. Nihai kararın cerrah, anestezi uzmanı, perioperatif hemşire ve ilgili diğer sağlık profesyonellerinden oluşan multidisipliner ekip tarafından verilmesi gerekir. İntraoperatif ve postoperatif süreçte elde edilen yeni verilerin modele aktarılması, sanal modelin güncellenmesini ve tahminlerin yeniden değerlendirilmesini sağlayarak dijital ikize özgü geri bildirim döngüsünü tamamlamaktadır (Venkatesh et al., 2022; Meijer et al., 2023; Asciak et al., 2025).

Preoperatif ve İntraoperatif Süreçte Karar Desteği

Preoperatif dönemde DTAS, hastaya ait anatomik ve fizyolojik özelliklerin ameliyat öncesinde bütüncül olarak değerlendirilmesine katkı sağlayabilir (Asciak et al., 2025). Hastaya özgü modeller aracılığıyla farklı cerrahi yaklaşımların sanal ortamda karşılaştırılması, riskli anatomik yapıların belirlenmesi ve planlanan girişimin olası sonuçlarının değerlendirilmesi mümkün olabilir. Bu modellerden elde edilen görüntü ve simülasyonların multidisipliner vaka sunumlarında kullanılması, ortak cerrahi planın oluşturulmasını ve ekip üyelerinin olası riskler hakkında önceden bilgilendirilmesini destekleyebilir. Bununla birlikte bu yararların büyük ölçüde kavramsal çalışmalar ve araştırma düzeyindeki uygulamalara dayandığı göz önünde bulundurulmalıdır (Ahmed & Devoto, 2021; Asciak et al., 2025; Mekki et al., 2025).

Genişletilmiş gerçeklik ve cerrahi navigasyon sistemleriyle bütünleştirilen dijital modeller, hedef anatomik yapıların ve riskli bölgelerin ameliyat sırasında görüntülenmesine, cerrahi aletlerin konumunun izlenmesine ve planlanan girişim yolunun doğrulanmasına yardımcı olabilir. Kafa tabanı cerrahisi için geliştirilen Twin-S sistemi cerrahi aleti, anatomik modeli ve cerrahi kamerayı optik izleme yoluyla takip ederek cerrahi işlem sırasında meydana gelen değişiklikleri sanal modele gerçek zamanlı

olarak aktarmak üzere tasarlanmıştır. Ancak sistemin değerlendirilmesi cerrahi fantom kullanılan deneysel bir ortamda gerçekleştirilmiştir. Bu nedenle Twin-S, rutin klinik uygulamaya geçmiş bir sistemden çok, dijital ikiz destekli cerrahi navigasyonun uygulanabilirliğini gösteren bir araştırma prototipi olarak değerlendirilmelidir (Shu et al., 2023).

İntraoperatif dönemde fizyolojik monitörlerden, görüntüleme sistemlerinden, robotik platformlardan ve diğer cerrahi cihazlardan elde edilen verilerin sanal modele aktarılması, hastanın anatomik ve fizyolojik durumundaki değişikliklerin gerçek zamana yakın biçimde değerlendirilmesini sağlayabilir. Model, farklı müdahale seçeneklerinin olası sonuçlarını karşılaştırarak cerrah, anestezi uzmanı ve perioperatif ekibe karar desteği sunabilir. Bununla birlikte gerçek zamanlı veri senkronizasyonu, yumuşak doku deformasyonlarının izlenmesi, hesaplama gecikmeleri, model belirsizliği ve farklı sistemler arasında veri aktarımı gibi sorunlar klinik kullanımı sınırlandırmaktadır. Bu nedenle intraoperatif DTAS uygulamalarının önemli bir bölümü henüz prototip veya erken doğrulama aşamasındadır (Qin & Wu, 2022; Asciak et al., 2025; Mekki et al., 2025).

Postoperatif İzlem ve Uzun Dönem Hasta Yönetimi

Postoperatif dönemde dijital ikiz modelinin klinik gözlemler, laboratuvar sonuçları, fizyolojik monitörizasyon verileri, giyilebilir sensörlerden elde edilen ölçümler ve hasta tarafından bildirilen sonuçlarla güncellenmesi, iyileşme sürecinin hastaya özgü olarak izlenmesine katkı sağlayabilir (Mekki et al., 2025). Model tarafından öngörülen iyileşme örüntüsü ile hastanın gerçek klinik seyri arasındaki farklılıkların belirlenmesi hastanın yeniden değerlendirilmesi, komplikasyon olasılığının gözden geçirilmesi ve bakım gereksinimlerinin yeniden planlanması için erken uyarı sağlayabilir. Ancak bu çıktılar doğrudan komplikasyon tanısı olarak değil, klinik değerlendirmeyi başlatan karar destek bilgileri olarak ele alınmalıdır (Lonsdale et al., 2022; Mekki et al., 2025).

Keller ve arkadaşları (2023), baş boyun kanseri tedavisinde hasta yolculuğunun farklı aşamalarını desteklemek amacıyla ortak bir dijital tıbbi ikiz altyapısı üzerinde geliştirilen klinik uygulama prototiplerini tanımlamıştır. Bu çalışma, dijital ikizlerin farklı bakım aşamalarındaki bilgileri bütünleştirme potansiyelini göstermesine karşın sürekli postoperatif fizyolojik izlemin veya komplikasyonların erken belirlenmesinin klinik etkinliğini doğrulayan bir çalışma değildir. Daha somut bir uygulamada Aubert ve arkadaşları (2021), tibial kırığı bulunan bir hastaya ait modelinde farklı stabilizasyon ve kemik iyileşmesi senaryolarını karşılaştırarak postoperatif yönetime yönelik biyomekanik bilgiler üretmiştir. Bununla birlikte bu çalışma da tek hastaya dayalı bir modelleme çalışması olup gerçek zamanlı postoperatif izlem sistemi niteliğinde değildir.

Perioperatif hemşirelik açısından dijital ikizler yaşam bulguları, ağrı, bulantı ve kusma, yara bulguları, mobilizasyon, beslenme durumu ve hasta tarafından bildirilen belirtilerin birlikte değerlendirilmesine olanak sağlayabilir. Bu verilerin hastanın beklenen iyileşme süreciyle karşılaştırılması izlem sıklığının, hasta eğitiminin, taburculuk planının ve taburculuk sonrası izlemin bireyselleştirilmesini destekleyebilir. Bununla birlikte dijital ikiz destekli hemşirelik bakım planlarının komplikasyon, hastanede kalış süresi, yeniden yatış ve hasta tarafından bildirilen sonuçlar üzerindeki etkisini gösteren doğrudan klinik kanıtlar henüz sınırlıdır. Bu nedenle söz konusu uygulamaların klinik yararının farklı hasta gruplarında yürütülecek prospektif ve çok merkezli çalışmalarla değerlendirilmesi gerekmektedir (Lonsdale et al., 2022; Asciak et al., 2025; Mekki et al., 2025).

AMELİYATHANE OPERASYONLARININ OPTİMİZASYONU VE PERİOPERATİF İŞ AKIŞLARI

Dijital ikiz teknolojisi yalnızca hastaya özgü klinik modellerin oluşturulmasında değil, ameliyathane gibi karmaşık sağlık hizmeti ortamlarının ve iş akışlarının modellenmesinde de kullanılabilir. Bu kapsamda operasyonel dijital ikizin fiziksel karşılığı hasta değil, ameliyathane sistemi veya perioperatif süreçtir (Vallée, 2023; Li et al., 2024). Operasyonel dijital ikizler ameliyathane odaları, hasta geçişleri, personel, tıbbi cihazlar ve destek hizmetlerine ilişkin verileri ortak bir sanal model içerisinde bütünleştirerek mevcut işleyişin analiz edilmesine ve alternatif süreçlerin simüle edilmesine olanak sağlayabilir (Vallée, 2023; Li et al., 2024; Pellegrino et al., 2024). Ameliyat programları, tahmini vaka süreleri, ameliyathane doluluk oranları, vaka değişim süreleri, personel gereksinimleri ve postanestezi bakım ünitesi veya yoğun bakım kapasitesi gibi verilerin birlikte değerlendirilmesi, kaynak planlamasını

destekleyebilir. Ameliyathane kullanımındaki sorunlar, vaka iptallerine bağlı çizelge değişiklikleri, hazırlık ve temizlik süreçlerindeki gecikmeler ile hasta transferinde yaşanan aksaklıklar sanal model üzerinde incelenebilir. Farklı çizelgeleme ve kaynak dağıtımı senaryolarının gerçek uygulamaya geçirilmeden önce denenmesi, alınması planlanan operasyonel kararların olası etkilerinin değerlendirilmesine yardımcı olabilir. Bununla birlikte ameliyathane ve derlenme alanlarının dijital ikiz yaklaşımıyla birlikte modellenmesine yönelik çalışmaların önemli bir bölümü henüz kavramsal model veya simülasyon düzeyindedir; hasta sonuçları ve kurum performansı üzerindeki etkileri yeterli klinik uygulamalarla gösterilmemiştir (Pellegrino et al., 2024).

Nesnelerin İnterneti tabanlı cihazlar, konum sensörleri, giyilebilir etiketler ve hastane bilgi sistemleri ameliyathane süreç ikizinin güncel tutulması için veri sağlayabilir. Bu teknolojiler aracılığıyla hastanın cerrahi birim içerisindeki hareketi, ameliyathane kullanım durumu, cihazların konumu ve perioperatif sürecin farklı aşamalarında geçirilen süreler izlenebilir. Bottani ve arkadaşları (2023), sensörlü bileklikler aracılığıyla perioperatif hastaların gerçek zamanlı olarak izlenmesini ve elde edilen verilerin ameliyathane planlamasında kullanılmasını amaçlayan bir geliştirme ve uygulanabilirlik protokolü sunmuştur. Ayrıca fizyolojik monitör ve anestezi cihazlarından elde edilen veriler öncelikle hastanın klinik durumunu temsil etmektedir. Bu veriler, bütünleşik bir mimaride hasta dijital ikizi ile ameliyathane süreç ikizi arasında bağlantı kurulması amacıyla kullanılabilir.

Tıbbi cihazların kullanım durumu, performans değişiklikleri ve arıza geçmişi üzerinden bakım gereksinimlerinin tahmin edilmesi ise ameliyathane süreç ikizinden çok cihaz veya varlık dijital ikizi kapsamında değerlendirilmelidir. Öngörücü bakım uygulamaları, plansız cihaz arızalarının ve hizmet kesintilerinin azaltılması açısından potansiyel taşımaktadır. Ancak bu konudaki kanıtların büyük bölümü endüstriyel sistemlerden elde edildiğinden, yöntemlerin ameliyathane cihazlarının güvenliği, bakım maliyetleri ve hizmet sürekliliği üzerindeki etkilerinin sağlık hizmeti ortamında ayrıca doğrulanması gerekmektedir (van Dinter et al., 2022).

Akıllı ameliyathane platformları ve Ameliyathane Kara Kutusu sistemleri cerrahi video, ses, fizyolojik sinyaller, cihaz ve cerrahi alet verileri ile ameliyathane ortamına ve ekip etkileşimlerine ilişkin farklı veri türlerini eş zamanlı olarak kaydedebilmektedir. Bu sistemler tek başına dijital ikiz değildir; ancak ürettikleri zaman açısından eşleştirilmiş çok kaynaklı veriler ameliyathane iş akışının veya cerrahi sürecin dijital ikiz modelinin geliştirilmesinde kullanılabilir. Bu verilerin analizi, iş akışındaki kesintilerin, çevresel dikkat dağıtıcıların, teknik hataların ve ekip etkileşimlerine ilişkin sorunların belirlenmesine katkı sağlayabilir (Jung et al., 2020; Watson et al., 2025).

Toplanan veriler vaka sonrası değerlendirmelerde, ramak kala olayların incelenmesinde, yapılandırılmış ekip çözümlemelerinde ve kalite geliştirme çalışmalarında kullanılabilir. Bununla birlikte sağlık profesyonellerine ait ses, görüntü ve hareket verilerinin kaydedilmesi mahremiyet, bilgilendirme ve onam, veri sahipliği, erişim yetkisi ve kayıtların hukuki süreçlerde kullanılması gibi önemli sorunlar doğurmaktadır. Kayıt sistemlerinin çalışanları cezalandırmak veya bireysel performans gözetimi yapmak amacıyla kullanılacağı yönündeki kaygılar, çalışan katılımını ve güvenlik kültürünü de olumsuz etkileyebilir. Bu nedenle veri toplamanın amacı, erişim yetkileri, saklama süreleri ve kalite geliştirme süreçlerinde kullanım koşulları kurumsal politikalarla açık biçimde tanımlanmalıdır (van Dalen et al., 2019; Iqbal et al., 2022).

Operasyonel dijital ikizden elde edilen bilgilerin cerrahi, anesteziyoloji ve perioperatif hemşirelik ekiplerine ortak bir arayüz üzerinden sunulması, ekip üyelerinin hastanın hazırlık durumu, ameliyathane kapasitesi, ekipman kullanılabilirliği ve hasta transfer süreci hakkında ortak durumsal farkındalık geliştirmesini destekleyebilir. Bununla birlikte sistemin mevcut iş akışına uyumlu, kullanıcı rollerine göre düzenlenmiş ve klinik değerlendirmeyi destekleyecek biçimde tasarlanması gerekmektedir (Watson et al., 2025; Asciak et al., 2025).

MESLEKLER ARASI İŞ BİRLİĞİ

Paylaşılan hasta modeli, multidisipliner vaka toplantılarında ekip üyelerinin aynı anatomik ve klinik bilgiler üzerinden değerlendirme yapmasını destekleyebilir. Cerrahi yaklaşım, anestezi planı, hasta pozisyonu, gerekli ekipmanlar ve postoperatif bakım gereksinimleri ameliyat öncesinde ortak olarak değerlendirilebilir. Bu yaklaşım, farklı meslek gruplarının yalnızca kendi uzmanlık alanlarına ilişkin

bilgileri değil, diğer ekip üyelerinin gereksinimlerini ve perioperatif sürecin birbirine bağlı aşamalarını da görmesine katkı sağlayabilir (Kyeremeh et al., 2025).

Simülasyon sonrasında yapılan yapılandırılmış çözümleme ve geri bildirim toplantılarında klinik kararlar, iletişim sorunları, görev paylaşımı ve ekip etkileşimleri birlikte değerlendirilebilir. Ancak eğitim sonuçlarının yalnızca katılımcı memnuniyeti üzerinden değil, geçerli ve güvenilir ölçüm araçlarıyla değerlendirilmesi gerekmektedir. Ameliyathane ekip simülasyonlarını inceleyen bir sistematik derlemede belirlenen on programın yalnızca dördünde doğrulanmış değerlendirme araçlarının kullanılmış olması, bu alandaki metodolojik sınırlılığı göstermektedir (Robertson et al., 2017).

Dijital ikiz destekli perioperatif sistemlerde görev dağılımı, yerleşik bir mesleki standarttan çok önerilen iş birliği çerçevesi olarak ele alınmalıdır. Cerrahlar hastaya özgü anatomik modelleri ve cerrahi senaryoları değerlendirirken, anestezi uzmanları fizyolojik verilerin ve anesteziye ilişkin risklerin yorumlanmasına katkı sağlayabilir (Asciak et al., 2025). Perioperatif hemşireler hasta ve süreç verilerinin doğrulanması, cihaz verilerinin klinik gözlemlerle karşılaştırılması, bakım gereksinimlerinin belirlenmesi ve hasta güvenliğinin sürdürülmesinde rol alabilir. Biyomedikal mühendisleri ve veri bilimciler modelin teknik performansı, kalibrasyonu ve algoritmik doğrulamasıyla; bilgi teknolojileri uzmanları ise veri paylaşımı, altyapı ve siber güvenlikle ilgili süreçleri destekleyebilir (Armeni et al., 2022; Asciak et al., 2025).

Sağlık yöneticileri, etik kurullar ve hukuk uzmanları da veri yönetişimi, kurumsal sorumluluk, mahremiyet ve düzenleyici uyum açısından sürece katılmalıdır. Sistemin hangi verileri ürettiği, bu verilerin kimler tarafından yorumlanacağı ve klinik karar sorumluluğunun nasıl paylaşılacağı uygulamaya geçmeden önce belirlenmelidir. Eğitim amacıyla kullanılan hasta verilerinin kimliksizleştirilmesi ve erişim yetkilerinin sınırlandırılması da gerekmektedir (Iqbal et al., 2022; Kyeremeh et al., 2025).

DİJİTAL İKİZ DESTEKLİ CERRAHİNİN SINIRLILIKLARI VE GELECEK PERSPEKTİFLERİ

Teknik Altyapı, Veri Kalitesi ve Birlikte Çalışabilirlik

Dijital ikizlerin perioperatif süreçlerde güvenilir biçimde kullanılabilmesi fizyolojik sinyallerin, cerrahi video kayıtlarının, tıbbi görüntülerin, cihaz verilerinin ve elektronik sağlık kayıtlarının doğru ve zamansal olarak uyumlu biçimde bütünleştirilmesine bağlıdır (Asciak et al., 2025). Bununla birlikte bu kaynaklar veri biçimi, örnekleme sıklığı, çözünürlük ve güvenilirlik bakımından farklılık göstermektedir. Fizyolojik monitörlerden çok kısa aralıklarla veri elde edilirken, görüntüleme sistemleri ve elektronik sağlık kayıtları daha farklı zaman ölçeklerinde güncellenebilmektedir. Bu durum çok kaynaklı verilerin eşleştirilmesini ve sanal modelin hastanın güncel durumunu yansıtacak biçimde yenilenmesini güçleştirmektedir (Watson et al., 2025; Asciak et al., 2025).

Modern ameliyathanelerde çok sayıda monitör, sensör, görüntüleme sistemi ve cerrahi cihazdan yüksek hacimli veri üretilmesi, yeterli hesaplama gücü, veri depolama kapasitesi ve güvenilir ağ altyapısı gerektirmektedir (Asciak et al., 2025). Veri aktarımındaki gecikmeler, bağlantı kesintileri veya işlem süresinin klinik karar verme gereksinimlerini karşılayamaması, gerçek zamanlı karar desteğinin güvenilirliğini azaltabilir. Ayrıca farklı üreticilere ait cihazlarda veri standartlarının tutarlı biçimde uygulanmaması, sistemler arası veri alışverişini ve ortak bir dijital ikiz modelinin oluşturulmasını sınırlandırmaktadır (Venkatesh et al., 2022; Li et al., 2024; Asciak et al., 2025).

Modelin güvenilirliği yalnızca veri miktarına değil, verilerin doğruluğuna, eksiksizliğine, güncelliğine ve kaynağının izlenebilirliğine de bağlıdır (Asciak et al., 2025). Eksik kayıtlar, hatalı sensör ölçümleri, görüntü artefaktları ve tutarsız veri girişleri, model çıktılarında belirsizliğe veya hatalı tahminlere yol açabilir. Canlı dokuların deformasyonu, organ hareketleri ve cerrahi müdahaleye bağlı anatomik değişikliklerin eş zamanlı olarak modellenmesi de önemli bir teknik güçlüktür (Asciak et al., 2025). Bu nedenle DTAS modellerinin klinik kullanım öncesinde teknik doğrulama, klinik geçerleme ve belirsizlik nicelendirmesi yönünden değerlendirilmesi; kullanım süresince ise güncel hasta verileriyle yeniden kalibre edilmesi gerekmektedir (Meijer et al., 2023; Asciak et al., 2025).

Klinik Doğrulama, Algoritmik Güvenilirlik ve İnsan Faktörü

Dijital ikiz destekli sistemlerin ürettiği tahminlerin güvenilirliği, kullanılan algoritmaların yanı sıra bu algoritmaların geliştirildiği veri kümelerinin niteliğine bağlıdır. Eğitim verilerinin farklı yaş, cinsiyet, etnik köken, hastalık şiddeti ve eşlik eden hastalık gruplarını yeterince temsil etmemesi algoritmik yanlılığa neden olabilir (Asciak et al., 2025). Belirli bir sağlık kurumunda geliştirilen modelin farklı hasta gruplarında, cihazlarda ve klinik ortamlarda aynı performansı göstermemesi de genellenebilirlik açısından önemli bir sınırlılıktır (Hashimoto et al., 2018; Asciak et al., 2025).

Dijital ikiz modellerinin rutin klinik kullanıma geçirilmeden önce teknik performans, klinik geçerlik, genellenebilirlik ve hasta sonuçları üzerindeki etkileri yönünden değerlendirilmesi gerekmektedir. Model performansı, kullanım amacına göre yalnızca genel doğruluk oranıyla değil ayırt etme gücü, kalibrasyon, duyarlılık ve özgüllük, yanlış pozitif ve yanlış negatif sonuçlar ile klinik yararlılık gibi ölçütlerle incelenmelidir (Asciak et al., 2025). Modellerin bağımsız veri kümelerinde dış doğrulamasının yapılması, farklı merkez ve hasta gruplarında prospektif olarak değerlendirilmesi ve klinik iş akışı üzerindeki gerçek etkisinin gösterilmesi önemlidir (Venkatesh et al., 2022; Meijer et al., 2023; Mekki et al., 2025).

DTAS tarafından üretilen bilgilerin doğru zamanda, uygun öncelik düzeyinde ve kullanıcının görevine uygun bir arayüz aracılığıyla sunulması gerekmektedir. Kullanıcı arayüzleri yalnızca cerrahların değil, anestezi uzmanlarının, perioperatif hemşirelerin ve diğer ekip üyelerinin bilgi gereksinimleri dikkate alınarak tasarlanmalıdır. Sistemin hangi hasta verilerini kullandığını, önerinin hangi gerekçelere dayandığını ve tahminin ne ölçüde belirsizlik taşıdığını anlaşılır biçimde gösterebilmesi, güvenli kullanım açısından önemlidir (Hashimoto et al., 2018; Lam et al., 2021).

Gereğinden fazla veya klinik açıdan düşük öneme sahip uyarı sunulması, bilişsel yükü artırabilir ve önemli bilgilerin gözden kaçırılmasına neden olabilir. Teknolojiye aşırı güvenilmesi ise klinik bulgularla sistem önerisi arasında uyumsuzluk bulunduğunda hatalı önerinin yeterince sorgulanmadan kabul edilmesine yol açabilir (Asciak et al., 2025). Bu nedenle dijital ikiz çıktıları bağımsız kararlar olarak değil, klinik değerlendirmeyi destekleyen bilgiler olarak kullanılmalı ve nihai karar sorumluluğu sağlık profesyonellerinde kalmalıdır. Hasta özellikleri ve klinik uygulamalar zaman içerisinde değişebileceğinden, kullanıma alınan modellerin performansı sürekli izlenmeli ve gerektiğinde yeniden kalibre edilmelidir (Lam et al., 2021; Asciak et al., 2025).

Etik, Hukuki, Düzenleyici ve Siber Güvenlik Sorunları

Dijital ikiz sistemleri tıbbi görüntüler, elektronik sağlık kayıtları, genomik bilgiler ve gerçek zamanlı fizyolojik ölçümler gibi yüksek hacimli ve hassas hasta verilerine dayanmaktadır. Bu verilerin hangi amaçlarla toplanacağı, kimler tarafından işleneceği, kimlerle paylaşılacağı, ne kadar süreyle saklanacağı ve hangi koşullarda silineceği açık biçimde tanımlanmalıdır. Verilerin yalnızca gerekli ölçüde toplanması, erişim yetkilerinin sınırlandırılması ve ikincil kullanımların şeffaf biçimde açıklanması gerekmektedir. Dijital ikiz verilerinin araştırma, eğitim veya ticari amaçlarla kullanılması durumunda bilgilendirilmiş onam, hastanın verileri üzerindeki hakları ve veri yönetişimi ayrıca ele alınmalıdır (Bruynseels et al., 2018; Iqbal et al., 2022; Lam et al., 2021).

Algoritmanın hatalı bir öneri üretmesi veya sistem kesintisi nedeniyle klinik zarar ortaya çıkması durumunda sağlık profesyoneli, sağlık kurumu, yazılım geliştiricisi ve cihaz üreticisi arasındaki sorumlulukların nasıl paylaşılacağı önemli bir hukuki sorundur (Asciak et al., 2025). Klinik kararları doğrudan etkileyen bazı dijital ikiz bileşenleri, kullanım amaçlarına ve yürürlükteki düzenleyici çerçeveye bağlı olarak yazılım tabanlı tıbbi cihaz kapsamında değerlendirilebilir. Bu durumda risk sınıflandırması, klinik değerlendirme, performans izlemi, yazılım güncellemeleri, sürüm kontrolü ve denetlenebilirlik gibi gerekliliklerin ürün yaşam döngüsü boyunca ele alınması gerekir (Venkatesh et al., 2022; Asciak et al., 2025).

Gerçek zamanlı hasta verilerinin ağ bağlantılı veya bulut tabanlı ortamlarda işlenmesi, siber güvenlik risklerini artırmaktadır. Yetkisiz erişim, veri manipülasyonu, kötü amaçlı yazılımlar ve hizmet kesintileri yalnızca hasta mahremiyetini değil, cerrahi işlemin güvenliğini de etkileyebilir. Bu nedenle güçlü kimlik doğrulama, veri şifreleme, görev temelli erişim yetkilendirmesi, ağ segmentasyonu,

güvenlik güncellemeleri, düzenli testler ve olay müdahale planları dijital ikiz altyapısının temel bileşenleri olmalıdır (Coventry & Branley, 2018; Asciak et al., 2025).

Maliyet, Erişilebilirlik ve Kurumsal Hazırlık

Dijital ikiz altyapısının kurulması; yüksek performanslı bilgi işlem sistemleri, veri depolama kapasitesi, sensörler, yazılımlar, siber güvenlik çözümleri ve teknik destek yatırımları gerektirmektedir. İlk kurulum maliyetine ek olarak bakım, lisans, yazılım güncellemesi, personel eğitimi ve teknik destek giderleri de değerlendirilmelidir (Armeni et al., 2022). Bu gereksinimler özellikle kaynakları sınırlı sağlık kurumlarında teknolojiye erişimi güçleştirebilir ve kurumlar arasındaki dijital eşitsizlikleri artırabilir. Bu nedenle klinik veya operasyonel yarar gösterilmeden yatırımın maliyetleri karşılayacağı varsayılmamalı; maliyet-etkinlik ayrıca değerlendirilmelidir (Armeni et al., 2022; Li et al., 2024; Mekki et al., 2025).

Teknolojik altyapının kuruma kazandırılması, başarılı klinik entegrasyon için tek başına yeterli değildir. Mevcut iş akışlarının analiz edilmesi, kullanıcı gereksinimlerinin belirlenmesi ve sistemi kullanacak sağlık profesyonellerinin tasarım ve değerlendirme süreçlerine katılması gerekmektedir. Cerrahların, anestezi uzmanlarının, perioperatif hemşirelerin, biyomedikal mühendislerinin ve bilgi teknolojileri çalışanlarının sistemin işlevleri, sınırlılıkları ve güvenli kullanım ilkeleri konusunda eğitilmesi önemlidir. Kesintisiz teknik destek ve açık görev tanımları da kurumsal sürdürülebilirliğin sağlanmasına katkı sağlayabilir (Asciak et al., 2025; Mekki et al., 2025).

Kurumsal uygulamaya, kapsamı ve hedefleri önceden belirlenmiş pilot çalışmalarla başlanması daha güvenli bir yaklaşım olacaktır. Pilot uygulamalarda hasta güvenliği, model performansı, iş akışına etkisi, kullanıcı kabulü, iş yükü ve maliyet gibi ölçütler birlikte değerlendirilmelidir. Önceden belirlenmiş başarı ve durdurma ölçütlerine göre sistemin sürdürülmesine, değiştirilmesine veya kapsamının kademeli biçimde genişletilmesine karar verilmelidir (Venkatesh et al., 2022; Mekki et al., 2025).

Gelecek Perspektifleri

Gelecekteki araştırmaların temel hedeflerinden biri, moleküler, hücresel, doku, organ ve bütüncül hasta düzeyindeki verilerin birlikte değerlendirilebildiği çok ölçekli dijital ikiz modellerinin geliştirilmesidir. Günümüzde özellikle kardiyoloji alanında tıbbi görüntüleme, elektrokardiyografi ve fizyolojik ölçümlerin bütünleştirildiği organ düzeyindeki modeller öne çıkmaktadır (Corral-Acero et al., 2020). Bununla birlikte mevcut organ modelleri hastanın sistemik fizyolojisini, eşlik eden hastalıklarını ve cerrahi travmaya verdiği bireysel yanıtı çoğu zaman tam olarak temsil edememektedir (Meijer et al., 2023).

Dijital ikizlerin rutin perioperatif bakıma entegre edilebilmesi için standartlara dayalı veri paylaşımının, açıklanabilir algoritmaların ve farklı kurumlarda çalışabilecek teknik mimarilerin geliştirilmesi gerekmektedir. Araştırmalarda kullanılan model geliştirme ve doğrulama süreçleri şeffaf ve yeniden üretilebilir biçimde raporlanmalıdır. Prospektif, çok merkezli ve karşılaştırmalı çalışmalarla yalnızca teknik performans değil; klinik yararlılık, hasta güvenliği, maliyet-etkinlik, sağlık profesyonellerinin iş yükü, kullanıcı deneyimi, ekip iletişimi ve bakım kalitesi üzerindeki etkiler de değerlendirilmelidir (Venkatesh et al., 2022; Meijer et al., 2023; Mekki et al., 2025).

Dijital ikizler gelecekte kişiselleştirilmiş ve öngörücü perioperatif bakımın önemli bileşenlerinden biri olabilir. Ancak bu potansiyelin rutin klinik uygulamaya dönüşmesi, teknolojik performansın yanı sıra ölçülebilir klinik yararın gösterilmesine, etik ve hukuki yönetişimin sağlanmasına, siber güvenlik önlemlerinin uygulanmasına ve sistemlerin multidisipliner ekiplerle birlikte geliştirilmesine bağlıdır.

SONUÇ VE ÖNERİLER

Dijital ikiz teknolojisi; hastaya özgü anatomik, fizyolojik ve klinik verilerin dinamik sanal modellerde bütünleştirilmesi yoluyla cerrahi planlama, intraoperatif karar desteği, postoperatif izlem, ameliyathane iş akışlarının yönetimi ve perioperatif eğitim açısından önemli bir potansiyel taşımaktadır. Ortak bir hasta veya süreç modelinin kullanılması, cerrahların, anestezi uzmanlarının, perioperatif hemşirelerin ve teknik ekiplerin aynı güncel bilgiler üzerinden değerlendirme yapmasını destekleyerek multidisipliner iş birliğine katkı sağlayabilir.

Bununla birlikte mevcut literatürün önemli bir bölümü kavramsal çalışmalar, teknik modeller, simülasyonlardan oluşmaktadır. Rutin klinik uygulamadan önce veri kalitesi ve birlikte çalışabilirlik sağlanmalı modeller teknik doğrulama, klinik geçerleme, belirsizlik nicelendirmesi ve dış doğrulama süreçlerinden geçirilmelidir. Sistem çıktıları sağlık profesyonellerinin kararlarının yerine geçmemeli, klinik değerlendirmeyi destekleyen bilgiler olarak kullanılmalıdır. Perioperatif hemşireler de veri doğrulama, bakım gereksinimlerinin değerlendirilmesi, hasta güvenliği, kullanılabilirlik ve iş akışı aşamalarına etkin biçimde katılmalıdır. Hasta mahremiyeti, veri yönetimi, hukuki sorumluluk, düzenleyici uygunluk ve siber güvenlik konularında açık kurumsal politikalar oluşturulmalıdır.

Sonuç olarak dijital ikiz destekli klinik karar destek sistemleri, perioperatif bakımın dijital dönüşümünde önemli bir potansiyel taşımaktadır. Ancak bu potansiyelin güvenli ve sürdürülebilir klinik yarara dönüşmesi; teknolojik gelişmenin klinik kanıt, insan merkezli tasarım, etik yönetişim, siber güvenlik ve multidisipliner iş birliğiyle birlikte yürütülmesine bağlıdır.

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HARPETOFOUNAL DIVERSITY IN RAM JHARNA RIVERINE- FOREST ECOSYSTEM

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ABSTRACT

This study aimed to investigate the herpetofauna diversity at Ram Jharna, Raigarh district, Chhattisgarh, India. The research was conducted from June 2025 to February 2026. Samples were collected from the Ram Jharna Forest ecosystem using various methodologies and subsequently identified with a taxonomic key developed for Indian herpetologists. The primary objective of this study was to assess the species richness of amphibians and reptiles and to compile a comprehensive species checklist for the insect fauna. This study constitutes the first systematic, habitat-stratified inventory of herpetofauna in the Ram-Jharna Area. A total of 14 species, representing 9 families, were documented within the study area. This research provides significant and current data regarding the herpetofauna diversity within the Ram Jharna region of Raigarh District, Chhattisgarh and is expected to serve as a valuable resource for future investigations into amphibian and reptile fauna.

Key words- Herpetofauna, Amphibian, Reptile, Ram-Jharna, Diversity.

ARTIFICIAL INTELLIGENCE AND DIGITAL APPLICATIONS IN DIABETES MANAGEMENT: A REVIEW OF CURRENT EVIDENCE

DİYABET YÖNETİMİNDE YAPAY ZEKA VE DİJİTAL UYGULAMALAR: GÜNCEL KANITLARIN DERLEMESİ

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ÖZET

Giriş ve Amaç: Bu derlemenin amacı, diyabet yönetiminde giderek yaygınlaşan yapay zeka ve dijital sağlık uygulamalarını; klinik kanıt gücü, teknolojik olgunluk düzeyi güncel literatür ışığında değerlendirmektir. Diyabet, sürekli öz-yönetim gerektiren, küresel ve ulusal düzeyde ağır bir yük oluşturan kronik bir hastalıktır. Son yıllarda gelişen teknoloji ile parmak ucu kan şekeri ölçümü ve HbA1c temelli klasik izlemden; sürekli, otomatik ve algoritma destekli veri akışına geçiş, "hedef aralıkta geçirilen süre" (Time in Range) gibi yeni glisemik ölçütleri klinik pratiğe kazandırmıştır.

Materyal ve Metod: Bu derlemede uygulamalar altı ana başlıkta ele alınmaktadır: (1) sürekli glukoz izleme (CGM) ve flash izlem sistemleri; (2) otomatik insülin verme ve kapalı döngü (yapay pankreas) sistemleri; (3) makine öğrenmesi ile glukoz ile hipoglisemi tahmini ve klinik karar destek sistemleri; (4) yapay zeka temelli komplikasyon taraması (özellikle diyabetik retinopati, ayak ve nefropati); (5) mobil sağlık uygulamaları ve dijital öz-yönetim platformları; (6) teletıp ile yapay zeka sohbet botları ve büyük dil modelleridir.

Sonuç: Yapay zeka ve dijital uygulamalar diyabet yönetiminde glisemik kontrolü iyileştirme, komplikasyonları erken saptama ve öz-yönetimi güçlendirme potansiyeli taşımaktadır. Ancak bu araçların klinik faydası; klinisyen gözetiminde, mevcut bakımın yerine değil tamamlayıcısı olarak ve sağlık okuryazarlığı, dijital eşitlik, dış doğrulama ile veri gizliliği güvenceleriyle birlikte konumlandırıldığında gerçekleşecektir. Bu alanda Türkiye'ye özgü, prospektif ve hasta-merkezli çalışmalara ihtiyaç vardır.

Anahtar Kelimeler: Diyabet, Yapay zeka, Dijital sağlık, Diyabet öz-yönetimi, Sürekli glukoz izleme

ABSTRACT

Introduction and Purpose: The aim of this review is to evaluate the increasingly common artificial intelligence and digital health applications in diabetes management, considering their clinical evidence strength and technological maturity level in light of current literature. Diabetes is a chronic disease that requires continuous self-management and constitutes a heavy burden at both global and national levels. In recent years, technological advancements have led to a shift from classic monitoring based on fingertip glucose measurement and HbA1c to continuous, automated, and algorithm-supported data flow, introducing new glycemic measures such as "Time in Range" into clinical practice.

Material and Methods: This review addresses applications under six main headings: (1) continuous glucose monitoring (CGM) and flash monitoring systems; (2) automated insulin delivery and closed-loop (artificial pancreas) systems; (3) machine learning-based glucose and hypoglycemia prediction and clinical decision support systems; (4) AI-based complication screening (especially diabetic retinopathy, foot, and nephropathy); (5) mobile health applications and digital self-management platforms; (6) telemedicine, AI chatbots, and large language models.

Conclusion: Artificial intelligence and digital applications have the potential to improve glycemic control, detect complications early, and strengthen self-management in diabetes management. However, the clinical benefit of these tools will be realized when they are positioned under clinician supervision, as a complement to existing care rather than a replacement, and with assurances of health literacy, digital equity, external validation, and data privacy. Prospective and patient-centered studies specific to Turkey are needed in this area.

Keywords: Diabetes, Artificial intelligence, Digital health, Diabetes self-management, Continuous glucose monitoring

GİRİŞ

Diyabet, dünya genelinde hızla yayılan ve sağlık sistemleri üzerindeki yükü giderek ağırlaşan kronik bir metabolik hastalıktır. Uluslararası Diyabet Federasyonu'nun (International Diabetes Federation/IDF) 2024 verilerine göre 20-79 yaş aralığındaki yetişkinlerin %11,1'i, yani 589 milyon kişi diyabetle yaşamakta ve bu sayının 2050 yılında 853 milyona (%13) çıkması beklenmektedir[1]. Türkiye'de TURDEP-II çalışması sonuçlarına göre erişkinlerde diyabet yaygınlığı %16,5 (yeni tanı %7,5, bilinen diyabet %9,0) ve yaklaşık 6,5 milyon yetişkin, prediyabet yaygınlığı ise %30,8 olarak saptanmıştır. On iki yıl önce yürütülen TURDEP-I popülasyonuna göre yaşa standardize edildiğinde ulaşılan %13,7'lik yaygınlık, aradan geçen sürede diyabetin anlamlı biçimde arttığını göstermektedir[2].

Diyabetin seyri büyük ölçüde günlük yaşamda alınan kararlarla, yani beslenme, fiziksel aktivite, ilaç ve insülin dozlaması ile glukoz takibiyle belirlenir; bu yüzden hastanın öz-yönetimi bakımın merkezinde durur. Aralarında Amerikan Diyabet Birliği'nin de yer aldığı yedi meslek kuruluşunun ortak konsensüs raporu, diyabette öz-yönetim eğitimi ve desteğini (DSMES) kapsamlı bakımın temel bileşeni sayar. Rapora göre DSMES HbA1c değerlerini iyileştirir, komplikasyonların başlangıcını ve kötü gidişi geciktirir, yaşam kalitesini yükseltir ve diyabete bağlı distresi azaltır[3].

Son zamanlardaki teknolojinin hızlı gelişimi glukoz izlemine ilişkin teknolojik gelişmeleride etkilemiş ve diyabet yönetiminde köklü bir dönüşüm başlatmıştır. İzlem uzun yıllar boyunca parmak ucundan yapılan aralıklı kan şekeri ölçümlerine ve son üç ayın ortalamasını yansıtan HbA1c değerine dayanıyordu, ancak gün içi glukoz dalgalanmalarını, hipoglisemi süresini ya da glisemik değişkenliği yeterince göstermiyordu. Sürekli glukoz izleme (Continuous glucose monitoring/CGM) sistemleri yaygınlaştıkça izlem kesintisiz, otomatik ve algoritma destekli bir veri akışına dönüştü, bu veri zenginliği de HbA1c'yi tamamlayan yeni ölçütlerin doğmasına yol açtı. Bunların başında, hastanın gün boyunca hedef glukoz aralığında geçirdiği süreyi ifade eden 'hedef aralıkta geçirilen süre' (Time in Range) gelir; ölçüt, uluslararası bir konsensüsle standart tanımına kavuşmuştur[4]. Bu tür dijital izlem araçları ve öz-yönetim uygulamaları güncel diyabet bakım standartlarına da giderek daha fazla girmektedir[5].

Glukoz verisinin hem hacmindeki hem de sürekliliğindeki bu artış, yapay zeka (YZ) yöntemlerinin diyabet bakımına uygulanması için verimli bir zemin oluşturmuştur. Mobil sağlık platformlarında YZ kullanımını inceleyen kapsamlı bir derleme, üç temel yöntemin, yani makine öğrenmesi, derin öğrenme ve doğal dil işlemenin beş uygulama alanında kullanıldığını ortaya koyar: prediktif analitik sürekli glukoz izleme, kişiselleştirilmiş öz-yönetim, erken risk değerlendirmesi ve klinik karar desteği[6]. Diyabet bakımında YZ ve dijital sağlık teknolojileri başlıca şu işlevler etrafında toplanabilir: sürekli ve otomatik izlem, insülin verilmesinin otomasyonu, glukoz seyri ile advers olayların tahmini ve klinik karar destek sistemleri, komplikasyonların taranması, hastaya özgü öz-yönetim desteği ve hasta ile sağlık ekibi arasındaki iletişimdir. Ancak veri gizliliği, algoritmik önyargı, regülasyon engelleri ve dijital okuryazarlığı düşük kullanıcılar üzerinde ek yük yaratma tehlikesi gibi riskleri de gündeme

getirir[6].Türkiye'de e-Nabız gibi ulusal dijital sağlık altyapıları bu uygulamaların yaygınlaşması için elverişli bir zemin sunar[7].

Bu derleme, diyabet yönetiminde YZ ve dijital uygulamalara ilişkin literatürü bir araya getirmeyi amaçlar; her uygulama alanının kanıt gücünü, klinik olgunluk düzeyini ve sınırlılıklarını eleştirel bir gözle değerlendirmeyi hedefler. Böylece sürekli glukoz izlemeden otomatik insülin verme sistemlerine, glukoz tahmini ve karar destek algoritmalarından komplikasyon taramasına uzanan geniş yelpazenin güncel durumu bütüncül bir çerçevede ortaya konacak; hem klinik uygulamaya hem de gelecekteki araştırmalara yön verecek bir zemin oluşturulacaktır.

KAVRAMSAL ÇERÇEVE

Sürekli Glukoz İzleme ve Otomatik Veri Sistemleri

Sürekli glukoz izleme ile flash ya da aralıklı taramalı glukoz izleme sistemleri, parmak ucundan yapılan geleneksel kan şekeri ölçümünün verdiği tek tek ve kesintili değerlerle yetinmez; gün boyu kendiliğinden akan bir glukoz verisi üretir. Böyle bir veri, glisemik durumu saatler ve günler içindeki gidişatıyla gösterir. Bu da hedef aralıkta geçirilen süre (time in range/TIR) gibi yeni metriklerin klinik değerlendirmeye girmesinin önünü açmıştır. TIR, uzun dönem ortalamayı yansıtan ama günlük dalgalanmaları ve hipoglisemi yükünü gizleyebilen HbA1c'nin açık bıraktığı yeri doldurur; glisemik değişkenliğin ve güvenliğin çok daha ayrıntılı izlenmesine olanak tanır[4].

Bu metriklerin klinik yorumu cihazdan cihaza, hekimden hekime değişmesin diye 2019'da Uluslararası Hedef Aralıkta Geçirilen Süre Konsensüsü yayımlandı; CGM verisinin nasıl okunacağına dair ortak hedefler çıkarıldı. Konsensüs, Tip 1 ve Tip 2 diyabetli erişkinlerin çoğu için hedef aralıkta (3,9-10,0 mmol/L; yaklaşık 70-180 mg/dL) geçirilen sürenin toplam zamanın %70'ini aşmasını, hipoglisemik aralıkta (3,9 mmol/L altı) geçirilen sürenin %4'ün altında kalmasını, ağır hipoglisemide (3,0 mmol/L altı) geçirilen sürenin ise %1'i aşmamasını önerdi[4]. Ortak eşikler belirlenince farklı cihazları ve farklı hastaları aynı dille karşılaştırmak mümkün oldu; sürekli izleme verisi böylece klinik pratikte tutarlı biçimde kullanılabilir hale geldi.

CGM'nin glisemik kontrole katkısı, farklı diyabet tipleri ve tedavi rejimleri üzerinde yürütülen randomize kontrollü çalışmalarla ortaya konmuştur. Çoklu doz insülin kullanan erişkin Tip 1 diyabetlilerdeki DIAMOND çalışması bunun tipik bir örneğidir. Yirmi dört haftalık izlem sonunda CGM grubundaki HbA1c düşüşü, kontrol grubundakinden anlamlı derecede büyüktü: CGM ile yaklaşık 1,0 puan gerileme görülürken kontrol grubunda düşüş yaklaşık 0,4 puanda kaldı ($p<0,001$). Hipoglisemi tarafında da benzer bir ayrışma vardı; 24. haftada günlük hipoglisemi süresi (glukoz 70 mg/dL altı) CGM grubunda medyan 43 dakika iken kontrol grubunda 80 dakikaydı, yani CGM grubu anlamlı olarak daha kısa süre hipoglisemide kaldı (p değeri 0,002)[8]. Bu yarar Tip 1 ile de sınırlı değil. Bazal insülin alan ve birinci basamakta izlenen Tip 2 diyabetlilerde yürütülen MOBILE çalışmasında, 8 aylık izlemde CGM grubunun HbA1c'si %9,1'den %8,0'a inerken geleneksel kan şekeri ölçüm cihazı kullanan grupta %9,0'dan %8,4'e geriledi; CGM ile sağlanan düşüş (1,1 puana karşı 0,6 puan) anlamlı olarak daha belirgindi[9].

Flash (aralıklı tarama) ile yapılan beş randomize kontrollü çalışmayı birleştiren bir sistematik derleme ve meta-analiz, flash izlemenin HbA1c'de anlamlı bir azalma sağlamadığını buldu (ortalama fark 0,17 puan; P değeri 0,164). Yapılan analizlerde bu izlemenin hedef aralıkta geçirilen süreyi günde yaklaşık 69 dakika (ortalama fark 1,16 saat) uzattığı, 24 saatteki hipoglisemik epizot sıklığını da azaltığıydı[10]. Buradan çıkan sonuç, flash sistemlerin önemli değerinin ortalama glisemiyi düşürmekten çok, glisemik değişkenliği ve hipoglisemi güvenliğini iyileştirmesidir.

Otomatik İnsülin Verme ve Kapalı Döngü Sistemleri (Yapay Pankreas)

Otomatik insülin verme (automated insulin delivery, AID) sistemleri, sürekli glukoz izlemini (CGM), insülin pompasını ve glukoza yanıt veren bir kontrol algoritmasını tek bir yapı altında toplayan yapay pankreas teknolojileridir; literatürde hibrit kapalı döngü sistemleri olarak da anılır. Bu sistemler insülin dozunu gerçek zamanlı ayarlar. Ölçülen glukoz değerine göre bazal salımı dinamik biçimde artırıp azaltmaları, hastanın gün içinde vermek zorunda kaldığı manuel karar yükünü belirgin biçimde

hafifletir. Randomize kontrollü çalışmaların sistematik derleme ve meta-analizleri, Tip 1 diyabette AID sistemlerinin sensör destekli pompa ve çoklu doz enjeksiyon gibi güncel standart karşılaştırıcıları tutarlı biçimde geride bıraktığını göstermektedir[11].

Bu üstünlük en açık biçimde, hedef glukoz aralığında (TIR 70-180 mg/dL) geçirilen sürede kendini gösterir. On iki ile doksan altı hafta arasında değişen çalışmaları birleştiren meta-analizde AID kullanımı, TIR değerini standart tedaviye kıyasla ortalama % 10,87 yükseltmiştir[11.] Suboptimal kontrollü hastalarla yürütülen on iki haftalık çok merkezli bir çalışmada kapalı döngü grubu hedef aralıkta %65'e ulaşırken, kontrol grubu %54'te kalmıştır[12]. Altı aylık yapılan bir çalışmada ise hedef aralıkta geçirilen süre kapalı döngü kolunda %71, kontrol kolunda %59 bildirilmiştir[13].

AID sistemlerinin bir başka önemli üstünlüğü, glisemik kontrolü iyileştirirken hipoglisemi yükünü de azaltabilmesidir. Yoğun insülin tedavisinde bu iki hedef çoğu zaman birbiriyle çelişirken, kapalı döngü ikisini aynı anda sağlayabilmektedir. Dahası glisemik iyileşme, ağır hipoglisemi riskini artırmadan elde edilmektedir[12,13]. Ayrıca bir meta-analiz de kapalı döngü sistemlerinin diyabetik ketoasidoz riskini artırmadığını ortaya koymaktadır[11].

Sağlanan bu yararlar geniş bir yaş aralığında ve farklı klinik profilleri içermektedir. Yetişkinler ve ergenlerin yanında iki ile altı yaş arası çok küçük çocuklarda bile belirgin iyileşme gösterilmiştir. Yapılan bir çalışmada hibrit kapalı döngü kullanan küçük çocuklar hedef aralıkta %69,3 süre geçirmiş, standart tedavi grubunda bu oran %55,9'da kalmış; kapalı döngü grubu günde yaklaşık üç saat daha uzun süre hedefte kalmıştır[14]. Yarar, daha önce pompa ve CGM kullandığı halde glisemik hedeflerine ulaşamamış suboptimal kontrollü hastalarda da, denetimsiz ev koşullarındaki gerçek yaşam kullanımında da sürmüş, sistem güvenle uygulanabilmiştir[12]. Bu birikimli kanıt, güncel konsensüsün AID sistemlerini Tip 1 diyabette glisemik kontrolü iyileştiren ve hipoglisemiyi azaltan, güçlü kanıta dayalı bir tedavi seçeneği olarak sunulmasının temelini oluşturmuştur.

Makine Öğrenmesi ile Glukoz-Hipoglisemi Tahmini ve Klinik Karar Destek Sistemleri

Kısa vadeli kan şekeri seyrini öngörme çabası, diyabet yönetiminde makine öğrenmesi (machine learning/ML) ve derin öğrenme yöntemlerinin olgunlaşmaya başladığı bir araştırma alanıdır. Alandaki birikim, sürekli glukoz izleme (CGM) verisinden yararlanan sinir ağı temelli mimarilerin (örneğin LSTM, DRNN ve GluNet) geleneksel makine öğrenmesi yaklaşımlarına göre daha yüksek tahmin doğruluğu sağladığına işaret eder. Kırk altı çalışmayı bir araya getiren bir meta-analizde 30 dakikalık tahmin ile en iyi sıralamayı genişletilmiş (dilate) tekrarlayan sinir ağı (DRNN) modeli almıştır [15].

Bu öngörü sistemi, hipoglisemi gibi advers glisemik olaylarda erken uyarı sağladığı için klinik açıdan değerlidir. Hastanede yatan, Tip 1 diyabetli 406 erişkin hastayla yürütülen bir çalışmada gece hipoglisemisinin öngörülmesinde Rastgele Orman (Random Forest) modeli, CGM ile klinik verileri birleştirerek 15 dakikalık tahminde 0,97, 30 dakikalık tahminde ise 0,942 değerine ulaşmıştır. Modelin en güçlü belirleyicileri bazal insülin dozu, diyabet süresi, proteinüri ve HbA1c düzeyi gibi klinik değişkenlerin yanı sıra CGM türevli bir metrik olan düşük kan glukozu indeksi (Low Blood Glucose Index) olmuştur[16]. Ancak literatürde hala bu modellerin yaklaşan bir glisemik olayı öngörmede, halihazırda gelişmekte olan bir olayı gerçek zamanlı yakalamaya kıyasla daha başarılı olduğu; gerçek zamanlı tespitte ise geliştirilmeye açık bir alanı olduğu vurgulanmaktadır.

Karar destek sistemleri, tahmin modellerinin bir adım ötesinde insülin doz ayarında da giderek daha görünür bir rol üstleniyor. Tip 1 diyabetli gençlerle yürütülen randomize kontrollü bir çalışmada, yapay zeka temelli otomatik insülin-doz karar destek sistemi doz optimizasyonunda uzman hekim yönetiminden geri kalmamış ve güvenli bulunmuştur[17]. Tip 2 diyabette de sonuçlar buna benzer ilerlemekte, 149 yatan hastayla yürütülen randomize kontrollü bir çalışmada, yapay zeka destekli insülin titrasyon sistemi (iNCDSS), hedef glukoz aralığında geçirilen süre bakımından hekim yönetimine denk etkinlik göstermiş (%76,4'e karşı %73,6) ve non-inferiorite ölçütünü karşılamıştır[18].

Klinik kabul açısından bu sistemlerin güvenlik profili de önemlidir. Tip 2 diyabetteki aynı randomize kontrollü çalışmada her iki tedavi kolunda da ağır hipoglisemi (40 mg/dL altı) veya ketoasidoz olayı görülmemiş, hekimlerin sistemce üretilen doz önerilerini kabul oranı ise %98,9'a ulaşmıştır[18]. Bu da yapay zeka tabanlı doz desteğinin glisemik kontrolü ağır hipoglisemi riskini artırmadan sağlayabildiği göstermiştir.

Alandaki genel eğilimde, CGM verisiyle klinik değişkenleri birlikte kullanan, yorumlanabilir ve hastaya özgü kişiselleştirilmiş modellere doğrudur. Tip 1 ve Tip 2 diyabette elde edilen randomize kontrollü kanıtlar, yapay zeka temelli karar destek sistemlerinin uzman hekim yönetimine denk etkinlik ve güvenlik sunabildiğini gösteriyor. Kısa vadeli glukoz tahmini ve advers olay öngörüsündeki başarı da eklendiğinde, bu teknolojilerin klinik uygulamaya entegrasyonu giderek daha sağlam bir zemine oturmaktadır.

Yapay Zeka ile Diyabetik Komplikasyon Taraması

Yapay zekanın diyabetik komplikasyonlarda en gelişmiş ve klinik olarak en sağlam kanıta ulaştığı alan, kuşkusuz diyabetik retinopati (DR) taramasıdır. Bu olgunluğun temelinde, derin öğrenmenin retina fundus fotoğraflarını oftalmolog düzeyinde okuyabildiğini gösteren çalışmalar yatar. Gulshan ve arkadaşlarının geliştirdiği derin konvolüsyonel sinir ağı, EyePACS-1 doğrulama setinde iki ayrı çalışma noktasında sınanmıştır: yüksek özgüllük noktasında %90,3 duyarlılık ve %98,1 özgüllük, duyarlılık öncelikli noktada ise %97,5 duyarlılık ve %93,4 özgüllük elde etmiş, böylece uzman değerlendirmesiyle karşılaştırılabilir bir başarı ortaya koymuştur[19]. Otonom DR taramasının kavramsal ve metodolojik zemini bu çalışmayla kurulmuş, sonraki yılların tam otonom sistemlerine de kapı açılmıştır[19].

Bu bilimsel birikime dayalı olarak 2018 yılında ABD Gıda ve İlaç Dairesi (FDA) tarafından De Novo yoluyla onaylanmış ve tıbbın herhangi bir dalında bir uzmanın yorumuna ihtiyaç duymadan tanı koyabilen ilk tam otonom yapay zeka sistemi IDx-DR (yeni adıyla LumineticsCore) kurulmuştur. Sistem, birinci basamakta 22 yaş üstü ve daha önce DR tanısı almamış diyabetli bireylerde orta düzeyden ileri diyabetik retinopatiyi saptamak üzere yetkilendirilmiştir[20]. Onayın dayanağı olan pivotal çalışma on ABD birinci basamak merkezinde yürütülmüş; 819 analiz edilebilir hastada, Wisconsin Fundus Fotoğraf Okuma Merkezi referansına karşı %87,2 duyarlılık, %90,7 özgüllük ve %96,1 görüntülenebilirlik değerleri elde edilmiştir[20].

Diyabetik ayak ülserinde çalışmalar (DAÜ) ağırlıklı olarak retrospektif ve ülser riskinin sınıflandırılması ile gelişiminin öngörülmesi çerçevesinde ilerlemektedir. On sekiz çalışmayı bir araya getiren sistematik bir derleme, makine öğrenmesi modellerinin sağlıklı deriyi ülserli dokudan ayırmada ve ülser ilerlemesini tahmin etmede umut verdiğini bildirmiş; duyarlılık %74,5 ile %98, doğruluk ise %64,6 ile %99,3 arasında değişmiştir[21]. Aynı derleme, modellerin belirgin biçimde heterojen olduğunu ve tanı ile tahminde kullanılabilecek standardize edilmiş tek bir cihazın ya da algoritmanın henüz geliştirilmediğini vurgulamaktadır. [21].

Diyabetik böbrek hastalığında (DBH) da Tip 2 diyabetli hastalarda DBH riskini öngören makine öğrenmesi modellerini inceleyen, 26 çalışma ve 94 modeli kapsayan bir sistematik derleme ve meta-analizde dikkat çekici biçimde diyabetik retinopati, böbrek hastalığı riskini öngörmede önemli bir değişken olarak öne çıkmış, 26 çalışmanın yalnızca sekizinde dış doğrulama yapılmış, modellerin genellenebilirliği ve yaygın klinik kullanımını sınırlı bulunmuştur.

Üç komplikasyon alanına birlikte bakıldığında otonom klinik dağıtıma, düzenleyici onaya ve prospektif gerçek dünya kanıtına ulaşan tek alan diyabetik retinopati taramasıdır; diyabetik ayak ve nefropatiye yönelik uygulamalar büyük ölçüde retrospektif geliştirme aşamasında durmaktadır[20-22]. Bu son iki alanda dış doğrulama, standardizasyon ve prospektif klinik çalışma ihtiyacı hâlâ giderilmiş değildir; retinopati modeliyle kıyaslandığında kanıt düzeyleri henüz olgunlaşmamış görünmektedir[21,22]. Kısacası yapay zeka, retinopatide yakaladığı otonom ve kanıta dayalı başarıyı diğer komplikasyonlara taşıyabilmek için çok daha güçlü ve ileriye dönük klinik doğrulamaya gereksinim duymaktadır.

Mobil Sağlık Uygulamaları ve Dijital Öz-Yönetim Platformları

Mobil sağlık (mHealth) uygulamaları ile dijital öz-yönetim platformları, Tip 2 diyabette glisemik kontrolü iyileştiren araçlar arasında giderek daha görünür bir yer tutmaktadır. Bu görünürlük randomize kontrollü çalışmalar (RKÇ) ve meta-analizlerle ortaya konmaktadır. 57 çalışma ve 7.365 katılımcıyla yürütülen bir meta-analizde HbA1c'deki düşüş -0,36 puan olarak bulunmuştur[23]. 41 randomize kontrollü çalışma ve 5.869 katılımcıyı kapsayan bir diğer meta-analizde ise düşüş -%0,49 düzeyinde bildirilmiştir[24].

Bu çalışmalarda etkiyi belirleyen en güçlü etmenlerden biri, uygulamaya yerleştirilen davranış değişikliği tekniklerinin niteliğidir. Davranışın öz-izlemi (self-monitoring) içeren uygulamalar, çok

daha belirgin bir HbA1c düşüşü sağlamıştır. Benzer şekilde davranış açısından da ilaç alımını ve tedaviye uyumu önceleyen uygulamalar anlamlı ölçüde daha güçlü bir etki göstermiştir[23]. Yani belirleyici olan teknolojinin salt varlığı değil, araca hangi davranış değişikliği stratejisinin eklendiğidir.

İkinci belirleyici sistem mimarisi ve teknolojik işlevselliktir. Glukoz izleme, diyet takibi, ilaç hatırlatma ve gerçek zamanlı geri bildirimi tek çatı altında toplayan kapsamlı yönetim uygulamaları, bunların yanında kişiselleştirilmiş eğitim ve bilgi desteği sunan uygulamalar en etkili uygulamalardır. Otomatik veri analitiği, anormal değerlerde uyarı üreten uzaktan izleme, yapay zeka temelli kişiselleştirme (örneğin insülin doz hesaplaması) ve oyunlaştırma da daha iyi glisemik sonuçlarla ilişkilendirilmiştir[24]. Kısacası klinik değer, basit hatırlatma ya da günlük tutma araçlarının ötesine geçen, veri odaklı ve uyarlanabilir mimarilerden kaynaklanmaktadır.

Dijital kanallarla sunulan diyabet öz-yönetim eğitimi ve desteği (DSME/S) de Tip 2 diyabette tutarlı bir yarar sağlamaktadır. 43 RKÇ ve 9.328 katılımcılık bir meta-analizde tek başına eğitim (DSME) HbA1c'de -4 mmol/mol bir değişiklik, tek başına destek (DSMS) -4 mmol/mol değişikilk ve eğitimle desteğin birlikte sunulması ise -2 mmol/mol düşüş sağlamıştır[25]. Yaşlı erişkinlerde mHealth uygulamalarını değerlendiren, 7 RKÇ ve 490 katılımcıdan oluşan bir meta-analizde HbA1c için etki büyüklüğü daha genç yaş gruplarında bildirilene yakın bulunmuştur. [26]

Bu çalışmalar göstermektedir ki, diyabet tipi, yaş, müdahale süresi ve coğrafi bölge, etkililiği doğrudan değiştiren faktörler arasındadır. Uygulamaların yaygınlaşmasının önünde ise dijital okuryazarlık eksikliği, veri güvenliği kaygıları ve elektronik sağlık kaydı sistemleriyle entegrasyon eksikliği gibi engeller bulunmaktadır[24]. Bir başka boşluk da yaşam kalitesi, öz-etkililik ve hasta memnuniyeti gibi öz-bildirim temelli çıktıların hâlâ görece az sayıda çalışmada ele alınmasıdır.

Teletıp, Telediyabet ve Uzaktan İzlem

Teletıp ve telesağlık, diyabet yönetiminde hasta ile sağlık ekibi arasındaki iletişimi fiziksel mesafeden bağımsız hâle getiren bir uygulamadır. Teledanışma, uzaktan glisemik izlem, tele-eğitim, hatırlatma sistemleri ve vaka yönetimi bu grubun başlıca bileşenleridir. Standart bakıma kıyasla sağladığı üstünlük randomize kontrollü çalışmalar ve meta-analizlerle desteklenmektedir; özellikle Tip 2 diyabette glisemik kontrolü anlamlı biçimde iyileştirdiği gösterilmiştir. COVID-19 dönemine odaklanan bir meta-analizde 12 randomize kontrollü çalışma ve 1.498 katılımcı üzerinden, telesağlık ile standart bakım arasında HbA1c açısından anlamlı farklılık tespit edilmiştir [27].Aynı meta-analizde etki yalnızca HbA1c ile sınırlı değildi; ikincil metabolik sonuçlarda da olumlu değişimler kaydedildi. Açlık kan şekerinde 16,06 mg/dL, beden kitle indeksinde 1,5 kg/m² ve LDL kolesterolde 7,78 mg/dL düşüş bildirilmiştir. Bu bulgular, uzaktan izlem temelli yaklaşımların glisemik hedeflerin ötesinde kardiyometabolik risk profiline de katkı sağlayabileceğine işaret etmektedir[27].

Benzer şekilde altı randomize kontrollü çalışma ve 3.995 hastayı içeren bir meta-analizde telesağlık, kan glukozu yönetiminde anlamlı bir etki göstermiştir Ancak çalışmalar arasındaki heterojenitenin yüksek olması etki büyüklüğünün müdahale tipine, hedef popülasyona ve izlem süresine göre değiştiğini düşündürmektedir[28].

Uzaktan izlemin ileri teknolojik araçlarla birleştirilmesine yönelik yapılan bir çalışmada, sürekli glukoz izlemini (CGM) uzaktan telemonitoring destekli sanal eğitmen ziyaretleriyle bir araya getiren randomize bir çalışmada, bu birleşik model insülin kullanmayan Tip 2 diyabetli erişkinlerde geliştirilmiş standart bakıma üstün bulunmuştur. HbA1c düşüşü müdahale kolunda -0,69, kontrol kolunda -0,33 bulunmuş, bu da uzaktan izlem stratejilerinin insülin bağımlı olmayan hasta gruplarında bile anlamlı katkı sunabildiğini göstermiştir[29].

Tüm bu olumlu bulgulara rağmen telesağlığın etkinliği her koşulda aynı değildir. Otuz Tip 2 diyabet hastasıyla yürütülen randomize kontrollü bir çalışmada, kapsamlı tele-eğitim rutin eğitime kıyasla anlamlı bir üstünlük sağlamamış; yalnızca beslenme alanında sınırlı bir olumlu etkiden söz etmiştir[30].

Yapay Zeka Sohbet Botları, Konuşma Ajanları ve Büyük Dil Modelleri

Konuşma ajanları (chatbot) ve büyük dil modelleri (ing. large language model, LLM), diyabet yönetiminde hızla büyüyen bir araştırma alanıdır. Eldeki kanıtlar umut verici, ama henüz olgunlaşmış değildir. Meta-analiz düzeyinde bakıldığında chatbot destekli öz-yönetim müdahaleleri, glisemik

kontrolde istatistiksel olarak anlamlı, klinik açıdansa küçük bir iyileşme sağlamaktadır. Dört çalışmayı ve 219 katılımcıyı bir araya getiren çalışmada HbA1c'de ortalama 0,30 düşme, vücut ağırlığında ise anlamlı bir etki elde edilememiştir[31].

My Diabetes Coach çalışmasında 'Laura' adlı etkileşimli konuşma ajanı kullanılmış, Tip 2 diyabetli 187 katılımcıyla yürütülmüştür. 12 ayın sonunda gruplar arasında HbA1c bakımından anlamlı bir fark çıkmamıştır. Sağlıkla ilişkili yaşam kalitesi anlamlı biçimde iyileşmiştir[32].

Büyük dil modellerinin hasta eğitimindeki performansını sınayan değerlendirme çalışmalarının çoğu Türk endokrinoloji ekiplerinden gelmektedir. Bunlardan biri, Tip 2 diyabet yönetimine dair hasta sorularını ele almış; yanıtların hiçbirinde yanlış ya da yanıltıcı bilgiye rastlanmamış, ortalama DISCERN skoru da 60,2 (iyi-mükemmel aralığı) çıkmıştır[33]. Asıl sorun içeriğin doğruluğu değil, okunabilirliğidir. Üretilen yanıtlar üniversite düzeyinde okuryazarlık gerektirmekte; okunabilirlik yanıtların yaklaşık %92'sinin (%50'si 'zor', %42'si 'çok zor') zor veya çok zor düzeyde sınıflandırmıştır[33].

ChatGPT-4o'yu diyabet teknolojisi eğitimi açısından inceleyen bir başka çalışma da yanıtların kalitesi yüksek olsa da güvenilirlik yalnızca orta düzeyde kalmış, okunabilirlik yine üniversite düzeyi okuryazarlık gerektirmiş, üstelik Türkçe yanıtların İngilizce yanıtlara kıyasla daha az ayrıntılı ve yer yer güncelliğini yitirmiş olduğu bildirilmiştir[34]. Buradan çıkan sonuç, düşük sağlık okuryazarlığına sahip hastalar için asıl engelin erişilebilirlik olduğudur.

Çalışmaların ortak vardığı nokta açıktır: yapay zeka temelli chatbot ve LLM araçları, klinisyen liderliğindeki hasta eğitiminin yerini almak için değil, onu tamamlamak için vardır. Tutarsız ya da hatalı yanıt üretme olasılığı, mahremiyet ve erişilebilirlik sorunları, bir de kaynak şeffaflığındaki eksiklikler, bu teknolojilerin ancak klinik gözetim altında kullanılmasını zorunlu kılmaktadır[33,34]. Bugünkü kanıt düzeyinde bu araçlara biçilecek rol, diyabet öz-yönetiminde bağlılığı ve hasta deneyimini güçlendiren yardımcı bileşen olmaktır. Glisemik sonuçlara gerçek katkılarının ne olduğu ise ancak daha kapsamlı ve yüksek kaliteli randomize çalışmalarla netleşecektir[31,32].

SONUÇ

Bu derlemede incelenen kanıtlar, diyabet yönetiminde yapay zeka ve dijital uygulamaların etkinliğinin tek tip olmadığını; sistemin insan kararına bağımlılığı azaldıkça kanıt gücünün belirgin biçimde arttığını ortaya koymaktadır. Kanıtın en güçlü ve klinik olarak yerleşik olduğu alan, otomatik insülin verme sistemleri (kapalı döngü) olarak öne çıkmaktadır; çok merkezli randomize kontrollü çalışmalar ve bunları birleştiren meta-analizler, geniş bir yaş aralığında ve gerçek yaşam koşullarında hedef aralıkta geçirilen süre (TIR) ile HbA1c değerlerinde tutarlı iyileşme ve hipoglisemi riskinde azalma göstermiş, güvenlik profilini net biçimde ortaya koymuştur. Sürekli glukoz izlemi (CGM), Tip 1 ve Tip 2 diyabette yürütülen iki büyük randomize kontrollü çalışma ve uluslararası konsensüs raporlarıyla standartlaşarak glisemik izlem paradigmasını dönüştürmüştür. Diyabetik retinopati taraması ise, algoritma geliştirme ve doğrulama çalışmalarının ardından tam otonom klinik dağıtıma ve düzenleyici onaya ulaşan, prospektif gerçek dünya kanıtına dayanan tek yapay zeka uygulaması olarak bu grupta yerini almaktadır.

Buna karşılık, yazılım merkezli araçların sağladığı yarar gerçek ancak mütevazıdır. Mobil sağlık uygulamaları, diyabet öz-yönetim eğitimi ve desteği ile teletıp uygulamaları randomize kontrollü çalışmalar ve meta-analizlerle tutarlı biçimde desteklenmekle birlikte, diyabet tipi, yaş, hastalık süresi, coğrafya ve dijital okuryazarlık gibi düzenleyici etkenlere bağlı değişkenlik göstermektedir.

Yapay zeka temelli sohbet robotları ve büyük dil modellerinde glisemik yarar küçük ve tutarsızdır. Makine öğrenmesi tabanlı öngörü modelleri hipoglisemi gibi olayların önceden tahmininde yüksek başarım gösterse de, gelişmekte olan bir olayın gerçek zamanlı tespiti hâlâ geliştirilmeye açık bir alandır. Ayrıca yaşam kalitesi, öz-etkililik ve memnuniyet gibi hasta bildirimli sonuçların hâlâ az sayıda çalışmada ele alınması, alandaki önemli bir ölçüm boşluğunu işaret etmektedir.

Bütünsel olarak değerlendirildiğinde, kanıt gücü sistemin donanım-algoritma entegrasyonu ve otonomi düzeyi arttıkça, yani insan kararına bağımlılığı azaldıkça yükselmekte; buna karşılık uygulama, sohbet robotu ve serbest metin iletişimi gibi insan davranışına dayanan çözümlerde etki mütevazılaşmakta, değişkenlik ve erişim eşitsizliği riski büyümektedir. Bu nedenle dijital ve yapay zeka çözümleri, mevcut

klinik bakımın yerine geçen değil onu tamamlayan araçlar olarak ve klinisyen gözetiminde konumlandırılmalıdır. Alanın ilerlemesi için kişiselleştirme, model yorumlanabilirliği ve klinik iş akışlarına sorunsuz entegrasyon öncelikli hedefler olmalı; sağlık okuryazarlığı, dijital eşitlik, dış doğrulama ve veri gizliliği güvenceleri tasarımın ayrılmaz parçası haline getirilmelidir.

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EVALUATION OF YIELD AND QUALITY CHARACTERISTICS OF BREAD WHEAT (*Triticum aestivum* L.) GENOTYPES UNDER TOKAT ECOLOGICAL CONDITIONS

TOKAT EKOLOJİK KOŞULLARINDA EKMEKLİK BUĞDAY (*Triticum aestivum* L.) GENOTİPLERİNİN VERİM VE KALİTE ÖZELLİKLERİNİN DEĞERLENDİRİLMESİ

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ÖZET

Dünya genelinde milyonlarca insan yeterli ve dengeli beslenmeden yoksunken, sürdürülebilir bir şekilde buğday üretimini artırmak, küresel gıda arzının devamlılığı için büyük önem taşımaktadır. Bu çalışma, 2023-2024 büyüme sezonunda Tokat ekolojik koşullarında yağışa dayalı üretim sistemi altında gerçekleştirilmiştir.

Çalışmada 20 ileri ekmeklik buğday hattı ile 5 standart çeşit tesadüf blokları deneme desenine göre dört tekerrürlü olarak değerlendirilmiştir. Genotiplerde tane verimi, başaklanma süresi, bitki boyu ve bazı kalite özellikleri ile sarı pas, kahverengi pas, kara pas ve Fusarium başak yanıklığı (FHB) reaksiyonları incelenmiştir. Veriler JMP 7.0 paket programı kullanılarak analiz edilmiştir.

Genotipler arasında tane verimi ve hektolitre ağırlığı bakımından %1 düzeyinde önemli farklılıklar belirlenmiştir. En yüksek tane verimi 1019,2 kg da^{-1} ile Hat-18'den, en yüksek hektolitre ağırlığı ise 83,3 kg hL^{-1} ile Kirve çeşidinden elde edilmiştir. Kalite analizlerinde en yüksek protein (%16,6), yaş glüten (%39,2), beklemeli sedimentasyon (84,0 mL) ve alveograf enerji değeri (375,5 MJ) Kirve çeşidinde belirlenirken, Hat-10, Hat-11, Hat-15, Hat-7 ve Hat-14 kalite özellikleri bakımından öne çıkmıştır. En yüksek tane sertliği değeri 85,7 HI ile Hat-20'de saptanmıştır. Hastalık değerlendirmelerinde ileri hatların büyük bölümünün pas hastalıklarına dayanıklı veya immün, Fusarium başak yanıklığına karşı ise orta dayanıklı olduğu belirlenmiştir. Korelasyon analizinde tane verimi ile protein, yaş glüten ve SDS arasında önemli negatif; nişasta ile pozitif ilişki belirlenmiştir. Protein oranının yaş glüten, SDS ve alveograf enerji değeri ile çok güçlü pozitif ilişkili olduğu saptanmıştır. Genel değerlendirmede Hat-18 yüksek verim potansiyeliyle öne çıkarken, Hat-7, Hat-15 ve Hat-19 verim ve kalite özelliklerini birlikte sergileyen, ıslah çalışmalarında değerlendirilebilecek umut verici genotipler olarak belirlenmiştir.

Anahtar Kelimeler: Ekmeklik buğday, verim, kalite, pas hastalıkları, Fusarium başak yanıklığı.

ABSTRACT

While millions of people around the world suffer from adequate and balanced nutrition, increasing wheat production in a sustainable way is of great importance for the continuity of the global food supply. This study was carried out under the rainfall-based production system in Tokat ecological conditions in the 2023–2024 growing season.

In this study, 20 advanced bread wheat lines and 5 standard varieties were evaluated in a randomized block design with four replications. The genotypes were evaluated in terms of grain yield, heading days, plant heigh, some quality characteristics, and reactions to yellow rust, leaf rust, stem rust, and Fusarium head blight (FHB). Data were analyzed using the JMP 7.0 software package.

Significant differences at the 1% level were determined among genotypes in terms of grain yield and hectolitre weight. The highest grain yield was obtained from Line-18 with 1019.2 kg da^{-1}, and the

highest hectolitre weight was obtained from the Kirve variety with 83.3 kg hL^{-1}. In quality analyses, the highest protein (16.6%), wet gluten (39.2%), delayed sedimentation (84.0 mL), and alveograph energy value (375.5 MJ) were determined in the Kirve variety, while Line-10, Line-11, Line-15, Line-7, and Line-14 stood out in terms of quality characteristics. The highest grain hardness value was found in Line-20 with 85.7 HI. In disease evaluations, it was determined that most of the advanced lines were resistant or immune to rust diseases, and moderately resistant to Fusarium ear blight. In correlation analysis, a significant negative correlation was determined between grain yield and protein, wet gluten, and SDS; and a positive correlation with starch. Protein content was found to have a very strong positive correlation with wet gluten, SDS, and alveograph energy value. In the overall evaluation, Line-18 stood out with its high yield potential, while Line-7, Line-15, and Line-19 were identified as promising genotypes exhibiting both yield and quality characteristics, and could be evaluated in breeding studies.

Keywords: Bread wheat, yield, quality, rust diseases, Fusarium head blight.

GİRİŞ

Buğday (*Triticum aestivum* L.), dünyada yaygın olarak yetiştirilen ve insan beslenmesinde önemli bir yere sahip olan, başlıca nişasta ve enerji kaynaklarından biri olmasının yanı sıra protein, vitamin, mineral, diyet lifi ve sağlık açısından yararlı fitokimyasalların sağlanmasına da katkıda bulunmaktadır **(Shewry & Hey (2015).** Ayrıca un, ekmek, makarna, bisküvi ve çeşitli unlu mamullerin temel hammaddesini oluşturması nedeniyle gıda sanayisi ve uluslararası tarım ticareti açısından başlıca tarımsal ürünlerden biridir. Birleşmiş Milletler Gıda ve Tarım Örgütü (FAO) verilerine göre, 2024–2025 sezonunda küresel buğday üretimi yaklaşık 796 milyon ton olarak gerçekleşmiştir (FAO, 2026).

Türkiye, buğdayın önemli gen merkezlerinden biri olması nedeniyle genetik kaynaklar bakımından zengin bir ülkedir. Buğday; geniş ekiliş alanı, üretim miktarı, insan beslenmesindeki yeri ve tarıma dayalı sanayiye sağladığı hammadde nedeniyle Türkiye tarımının stratejik ürünlerinden biri olma özelliğini korumaktadır. Türkiye İstatistik Kurumu verilerine göre, Türkiye'nin buğday üretimi 2025 yılında bir önceki yıla göre %13,7 azalarak 17,9 milyon ton olarak gerçekleşmiştir (TÜİK, 2025). Üretimde meydana gelen bu tür dalgalanmalar, farklı ekolojik koşullara uyum sağlayabilen, yüksek verimli ve üstün kalite özelliklerine sahip yeni çeşitlerin geliştirilmesinin önemini artırmaktadır.

Ekmeklik buğday ıslahında yalnızca yüksek tane veriminin sağlanması yeterli olmayıp değirmencilik, işleme ve son ürün kalitesini belirleyen özelliklerin de birlikte geliştirilmesi gerekmektedir. Protein oranı, yaş gluten miktarı, SDS sedimentasyon değeri, hektolitre ağırlığı, tane sertliği ve alveograf enerji değeri, ekmeklik buğday genotiplerinin teknolojik kullanım potansiyelinin belirlenmesinde kullanılan başlıca kalite kriterleridir. Özellikle glüten proteinlerinin miktarı ve bileşimi; hamurun viskoelastik yapısı, kuvveti, elastikiyeti, gaz tutma kapasitesi ve ekmek yapımına uygunluğu üzerinde belirleyici rol oynamaktadır. Bu nedenle stabil ve yüksek tane verimi ile üstün kalite özelliklerinin birlikte değerlendirilmesi, sanayinin ve tüketicilerin beklentilerini karşılayabilecek yeni ekmeklik buğday çeşitlerinin geliştirilmesinde temel ıslah hedeflerinden biridir (Guzmán & ark., 2022; Peña, 2002; Reynolds & ark., 2009; Shewry, 2009).

Ekmeklik buğday ıslahında yalnızca yüksek tane veriminin sağlanması yeterli olmayıp değirmencilik, işleme ve son ürün kalitesini belirleyen özelliklerin de birlikte geliştirilmesi gerekmektedir. Protein oranı, yaş glüten miktarı, SDS sedimentasyon değeri, hektolitre ağırlığı, tane sertliği ve alveograf enerji değeri, ekmeklik buğday genotiplerinin teknolojik kullanım potansiyelinin belirlenmesinde yararlanılan başlıca kalite ölçütleri arasında yer almaktadır (Guzmán & ark., 2022; Peña, 2002). Özellikle glüten proteinlerinin miktarı ve bileşimi; hamurun viskoelastik yapısı, kuvveti, elastikiyeti, gaz tutma kapasitesi ve ekmek yapımına uygunluğu üzerinde belirleyici rol oynamaktadır (Peña, 2002; Shewry, 2009). Bu nedenle yüksek ve stabil tane verimi ile üstün kalite özelliklerinin birlikte değerlendirilmesi,

sanayinin ve tüketicilerin beklentilerini karşılayabilecek yeni ekmeklik buğday çeşitlerinin geliştirilmesinde temel ıslah hedeflerinden biridir (Guzmán & ark., 2022).

Güçlü ekmeklik buğdaylarda hektolitre ağırlığının 78 kg hL^{-1} ve üzerinde, protein oranının en az %12,5–13,0 ve yaş glüten miktarının %28'in üzerinde olması arzu edilmektedir. Zeleny sedimentasyon değerinin 33–36 mL'nin üzerinde olması genellikle güçlü glüten kalitesiyle ilişkilendirilmektedir. SDS sedimentasyon değerleri ise kullanılan analiz yöntemi, örnek miktarı ve laboratuvar koşullarına bağlı olarak değişebildiğinden sonuçların aynı yöntemle analiz edilen standart çeşitlerle karşılaştırılarak değerlendirilmesi gerekmektedir. Hamur kuvvetinin göstergelerinden biri olan alveograf enerji değerinin genel ekmeklik kullanım için 200–300 x 10^{-4} J, endüstriyel tava ekmeği üretimi için ise 300 x 10^{-4} J'nin üzerinde olması tercih edilmektedir. Bununla birlikte alveograf enerji değerinin, hamurun direnç ve uzayabilirlik dengesini gösteren P/L oranıyla birlikte değerlendirilmesi daha kapsamlı bir kalite değerlendirmesi sağlamaktadır. Dolayısıyla yüksek ekmeklik kalite yalnızca yüksek protein ve glüten miktarına değil, aynı zamanda güçlü glüten yapısına, uygun tane sertliğine ve hamurun dengeli işlenme özelliklerine bağlıdır (Anonymous, 2022).

Bu araştırmada, 2023–2024 yetiştirme sezonunda Tokat ekolojik koşullarında ve yağışa dayalı üretim sisteminde yetiştirilen farklı orijinlere sahip ileri ekmeklik buğday genotiplerinin tane verimi, hektolitre ağırlığı, başaklanma süresi, bitki boyu, tane rengi, protein oranı, nişasta oranı, yaş glüten miktarı, SDS sedimentasyon değeri, tane sertliği ve alveograf enerji değeri bakımından performanslarının belirlenmesi amaçlanmıştır. Ayrıca genotiplerin sarı pas, kahverengi pas, kara pas ve Fusarium başak yanıklığına karşı tepkilerinin değerlendirilmesi, incelenen özellikler arasındaki ilişkilerin ortaya konulması ve üstün performans gösteren genotiplerin belirlenmesi hedeflenmiştir. Araştırmadan elde edilen bulguların, Tokat ve benzer ekolojik koşullara uygun; yüksek verimli, üstün kalite özelliklerine sahip ve önemli buğday hastalıklarına toleranslı yeni ekmeklik buğday çeşitlerinin geliştirilmesine katkı sağlaması beklenmektedir.

Materyal ve Metot

Materyal

Araştırma, 2023–2024 üretim sezonunda Tokat ili Orta Karadeniz Geçit Kuşağı Tarımsal Araştırma Enstitüsü Müdürlüğü deneme alanında yağışa dayalı koşullarda yürütülmüştür. Materyal olarak 20 ileri ekmeklik buğday hattı ile 5 standart çeşit kullanılmıştır. Standart çeşitler olarak Karadeniz Tarımsal Araştırma Enstitüsü tarafından geliştirilen Altındane, Kirve ve Nevzatbey ekmeklik buğday çeşitleri; Doğu Akdeniz Tarımsal Araştırma Enstitüsü tarafından geliştirilen Pandas ile TAREKS A.Ş. tarafından geliştirilen Flamura-85 çeşitleri kullanılmıştır (Çizelge 1). Deneme alanına ait iklim ve toprak özellikleri sırasıyla Çizelge 2 ve Çizelge 3 'te verilmiştir.

Metot

Çalışma tesadüf blokları deneme desenine göre dört tekerrürlü olarak yürütülmüştür. Ekim işlemi 04 Kasım 2023 tarihinde altı sıralı parsel mibzeri kullanılarak 7,7 m^2 parsel alanı ve 550 bitki/m^{-2} ekim normu esas alınarak gerçekleştirilmiştir. Hasat işlemi ise 04 Temmuz 2024 tarihinde parsel biçerdöveri ile 6 m^2 hasat alanı üzerinden yapılmıştır.

Ekimle birlikte dekara 6 kg saf azot ve 6 kg saf fosfor uygulanmış, sapa kalkma döneminde ise üst gübre olarak dekara 10 kg saf azot verilmiştir. Yabancı ot mücadelesinde Halauxifen-methyl + Pyroxsulam + Cloquintocet-acid etkili maddelerini içeren herbisit önerilen dozlarda uygulanmıştır.

Araştırmada genotipler; tane verimi, hektolitre ağırlığı, başaklanma süresi, bitki boyu, yatma durumu, tane rengi, protein oranı, nişasta oranı, yaş gluten, beklemeli sedimentasyon (SDS), tane sertliği, alveograf enerji değeri ile sarı pas, kahverengi pas, kara pas ve *Fusarium* başak yanıklığı (FHB) bakımından değerlendirilmiştir. Tane verimi, 6 m^2 hasat alanından elde edilen tane ağırlığının dekara çevrilmesiyle hesaplanmıştır. Hektolitre ağırlığı 1 litre hacimde buğdayın gram cinsinden ağırlığı klasik yöntem ile ölçülerek 100 litre hacimdeki buğdayın kilogram cinsinden ağırlığına uyarlanmıştır. Başaklanma gün sayısı gözlemlerinde başlangıç olarak 1 Ocak tarihi dikkate alınmıştır. Bitki boyu ölçümlerinde toprak yüzeyi ile bitki başak ucu (kılçık hariç) arası yükseklik esas alınmıştır. Yatma

gözlemlerinde 00-99 skalası kullanılmıştır. İlk rakam parselde yatan alanı, ikinci rakam ise yatma şiddetini ifade etmektedir. Kalite analizleri NIRs cihazı yardımı ile yapılmıştır.

Pas hastalıklarına karşı reaksiyon değerlendirmeleri modifiye edilmiş Cobb's skalası (Peterson & ark., 1948) kullanılarak yapılmıştır. Hastalık şiddeti 0-100, enfeksiyon tipi ise (R: Resistant, MR: Moderately Resistant, MS: Moderately susceptible, S: susceptible) olarak değerlendirilmiştir. Hastalık şiddeti ile enfeksiyon tipi için belirlenen sabitler (0=0; R=0.2; MR=0.4; I=0.6; MS=0.8; and S=1) çarpılarak enfeksiyon katsayıları (0 immune, 0.1-5.0 dayanıklı, 5.1-20.0 orta dayanıklı, 20.1-40.0 orta hassas ve 40.1-100 hassas) belirlenmiştir. Fusarium başak yanıklığı reaksiyon belirleme gözlemlerinde ise 0-9 skalası dikkate alınmıştır (Malihipour & ark., 2012).

Elde edilen verilerin istatistiksel analizleri JMP 7.0 paket programı kullanılarak yapılmıştır. Genotip ortalamaları arasındaki farklılıklar LSD testi (P≤0,05 ve P≤0,01) ile belirlenmiş, incelenen özellikler arasındaki ilişkiler ise Pearson korelasyon analizi kullanılarak değerlendirilmiştir (Kalaycı, 2005).

Çizelge 1. Denemede Kullanılan Ekmeklik Buğday Hat ve Çeşitlerin Melez Bilgileri

Genotip No		Melez	Islahçı kuruluş
1		YAV_3/SCO//JO69/CRA/3/YAV79/4/AE……..	
	CIMMYT		
2		KINGBIRD//ALPU/VP5053(WA#FM/201/23*2/….	CIMMYT
3		PATWIN YR5/4/PEHL//RPB 8-68/CHRC/3/…..	CIMMYT
4		PRINIA/BERKUT//PFAU/MILAN/3/NIKIFOR	
	CIMMYT		
ALTINDANE	Stamdart		KTAE
6		SUNSTATE/4/VEE/MJI//2*TUI/3/PASTOR/5/….	CIMMYT
7		OASIS/SKAUZ//4*BCN/4/VISTA/KS87H6//…..	CIMMYT
8		ROLF07*2/5/FCT/3/GOV/AZ//MUS/4/DOVE/…….	
	CIMMYT		
9		PYN/PARUS/3/VPM/MOS83-11-4-8//PEW/4/….	CIMMYT
NEVZATBEY	Standart	KTAE	
11		KS13DH0030-22	CIMMYT
12		TRCH/SRTU//KACHU/7/VEE#8//JUP/BJY/…..	CIMMYT
13		LUKILLUS/BTZ7	
	CIMMYT		
14		BABAX/LR42//BABAX*2/3/KURUKU/4/….	
	CIMMYT		
KİRVE	Standart	KTAE	
16		FRET2*2/SHAMA/3/PFAU/WEAVER//….	
	CIMMYT		
17		FRET2*2/KUKUNA//PRINIA/PASTOR/8/2….	
	CIMMYT		
18		COPIO/3/ATTILA*2/PBW65*2//KACHU/4/….	
	CIMMYT		
19		KS14DH0024-61	CIMMYT
PANDAS		Standart	DATAE
21		MUCUY//KACHU/KIRITATI/3/MUTUS*2/TECUE #1	
	CIMMYT		
22		ATTILA*2/ESDA//MASON)/(HBK0935-7-4/…..	CIMMYT
23		MUTUS*2/MUU/6/ATTILA/3*BCN//BAV92/3/…	CIMMYT
24		DORADE-5/3/SHI#4414/CROWS"//…	CIMMYT
FLAMURA-85	Standart	TAREKS	

CIMMYT: Uluslararası Mısır ve Buğday Geliştirme Merkezi, TAREKS A.Ş: Tarım kredi Tohumculuk, KTAE: Karadeniz Tarımsal Araştırma Enstitüsü, DATAE: Doğu Akdeniz Tarımsal Araştırma Enstitüsü

Çizelge 2. 2023-2024 Yetiştirme Sezonundaki Tokat Lokasyonuna Ait Yağış, Sıcaklık ve Nisbi Nem Değerleri

Lokasyon		TOKAT		
Ay/Yıl		Yağış (mm)	Nem (%)	Sıcak. (^{0}C)
Ekim	2023	18,80	62,90	15,50
Kasım		49,20	60,50	12,70
Aralık		31,60	75,10	7,20
Ocak	2024	60,70	73,40	4,80
Şubat		6,90	57,00	8,30
Mart		34,40	64,40	8,90
Nisan		16,90	50,80	17,20
Mayıs		84,50	63,80	15,90
Haziran		6,50	52,40	23,30
Temmuz		18,20	57,40	24,60
TOPLAM		327,70	-	-

Çizelge 3. 2023 Yılı Deneme Alanına ait Toprak Özellikleri

Lokasyon	Bünye Sınıfı		Toplam Tuz (%)	PH	Kireç CaCO3 (%)	Fosfor (kgda-1)	Organik Madde (%)	Su ile Doygunluk (%)
Tokat	Killi-Siltli	0,03	7,90	11,00	3,50	1,60	62,00	

Bulgular ve Tartışma

Tane Verimi

Tokat ekolojik koşullarında yürütülen araştırmada genotipler arasında tane verimi bakımından istatistiksel olarak çok önemli farklılıklar belirlenmiştir ($P < 0,01$; Çizelge 4). Genotiplerin tane verimleri 659,2–1019,2 kg da^{-1} arasında değişmiştir. En yüksek tane verimi 1019,2 kg da^{-1} ile Hat-18'den elde edilirken, bu hattı Hat-19 (994,6 kg da^{-1}), Hat-5 (973,3 kg da^{-1}), Hat-7 (969,2 kg da^{-1}) ve Hat-16 (966,7 kg da^{-1}) izlemiştir. En düşük tane verimleri ise standart çeşitlerden Nevzatbey (659,2 kg da^{-1}) ve Pandas'ta (660,8 kg da^{-1}) belirlenmiştir. En yüksek ve en düşük tane verimleri arasında 360,0 kg da^{-1} fark bulunması, incelenen genotiplerin verim potansiyelleri bakımından geniş bir varyasyona sahip olduğunu göstermektedir. Bazı ileri hatların standart çeşitlerden daha yüksek tane verimi sağlaması, bu genotiplerin 2023–2024 yetiştirme sezonunda Tokat koşullarında ümitvar bir performans sergilediğini göstermiştir. Özellikle Hat-18, Hat-19, Hat-5, Hat-7 ve Hat-16 yüksek tane verimleriyle öne çıkmıştır.

Aydın & ark. (2005), tane veriminin Samsun koşullarında 165,0–381,0 kg da^{-1}, Amasya koşullarında ise 228,8–547,3 kg da^{-1} arasında değiştiğini bildirmiştir. Mut & ark. (2017), Yozgat koşullarında üç yıllık ortalama tane verimlerinin 290,5–372,2 kg da^{-1} arasında olduğunu belirlerken, Karaman (2022) tane veriminin 200,2–712,9 kg da^{-1} arasında değiştiğini ve genel ortalamanın 462,8 kg da^{-1} olduğunu bildirmiştir. Aktaş & Gökdere (2025) ise Ege, Marmara, Akdeniz, Güneydoğu Anadolu ve Orta Anadolu bölgelerinde 2016–2017 ve 2017–2018 yetiştirme sezonlarında yürüttükleri bölgesel çalışmada, tane veriminin 426,0–813,7 kg da^{-1} arasında değiştiğini belirlemiştir. Mevcut araştırmada elde edilen tane verimlerinin Aydın & ark. (2005), Mut & ark. (2017) ve Karaman (2022) tarafından bildirilen değerlerden genel olarak daha yüksek olduğu; Aktaş & Gökdere (2025) tarafından bildirilen üst değerlerle ise daha fazla benzerlik gösterdiği görülmektedir. Çalışmalar arasındaki farklılıklar; kullanılan genotiplerin genetik yapısı, yağış miktarı ve dağılımı, sıcaklık, hastalık baskısı, toprak özellikleri ve yetiştirme uygulamalarındaki farklılıklarla ilişkilendirilebilir. Aydın & ark. (2005), aşırı yağışın yatma ve hastalık şiddetini artırarak tane verimini olumsuz etkileyebildiğini belirtmiştir.

Balmuk & ark. (2025), aynı genetik materyalin Samsun-Bafra ve Tokat koşullarındaki tane verimlerinin 476,6–1125,8 kg da^{-1} arasında değiştiğini ve genotiplerin verim performanslarının çevrelere göre farklılık gösterdiğini bildirmiştir. Mevcut araştırmadan elde edilen bulguların söz konusu çalışmayla genel olarak uyumlu olması, tane veriminin genotipik yapı, çevre koşulları ve genotip x çevre etkileşiminden önemli ölçüde etkilendiğini göstermektedir.

Genel olarak araştırma sonuçları, söz konusu hatların Tokat koşullarında yüksek tane verimi potansiyeline sahip olduğunu ortaya koymuştur. Bununla birlikte çeşit adaylarının belirlenmesinde yalnızca tane veriminin yeterli olmaması nedeniyle genotiplerin kalite özellikleri, hastalıklara dayanıklılıkları, farklı çevre koşullarındaki performansları ve verim stabilitelerinin birlikte değerlendirilmesi gerekmektedir. Bu değerlendirmeler sonucunda üstün ve dengeli performans gösteren hatlar, tescil denemelerine sunulabilecek materyaller arasında ele alınabilecektir.

Çizelge 4. Genotiplerin Tane Verimine İlişkin Değerleri

GNO	TOKAT	
Hat-1	909,20	a-f
Hat-2	924,20	a-f
Hat-3	833,30	b-f
Hat-4	947,50	a-d
Altındane	889,20	a-f
Hat-5	973,30	a-c
Hat-6	958,30	a-c
Hat-7	969,20	a-c
Hat-8	873,30	a-f
Nevzatbey	659,20	g
Hat-9	880,80	a-f
Hat-10	830,80	b-f
Hat-11	765,00	fg
Hat-12	913,30	a-f
Kirve	789,20	d-g
Hat-13	948,30	a-d
Hat-14	820,40	c-g
Hat-15	930,00	a-e
Hat-16	966,70	a-c
Pandas	660,80	g
Hat-17	847,50	b-f
Hat-18	1019,20	a
Hat-19	994,60	ab
Hat-20	915,00	a-f
Flamura85	770,00	e-g
Ort.	879,50	
DK%	13,20	
ÖD	**	
LSD	164	

Hektolitre Ağırlığı

Genotipler arasında hektolitre ağırlığı bakımından istatistiksel olarak çok önemli farklılıklar belirlenmiştir ($P < 0,01$; Çizelge 5). Hektolitre ağırlığı değerleri 77,8–83,3 kg hL^{-1} arasında değişmiştir. En yüksek değer 83,3 kg hL^{-1} ile kontrol çeşitlerinden Kirve'de belirlenirken, ileri hatlar arasında Hat-2 ve Hat-19, 82,5 kg hL^{-1} değerleriyle öne çıkmıştır. En düşük hektolitre ağırlığı ise 77,8 kg hL^{-1} ile Pandas çeşidinden elde edilmiştir. Genotipler arasında belirlenen 5,5 kg hL^{-1} düzeyindeki değişim, incelenen materyalin bu özellik bakımından önemli bir varyasyona sahip olduğunu göstermektedir.

Hektolitre ağırlığı; tane dolgunluğu, iriliği, şekli ve yoğunluğu gibi özelliklerden etkilenen önemli bir fiziksel kalite ölçütüdür. Yüksek hektolitre ağırlığı genellikle iyi tane gelişimi ve değirmencilik performansıyla ilişkilendirilmektedir. Bu bakımdan Hat-2 ve Hat-19'un yüksek hektolitre ağırlığı değerleri, söz konusu hatların fiziksel tane kalitesi yönünden dikkat çekici olduğunu göstermektedir.

Karaman & Aktaş (2020), hektolitre ağırlığının 76,5–85,4 kg hL^{-1} arasında değiştiğini ve genel ortalamanın 82,2 kg hL^{-1} olduğunu bildirmiştir. Erdem & Sakin (2023), bu özelliğin 77,6–82,3 kg hL^{-1}; Olgun & ark. (2022) ise 60,13–83,07 kg hL^{-1} arasında değiştiğini belirlemiştir. Bu çalışmalarda bildirilen üst değerler, mevcut araştırma bulgularıyla genel olarak benzerlik göstermiştir. Geniş değişim aralığının, araştırmada farklı tane yapısına sahip Siyez buğdayının da yer almasından kaynaklanmış olabileceği düşünülmektedir.

Güngör & ark. (2022), hektolitre ağırlığının 72,7–80,5 kg hL^{-1} arasında değiştiğini ve genel ortalamanın 76,5 kg hL^{-1} olduğunu bildirmiştir. Benzer şekilde Aktaş & Gökdere (2025), Ege, Marmara, Akdeniz, Güneydoğu Anadolu ve Orta Anadolu bölgelerinde 2016–2017 ve 2017–2018 yetiştirme sezonlarında yürüttükleri bölgesel çalışmada, hektolitre ağırlığının 77,2–79,2 kg hL^{-1} arasında değiştiğini belirlemiştir. Mevcut araştırmada elde edilen değerlerin bu çalışmalarda bildirilen değerlerden genel olarak daha yüksek olması; kullanılan genotiplerin genetik yapısı, tane dolum dönemindeki yağış ve sıcaklık koşulları, hastalık baskısı ve yetiştirme uygulamalarındaki farklılıklarla ilişkilendirilebilir.

Aydın & ark. (2005), hektolitre ağırlığının genotip ve çevre koşullarından önemli ölçüde etkilendiğini; yüksek yağış, yatma ve hastalıkların bu özelliği olumsuz etkileyebildiğini bildirmiştir. Balmuk & ark. (2025) ise aynı genetik materyalde hektolitre ağırlığının farklı lokasyonlarda 68,0–80,8 kg hL^{-1} arasında değiştiğini ve lokasyon etkisinin önemli olduğunu belirtmiştir. Bu sonuçlar, hektolitre ağırlığının genetik yapının yanı sıra çevre koşulları ve genotip x çevre etkileşiminden de etkilendiğini göstermektedir.

Genel olarak araştırma sonuçları, Kirve çeşidi ile Hat-2 ve Hat-19'un hektolitre ağırlığı bakımından üstün performans gösterdiğini ortaya koymuştur. Özellikle Hat-2 ve Hat-19'un 82,5 kg hL^{-1} değerine ulaşması, bu hatların tane dolgunluğu ve fiziksel kalite bakımından ümitvar olduğunu göstermektedir. Bununla birlikte genotiplerin değirmencilik ve ekmeklik kalite potansiyellerinin belirlenmesinde hektolitre ağırlığının protein oranı, tane sertliği, sedimentasyon değeri ve hamur reolojisi gibi diğer kalite özellikleriyle birlikte değerlendirilmesi gerekmektedir.

Çizelge 5. Genotiplerin Hektolitre Ağırlığına İlişkin Değerleri

GNO	TOKAT
Hat-1	80,50 d-g
Hat-2	82,50 ab
Hat-3	82,00 a-c
Hat-4	81,50 b-d
Altındane	80,00 e-g
Hat-5	82,00 a-c
Hat-6	80,80 c-f
Hat-7	81,00 c-f
Hat-8	81,50 b-d
Nevzatbey	82,00 a-c

Hat-9	80,00	e-g
Hat-10	81,30	b-e
Hat-11	80,50	d-g
Hat-12	82,00	a-c
Kirve	83,30	a
Hat-13	79,80	fg
Hat-14	80,30	d-g
Hat-15	80,80	c-f
Hat-16	80,00	e-g
Pandas	77,80	h
Hat-17	80,50	d-g
Hat-18	79,80	fg
Hat-19	82,50	ab
Hat-20	79,80	fg
Flamura85	79,30	g
Ort.	80,80	
DK%	1,30	
ÖD	**	
LSD	1,50	

Başaklanma Süresi ve Bitki Boyu

Araştırmada başaklanma süresi genotiplere göre 101–120 gün arasında değişmiştir (Çizelge 6). En erkenci genotip 101 gün ile Hat-4 olurken, Hat-11 ve Hat-12 120 gün ile en geç başaklanan genotipler olarak belirlenmiştir. Genotipler arasında gözlenen 19 günlük farklılık, incelenen materyalin erkencilik bakımından geniş bir varyasyona sahip olduğunu göstermektedir. Başaklanma süresindeki bu varyasyon, özellikle yağışın düzensiz olduğu ve tane dolum döneminde yüksek sıcaklıkların görülebildiği çevrelerde uygun genotiplerin belirlenmesi bakımından önem taşımaktadır.

Karaman & ark. (2017), başaklanma süresinin 107–119 gün arasında değiştiğini ve iki yıllık ortalamanın 113 gün olduğunu bildirmiştir. El-Orabey & ark. (2014) ise bu özelliğin Shibin El-Kom lokasyonunda 90,75–104,00 gün, Itay El-Baroud lokasyonunda 90,50–101,50 gün arasında değiştiğini belirlemiştir. Güran (2019), Diyarbakır koşullarında başaklanma süresinin 158,5–163,0 gün arasında olduğunu bildirmiştir. Çalışmalar arasında gözlenen farklılıkların kullanılan genotipler, ekim tarihleri, sıcaklık birikimi, rakım ve yetiştirme koşullarından kaynaklanabileceği düşünülmektedir. Bu nedenle farklı araştırmalarda gün olarak bildirilen başaklanma sürelerinin karşılaştırılmasında ekim tarihi ve hesaplama yönteminin dikkate alınması gerekmektedir.

Bitki boyu 65–107 cm arasında değişmiş; en kısa bitki boyu Pandas, en uzun bitki boyu ise Nevzatbey çeşidinde belirlenmiştir. İleri hatların büyük çoğunluğunun 73–95 cm arasında bitki boyuna sahip olduğu görülmüştür. Genotipler arasındaki bu farklılık, araştırma materyalinde bitki boyu bakımından yeterli varyasyon bulunduğunu göstermektedir. Orta boylu genotipler yatma riskinin azaltılması ve mekanik hasadın kolaylaştırılması bakımından avantaj sağlayabilirken, uzun boylu genotipler saman verimi yönünden üstünlük gösterebilmekte ancak uygun olmayan koşullarda yatmaya daha eğilimli olabilmektedir. Bu nedenle bitki boyunun yatma durumu, sap sağlamlığı, tane verimi ve çevre koşullarıyla birlikte değerlendirilmesi gerekmektedir.

Karaman & ark. (2017) bitki boyunun 74–98 cm, Aydoğan & Soylu (2017) 79,50–115,00 cm, Olgun & ark. (2022) ise 72,00–100,67 cm arasında değiştiğini bildirmiştir. Erdem & Sakin (2023), iki yıllık ortalamalara göre bitki boyunun 69,3–99,7 cm, Güngör & ark. (2022) ise 75,3–120,6 cm arasında olduğunu belirlemiştir. Bu çalışmalarda bildirilen değerler, araştırmamızdaki ileri hatların büyük

bölümünün ekmeklik buğdayda yaygın olarak gözlenen bitki boyu aralıklarında yer aldığını göstermektedir.

El-Orabey & ark. (2014), bitki boyunun iki farklı lokasyonda 107,50–136,25 cm arasında değiştiğini bildirirken, Albayrak & ark. (2022) 46,73–67,20 cm arasında değişen daha düşük değerler belirlemiştir. Çalışmalar arasındaki belirgin farklılıklar; genotipik yapı, yağış ve sıcaklık koşulları, toprak verimliliği ve yetiştirme uygulamalarının bitki boyu üzerindeki etkisiyle açıklanabilir. Nitekim farklı yıllarda elde edilen ortalamaların değişmesi, bitki boyunun çevre koşullarına duyarlı bir özellik olduğunu göstermektedir.

Genel olarak araştırma sonuçları, genotipler arasında hem başaklanma süresi hem de bitki boyu bakımından dikkate değer bir varyasyon bulunduğunu ortaya koymuştur. Hat-4 erkencilik özelliğiyle öne çıkarken, ileri hatların büyük bölümünün 73–95 cm arasında bitki boyuna sahip olması agronomik uygunluk bakımından olumlu değerlendirilmiştir. Bununla birlikte bu özelliklerin çevre koşullarından etkilenmesi nedeniyle, öne çıkan genotiplerin farklı yıl ve lokasyonlardaki performanslarının değerlendirilmesi gerekmektedir.

Çizelge 6. Genotiplerin Başaklanma Süresi ve Bitki Boyuna İlişkin Değerleri

GNO	TOKAT	
	Başaklanma (gün)	Bitki Boyu (cm)
Hat-1	112	75
Hat-2	110	70
Hat-3	110	75
Hat-4	101	75
Altındane	114	74
Hat-5	113	74
Hat-6	112	83
Hat-7	108	80
Hat-8	114	83
Nevzatbey	118	107
Hat-9	114	80
Hat-10	113	80
Hat-11	120	90
Hat-12	120	95
Kirve	113	80
Hat-13	108	77
Hat-14	110	73
Hat-15	113	80
Hat-16	117	82
Pandas	110	65
Hat-17	108	80
Hat-18	118	85
Hat-19	110	95
Hat-20	113	93
Flamura85	114	80
Ort.	113	81

Hastalık Reaksiyonları

Doğal epidemi koşullarında yapılan gözlemlerde genotiplerin sarı pas, kahverengi pas, kara pas ve Fusarium başak yanıklığına karşı reaksiyonları bakımından farklılık gösterdiği belirlenmiştir (Çizelge 7). İleri hatların büyük bölümü sarı pas ve kara pasa karşı dayanıklı veya immün reaksiyon gösterirken, kahverengi pasa karşı dayanıklılık düzeyleri genotiplere göre değişmiştir. Fusarium başak yanıklığı bakımından ise genotiplerin çoğunluğu orta dayanıklı grupta yer almıştır. Bu bulgular, incelenen materyalde hastalıklara dayanıklılık bakımından önemli bir varyasyon bulunduğunu göstermektedir.

Yazar & ark. (2013), ekmeklik buğday genotiplerinin büyük bölümünün sarı pasa karşı dayanıklı veya toleranslı reaksiyon gösterdiğini bildirmiştir. Bu sonuçlar, araştırmamızda sarı pasa karşı elde edilen bulgularla benzerlik göstermektedir. El-Orabey & ark. (2014) ise kahverengi pas şiddetinin farklı yıl ve lokasyonlarda %0–80, kara pas şiddetinin %0–70 ve sarı pas şiddetinin %0–50 arasında değiştiğini belirlemiştir. Araştırmacılar, bazı hatların üç pas hastalığına karşı dayanıklı olmasına karşılık bazı genotiplerin hassas reaksiyon gösterdiğini bildirmiştir. Bu sonuçlar, pas hastalıklarına karşı reaksiyonların genotipik yapının yanı sıra yıl ve çevre koşullarından da etkilendiğini göstermektedir.

Doğal epidemi koşullarında hastalık gelişimi; inokulum miktarı, sıcaklık, yağış, bağıl nem ve bitkinin gelişme dönemi gibi faktörlere bağlı olarak değişebilmektedir. Özellikle Fusarium başak yanıklığına karşı genotiplerin çoğunluğunun orta dayanıklı bulunması, incelenen materyalde belirli bir tolerans düzeyi bulunduğunu göstermekle birlikte, hastalık reaksiyonlarının farklı yıl ve lokasyonlarda veya kontrollü inokulasyon koşullarında doğrulanması gerekmektedir.

Vera (2021), sarı pasın hassas ekmeklik buğday çeşitlerinde tane verimi, bin tane ağırlığı, hektolitre ağırlığı ve protein oranını olumsuz etkilediğini bildirmiştir. Araştırmacı, hastalıklarla mücadelede genetik dayanıklılık ile gerektiğinde fungisit uygulamasının birlikte kullanılmasının daha etkili ve sürdürülebilir bir yaklaşım olduğunu belirtmiştir. Bu bakımdan pas hastalıklarına karşı dayanıklı veya kabul edilebilir reaksiyon gösteren ileri hatların belirlenmesi, hastalık kaynaklı verim ve kalite kayıplarının azaltılması açısından önem taşımaktadır.

Genel olarak araştırma sonuçları, bazı ileri hatların yüksek verim ve kalite performansının yanı sıra önemli buğday hastalıklarına karşı kabul edilebilir dayanıklılık düzeyine sahip olduğunu göstermiştir. Bununla birlikte doğal epidemi koşullarında elde edilen sonuçların farklı yıl ve çevrelerde doğrulanması, hastalık dayanıklılığı bakımından istikrarlı performans gösteren hatların belirlenmesi ve tescil denemelerine sunulabilecek materyallerin seçiminde dikkate alınması gerekmektedir.

Çizelge 7. Genotiplerin Yatma, Tane ve Hastalık Durumuna İlişkin Değerleri

GNO	Yatma (00-99)	Tane Rengi	Tane Notu	Sarı Pas	Kahverengi pas	Kara Pas	Fhb(0-9)
Hat-1	35	B	3,70	0	12	10	3
Hat-2	0	B	3,30	0	4	0	5
Hat-3	83	B	3,70	0	2	0	4
Hat-4	85	K	2,70	0	2	0	4
Altındane	0	B	2,70	2	12	0	6
Hat-5	0	B	3,30	4	4	0	5
Hat-6	0	B	3,30	0	2	0	5
Hat-7	0	K	3,30	0	32	0	4
Hat-8	0	B	3,30	0	32	0	4
Nevzatbey	0	B	3,30	16	8	10	5
Hat-9	0	K	3,00	16	0	0	3
Hat-10	0	B	3,00	0	24	0	2
Hat-11	0	K	3,00	0	70	0	7
Hat-12	0	K	3,30	2	0	0	4
Kirve	0	B	3,70	12	5	40	4
Hat-13	45	K	2,30	0	10	20	5
Hat-14	55	K	3,00	2	0	0	5

Hat-15	0	B	3,00	2	0	0	6
Hat-16	0	K	2,70	2	8	2	4
Pandas	0	K	2,70	4	0	30	7
Hat-17	0	K	3,00	2	4	5	6
Hat-18	0	B	3,30	0	8	10	4
Hat-19	75	B	3,30	0	4	0	4
Hat-20	0	K	3,30	0	12	0	4
Flamura85	0	K	2,30	60	0	8	7

Kalite Özellikleri

Araştırmada genotiplerin protein oranı %12,8–16,6, yaş gluten miktarı %30,5–39,2, SDS sedimentasyon değeri 51,3–84,0 mL ve alveograf enerji değeri 252,7–375,5 x 10^{-4} J arasında değişmiştir (Çizelge 8). Kontrol çeşitleri içerisinde Kirve, kalite özelliklerinin büyük bölümü bakımından yüksek değerler göstermiştir. İleri hatlardan Hat-10, Hat-11, Hat-15, Hat-7 ve Hat-14 protein oranı, SDS sedimentasyon ve alveograf enerji değeri; Hat-20 ise tane sertliği bakımından öne çıkmıştır. Bu farklılıklar, araştırma materyalinde ekmeklik kalite özellikleri yönünden geniş bir varyasyon bulunduğunu göstermektedir.

Aydın & ark. (2005), Yazar & ark. (2013) ile Özen & Akman (2015), protein oranının sırasıyla %10,9–11,6, %10,5–13,4 ve %7,5–12,9 arasında değiştiğini bildirmiştir. Bu değerler, araştırmamızda elde edilen sonuçlardan genel olarak daha düşüktür. Buna karşılık Karaman & ark. (2017), Güran (2019), Karaman & Aktaş (2020) ile Erdem & Sakin (2023) tarafından bildirilen %12,4–16,9 aralığındaki değerler, mevcut bulgularla büyük ölçüde benzerlik göstermiştir. Benzer şekilde Aktaş & Gökdere (2025), 2016–2017 ve 2017–2018 yetiştirme sezonlarında Ege, Marmara, Akdeniz, Güneydoğu Anadolu ve Orta Anadolu bölgelerinde buğdayların bölgesel protein içeriğinin %13,4 ile %14,7 arasında değiştiğini belirlemiş olup, bu değerlerin de araştırmamızda elde edilen sonuçlarla uyumlu olduğu görülmüştür.

Çalışmalar arasındaki farklılıkların genotipik yapı, sıcaklık ve yağış koşulları, azot alımı ve tane verimi düzeyinden kaynaklanabileceği düşünülmektedir. Aydın & ark. (2005), Özen & Akman (2015) ve Kılıç & ark. (2014), tane verimi ile protein oranı arasında negatif ilişkiler bulunduğunu bildirmiştir.

Yaş gluten miktarı bakımından elde edilen %30,5–39,2 aralığı, Özen & Akman (2015) tarafından bildirilen %15,4–30,4 aralığından daha yüksek bulunmuştur. Güran (2019), yaş gluten miktarının %29,4–33,7 arasında değiştiğini bildirmiştir. Protein ve yaş gluten miktarının birlikte yüksek olması olumlu bir kalite göstergesi olmakla birlikte, gluten kuvvetinin değerlendirilmesinde SDS sedimentasyon ve alveograf enerji değerlerinin de dikkate alınması gerekmektedir.

Kurt (2012), sedimentasyon değerinin ekmeklik buğday genotiplerinin kalite düzeylerinin belirlenmesinde önemli bir ölçüt olduğunu; Karaman & ark. (2017) ise protein oranı ile Zeleny sedimentasyon değeri arasında güçlü pozitif bir ilişki bulunduğunu bildirmiştir. Bu sonuçlar, araştırmamızda protein oranı ile SDS sedimentasyon değeri arasında belirlenen güçlü pozitif ilişkiyi desteklemektedir. Balmuk & ark. (2025), aynı genetik materyalde Zeleny sedimentasyon değerinin 32–75 mL, alveograf enerji değerinin ise 105–385 x 10^{-4} J arasında değiştiğini bildirmiştir. Kılıç & ark. (2014) tarafından bildirilen alveograf enerji değerleri 37–233 x 10^{-4} J arasında bulunmuştur. Benzer şekilde Aktaş & Gökdere (2025), 2016–2017 ve 2017–2018 yetiştirme sezonlarında Ege, Marmara, Akdeniz, Güneydoğu Anadolu ve Orta Anadolu bölgelerinde yürüttükleri çalışmada, alveograf enerji değerlerinin bölgelere göre 191,2 ile 276,4 x 10^{-4} J arasında değiştiğini belirlemiştir. Bu bulgular, araştırmamızda elde edilen alveograf enerji değerlerinin önceki çalışmalarla genel olarak uyumlu olduğunu göstermektedir. Mevcut sonuçlar, özellikle Hat-10, Hat-11, Hat-15, Hat-7 ve Hat-14'ün glüten kuvveti ve ekmeklik kalite potansiyeli bakımından dikkat çektiğini ortaya koymaktadır.

Sedimentasyon yöntemleri arasında kullanılan örnek miktarı, çözelti ve analiz süresi bakımından farklılıklar bulunduğundan, Zeleny, uzatmalı sedimentasyon ve CIMMYT-SDS sonuçlarının doğrudan sayısal olarak karşılaştırılması uygun değildir. Olgun & ark. (2022) tarafından bildirilen 4,67–17,17 arasındaki CIMMYT-SDS değerlerinin araştırmamızdaki sonuçlardan düşük olması da yöntem

farklılığıyla açıklanabilir. Bu nedenle sedimentasyon sonuçlarının aynı yöntemle analiz edilen genotipler ve standart çeşitler üzerinden değerlendirilmesi daha doğru olacaktır.

Tane sertliği bakımından en yüksek değerin Hat-20'de belirlenmesi, bu hattın öğütme ve teknolojik kullanım özellikleri yönünden farklı bir potansiyele sahip olduğunu göstermektedir. Aydoğan & Soylu (2017), PSI değerlerinin 41,27–64,82; Olgun & ark. (2022) ise farklı bir yöntemle belirlenen tane sertliği değerlerinin 13,99–86,12 arasında değiştiğini bildirmiştir. Tane sertliği farklı yöntemlerle ölçülebildiğinden, çalışmalar arasındaki sayısal karşılaştırmalarda kullanılan yöntemin dikkate alınması gerekmektedir.

Genel olarak araştırma sonuçları, Hat-10, Hat-11, Hat-15, Hat-7 ve Hat-14'ün protein oranı, sedimentasyon değeri ve hamur kuvveti bakımından; Hat-20'nin ise tane sertliği yönünden öne çıktığını göstermiştir. Bununla birlikte ekmeklik kalite yalnızca tek bir özellik üzerinden değerlendirilmemeli; protein oranı, glüten miktarı ve kalitesi, sedimentasyon değeri, tane sertliği ve hamur reolojisi birlikte ele alınmalıdır.

Öne çıkan hatların farklı yıl ve çevrelerde değerlendirilmesi, kalite özelliklerinin stabilitesinin belirlenmesi ve tescil denemelerine sunulabilecek materyallerin seçiminde daha güvenilir sonuçlar sağlayacaktır.

Çizelge 8. Genotiplerin Kalite Analizi Değerleri

GNO	Rutubet(%)	Protein(%)	Nişasta(%)	Yaş Gluten(%)	Sds Bek.(ml)	Sertlik(HI)	Alweo W(Mj/kg)
Hat-1	11,70	14,20	68,30	33,50	60,00	66,00	334,70
Hat-2	11,60	13,60	68,50	32,10	58,00	52,00	311,70
Hat-3	11,70	14,00	68,30	33,30	62,00	51,00	302,30
Hat-4	11,80	13,50	67,90	31,90	56,70	72,30	294,00
Altındane	11,80	14,90	68,10	35,10	68,00	45,70	346,30
Hat-5	11,70	13,40	68,70	31,80	57,30	50,00	290,30
Hat-6	11,90	13,80	68,70	32,70	58,00	50,00	261,70
Hat-7	11,60	14,90	67,50	35,30	68,00	67,70	336,00
Hat-8	11,80	14,10	67,70	33,50	64,70	45,70	313,00
Nevzatbey	11,60	15,80	67,80	37,40	76,00	48,00	365,00
Hat-9	11,80	13,20	68,60	31,30	51,30	81,00	254,70
Hat-10	11,70	15,80	66,60	37,30	78,70	42,70	371,30
Hat-11	11,80	15,20	67,10	36,10	70,00	78,30	336,00
Hat-12	11,80	14,40	67,90	34,00	60,00	84,70	287,70
Kirve	11,60	16,60	67,10	39,20	84,00	28,50	375,50
Hat-13	11,70	12,80	68,60	30,50	51,30	63,70	252,70
Hat-14	11,60	14,80	67,40	35,10	66,70	71,00	318,30
Hat-15	11,60	14,70	67,90	34,90	66,30	59,00	337,00
Hat-16	11,80	13,90	68,40	32,90	57,70	73,70	274,70
Pandas	11,80	14,70	68,10	34,80	63,00	82,50	292,00
Hat-17	11,60	14,60	67,20	34,70	64,30	77,00	317,00
Hat-18	11,70	13,70	68,60	32,40	59,70	50,00	307,30
Hat-19	11,70	14,20	68,00	33,60	63,00	56,70	340,00
Hat-20	11,80	13,80	68,30	32,60	55,30	85,70	275,00
Flamura85	11,90	14,30	67,80	34,00	61,00	77,50	272,50
Ort.	11,70	14,40	68,00	34,00	63,20	62,40	310,70

Korelasyon Analizi

İncelenen özellikler arasındaki ilişkileri belirlemek amacıyla Pearson korelasyon analizi yapılmış ve elde edilen korelasyon katsayıları Çizelge 9'da verilmiştir. Tane verimi ile protein oranı ($r = -0,6049$; $P < 0,01$), yaş gluten miktarı ($r = -0,6128$; $P < 0,01$) ve SDS sedimentasyon değeri ($r = -0,5217$; $P < 0,01$) arasında negatif ve önemli ilişkiler belirlenmiştir. Buna karşılık tane verimi ile nişasta oranı arasında pozitif ve önemli bir ilişki saptanmıştır ($r = 0,4753$; $P < 0,05$). Bu sonuçlar, yüksek tane verimine sahip genotiplerde bazı kalite özelliklerinin daha düşük olabileceğini göstermektedir.

Tane verimi ile protein oranı arasındaki negatif ilişki, Aydoğan & Soylu (2017) tarafından bildirilen $r = -0,4005$ ve Olgun & ark. (2022) tarafından bildirilen $r = -0,423$ değerleriyle benzerlik göstermiştir. Verim ile protein oranı arasındaki bu ters yönlü ilişkinin, tane verimindeki artışla birlikte proteinin tanede oransal olarak seyrelmesinden kaynaklanabileceği düşünülmektedir.

Araştırmada tane verimi ile bitki boyu arasındaki ilişki istatistiksel olarak önemli bulunmamıştır. Buna karşılık Olgun & ark. (2022) ile Albayrak & ark. (2022), bu iki özellik arasında sırasıyla $r = 0,347$ ve $r = 0,3827$ düzeyinde pozitif ve önemli ilişkiler bildirmiştir. Çalışmalar arasındaki farklılıkların genotip, çevre koşulları ve yetiştirme uygulamalarından kaynaklanabileceği değerlendirilmektedir.

Protein oranı ile yaş gluten miktarı ($r = 0,9997$; $P < 0,01$), SDS sedimentasyon değeri ($r = 0,9702$; $P < 0,01$) ve alveograf enerji değeri ($r = 0,8352$; $P < 0,01$) arasında güçlü ve pozitif ilişkiler belirlenmiştir. Benzer şekilde SDS sedimentasyon değeri ile alveograf enerji değeri arasında da güçlü ve pozitif bir ilişki bulunmuştur ($r = 0,8888$; $P < 0,01$). Bu bulgular, protein oranındaki artışın gluten miktarı, sedimentasyon kapasitesi ve hamur kuvvetindeki artışla ilişkili olduğunu göstermektedir. Bununla birlikte ekmeklik kalitenin yalnızca protein miktarına değil, protein bileşimi ve gluten yapısına da bağlı olduğu dikkate alınmalıdır.

Aydoğan & Soylu (2017), verim ve kalite özellikleri arasındaki ilişkilerin incelenen özelliğe göre farklı yön ve büyüklüklerde ortaya çıkabileceğini bildirmiştir. Araştırmacılar protein oranı ile tane sertliği arasında pozitif, tane verimi ile tane sertliği arasında negatif, hektolitre ağırlığı ile tane verimi arasında ise pozitif ilişkiler belirlemiştir.

Genel olarak korelasyon sonuçları, tane verimi ile bazı kalite özellikleri arasında ters yönlü bir ilişkinin bulunduğunu göstermiştir. Buna karşılık protein oranı, yaş gluten miktarı, SDS sedimentasyon değeri ve alveograf enerji değeri arasındaki güçlü pozitif ilişkiler, bu özelliklerin kalite değerlendirmelerinde birlikte ele alınabileceğini ortaya koymuştur.

Araştırmada tane verimi, agronomik özellikleri, kalite kriterleri ve önemli fungal hastalıklara karşı reaksiyonları değerlendirilmiştir. İncelenen özellikler bakımından genotipler arasında önemli farklılıkların bulunması, araştırma materyalinin verim, kalite ve hastalıklara dayanıklılık yönünden geniş bir varyasyona sahip olduğunu göstermiştir.

Tane verimi bakımından Hat-18 en yüksek performansı gösterirken Hat-19, Hat-5, Hat-7 ve Hat-16 da yüksek verim değerleriyle öne çıkmıştır. Kalite özellikleri yönünden Hat-10, Hat-11, Hat-15, Hat-7 ve Hat-14; protein oranı, SDS sedimentasyon değeri ve alveograf enerji değeri bakımından dikkat çekmiştir. Hat-20 tane sertliği, Hat-2 ve Hat-19 ise hektolitre ağırlığı bakımından üstün değerler göstermiştir.

Hastalık değerlendirmelerinde ileri hatların büyük bölümünün sarı pas ve kara pasa karşı dayanıklı veya immün reaksiyon gösterdiği belirlenmiştir. Kahverengi pasa karşı reaksiyonlar genotiplere göre değişirken, Fusarium başak yanıklığı bakımından genotiplerin çoğunluğu orta dayanıklı grupta yer almıştır.

Genel değerlendirmede Hat-7, Hat-15 ve Hat-19 verim ve kalite özelliklerinin birlikte değerlendirilmesi bakımından, Hat-18 ise yüksek tane verimi yönünden dikkat çeken genotipler olmuştur. Korelasyon sonuçları, tane verimi ile bazı kalite özellikleri arasında negatif ilişkilerin bulunabileceğini ve seleksiyonun yalnızca tek bir özellik üzerinden yapılmaması gerektiğini göstermiştir.

Çizelge 9. İncelenen Özellikler Arasındaki Pearson Korelasyon Katsayıları

	Verim	HL	Başak.	Bitki Boyu	Renk	Protein	Nişasta	Yaş Gluten	SDS	Tane Sertliği	Enerji
Verim	1,00	0,17	-0,19	-0,06	-0,13	-0,61	0,48	-0,61	-0,52	-0,07	-0,3
HL	0,18	1,00	-0,03	0,29	-0,52	0,25	-0,19	0,24	0,36	-0,57	0,46
Başak.	-0,19	-0,03	1,00	0,54	-0,14	0,26	0,00	0,27	0,21	-0,03	0,11
Bitki Boyu	-0,06	0,3	0,54	1,00	-0,04	0,24	-0,13	0,24	0,20	0,03	0,18
Tane Rengi	-0,13	-0,52	-0,14	-0,04	1,00	-0,20	-0,13	-0,19	-0,35	0,87	-0,50
Protein	-0,61	0,25	0,26	0,24	-0,20	1,00	-0,80	1,00	0,97	-0,34	0,84
Nişasta	0,48	-0,19	0,00	-0,13	-0,13	-0,80	1,00	-0,81	-0,80	0,07	-0,67
Yaş Gluten	-0,61	0,24	0,27	0,24	-0,19	1,00	-0,81	1,00	0,97	-0,34	0,83
SDS	-0,52	0,36	0,21	0,20	-0,35	0,97	-0,80	0,97	1,00	-0,52	0,89
Tane Sertliği	-0,07	-0,57	-0,03	0,03	0,87	-0,34	0,07	-0,34	-0,52	1,00	-0,55
Enerji	-0,3	0,46	0,11	0,18	-0,50	0,84	-0,67	0,83	0,89	-0,55	1,00

HL: Hektolitre ağırlığı; Başak.: Başaklanma süresi; SDS: Beklemeli sedimentasyon değeri; Enerji: Alveograf enerji değeri.

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THERMODYNAMIC ASSESSMENT OF ORGANIC RANKINE CYCLE WORKING FLUIDS UNDER HEAVY DUTY DIESEL ENGINE OPERATING CONDITIONS

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ABSTRACT

This study models an Organic Rankine Cycle (ORC) waste heat recovery system integrated with a 340 kW heavy-duty diesel engine operating at 100%, 75%, 50%, and 25% engine loads under steady-state conditions using engine cooling water as condenser cooler. The objective is to investigate the effects of evaporator operating pressure, exhaust gas mass flow rate and temperature, built-in volume ratio (BVR) and working fluid mass flow rate on the system's performance. The thermodynamic potential of three working fluids: ethanol, pentane, and water for exhaust waste heat recovery examined in detail. Parametric analyses were performed to determine thermodynamic potentials of the working fluids under various constraints and engine operating conditions. Through the simulations it was found that working fluid saturation temperatures and built-in volume ratio have strong impacts the on the system due to creating a more effective pressure ratio between evaporator and condenser operating pressures respectively. Also thermal decomposition temperatures and high evaporation entalphy have considerable effect on the overall cycle performance, evaporator behaviour and working range of the system.

Keywords: WHR, ORC, Exhaust Gas Energy, Heavy Duty Diesel Engine.

INTRODUCTION

As the automotive industry continues to pursue higher engine efficiencies in response to increasingly stringent environmental regulations, such as Euro 7 or EPA Phase 3, meeting these requirements has become progressively more challenging for vehicle manufacturers. Owing to the inherent limitations of the conventional internal combustion engine technologies, a typical Heavy-Duty Diesel Engine (HDDE) can only convert around 40 – 45% of fuel energy into useful mechanical power delivered to crankshaft, while the remaining energy is dissipated through exhaust gases, engine coolant systems, and various other losses (Shu, 2014), (Shu, 2016), (Lion, 2017), (Pulkrabek, 2003). Because of these reasons, Organic Rankine Cycle Waste Heat Recovery (ORC-WHR) systems have attracted research interest in recent years, as they offer an alternative solution for recovering a portion of this wasted thermal energy, especially in the exhaust region, improving overall engine efficiency by reducing fuel consumption and helping with the emission regulations.

Numerous studies have been reported in the literature investigating different Organic Rankine Cycle–Waste Heat Recovery (ORC-WHR) applications, system configurations, and working fluids. Several

major heavy-duty engine manufacturers, including Daimler and Detroit Diesel through the U.S. Department of Energy (DOE) Super Truck Program, as well as Cummins, Hino, and others, have developed and evaluated ORC-WHR systems employing a variety of working fluids, such as R245fa, water, ethanol, and toluene. These studies have demonstrated improvements in engine thermal efficiency and fuel economy, with reported fuel consumption reductions and efficiency gains of up to 8% (Lion, 2017).

Considering these previous works (Lion, 2017) worked on a HDDE with a brake power of 302 kW with various working fluids, creating two different ORC architectures to recover heat from tail-pipe exhaust gas and both from exhaust and EGR. Results show that even though other fluids have better properties on some cases, water has a very high potential for waste heat recovery systems as a working fluid.

(Shu, 2014) investigated the high-temperature waste heat recovery potential of several alkane-based working fluids, including pentane, hexane, and cyclopentane, for an ORC system integrated with a six-cylinder, four-stroke heavy-duty diesel engine. The performance of the selected working fluids was evaluated using various thermodynamic performance indicators. The results demonstrated that alkane-based working fluids exhibit favorable thermodynamic performance for high-temperature waste heat recovery applications. Nevertheless, their practical implementation requires careful consideration due to inherent disadvantages, particularly their relatively high flammability and potential toxicity.

(Shu, 2016) investigated the comparison between R123 and R245fa on an experimental system under various engine loads. In the experimental system, instead of working fluids directly interacting with the exhaust source thermal oil is added to the ORC architectures to act as a buffer from exhaust gas fluctations and decrease the instantenaous impact, managing the thermal decomposition temepratures of the working fluids in the process. However this addition to the system lowered the efficiency and response time of the system. Results of this work shows us R123 shows its advantage for the waste heat recovery at heavy duty, while R245fa is more suitable at light and-medium duty.

(Yang, 2012) studied various working fluids under different expansion ratio values, indicating that with the increment of the expansion ratio; mass flow rate of the working fluids and their heat absorption rates are decreasing under same power output, while the irreversibility and thermal efficiency of some working fluids increases.

(Yasa, 2017) investigated the performance of various ORC working fluids by classifying them into low-pressure and high-pressure categories according to their operating characteristics. The thermodynamic analysis demonstrated that increasing the turbine inlet pressure led to an improvement in overall cycle performance. Among the working fluids considered, RC318 achieved the highest reported thermal efficiency of 13.6% at a turbine inlet pressure of 16 bar.

(Amicabile, 2015) worked on a 2006MY Cummins ISM 10.8L diesel engine at B50 (partial load) with a selected design methodology revolving around three parts; heat source selection, working fluid selection and thermodynamic cycle optimization. Ethanol, Pentane and R245fa are selected as working fluid in this work. Results for this work shows us that for the best performance, in terms of net power output, at subcritical cycles was provided by recupuretive cycles with working fluid as ethanol with BSFC (Brake Specific Fuel Consumption) improvement of 3.3%.

(Park, 2011) experimentally investigated three different ORC-WHR system configurations integrated with a 10.8 L Cummins ISM heavy-duty diesel engine under four distinct engine load conditions. The performance of each configuration was systematically evaluated, and the results demonstrated that the proposed systems achieved a reduction in engine fuel consumption of up to 3%.

(Wang, 2011) conducted a thermodynamic analysis of nine pure working fluids using a MATLAB-based model coupled with the REFPROP property database. The performance of each working fluid was evaluated under a fixed net power output of 10 kW to enable a consistent comparison. The results demonstrated that ORC thermal efficiency is strongly influenced by both the evaporating pressure and condensing temperature within the feasible operating region. In the analyses, thermal efficiency increased with decreasing condensing temperature and increasing evaporating pressure, while the condensing temperature effected more on system performance than the evaporating pressure.

(Kölsch, 2015) investigated methanol, toluene, and Solkatherm as working fluids for an Organic Rankine Cycle (ORC) using diesel engine waste heat as the thermal energy source. The thermodynamic performance of the working fluids was evaluated under various operating pressures and temperatures. The results showed that, for a given pressure level, the thermal efficiency increased almost linearly with increasing evaporation temperature. Furthermore, thermal efficiency showed an exponential increase with rising cycle working pressure. Among the investigated fluids, methanol achieved the highest thermal efficiency but required the largest heat transfer area with toluene demonstrating lower thermal efficiency while maintaining considerable work output potential under high-pressure and relatively low-temperature operating conditions.

(Sprouse C III, 2012) presented a comprehensive review of Organic Rankine Cycle (ORC) systems for internal combustion engine waste heat recovery, especially focusing on expander technologies and working fluid selection. Based on the reviewed studies, the authors concluded that water and organic working fluids provide comparable thermal efficiencies over the exhaust gas temperature range encountered in internal combustion engines. However, organic working fluids were found to more suitable for low-temperature heat sources, where water became increasingly favorable as the exhaust gas temperature increased.

(Wang T, 2011) presented a comprehensive review of Organic Rankine Cycle (ORC) systems for exhaust waste heat recovery, with particular emphasis on working fluid selection. The review pointed out that the thermal efficiency of an ORC system is strongly influenced by the evaporation temperature of the selected working fluid. Water identified as one of the most practical working fluids for waste heat recovery applications owing to its favorable thermophysical properties, including cost, safety, and superior heat transfer characteristics. But it was also noted that several limitations associated with water, such as the risk of freezing, increased corrosiveness under superheated steam conditions, and susceptibility to air infiltration.

(Köybaşı, 2025), in cooperation with Ford Otosan, investigated the waste heat recovery potential of an Organic Rankine Cycle (ORC) system integrated with a diesel engine under various exhaust gas mass flow rates and inlet temperatures. The results indicated that approximately 50% of the available exhaust energy could be transferred to the proposed ORC system. In the work, both mass flow rate and exhaust gas inlet temperature were found to have a significant influence on the thermal energy comşng into the evaporator of the system.

This study evaluates the thermodynamic performance of three working fluids—water, ethanol, and pentane—for an Organic Rankine Cycle waste heat recovery (ORC-WHR) system using a MATLAB-based simulation model integrated with the CoolProp thermophysical property library. The proposed system is designed to replicate the operating conditions of a 340 kW heavy-duty diesel engine by recovering waste heat from the turbine outlet exhaust gases upstream of the aftertreatment system (ATS), while utilizing the engine's existing jacket cooling water as the condenser cooling medium. To ensure physically feasible and practically applicable operating conditions, the simulations were subject to several thermodynamic constraints, including maintaining the working fluid in a subcooled liquid state at the pump inlet and a superheated vapor state at the expander inlet, while the exhaust gas temperature was required to remain above 240 °C to ensure compatibility with the operating requirements of the ATS. This configuration was selected to closely represent the practical operating conditions encountered in commercial heavy-duty diesel engines.

Although ORC-WHR systems for heavy-duty diesel engines have been extensively investigated, the specific integration strategy considered in this study has received limited attention in the existing literature. In particular, the simultaneous utilization of turbine outlet exhaust gases upstream of the ATS and the engine's existing cooling circuit, without the need for an additional cooling system, has rarely been examined. Therefore, the proposed system architecture, together with the comparative evaluation of the selected working fluids under realistic engine operating conditions and restraints constitutes the primary novelty and contribution of the present study.

MATERIALS AND METHOD

The simulations were performed in MATLAB using a basic Organic Rankine Cycle Waste Heat Recovery (ORC-WHR) configuration comprising a pump, an evaporator, an expander, and a condenser. A steady-state thermodynamic approach was adopted throughout the analysis. Both the evaporator and condenser were modeled as coaxial, counter-flow heat exchangers made of stainless steel. The pump and expander were assumed to operate with constant isentropic efficiencies of 70% throughout all simulation cases. The system layout was designed with the ORC-WHR unit positioned before the aftertreatment system (ATS) to maximize the use of the available exhaust gas thermal energy within the vehicle exhaust system. A figure explaining the layout is give below in Figure 1.

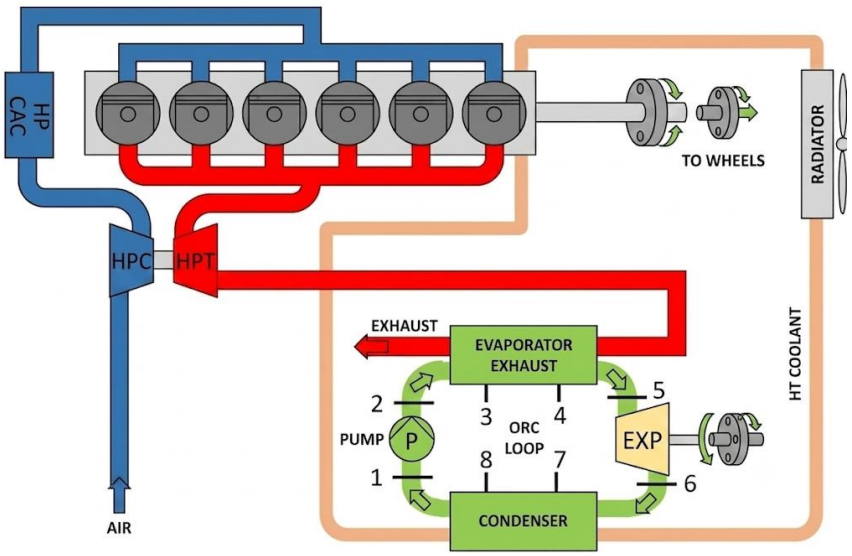

Figure 1) ORC System Schematic for the current work

The computational architecture of the cycle model is solved in two parts; a localized component-level solvers (inner loops) and a global system-level solver (outer loop). A figure explaining the working mechanism of the flow chart is given in the Figure 2.

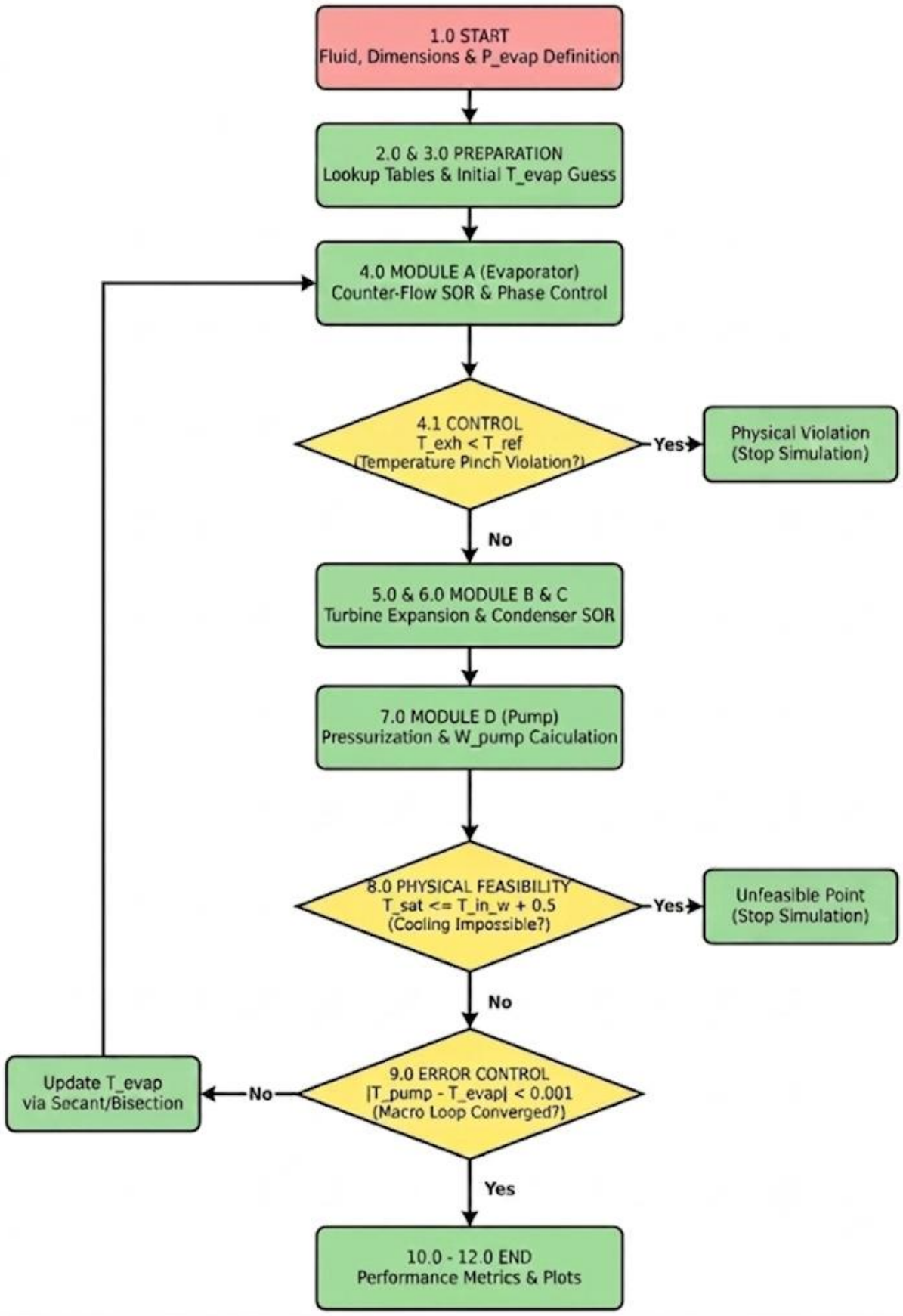

Figure 2) Code working mechanism flow chart

Component-Level Solvers

The evaporator and condenser are modeled as counter flow heat exchangers, which pose a two point boundary value problem: the working fluid's inlet condition is known, but the secondary (shell-side) fluids inlet condition is only known implicitly, through overall energy balance. This means the solution at one end depends on results computed at the other end, so the system cannot be solved directly in a single pass.

To address this, the established model employs an iterative fixed-point scheme, structured as given below:

1. **Initialization —** An initial temperature profile is assumed for the shell-side fluid.

2. **Forward Integration —** The working fluids enthalpy is marched forward element-by-element along the exchanger, using the initial shell-side temperature profile to compute local heat transfer.

3. **Profile Update —** The shell-side temperature profile is then recalculated by working backward through the locally computed heat duties.

4. **Under-Relaxation —** Instead of accepting the updated profile directly, the solver blends it with the previous iteration using a relaxation factor, which is adjusted dynamically: reduced when convergence appears to stall or oscillate, and increased when convergence is proceeding smoothly. This improves numerical stability without unnecessarily slowing the process.

5. **Convergence Check — S**teps 2–4 repeat until the shell-side profile stabilizes within a specified tolerance, subject to a maximum of 4,000 iterations per heat exchanger, per outer-loop pass.

Global System Closure (Outer Loop)

Because the ORC cycle is a closed loop, it is required that the assumed evaporator inlet temperature match the temperature actually produced at the pump outlet after the full cycle is evaluated. The outer loop of the code treats this as a root-finding problem: it assumes a value, evaluates all four cycle components in sequence, and computes the resulting discrepancy (residual) between assumption and outcome.

This residual is driven to zero using a Secant method, which uses the two most recent iterations to estimate a improved next guess and generally converges quickly. However, since thermophysical properties can vary sharply near phase-change conditions, the secant prediction may occasionally produce a non-physical or non-finite result. In these cases, the algorithm falls back to bisection, narrowing the search within known physical bounds.

CONDUCTION OF SIMULATIONS

Parametric analyses were conducted in MATLAB to evaluate the thermodynamic performance of the designed Organic Rankine Cycle Waste Heat Recovery (ORC-WHR) system under the propesed heavy-duty diesel engine operating conditions. Simulations were performed using three different working fluids; water, ethanol, and pentane. For each working fluid, sixteen operating cases were analyzed by systematically changing the primary cycle parameters, given in the Table 1 below. A steady-state thermodynamic approach was assumed throughout the study to ensure proper evaluation of the effects of each operating parameter on the overall cycle performance.

Table 1) Engine Load Mass Flow Rate and Exhaust Temperature Distribution

Simulation No	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Evaporator Pressure (bar)	10	10	10	10	20	20	20	20	10	10	10	10	20	20	20	20
Mass Flow Rate of Exhaust (kg/s)	0,58	0,46	0,32	0,18	0,58	0,46	0,32	0,18	0,58	0,46	0,32	0,18	0,58	0,46	0,32	0,18
Exhaust Inlet Temperature from Evap. (°C)	500	420	350	260	500	420	350	260	500	420	350	260	500	420	350	260
BVR Ratio	5	5	5	5	5	5	5	5	10	10	10	10	10	10	10	10
Expander Efficiency	0,7	0,7	0,7	0,7	0,7	0,7	0,7	0,7	0,7	0,7	0,7	0,7	0,7	0,7	0,7	0,7
Mass Flow Rate of Cooling Water (kg/s)	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Cooling Water Inlet Temperature from Cond. (°C)	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70
Minimum Exhaust Gas Outlet Temperature from Evap. (°C)	0,7	0,7	0,7	0,7	0,7	0,7	0,7	0,7	0,7	0,7	0,7	0,7	0,7	0,7	0,7	0,7

To ensure realistic operation, several thermodynamic constraints were defined throughout all simulation cases. These constrains are;

I. Working fluid was required to remain in the subcooled liquid region at the pump inlet and in the superheated vapor region at the expander inlet to guarantee stable operation and prevent component damage.

II. For the cooling side, the engine cooling water was directly used as the condenser cooling medium to avoid the need for an additional cooling circuit. The cooling water inlet temperature and mass flow rate were selected at constant values of 70°C and 1 kg/s, respectively, throughout all simulations.

III. To maintain the proper functionality of the aftertreatment system (ATS), the exhaust gas outlet temperature was constrained to remain above 240°C under all operating conditions. This temperature limit ensured sufficient thermal energy was available for efficient emissions control fort he ATS.

The engine operating conditions considered in the present study are presented in Table 2.

Table 2) Engine Load Mass Flow Rate and Exhaust Temperature Distribution

Parameter	100%	75%	50%	25%
Mass Flow Rate of Exhaust (kg/s)	0,58	0,46	0,32	0,18
Exhaust Inlet Temperature to Evap. (°C)	500	420	350	260

The selected operating conditions and thermodynamic constraints provided a physically realistic simulation framework for evaluating the ORC-WHR system. Consequently, the influence of working fluid selection, evaporator pressure, engine load, and expander BVR on the overall system performance could be systematically assessed.

SIMULATION RESULTS

A comprehensive set of results was obtained from the conducted simulations and is presented and discussed in this section. Although certain operating conditions satisfied the thermodynamic feasibility criteria, a minimum expander power output of 2.5 kW was imposed as an additional performance criterion for evaluating the simulation results. This limit was selected because expander power outputs below 2.5 kW does not provide a valid contribution to the overall energy recovery, making the implementation of the ORC system practically unjustifiable under such conditions.

Working fluid selection is a critical criterion for the ORC-WHR system performance and behaviour in general terms due to type of the selected working fluid and properties of these said fluids. One important property of working fluids that is worth mentioning for the ORC-WHR system behaviour is evaporation enthalpy. Evaporation enthalpy is the enthalpy value of the working fluid while changing phases. Magnitude of this value directly influences the working fluid phase in the evaporator / condenser sides.

To assess the evaporation enthalpy of different working fluids T-s graphs are usually used. The distance between the saturated liquid and saturated vapor lines at the given pressure indicates the magnitude of the evaporation enthalpy value of the working fluid. In the Figure 3 and Table 3 given below are the T-s diagrams of some of the most used ORC working fluids and their thermophysical properties taken from the Coolprop property library respectively.

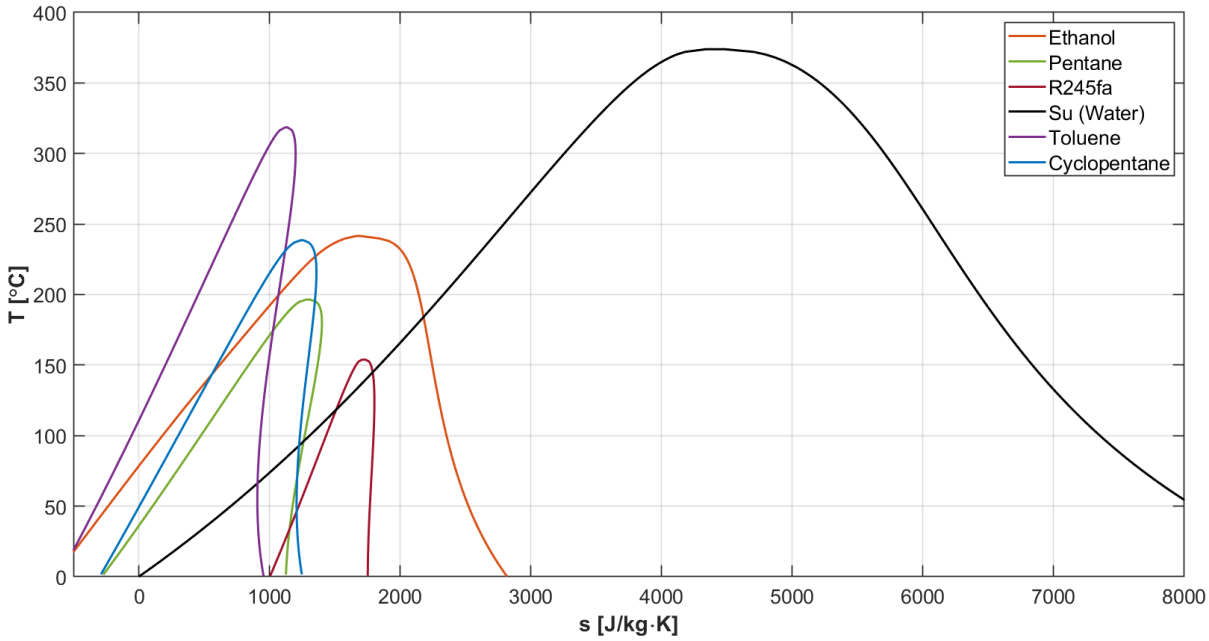

Figure 3) T-s graphs of various ORC fluids

Table 3) Thermophysical properties of various ORC fluids

Fluid	Saturation temperature (1 bar)	Decomposition Temperature (1 bar)	Evaporation Enthalpy (kJ/kg)	Molecular weight (g/mol)
Water	99.61 °C	>2000 °C	2257.5 kJ/kg	18.015 g/mol
Ethanol	78.03 °C	~ 350 °C	846.1 kJ/kg	46.07 g/mol
Pentane	35.69 °C	~ 280 °C	358.1 kJ/kg	72.15 g/mol
Toluene	110.23 °C	~ 315 °C	362.5 kJ/kg	92.14 g/mol
Cyclopentane	48.83 °C	~ 275 °C	389.3 kJ/kg	70.13 g/mol
R245fa	14.74 °C	~ 250 °C	196.2 kJ/kg	134.05 g/mol

The effect of the evaporation enthalpy and saturation temperature can be easily seen from Figure 4a, 4b and 4c, the evaporator temperature profile graphs.

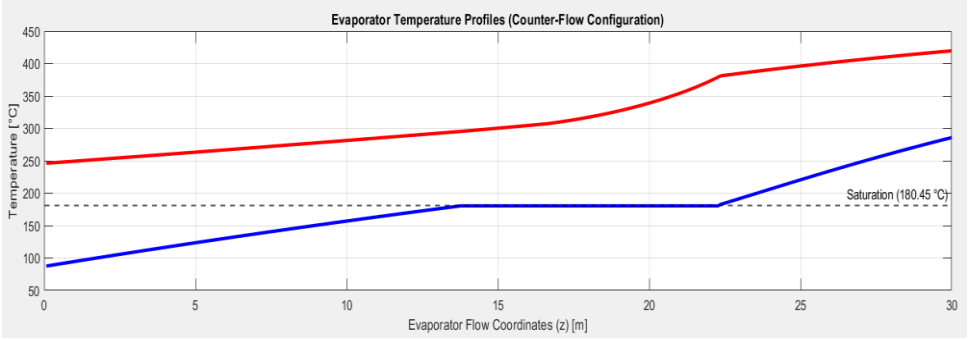

Figure 4a) Temperature Profile Graph of Ethanol at 10 bar

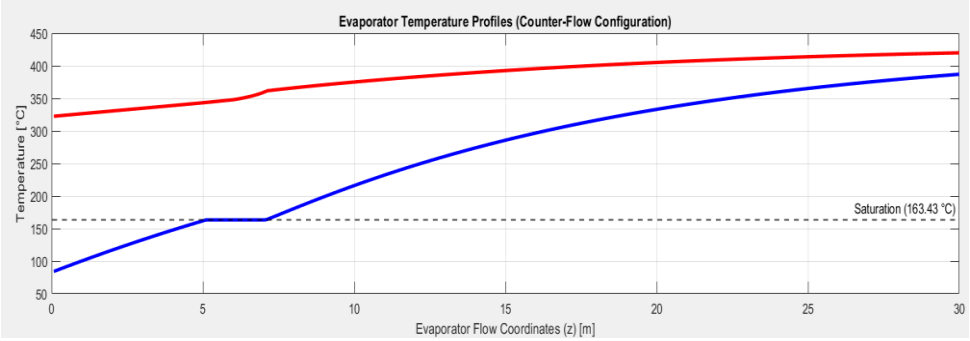

Figure 4b) Temperature Profile Graph of Pentane at 10 bar

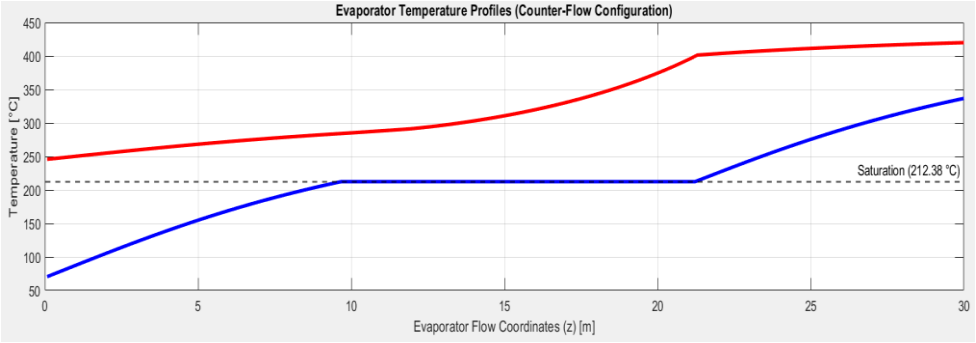

Figure 4c) Temperature Profile Graph of Water at 10 bar

In the Figure 4a, 4b and 4c given above are the temperature profile graphs of the chosen working fluids. It can be clearly said that higher evaporation enthalpy values causes working fluid to evaporate much more into the evaporator pipe. This in turn may affect system performance if the chosen working fluid is not superheated or the chosen evaporator is not consistent enough for the evaporator. Additionally, the saturation temperature creates the thermal plateau level during phase change, directly dictating the temperature difference available for heat transfer relative to the heat source. Therefore choosing a fluid with an appropriate saturation temperature is critical to maintaining an effective thermal driving force while preventing pinch-point limitations along the heat exchanger.

Another important consideration in working fluid selection is its thermal decomposition temperature. An example of thermal decomposition risk graphs for ethanol is given Figure 5a and 5b below.

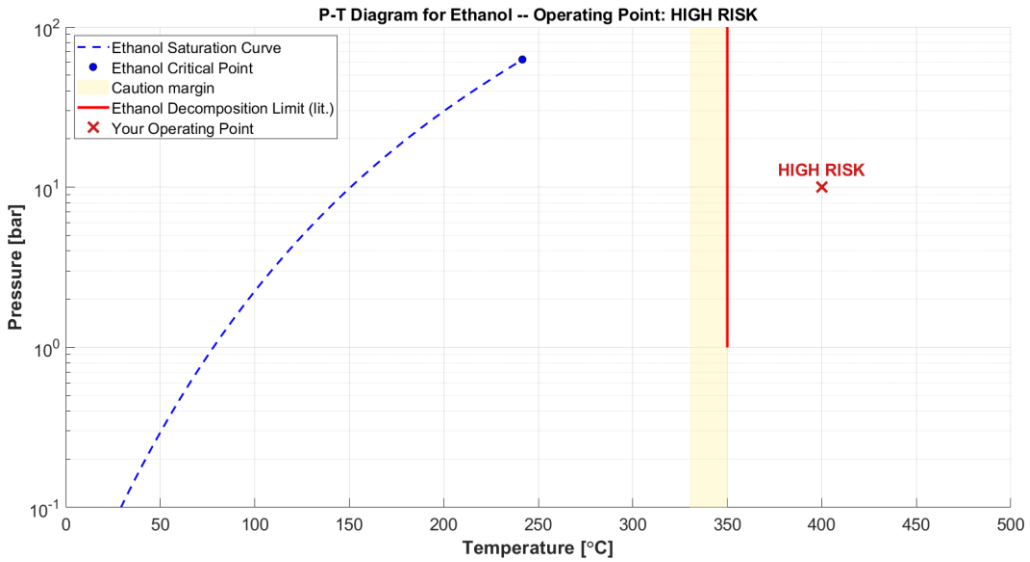

Figure 5a) Thermal Decomposition High Risk Graph for Ethanol

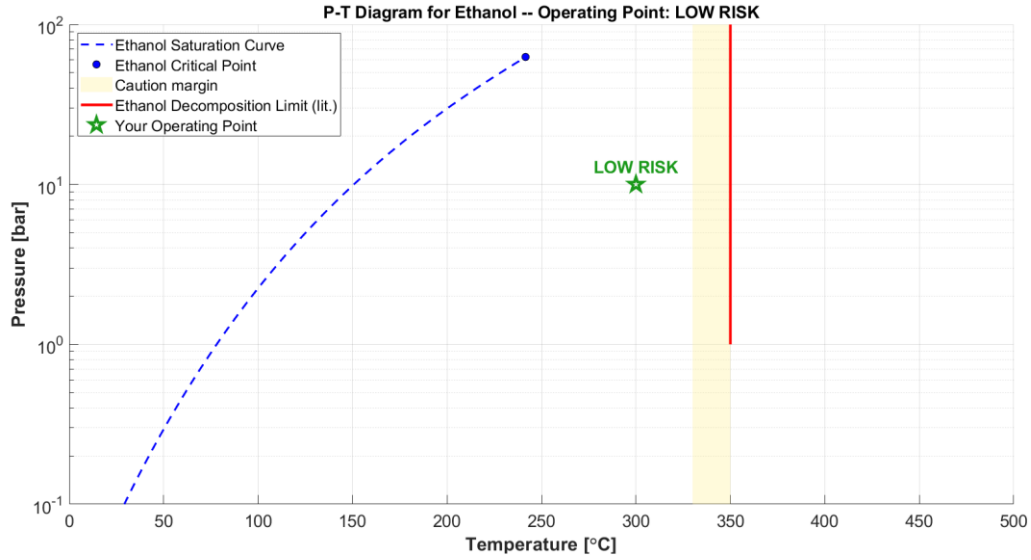

Figure 5b) Thermal Decomposition Low Risk Graph for Ethanol

The thermal decomposition temperature is defined as the temperature range at which the chemical structure of the working fluid begins to degrade, resulting in the formation of simpler chemical compounds. Such degradation can lead to the accumulation of particles within heat exchangers, material degredation or contamination of the expander, and a reduction in the overall thermodynamic

performance and long-term reliability of the ORC-WHR system. Therefore, the operating temperature of the working fluid must remain below its thermal decomposition limit to ensure stable operation, preserve component integrity, and maintain system efficiency.

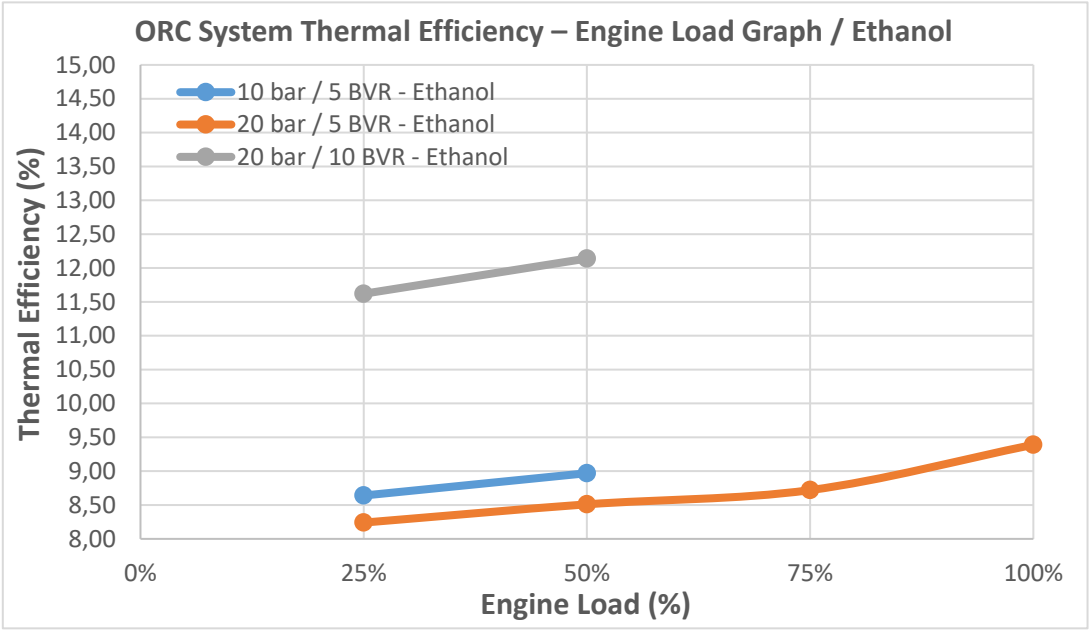

Figure 6) Thermal Efficiency – Engine Load graph for Ethanol

A system thermal efficiency / engine load graph for ethanol are given Figure 6 above. The results from the graph revealed that ethanol shows a tendency toward thermal decomposition because of its comparatively lower thermal decomposition temperature. For ethanol, thermally stable operation across the entire engine load range was achieved only at an evaporator pressure of 20 bar with a BVR of 5. Under the evaporator pressure of 10 and 20 bar, the predicted working fluid temperatures exceeded the thermal decomposition limit at high engine loads, restricting ethanol operation to 25% and 50% engine loads for all investigated BVR values. In addition to these, from the simulations it was seen that at 10 bar operating pressure and 10 BVR ratio ethanol cannot fully condense at the condenser outlet at the given conditions, thus rendering it unable to use at these ranges. Results indicate that the thermal decomposition limit is a critical design constraint that significantly limits the allowable operating range of ethanol-based ORC-WHR systems.

On the other hand, pentane exhibited the narrowest feasible operating range among the investigated working fluids. At a 25% engine load, stable operation was only achieved at an evaporator pressure of 20 bar with a BVR of 5. However, even under these conditions, the expander power output remained below the minimum feasibility criterion of 2.5 kW, rendering the system impractical for effective waste heat recovery. The limited operating range can be primarily attributed to the relatively low thermal decomposition temperature and unfavorable condensation characteristics of pentane. In most operating conditions, the corresponding saturation temperature at the condenser pressure remained below the available cooling water temperature of 70°C. Consequently, an adequate temperature difference for heat rejection could not be established, preventing complete condensation of the working fluid in the

condenser. As a result, stable ORC operation with pentane could not be maintained over the majority of the investigated operating conditions.

A system efficiency / engine load graph for water is given in Figure 7.

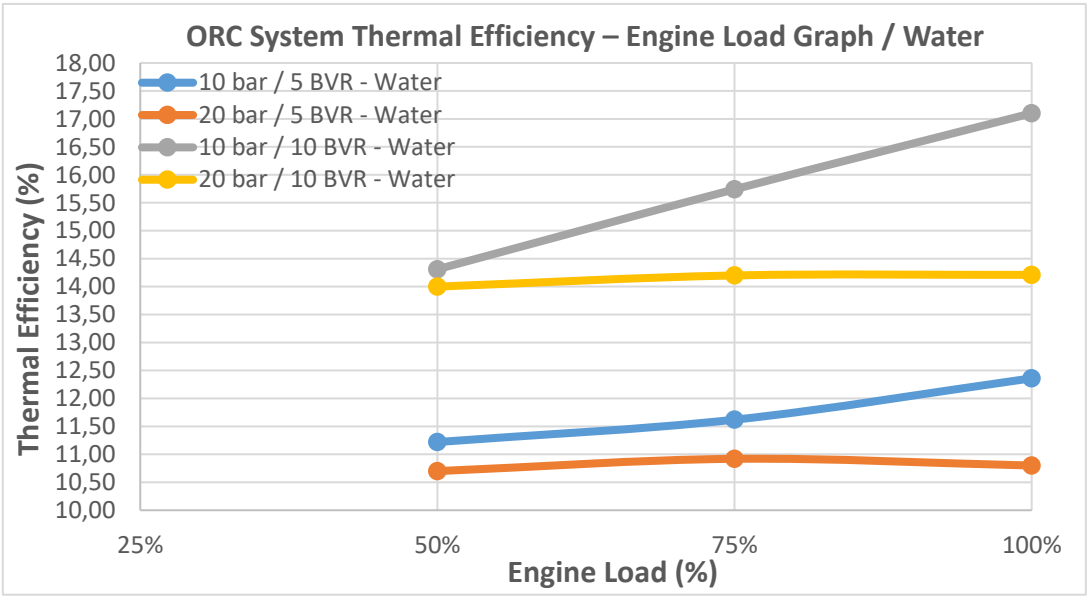

Figure 7) Thermal Efficiency – Engine Load graph for Water

From the graph it can be seen that among the investigated working fluids, water exhibited the widest feasible operating range across the examined engine loads owing to its high thermal stability and relatively high condensation temperatures. These properties allowed amore stable operation under a wider range of operating conditions compared to ethanol and pentane. However, water also presented a significant limitation under low-load conditions. Throughout all operating pressures and BVR ratios, at a 25% engine load, the available exhaust energy resulted in extremely low working fluid mass flow rates (approximately 1 g/s or lower), preventing the proposed ORC system from operating effectively. Consequently, despite being thermodynamically feasible, the recovered power under these conditions was insufficient for practical implementation.

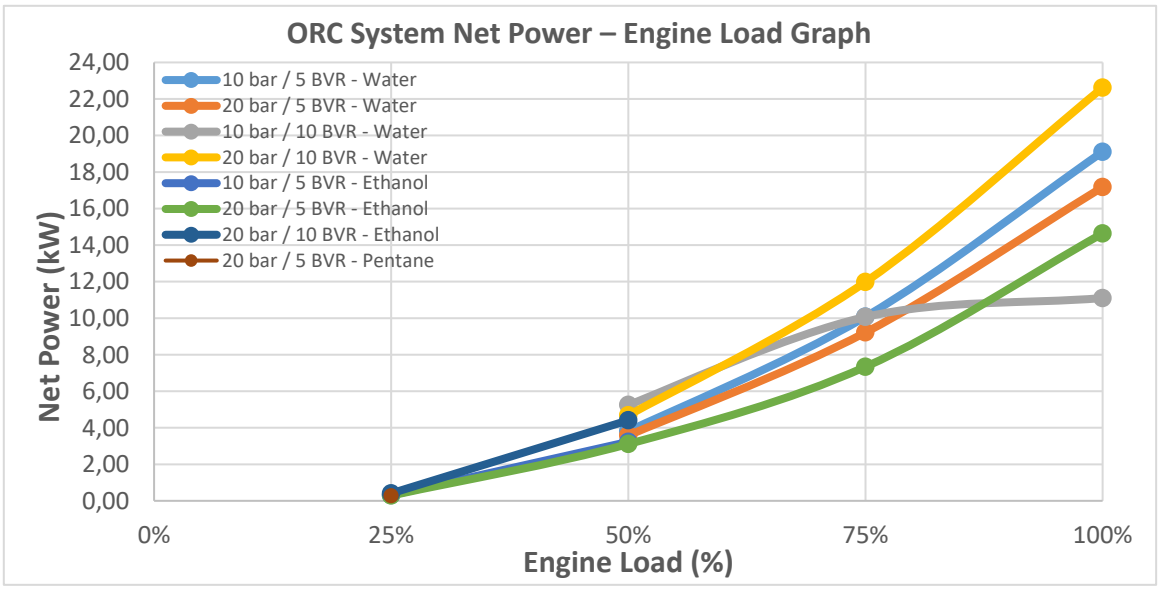

Figure 8) Net Power – Engine Load graph for working fluids

Taking the feasible operating ranges of all working fluids into account, as can be seen from Figure 8, water achieved the highest net power output of 22.61 kW, followed by ethanol with 14.64 kW. Pentane produced a maximum net power output of only 0.3 kW at a 25% engine load, which remained below the minimum feasibility criteria due to its insufficient expander power. Thus, pentane was marked as unsuitable for the proposed ORC system under the investigated operating conditions.

CONCLUSION

Based on the simulation results obtained under the investigated engine operating conditions, several key findings were identified regarding the thermodynamic performance of the proposed ORC waste heat recovery system. The effects of working fluid selection, evaporator operating pressure, and expander built-in volume ratio (BVR) on the overall system performance were systematically evaluated. The main conclusions drawn from this study are summarized as follows:

- Among the investigated working fluids, water showed the highest thermal efficiency within its feasible operating range, followed by ethanol and pentane. The performance of water can be attributed to its thermodynamic characteristics and wider operating range, whereas ethanol provided competitive performance only under specific operating conditions. Pentane yielded the lowest thermal efficiency among the investigated fluids.
- The feasible operating ranges of ethanol and pentane were considerably narrower than feasible range of water due to their lower thermal decomposition temperatures and condensation limitations. As a result, these fluids were unable to operate under some engine loads and operating conditions investigated, especially pentane, leading to lower overall system applicability and performance.
- The evaporator operating pressure and the expander built-in volume ratio (BVR) were identified as critical design and operating parameters in ORC performance. In general, higher evaporator pressures combined with suitable BVR values improved the thermodynamic matching between the working fluid and the expander, resulting in higher thermal efficiencies and greater power recovery.
- The thermophysical properties of the working fluids, particularly their saturation temperatures, evaporation enthalpies, and thermal stability, were found to have a great influence on system performance and operating range. These properties directly affected the evaporation and condensation processes, heat transfer characteristics, and the achievable operating range of the ORC system.

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THE EFFECTS OF SCHOOL PRINCIPALS' LEADERSHIP STYLES AND STRATEGIC PLANNING APPROACHES ON SCHOOL PERFORMANCE

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ABSTRACT

Schools are among the most important institutions responsible for preparing individuals for social and economic life. The effectiveness of these institutions largely depends on the quality of educational leadership and the strategic management practices implemented within schools. In an increasingly dynamic educational environment characterized by technological advancements, changing stakeholder expectations, and growing accountability requirements, school principals are expected to demonstrate effective leadership while adopting strategic planning approaches that ensure sustainable school development and improved organizational performance.

Leadership styles influence employees' motivation, organizational commitment, communication, collaboration, and decision-making processes, all of which directly or indirectly affect school performance. Similarly, strategic planning enables educational institutions to define their long-term objectives, allocate resources effectively, respond proactively to environmental changes, and establish a shared organizational vision. Therefore, leadership and strategic planning are considered complementary managerial processes that contribute to organizational effectiveness and continuous school improvement.

The primary objective of this study is to examine the effects of school principals' leadership styles and strategic planning approaches on school performance. In addition, the study aims to determine the relationships among these variables and evaluate the extent to which leadership styles and strategic planning approaches predict school performance.

The research is designed as a quantitative study employing the survey method. Research data will be collected from school principals and teachers working in educational institutions using standardized measurement instruments. The collected data will be analyzed using appropriate statistical techniques to examine the relationships among the variables and test the proposed research model.

The findings are expected to contribute to the literature on educational management by providing empirical evidence regarding the relationship between leadership styles, strategic planning approaches, and school performance. Furthermore, the study is expected to offer practical recommendations for school administrators, policymakers, and other stakeholders seeking to improve educational quality and organizational effectiveness.

Key Words: School Principals, Leadership Styles, Strategic Planning, School Performance, Educational Management.

NEW GLOBAL TRAMLINES: CENTRAL BANK CRYPTO-CURRENCIES

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ABSTRACT

Cryptocurrencies sit at the intersection of digital innovation and the shifting geopolitical order. This convergence is not obvious to cryptocurrency devotees and profit seekers. Wild price fluctuations, fortunes made and lost, create headlines but obscure the underlying narrative of global monetary change. Tracing this underlying story requires explanatory parsimony while identifying necessary components in multiple chains of causation in today's geopolitical changes. This is difficult given deep and complex interactions among many related factors: technology. commodities, minerals, international trade, global banking and finance. The present argument is that four elements form a 'critical chain' shaping a geopolitical reset of economic and monetary relations: the blockchain currency revolution, ongoing de-dollarization, the consolidating BRICS trade re-alignment, the establishment of mBridge and multipolar central banking digital currencies.

Keywords: cryptocurrency, fiat currency, mBridge, BRICS, de-dollarization, multipolar currencies

EFFECT OF PA6 POWDER-MODIFIED EPOXY ADHESIVE ON THE SHEAR STRENGTH OF FDM-PRINTED ABS SINGLE-LAP JOINTS

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ABSTRACT

Adhesive bonding has become an increasingly common joining route for parts produced by additive manufacturing (FDM/FFF), both to overcome the limited build volume of desktop systems and to assemble complex structures. The performance of such joints depends strongly on the behaviour of the adhesive interlayer. Toughening the adhesive with thermoplastic particles is an established strategy; however, the literature has largely relied on costly nanofillers or electrospun polyamide mats, while the direct use of readily available micron-scale thermoplastic powders as modifiers remains limited. In this study, PA6 powder, a material already present as additive-manufacturing feedstock, was added directly to a commercial two-part epoxy adhesive (Araldite 2015-1) at 0, 5, 10 and 15 g per 100 g of adhesive (phr), and the resulting modified adhesives were used to bond single-lap joints made from FDM-printed ABS adherends. The bondline thickness was fixed at 0.2 mm and the joints were tested under quasi-static tensile loading at a constant rate of 13 mm/min in accordance with ASTM D5868, with three replicates per condition. The best performance was obtained at 100:5, where the mean maximum load increased by 14.1% relative to the neat adhesive (from 498.7 N to 569.3 N), the energy to failure by 20.4% and the joint stiffness by 17.2%. One-way analysis of variance indicated a significant difference between groups in terms of maximum load ($p = 0.030$), and the Tukey HSD test showed that only the difference between the neat adhesive and 100:5 was statistically significant ($p = 0.029$). Further increases in powder content did not improve performance; at 100:15 the mean values remained high but the scatter increased markedly (coefficient of variation 8.2% versus 1.6–2.3% for the other groups). The findings indicate that a low PA6 powder content toughens the epoxy joint, whereas at higher contents the difficulty of achieving a homogeneous dispersion makes process-induced variability the dominant effect.

Keywords: Additive manufacturing; FDM; ABS; Epoxy adhesive; PA6 powder; Single-lap joint; Shear strength

INTRODUCTION

Additive manufacturing, and in particular fused deposition modelling (FDM/FFF), has moved beyond prototyping towards the production of functional parts. Nevertheless, the limited build volume of desktop systems prevents large or complex structures from being produced as a single piece, requiring parts to be printed as smaller modules and subsequently assembled. Unlike mechanical fasteners, adhesive bonding distributes stress over a wide area, requires no drilling and adds no appreciable weight, which makes it a suitable joining method for polymer parts (Tiwary et al., 2022).

Research on the adhesive bonding of additively manufactured parts has expanded rapidly in recent years. Kamer (2025) investigated the lap-shear strength of 3D-printed ABS and PLA plates bonded with

Araldite 2011, 2015-1 and 2021-1 under different curing conditions and showed that curing temperature markedly affects joint performance. Tiwary et al. (2022) addressed the influence of joint geometry, surface treatment and adhesive type. In these studies the variable was the adhesive grade, the curing regime or the joint geometry; the composition of the adhesive itself was not treated as a design variable.

The toughening of epoxy resins with thermoplastic particles constitutes a separate and mature field of research. Cardwell and Yee (1998) showed that pre-formed polyamide-12 particles toughen epoxies through a crack-bridging mechanism that relies on large plastic deformation of the particles. Heflin and Månsson (2022) reviewed polyamide–epoxy systems and summarised mechanisms such as crack bridging, crack pinning, crack path deflection and particle yielding, further reporting that epoxies containing approximately 5 wt% PA6 particles reach their highest fracture energy depending on mixing conditions.

In practice, however, these two fields rarely intersect. The modifiers used in the toughening literature are typically nanoparticles, electrospun polyamide nanofibres or purpose-made microspheres, all of which are costly and of limited availability. By contrast, few studies have evaluated micron-scale thermoplastic powders already present as feedstock in additive-manufacturing laboratories as direct adhesive modifiers.

The purpose of this study is therefore to determine the effect of a readily available PA6 powder, added directly to a commercial epoxy adhesive, on the shear performance of FDM-printed ABS single-lap joints. Powder content was treated as the single variable, and the study examined whether the powder acts as a toughening agent or as a stress-concentrating defect, and at which level an optimum content occurs.

MATERIALS AND METHODS

Materials

A single brand and single lot of ABS filament was used as the adherend material. Araldite 2015-1, a two-part toughened epoxy system widely used in structural applications, was selected as the adhesive (Huntsman Advanced Materials, n.d.). PA6 powder of additive-manufacturing feedstock grade was used as the modifier; because the powder is hygroscopic, it was dried before mixing and stored in a sealed container with desiccant.

Production of the Adherends

The adherends were produced using an enclosed-chamber FDM system (Bambu Lab X1C). All specimens were printed in the same build orientation and using identical parameters: a 0.1 mm layer height, 50% infill with a grid pattern, three top layers, and three bottom layers. The wall count and all other printing parameters were kept constant. The print pattern was not treated as a variable in this study; it was maintained consistently to ensure that the bonding surface characteristics were identical for all specimens.

The surfaces to be bonded were prepared using the same protocol for all specimens: light unidirectional abrasion followed by cleaning with isopropyl alcohol. Acetone was deliberately avoided because it dissolves the ABS surface and could introduce inconsistencies between specimens.

Preparation of the Modified Adhesive

PA6 powder was added to the epoxy adhesive on a phr basis (parts per hundred resin: grams of powder per 100 g of adhesive). This convention reflects directly how the mixtures were prepared in the laboratory; the corresponding contents expressed as a percentage of the total mass are given alongside in Table 1. Components A and B of the adhesive were first mixed homogeneously, after which the powder was added and dispersed until no agglomerates remained. Because the pot life is limited, the mixtures were prepared in small batches.

Table 1. Test matrix and powder content conventions.

Code	Content (phr)	By total mass (%)	Replicates
N0 (neat)	0	0.00	3
N5	100:5	4.76	3
N10	100:10	9.09	3
N15	100:15	13.04	3

Production of the Joints

The single-lap joints were produced according to the ASTM D5868 geometry: 25.4 mm overlap length and 25.4 mm width, giving a nominal bond area of 645.16 mm². The bondline thickness was fixed at 0.2 mm for all specimens, the adherends were positioned in an alignment fixture and the joints were cured under constant pressure. The curing condition was identical for all groups, so that the only difference between groups was the powder content.

Mechanical Testing and Evaluation

The joints were tested under quasi-static tensile loading at a constant crosshead rate of 13 mm/min at room temperature in accordance with ASTM D5868 (Figure 1). Three replicates were tested per condition, and load and position data were recorded at a sampling rate of 200 Hz.

For each specimen the maximum load (Fmax), the nominal lap-shear strength (τ = Fmax / A), the displacement at maximum load, the energy to failure (the area under the load–displacement curve up to the maximum load) and the joint stiffness (secant slope between 10% and 40% of the maximum load) were determined. Differences between groups were evaluated by one-way analysis of variance (ANOVA) and the Tukey HSD multiple-comparison test at a significance level of 0.05. The fracture surfaces were examined optically.

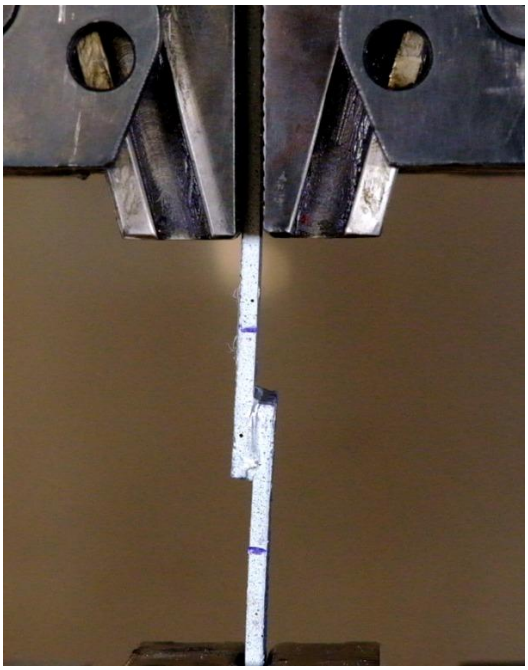

Figure 1. Single-lap joint specimen during the tensile test.

RESULTS AND DISCUSSION

Load–Displacement Behaviour

Representative load–displacement curves for each group are given in Figure 2, and the curves of all specimens are shown by group in Figure 3. In all conditions the behaviour consists of an initially near-

linear rise followed by an abrupt drop at the maximum load, which is consistent with the brittle, sudden failure characteristic of single-lap joints.

Relative to the neat group, both the slope of the curves and the peak load attained increased appreciably at 100:5. In the 100:15 group the curves extended over a longer displacement, with the mean displacement at maximum load rising from 2.84 mm to 3.43 mm; however, the differences between specimens within this group were far more pronounced than in the others.

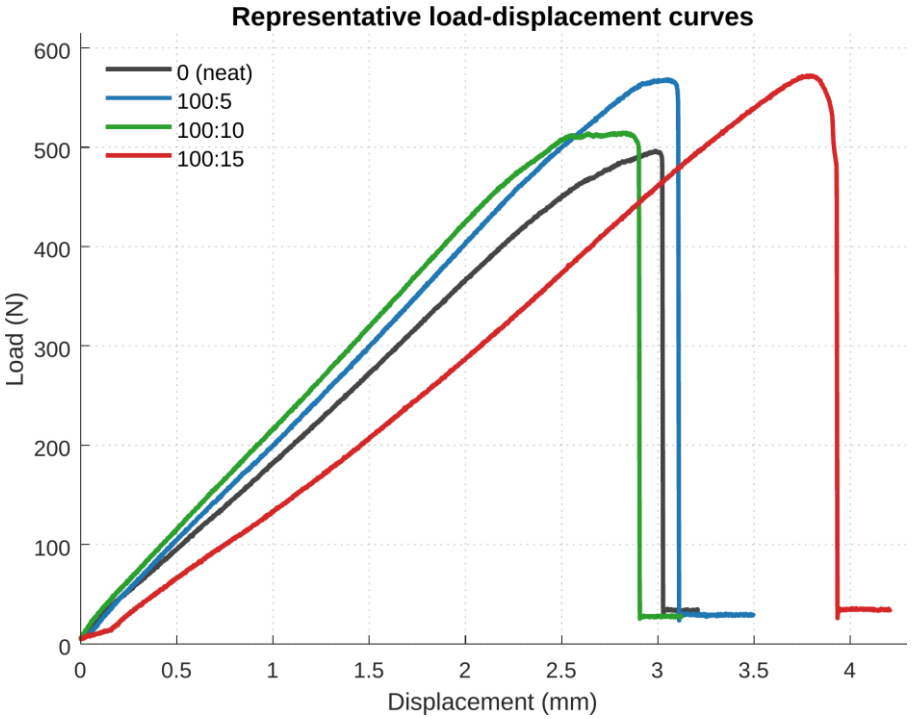

Figure 2. Representative load–displacement curves for each condition.

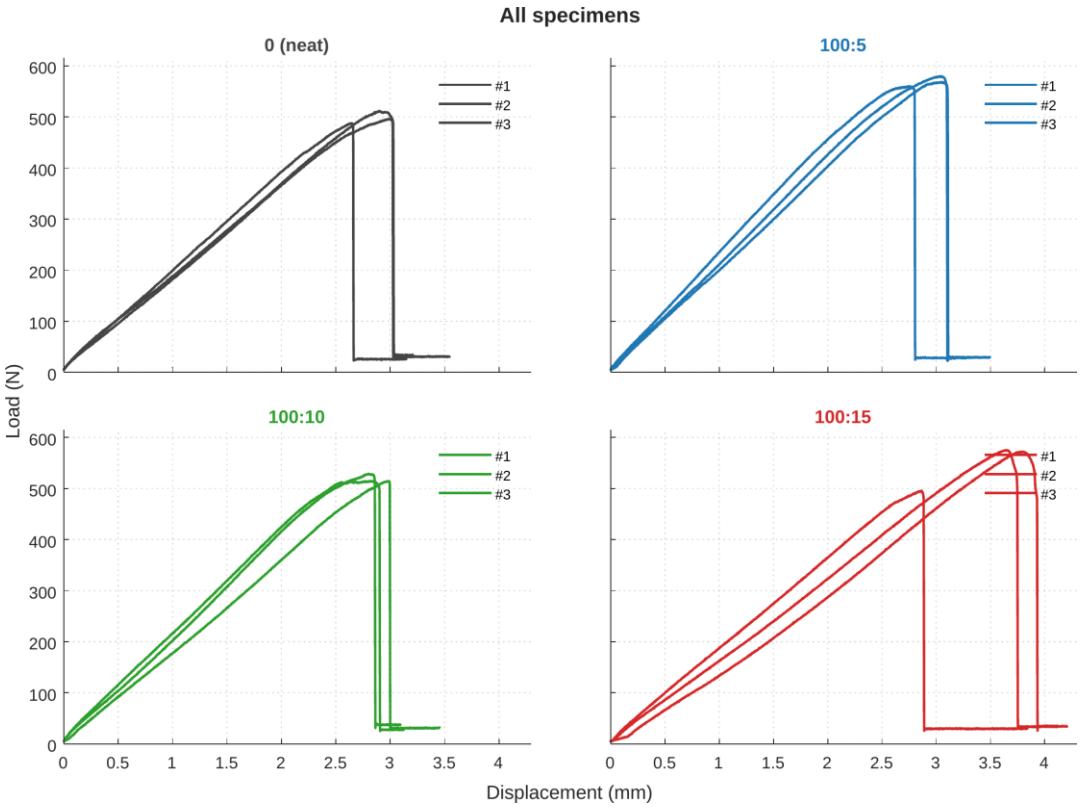

Figure 3. Load–displacement curves of all specimens, shown by group.

Joint Strength

The mean results are summarised in Table 2 and the lap-shear strength is shown in Figure 4. For the neat joints the mean maximum load was 498.7 ± 11.9 N (τ = 0.773 ± 0.018 MPa). At 100:5 the maximum load rose to 569.3 ± 9.7 N (τ = 0.882 ± 0.015 MPa), corresponding to an increase of 14.1% relative to the neat adhesive.

Increasing the powder content did not sustain this gain. At 100:10 the mean load was 519.4 ± 8.1 N (an increase of 4.1%), and at 100:15 it was 547.8 ± 44.9 N (an increase of 9.8%). In terms of strength, therefore, the peak occurs at 100:5, with no clear additional benefit at higher contents.

Energy to Failure and Stiffness

The energy to failure (Figure 5) increased from 757 ± 64 mJ for the neat adhesive to 912 ± 55 mJ at 100:5 (an increase of 20.4%) and 960 ± 180 mJ at 100:15 (an increase of 26.9%). This rise in energy is consistent with the expectation that PA6 particles toughen the joint.

The joint stiffness followed a different trend: it reached its highest value at 100:5 with an increase of 17.2%, fell back to an increase of 8.0% at 100:10, and at 100:15 was 7.3% below the neat value. The combination of decreasing stiffness and increasing displacement at high powder content indicates that the joint becomes more compliant. The relative changes in all metrics are summarised in Figure 6.

Table 2. Summary of the test results (mean ± standard deviation, n = 3).

Metric	N0 (neat)	N5 (100:5)	N10 (100:10)	N15 (100:15)
Maximum load, Fmax (N)	498.7 ± 11.9	569.3 ± 9.7	519.4 ± 8.1	547.8 ± 44.9
Lap-shear strength, τ (MPa)	0.773 ± 0.018	0.882 ± 0.015	0.805 ± 0.013	0.849 ± 0.070
Change in strength (%)	-	+14.1	+4.1	+9.8
Displacement at Fmax (mm)	2.84 ± 0.18	2.94 ± 0.17	2.87 ± 0.10	3.43 ± 0.49
Energy to failure (mJ)	757 ± 64	912 ± 55	809 ± 19	960 ± 180
Change in energy (%)	-	+20.4	+6.9	+26.9
Stiffness (N/mm)	148.5 ± 7.7	174.1 ± 4.1	160.4 ± 8.9	137.6 ± 10.0
Change in stiffness (%)	-	+17.2	+8.0	−7.3
Coefficient of variation, CV (%)	2.3	1.7	1.6	8.2

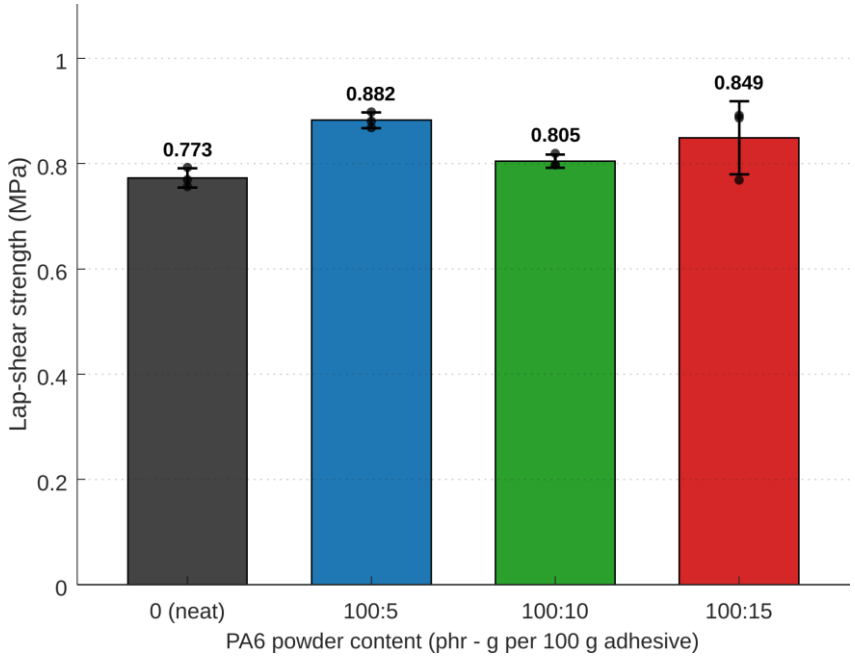

Figure 4. Lap-shear strength (mean ± standard deviation; points denote individual specimens).

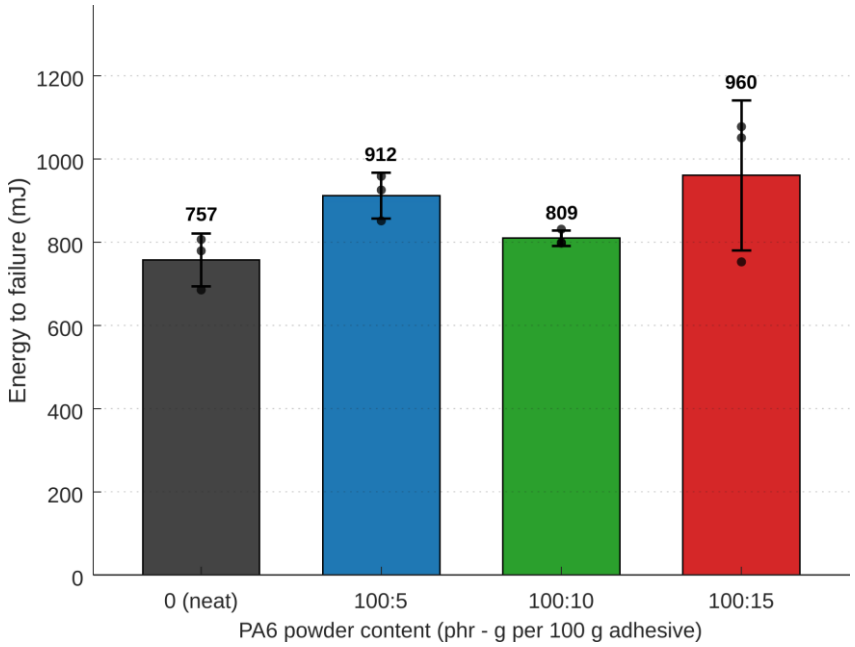

Figure 5. Energy to failure (mean ± standard deviation).

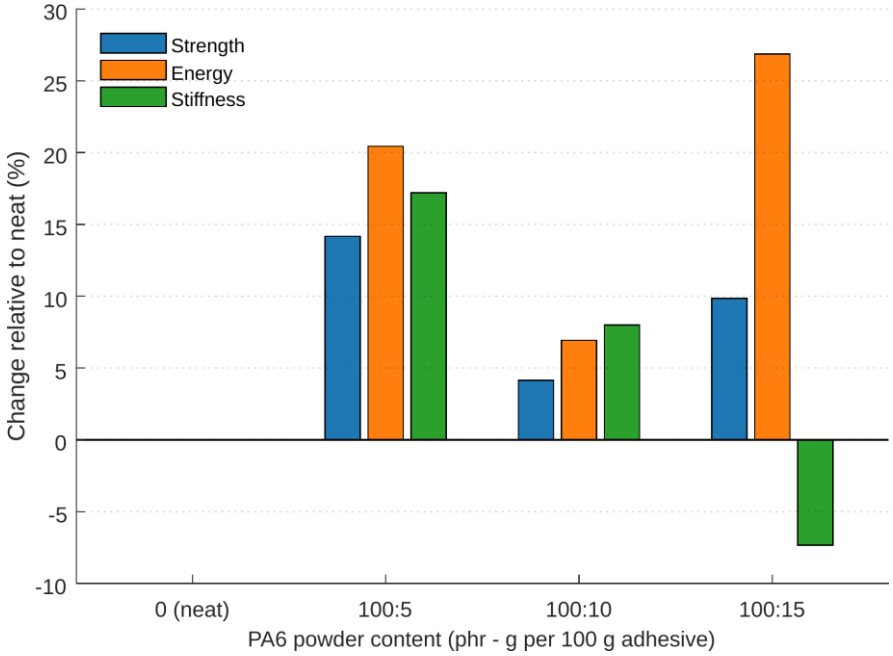

Figure 6. Relative change with respect to the neat adhesive.

Statistical Evaluation

One-way analysis of variance on the maximum load indicated a statistically significant difference among the four groups ($F = 5.011$; $p = 0.030$). The Tukey HSD multiple-comparison test clarified the source of this difference: only the difference between the neat group and the 100:5 group is significant (mean difference 70.7 N; $p = 0.029$). Relative to the neat group, the differences for 100:10 ($p = 0.725$) and 100:15 ($p = 0.134$) did not reach significance.

For the energy to failure, the analysis of variance did not indicate a significant difference between groups ($F = 2.595$; $p = 0.125$). The principal reason is the high scatter in the 100:15 group, where the standard deviation was 180 mJ compared with 19–64 mJ for the other groups. Accordingly, the coefficient of variation was 8.2% for 100:15 against 1.6–2.3% for the remaining three groups.

This pattern is decisive for the interpretation of the results: the 100:5 content yields both the highest mean strength and one of the lowest scatters, and therefore delivers an improvement that is not only

substantial but also repeatable. At high powder content, by contrast, the mean values remain high while repeatability deteriorates appreciably.

Table 3. Tukey HSD multiple-comparison results for maximum load (α = 0.05).

Comparison	Mean difference (N)	p value	Significant
N0 – N5	70.7	0.029	Yes
N0 – N10	20.7	0.725	No
N0 – N15	49.1	0.134	No
N5 – N10	−50.0	0.127	No
N5 – N15	−21.5	0.702	No
N10 – N15	28.4	0.508	No

Fracture Surfaces

The fracture surfaces after testing are shown in Figure 7. In the neat joints the adhesive residue remained as a thin, narrow band and most of the adherend surface was left clean, an appearance indicative of predominantly adhesive (interfacial) failure. In the powder-modified joints the amount of adhesive retained on both adherend surfaces increased and the residue exhibited a more irregular, wavy distribution, indicating an increased cohesive character.

This shift in failure mode is consistent with the mechanical results: the presence of PA6 particles makes it more difficult for the crack to propagate directly along the interface and contributes to deflecting the crack path into the adhesive.



Figure 7. Fracture surfaces after testing (right column: neat and 100:5; left column: 100:10 and 100:15).

Mechanism and Comparison with the Literature

The observed trend is consistent with the literature on thermoplastic particle toughening. Cardwell and Yee (1998) showed that polyamide particles toughen epoxies by crack bridging, a mechanism that relies on plastic deformation of the particles. Heflin and Månsson (2022) report that in polyamide–epoxy systems a PA6 content of the order of 5 wt% stands out in terms of fracture energy. The optimum found in the present study, 100:5, corresponds to 4.76 wt% and thus falls within that range.

The behaviour observed at high powder content points to a second mechanism. As the powder content increases, the viscosity of the mixture rises and it becomes more difficult both to disperse the powder

homogeneously and to remove entrapped air. In a bondline as thin as 0.2 mm, agglomerates and voids create local stress concentrations, which accounts for the growth in scatter despite the retention of a high mean strength. In other words, at high contents the powder continues to exert a toughening effect while simultaneously increasing the likelihood of process-induced defects.

In terms of absolute strength, the maximum loads measured here (499–569 N) fall below the values reported in the literature for 3D-printed ABS single-lap joints (approximately 1386–1744 N; Kamer, 2025). The principal reason is considered to be the comparatively thin cross-section of the adherends used, which allows adherend bending and the associated peel stresses to dominate in the single-lap configuration. Since the geometry and production conditions were identical for all groups, this does not affect the validity of the comparison between groups; it does, however, limit direct comparison of the absolute values with those obtained for different geometries.

CONCLUSIONS

This study examined the effect of modified adhesives, obtained by adding PA6 powder, already available as additive-manufacturing feedstock, directly to a commercial epoxy adhesive, on the performance of FDM-printed ABS single-lap joints. The following conclusions were drawn:

• Adding 5 g of PA6 powder per 100 g of adhesive (100:5) gave the best performance: the maximum load increased by 14.1%, the energy to failure by 20.4% and the joint stiffness by 17.2%.

• One-way analysis of variance indicated a significant difference between groups ($p = 0.030$), and the Tukey HSD test established that this difference is significant only between the neat adhesive and 100:5 ($p = 0.029$).

• Increasing the powder content provided no additional benefit. At 100:10 the increase fell to 4.1%, and at 100:15 the mean values remained high while the scatter grew four- to fivefold (CV 8.2%).

• Examination of the fracture surfaces showed that, with powder addition, the failure mode shifted from a predominantly adhesive character towards a more cohesive one.

• The results demonstrate that a low content of PA6 powder can serve as a low-cost and readily accessible toughening route that requires no additional equipment or specialised materials.

The main limitations of the study are the use of three replicates per condition and the comparatively thin adherend cross-section, which accentuates peel effects. Future work is planned to increase the number of replicates, to examine the particle size distribution of the powder and its dispersion within the bondline, and to reduce peel effects by using thicker adherends.

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ASSESSMENT OF CMEMS SEA LEVEL REANALYSIS USING OBSERVATIONS FROM THE MENTEŞ TIDE GAUGE STATION IN THE AEGEAN SEA

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ABSTRACT

Sea level variations are essential oceanographic parameters for monitoring coastal processes, assessing climate change impacts, conducting flood risk analyses, and supporting operational oceanography. Although recent sea level reanalysis products, derived from assimilating satellite altimetry into numerical ocean models, offer broad spatial and temporal coverage, their accuracy in coastal zones necessitates rigorous validation against in situ observations.

In this study, the Copernicus Marine Environment Monitoring Service (CMEMS) sea level reanalysis product is evaluated using observations from the Menteş Tide Gauge Station (TUDES) located in the eastern Aegean Sea. The comparisons spanned a joint observation period of 3,293 days. The agreement between the two datasets was assessed using the Pearson correlation coefficient, Root Mean Square Error (RMSE), Mean Absolute Error (MAE), mean bias, linear regression analysis, and the Bland–Altman method. Furthermore, the temporal evolution of the model's performance was evaluated on a monthly and seasonal basis.

The results demonstrate that the CMEMS product successfully represents the long-term variability of the observed sea level anomalies at the Menteş station. Overall validation metrics reveal a Pearson correlation coefficient of $R = 0.672$, an RMSE of 0.083 m, an MAE of 0.064 m, and a mean bias of approximately 0.000 m. The Bland–Altman analysis indicates that the vast majority of the differences fall within the 95% limits of agreement. Seasonal analyses highlight that model performance peaks during the spring, while error magnitudes are highest during the winter months. During the summer, despite a low RMSE driven by reduced sea level variance, the correlation coefficient decreases.

These results indicate that while CMEMS sea level products are reliable for coastal applications in the Eastern Aegean Sea, in situ tide gauge observations remain essential for accurately assessing high-frequency coastal processes and extreme sea level events.

Keywords: Sea level, CMEMS, Tide gauge, TUDES, Reanalysis, Eastern Aegean Sea

Introduction

Accurately determining sea level variations is essential for monitoring climate change impacts, assessing coastal flood risks, facilitating port planning, and supporting operational oceanography. Currently, numerical ocean reanalyses—developed by integrating satellite altimetry with advanced data assimilation techniques—are widely used to monitor global and regional sea level dynamics(Melet et al., 2021).

The Copernicus Marine Environment Monitoring Service (CMEMS) generates continuous sea level products by combining satellite observations and *in situ* measurements with sophisticated physical ocean models. However, in coastal regions, the accuracy of these reanalysis products can degrade compared to the open ocean due to complex bathymetry, near-shore satellite measurement uncertainties, high-

frequency atmospheric forcing, and physical processes that are constrained by limited model resolution(Birol et al., 2016).

Modeling sea level variations in the Eastern Aegean Sea is challenging due to its numerous islands, complex coastal geometry, variable bathymetry, and distinct seasonal atmospheric forcing. Furthermore, sea level dynamics in this region are significantly influenced by severe winter storms and persistent Etesian winds during the summer. Therefore, in situ tide gauge observations remain the most reliable reference data for validating model performance in such environments(Dangendorf et al., 2015).

The objective of this study is to evaluate the accuracy of the CMEMS sea level reanalysis product using observations from the Menteş Tide Gauge Station and to investigate the temporal and seasonal performance of the product within the Eastern Aegean Sea.

Study Area, Data, and Methodology

This study was conducted in the eastern Aegean Sea, a semi-enclosed basin where sea level dynamics are strongly driven by seasonal atmospheric forcing, such as intense winter storms and persistent summer Etesian winds. Validation involved two datasets covering 3,293 days from 2004 to 2012: daily non-tidal residual sea level observations from the Menteş Tide Gauge Station and the Mediterranean Sea Physics Reanalysis product from the Copernicus Marine Environment Monitoring Service. The CMEMS product integrates satellite altimetry with a numerical ocean general circulation model via data assimilation, featuring a 1/24° horizontal resolution and daily temporal resolution. We extracted modeled values from the CMEMS grid node nearest to the Menteş station. To remove datum offsets and isolate non-tidal residual variability, the long-term mean of the shared period was subtracted from both records to create daily anomaly series (Toomey et al., 2022).

Agreement between the two series was quantified using the Pearson correlation coefficient, the Root Mean Square Error, the Mean Absolute Error, the mean bias, and a simple linear regression. Absolute agreement was additionally examined through the Bland–Altman method, with the 95% Limits of Agreement defined as the mean difference plus or minus 1.96 times the standard deviation of the paired differences. To capture the seasonality of model performance, all metrics were recomputed separately for each season and each month of the common record.(Kotlarski et al., 2014)

Results and Discussion

Overall Model Performance

The time-series comparison demonstrates that the CMEMS reanalysis product effectively tracks long-term sea level anomalies at the Menteş Tide Gauge station. Based on an analysis of 3,293 data points, the Pearson correlation coefficient is $R = 0.672$, indicating a moderate-to-strong linear relationship between the model outputs and the field observations.

Overall error statistics are computed as $RMSE = 0.083$ m, $MAE = 0.064$ m, and $Bias \approx 0.000$ m. Our calculated near-zero mean bias indicates that the CMEMS product does not systematically over- or underestimate the sea level.

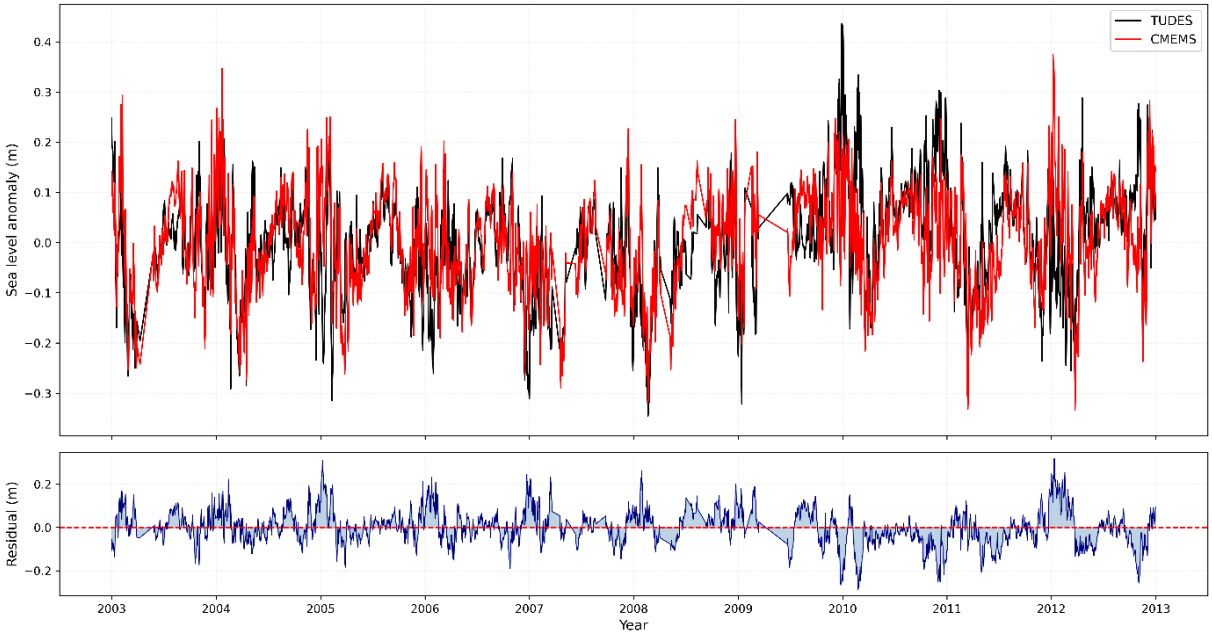

Figure 1. Time-series comparison of daily sea level anomalies (m) between TUDES observations (black line) and CMEMS reanalysis (red line). The bottom panel displays the residual differences (CMEMS - TUDES) over the study period.

Conversely, the scatter plot and linear regression analysis (Figure 2) reveal a slope of approximately 0.62, demonstrating that the model slightly dampens the amplitude of highly positive and negative sea level anomalies. This underestimation can be attributed primarily to the reanalysis product's inability to fully resolve high-frequency coastal processes and short-duration extreme events(Melet et al., 2021).

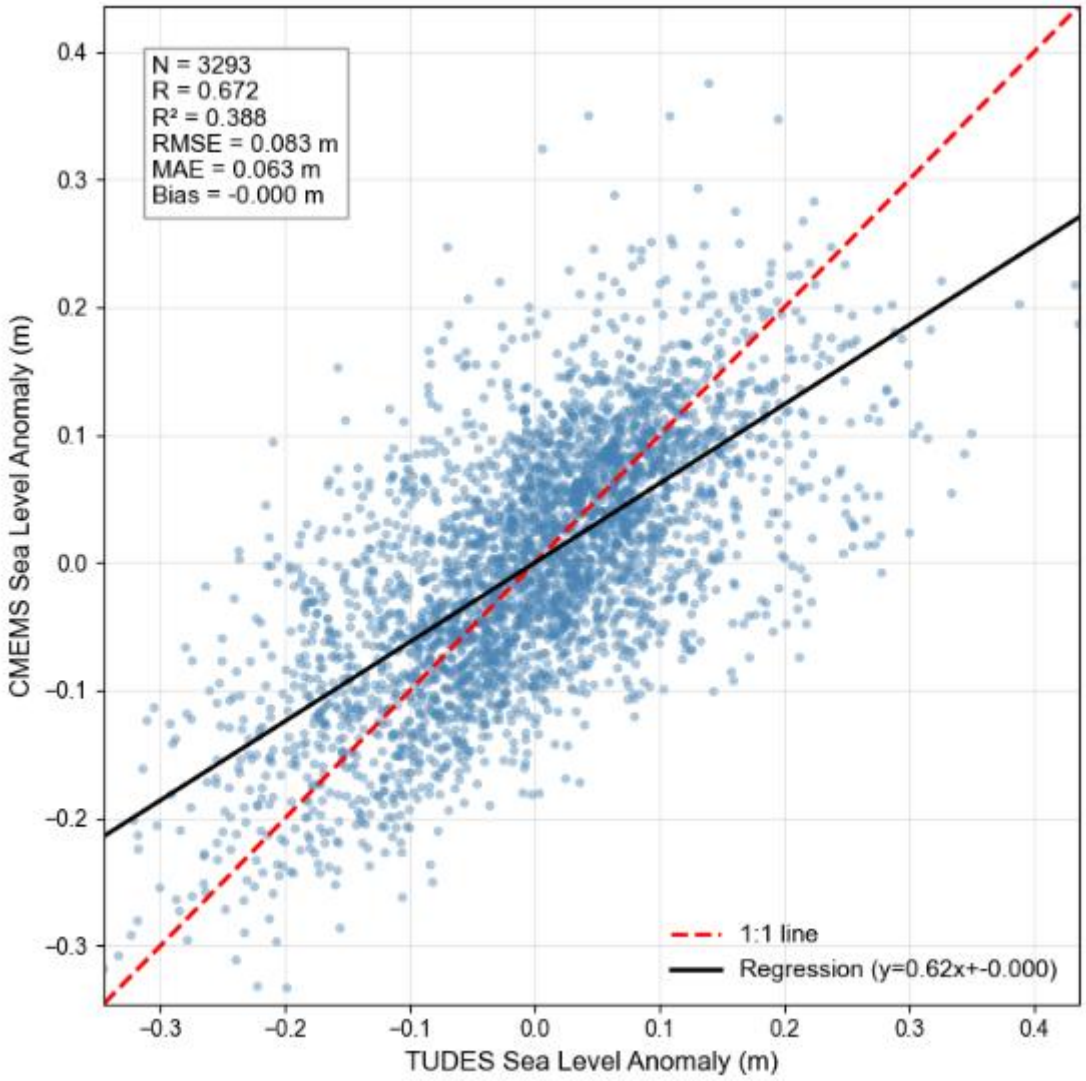

Figure 2. Scatter plot of daily sea level anomalies from TUDES against the CMEMS reanalysis product. The red dashed line represents the perfect agreement (1:1 reference line), and the black solid line indicates the linear regression fit ($y = 0.62x - 0.000$).

Bland–Altman Analysis

Agreement between CMEMS and TUDES observations was evaluated using the Bland–Altman method. The analysis yielded a mean difference of approximately 0 m, confirming the absence of systematic bias between the datasets.

The 95% Limits of Agreement (LoA) were calculated as ± 0.163 m, with only 6.1% of the observations falling outside these boundaries. As the hexbin density shows in Figure 3, the majority of the differences are distributed symmetrically around zero, and no distinct proportional bias is observed. These results indicate that the CMEMS product provides reliable sea level anomalies at the Menteş station.

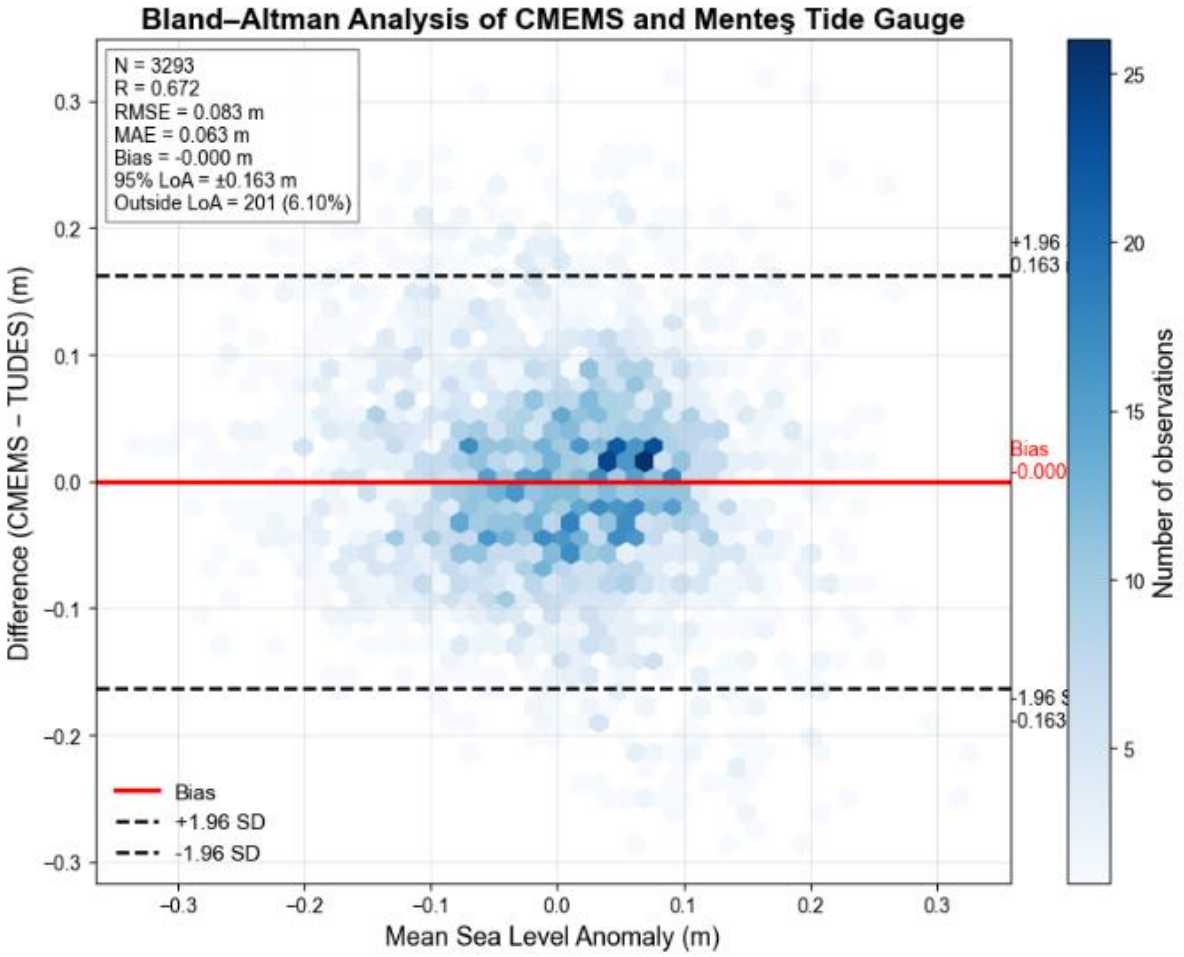

Figure 3. Bland–Altman diagram analyzing the agreement between CMEMS and Menteş Tide Gauge observations. The horizontal red line represents the mean difference (bias), while the black dashed lines denote the 95% Limits of Agreement (LoA). Hexbin density colors indicate the number of observations.

Seasonal Variability

The distribution of sea level anomalies exhibits pronounced seasonal variations, as shown in the seasonal boxplots (Figure 4).

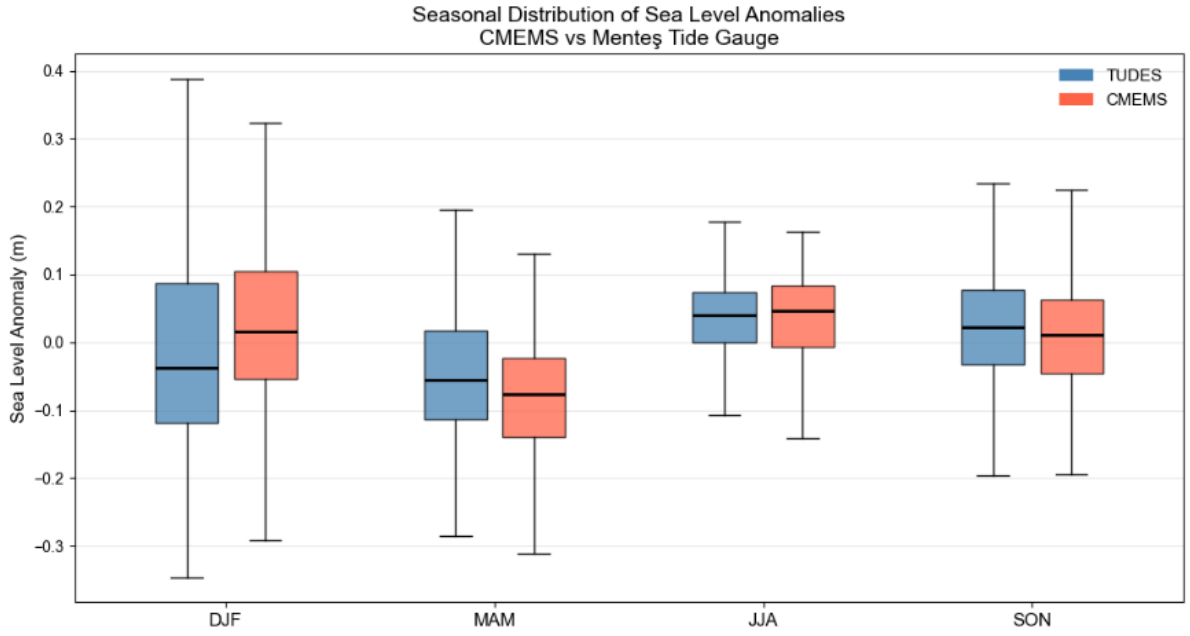

Figure 4. Seasonal distribution of sea level anomalies for TUDES (blue boxes) and CMEMS (red boxes) representing Winter (DJF), Spring (MAM), Summer (JJA), and Autumn (SON).

As presented in the seasonal validation metrics (Figure 5), the correlation coefficient reaches its maximum ($R \approx 0.74$) during the spring months, indicating optimal representation of the observations by the model. In the summer period, while the RMSE drops to its lowest level of approximately 0.055 m, the correlation coefficient simultaneously decreases to $R \approx 0.57$. This is primarily driven by the inherently low variance in sea level during the summer. Under these conditions, minor phase shifts reduce the correlation coefficient, even though the absolute error remains negligible.

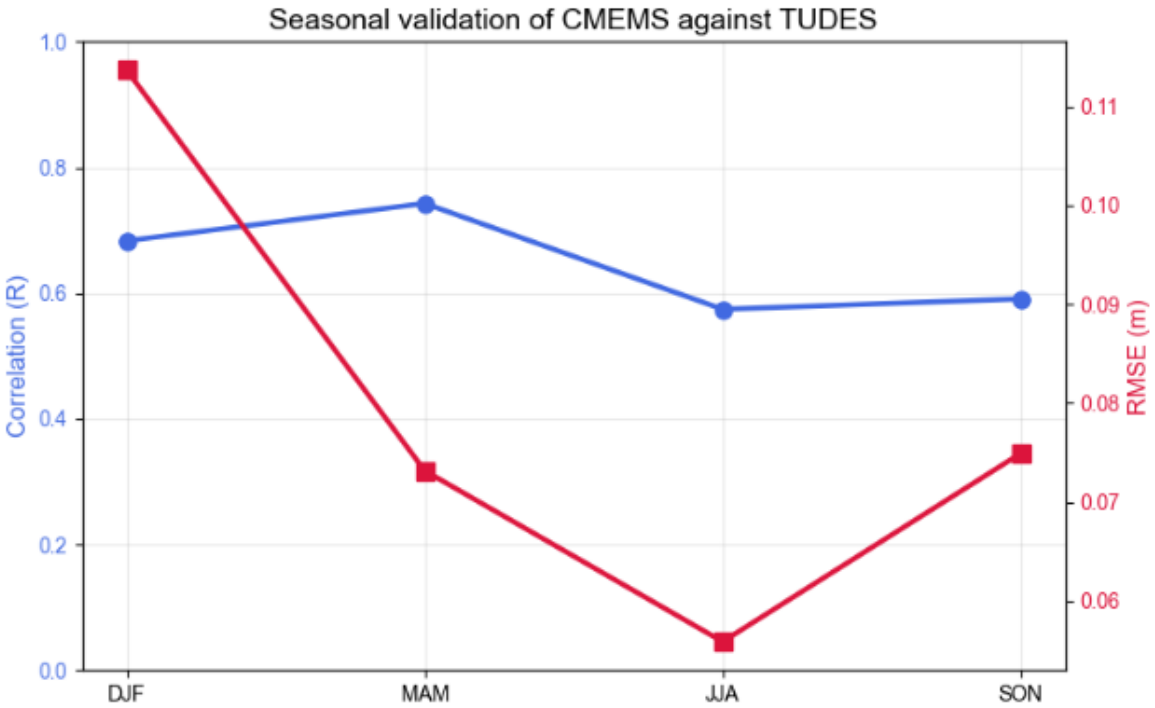

Figure 5. Seasonal validation metrics for the CMEMS product against TUDES, illustrating the variations in the Pearson correlation coefficient (R, blue line) and Root Mean Square Error (RMSE, red line) across the four seasons.

Conversely, during the winter months, intensified atmospheric forcing drives the RMSE up to approximately 0.113 m (Figure 5). The monthly validation metrics (Figure 6) further detail this degradation; January, in particular, exhibits the highest RMSE (> 0.12 m) and MAE values across the year. This degradation in performance stems from the reanalysis product's limitations in fully resolving storm surges, rapid atmospheric pressure fluctuations, and high-frequency coastal processes.

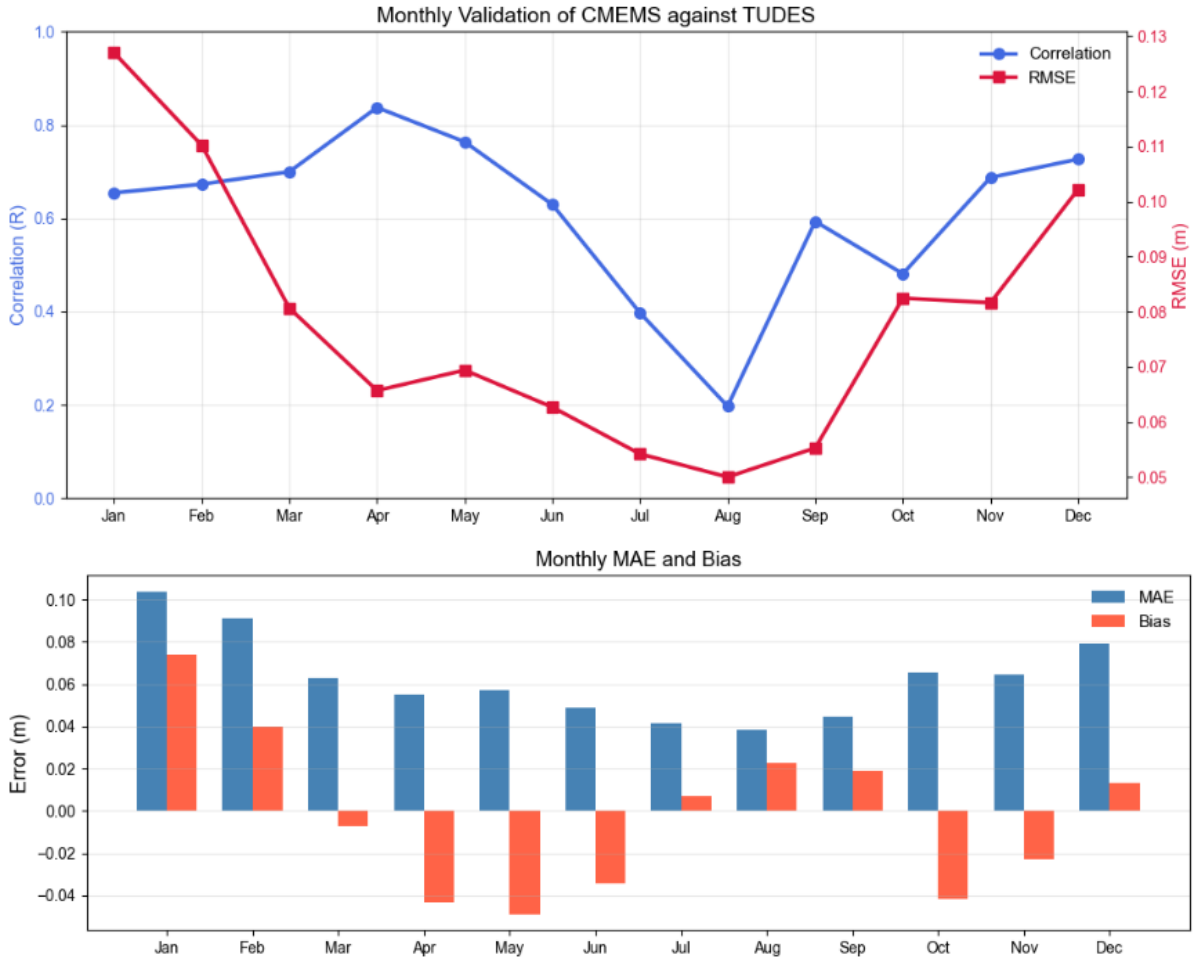

Figure 6. Monthly validation of CMEMS against TUDES observations. The top panel shows the monthly progression of Correlation (R) and RMSE. The bottom panel details the monthly Mean Absolute Error (MAE) and mean bias distribution.

Conclusions

This study presents a comprehensive validation of the CMEMS sea level reanalysis product using observations from the Menteş Tide Gauge Station in the eastern Aegean Sea. The results demonstrate that the CMEMS product reliably represents the long-term variability of sea level anomalies. The overall correlation coefficient of 0.672, an RMSE of 0.083 m, and a near-zero mean bias collectively indicate a satisfactory level of model performance.

However, regression analysis reveals that the model partially dampens the amplitude of extreme sea level anomalies. The Bland–Altman analysis confirms the absence of systematic bias, with the vast majority of observations situated within the 95% limits of agreement.

Seasonal assessments show that model performance peaks in the spring and reaches its lowest point during the winter. In the summer, a reduction in the correlation coefficient occurs despite low absolute errors, primarily due to diminished sea level variance.

In conclusion, the CMEMS sea level reanalysis product serves as a reliable data source for monitoring coastal sea level changes and supporting operational oceanography applications in the eastern Aegean Sea(Melet et al., 2021). Nevertheless, the continued use of *in situ* tide gauge observations remains of critical importance for accurately evaluating extreme coastal events and resolving high-frequency local processes.

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THE EFFECT OF MENTORING ON THE DEVELOPMENT OF CRITICAL THINKING SKILLS: A STUDY OF GIFTED STUDENTS

MENTÖRLÜĞÜN ELEŞTİREL DÜŞÜNME BECERİLERİ GELİŞİMİNDE ETKİSİ: ÖZEL YETENEKLİ ÖĞRENCİLER ÜZERİNDE BİR ÇALIŞMA

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Özet

Eleştirel düşünme becerisi, yirmibirinci yüzyıl eğitim hedefleri arasında yer alan üst düzey düşünme biçimlerinden birisi olarak kabul edilmektedir. Mentörlük, eleştirel düşünme becerilerinin geliştirilmesinde kullanılabilecek eğitsel müdahelelerden birisidir. Özel yetenekli öğrenciler akranlarından öğrenme durumlarını etkileyebilecek bir takım sosyo-duygusal ve bilişsel özellikleriyle farklılık sergilemektedirler. Mentörlük ise özel yetenekli öğrencilerin öğrenme durumlarını en üst düzeyde sağlamaya aday uygulamalar arasında yer almaktadır. Bu çalışmanın genel amacı, özel yetenekli öğrencilere uygulanan mentörlük programının eleştirel düşünme becerileri gelişimi üzerindeki etkisinin belirlenmesidir. Bu araştırma, Düzce Bilsem'de kayıtlı olan özel yetenekli öğrencilerle gönüllük esasına dayalı katılımları ile sürdürülmüştür. Çalışma kapsamında, müdahale olarak bir yıl süresince 2024-2025 eğitim-öğretim döneminde, 120 saatlik, bir mentörlük programı uygulanmıştır. Danışanların eleştirel düşünme becerileri gelişimi, Şahin ve Yılmaz (2018) tarafından özel yetenekli çocuklara yönelik uyarlanmış olan "Eleştirel Düşünme Ölçeği" kullanılarak belirlenmiştir. Analizler sonucu, programa katılan öğrencilerin eleştirel düşünme becerilerinin anlamlı ve yüksek etki düzeyinde geliştiği saptanmıştır. Çalışma sonucu, mentörlüğün özel yetenekli çocukların eleştirel düşünme becerilerini geliştirmede etkili olarak kullanılabilecek uygulamalardan birisi olduğu sonucuna ulaşılmıştır.

Anahtar kelimeler: Mentörlük, eleştirel düşünme becerileri, özel yetenekli öğrenci.

ABSTRACT

Critical thinking is recognized as one of the higher-order thinking skills included among 21st-century educational goals. Mentoring is one of the educational interventions that can be used to develop critical thinking skills. Gifted students differ from their peers in terms of certain socio-emotional and cognitive characteristics that may influence their learning experiences. Mentoring is among the practices that aim to optimize the learning experiences of gifted students. The overall objective of this study is to determine the effect of a mentoring program implemented for gifted students on the development of critical thinking skills. This research was conducted with gifted students enrolled at Düzce Bilsem, based on their voluntary participation. As part of the study, a 120-hour mentoring program was implemented as an intervention over the course of one year during the 2024–2025 academic year. The development of the participants' critical thinking skills was assessed using the "Critical Thinking Scale," which was adapted for gifted children by Şahin and Yılmaz (2018). The analyses revealed that the critical thinking skills of the students participating in the program improved significantly and to a high degree. The study

concluded that mentoring is one of the effective practices that can be used to develop the critical thinking skills of gifted children.

Keywords: Mentoring, critical thinking skills, gifted student.

GİRİŞ

Eleştirel düşünme, Sokrates'in sorgulayıcı yaklaşımı ile başladığına ilişkin geniş bir literatür bulunmaktadır. Elbette ki, Sokrates'ten günümüze eleştirel düşünme becerilerinin içeriği ve kapsamında ilişkin kavramsal çerçeve ve konuya ilişkin bilgi birikiminde ciddi bir gelişme olmuştur. Alanyazında üzerinde uzlaşı sağlanmış tek bir eleştirel düşünme tanımı bulunmamaktaır. Örneğin, Halpern (2014) eleştirel düşünmeyi "Problem çözme, çıkarımları varma, olasılıkları hesaplama ve kararlar vermeyi gerektiren amaçlı, mantıklı ve hedefe yönelme" biçiminde tanımlamaktadır. Facione'nin (1990/2011) delfi yöntemi kullanarak kavramın içeriğini belirlemeye yönelik yaptığı çalışmada ise söz konusu düşünme becerilerinin yorumlama, analiz, değerlendirme, yorum, açıklama ve öz düzenleme alt boyutlarından oluştuğu kanaatine varılmıştır. Bu bakış açısı, Amerika Felsefe Birliğince (American Philisophy Associate [APA]) benimsenmiştir. Bu çalışmadaki tartışma Facione'nin bakış açısı ile sınırlı olarak sürdürülecektir.

Eleştirel düşünme; öğrenilebilir, öğretilebilir, ve geliştirilebilir becerilerdir. Örneğin, Ennis (1989) ve Paul ve Elder (2002) gibi alanda öne çıkan araştırmacılar eleştirel düşünme becerilerini geliştiren tekniklere odaklanmıştır. Alanyazında, eleştirel düşünme becerilerinin öğretiminde farklı teknik, strateji ve yöntemlerin de kullanıldığı görülmektedir. Örneğin, 7E sorgulamaya dayalı öğrenme (Mecit, 2006), argümantasyon tabanlı öğretim (Güzelküçük, 2022), işbirlikçi öğrenme (Uysal, 2009), proje tabanlı yaklaşımlar (Mutakinati, vd., 2018), satranç oynanmasına dayalı yaklaşım (Şahin, 2024), disiplinlerarası öğretim yaklaşımı (Kaynar & Kurnaz, 2024) bunlardan öne çıkan bir kaçıdır. Eleştirel düşünme becerilerinin geliştirilmesinde kullanılabilecek eğitsel müdahalelerden birisi de mentörlüktür.

Mentörlük-Eleştirel Düşünme Becerileri

Richard Paul ve Linda Elder (2002) ile Diane Halpern (2003) gibi alanyazının öncülerine göre eleştirel düşünme, bireyin kendi düşünme süreçlerini izlemesi ve geliştirmesini gerektirir. Lev Vygotsky'nin Sosyo-Kültürel Gelişim Kuramına göre eleştirel düşünme gibi üst düzey bilişsel işlevler, önce sosyal düzlemde bireyler arası olarak başlatılır, devamında ise bilişsel düzeyde etkileşimden öğrenilenler içselleştirilir. Facione'ye (1990/2011) göre eleştirel düşünme, soyut bir zihinsel kapasite ile sınırlandırılamaz; sözkonusu düşünme biçimi bireyin sosyal etkileşimine ve bireye verilen dönütlere bağlı olarak genişleyen dinamik bir süreçtir. Bu çerçeveden bakıldığında, mentörler mentileriyle girdikleri etkileşimde onlara yeni bilgi öğreterek bilişsel gelişimlerini sağlama yanısıra; meraklı olma, sebatkarlık, problem çözümünde ısrarcı olma, makul risk alma (Şahin, 2020) gibi eleştirel düşünme becerilerini destekleyecek duyuşsal becerilerle de model olurlar.

Vygotskiyen bir bakış açısı ile mentörlügün eleştirel düşünme becerilerine etkisi teorik olarak şu şekilde açıklanabilir: Mentörler mentilerinin, "Yorumlama" alt becerisinin gelişimini bilişsel olarak model olarak desteklerler. Bir problem çözümünde mentör kendi düşünme süreçlerini sesli olarak mentiyle paylaşarak ona bilişsel bir harita sunar. Bu anlamlandırma stratejisinin, zamanla tekrarlamasına bağlı olarak menti tarafından içselleştirilmesine ve kendi bilişsel becerisinin bir parçası haline gelir. Analiz alt becerisinde ise karmaşık bir problemin çözümü yüksek düzeyde soyutlama gerektirir. Mentörün alternatif çözümler sunarak (Ör.vaka analizi yapması) mentiye rehberlik etmesi bilişsel iskele kurmaya (Scaffolding) örnek olarak gösterilebilir. Mentör ana değişkenleri belirlemesi, sınıflandırması ve arasındaki ilişkileri ayırt etmesi için sorular, ipuçları ve şablonlar kullanarak destek sunar. Değerlendirme becerisi ise bireyin yakınsal gelişim alanında yer alan bir görevi tamamlayabilmesi için daha deneyimli ve bilgili bir kişi ile (mentör) girilecek etkileşimler ile gelişecektir. Mentinin ön yargı veya sınırlı bilgi düzeyine bağlı sınırlılıkları dış kaynaktan gelen dönütlerle gelişebilir. Böylece de, mentinin yakınsal gelişim alanı dışarıdan gelen uyaranların içselleşmesine doğru evrilerek gelişecektir. Bir diğer alt beceri "Çıkarım yapma"dır. Bu beceri, repertuardaki verilerin ötesine geçerek öngörü üretebilme becerisidir. Mentör, mentinin yakınsal gelişim alanında yer alan henüz olgunlaşmamış ama olgunlaşmakta olan çıkarım yapma becerisini "Eğer, bu önerilen doğruysa, X koşulları altında nasıl bir

durumla karşılaşırız?" gibi sorularla uyararak onları işlevselleştirirler. Açıklama, eleştireld düşünmenin beşinci alt boyuttur. Vygotsky'ye göre düşünce-dil arasındaki ilişki diyalektiktir. Mentör – menti etkileşimi kapsamında yer alan tartışmalar, diyaloglar, deneyim paylaşımları ile menti zihnindeki dağınık düşünceleri yapılandırarak ifade edici dil (Açıklama) formunda yansıtır. Bu esnada, dilin kültürel ve bilişsel paylaşımın bir aracı olarak kullanılması, mentinin düşünme sürecini rasyonel ve tutarlı olarak geliştirir. Mentörlük içerikli eleştirel düşünme becerileri gelişimine etkisinin incelendiği sınırlı sayıdaki ampirik çalışmalarda, mentörlük stilinin eleştirel düşünme eğilimi arasında pozitif bir korelasyon olduğu (Zhou, vd., 2025), mentörü olan öğrencileri mentörü olmayan öğrencilere göre eleştirel düşünme eğilimlerinin anlamlı düzeyde yüksek olduğu (Nelson, vd., 2018) saptanmıştır.

Problem durumu

Bu çalışmanın hedef kitlesi özel yetenekli öğrencilerdir. Özel yetenekliler, akranlarından karmaşık ve komplek düşünme, gelişmiş hafıza becerileri gibi bir takım bilişsel farklılıklarından dolayı yaratıcılık veya eleştirel düşünme gibi üst düzey düşünme becerilerini daha gelişmiş olarak kullanma potansiyeline sahip bireylerdir (Şahin, 2026, 2025, 2020, 2014). Tipik gelişim gösteren öğrenciler için dahi çok önemli kabul edilen eleştirel düşünme becerileri, özel yetenekli bireylerin eğitiminde vazgeçilmez bir noktadadır. Özel yeteneklilere bu becerileri edindirebilmek için farklı eğitsel müdaheleler, modeller ve uyarlamalara başvurulabilmektedir. Bunlardan birisi de mentörlüktür (Şahin, 2018).

Mentörlük, Vygotskiyan bakış açısıyla örtüşen ilkelere sahip, doğası gereği de eleştirel düşünme becerilerini desteklemek için en uygun eğitsel uygulamalardan birisi olarak kabul edilebilir. Alanyazına göz atıldığında, mentörlük içeren müdahalelerin doğrudan eleştirel düşünme becerileri gelişimine etkisinin incelendiği oldukça sınırlı sayıda araştırmaya ulaşılabilmiştir. Söz konusu araştırmaların odağı ise bu araştırmada izlenen yüzyüze ve küçük grup mentörlüğü uygulamasından ve hedef kitle olarak özel yetenekli çocuklarla sürdürülmüş olması boyutları ile farklılaşmaktadır. Bu çalışmanın genel amacı, mentörlük destekli uygulanan BİLSEM destek eğitim programının özel yetenekli öğrencilerde eleştirel düşünme becerileri gelişimine etkisinin belirlenmesidir. Bu genel amaç kapsamında araştırmada "Mentörlük destekli uygulanan BİLSEM destek eğitim programı özel yetenekli öğrencilerin eleştirel düşünme becerileri gelişimini sağlamakta mıdır?" sorusuna yanıt aranmıştır.

METOD

Araştırma deseni

Bu çalışma, nicel desende ön test – son test yarı kontrol grupsuz yarı deneysel desende sürdürülmüştür. Bu aşamada, deney grubuna mentörlük strateji yardımıyla eleştirel düşünme becerilerinin geliştirilmesi için mentörlük destekli bir müfredat uygulanmıştır. Araştırmanın bağımsız değişkeni, mentörlük destekli eğitim program, bağımlı değişkeni ise öğrencilerin eleştirel düşünme becerileridir.

Katılımcılar

Araştırma, Düzce Bilim ve Sanat Merkezine (BİLSEM) kayıtlı öğrencilerle sürdürülmüştür. BİLSEM'ler, Türkiye'de ulusal düzeyde uygulanan ve Milli Eğitim Bakanlığı bünyesinde yer alan okul sonrası programlardır. Programa, resmi olarak üstün zeka tanısı olan (130≥ IQ puanına sahip; +2≥ standart sapma) öğrenciler katılabilmektedir. Bu çalışmada örneklem seçimine gidilmemiştir. BİLSEM'deki "Destek Eğitim Programına" kayıtlı ve çalışmaya gönüllü öğrencilerin tamamı ile çalışma sürdürülmüştür. Çalışma grubunda yer alacak öğrenciler belirlenirken BİLSEM'de kayıtlı olan öğrencilere bilgilendirme yapılmış, kendi rızaları ve ailelerinden onam alındıktan sonra çalışmanın uygulama aşamasına geçilmiştir. Çalışma grubunda toplamda 45 öğrenciden dönen veriler ile analizler gerçekleştirilmiştir.

Veri toplama aracı

Eleştirel Düşünme Ölçeği

Bu çalışmada katılımcıların eleştirel düşünme beceri düzeyini ölçmek için APA'nın eleştirel düşünme bakış açısına göre Demir (2006) tarafından normal öğrenci gruplarına yönelik geliştirilen ve Şahin ve

Yılmaz (2018) tarafından özel yetenekli öğrencilere yönelik uyarlanmış olan tasklerdan yararlanılarak oluşturulan toplam 39 sorudan oluşan form uzman görüşü sonrasında kullanılmıştır.

APA'ya göre, eleştirel düşünme alt boyutları arasında yer alan "Analiz" fikirleri inceleme, argümanları belirleme ve argümanları analiz etmeyi içerir (Facione, 1990). Bu çalışmada, bu becerinin ölçümü için iki farklı ifadeye dayalı olarak verilen yeni bir durumun doğrulanması veya reddedilmesine yönelik görevler kullanılmıştır. Örneğin "Bu ifadeleri doğru kabul edecek olursanız (i) Bütün beşinci sınıf öğrencileri sosyal bilgiler dersi alır, (ii) Arda beşinci sınıf öğrencisidir, "Arda, sosyal bilgiler dersi almaz" ifadesi doğru mudur?".

Çıkarım; kanıtları sorgulamayı, alternatifleri düşünmeyi ve sonuçlara varmayı içerir. Ayrıca, değerlendirme, iddiaları ve argümanları değerlendirmeyi kapsar (Facione, 1990). Bu çalışmada, "Çıkarım" ölçümü için verilen bir durum ifadesine ilişkin çıkarıma varılması beklenmektedir. Örneğin, "Ülkemizde okuma yazma bilmeyen insan sayısı her geçen gün artmaktadır, ifadesinden yola çıkarak; ülkemizde okuma yazma öğrenmek zorlaşmıştır yorumuna varılabilir mi?". Bir diğer beceri olan, "Değerlendirme" ölçümü için ise bir argumanın değerlendirilmesine odaklanılmıştır. Örneğin, "Televizyon programları insanlar için çok yararlıdır, ifadesi doğru kabul edilirse; Televizyon izlemek insanları tembelliğe alıştırır, görüşü desteklenmiş olur mu?". Katılımcılar, bu üç beceriye iki uçlu yanıt oluşturmaktadır (Evet-hayır; destekler - desteklemez). Diğer beceri ise "Yorumlama'dır". Bu beceri, sınıflandırma, anlamı çözme ve anlamı netleştirmeyi içerir. Ayrıca, bir diğer alt boyut olan açıklama, sonuçları belirtmeyi, prosedürleri gerekçelendirmeyi ve argümanları sunmayı da kapsar (Facione, 1990). Her iki alt boyuttaki beceriyi ölçebilmek için bir senaryoya bağlı hazırlanmış olan metinden yola çıkarak yanıtlanması gereken dört seçenekli toplam 17 soru (9 Yorumlama, 8 Açıklama) yer almaktadır. Puanlamada, doğru yanıtlara 1, hatalı olanlar ise 0 verilmektedir. Alınabilecek en yüksek puanlar; "Analiz" ve "Açıklama" için 8, "Değerlendirme" ve "Çıkarım" için 7 ve "Yorumlama" için 9 puan ve toplam ölçek için ise 39'dur.

Müdahale programı

Bu çalışmada uygulanan eğitsel müdahale, MEB tarafından BİLSEM'lerle tavsiye niteliğinde paylaşılan destek eğitim çerçeve programı eleştirel düşünme becerilerini gelişimini destekleyecek biçimde uyarlanarak kullanılmıştır. Örneğin öğrencileri derinlemesine düşüncelere sevk edecek Sokratik sorgulama, küçük grup oturumlarında öğrencilerin farklı bakış açılarını keşfedebilmeleri ve kendi inanaçlarını sorgulamalarına olanak tanıyan tartışmalar, öğrencilere yansıtıcı yazma etkinliği aracılığıyla kendi düşünme süreçlerine öğretmeye yönelik metabiliş öğretim, problem çözme etkinlikleri, vaka analizleri, açık uçlu sorular yöneltilmesi, birbirlerinin düşüncelerini duyabilmeleri için beyin fırtınası, karşılaştırmalar ve zıtlıkların ortaya konulması, tartışmalarda üretilen argümanların önceki bilinenlerle bağlantısının sağlanması, disiplinler arası bakış açısına yer verilmesi, öğrencilerin savundukları veya reddettikleri hipotezleri verilere dayalı olarak red/savunma yapması gibi teknik, yaklaşım ve yöntemlerin sıklıkla kullanılmasına başvurularak farklılaştırma yapılmıştır.

Uygulama süreci ve verilerin toplanması

Uygulamalar, iki farklı eğitimci tarafından küçük gruplara yönelik hafta içi akşam veya hafta sonu olmak üzere iki farklı zaman diliminde uygulanmıştır. Grup büyüklüğü 3-7 katılımcıdan oluşmaktadır. Uygulama gruplarının oluşturulmasında BİLSEM'in kapasitesi ve öğrencilerin düzeyi göz önünde bulundurularak bir planlamaya gidilmiştir. Uygulamalar, 2024-2025 Eğitim-öğretim döneminde sürdürülmüş, toplamda 120 saat sürmüştür. Uygulama, iki farklı araştırmacı tarafından görevli oldukları atölyelere dahil olan öğrencilerle sürdürülmüştür. Uygulama birlikteliği sağlanabilmesi için her iki araştırmacı içerikleri, benzer biçimde sunmuş, mentilerinde eleştirel düşünme becerilerini geliştirebilmek için birlikte hareket etmişlerdir. Araştırma verileri gönüllülük esasına göre uygulama öncesi ve uygulama sonrasında iki defa BİLSEM ortamında mentör olarak çalışmaları sürdürenlerce toplanmıştır.

Verilerin analizi

Analizlerden önce veri setinde eksik girilen değerler incelenmiştir. Eksik veri girilen bir ölçme aracı belirlenememiştir. Dağılımın normalliği için veri setinin basıklık ve çarpıklık katsayısı incelenmiştir. Söz konusu değerlerin ±3 sınırları aralığında yer aldığı belirlenmiştir (Öntest – Son test çarpıklık ranjı:

–.908 - -.842, SS:.354 - .354; Öntest- Son test basıklık ranjı: 1.58 - .751, SS:.695 - .695). Bu durum, veri setinin dağılımın normallik koşulunu sağladığı yönünde yorumlanmıştır (Büyüköztürk vd., 2016). Bu noktadan hareketle, araştırma sorusuna yanıt aranırken eşleştirilmiş örneklemler t testi uygulanmasına karar verilmiştir.

BULGULAR, TARTIŞMA VE SONUÇLAR

Bu çalışmada "Mentörlük destekli uygulanan BİLSEM destek eğitim programı özel yetenekli öğrencilerin eleştirel düşünme becerileri gelişimini sağlamakta mıdır?" sorusuna yanıt aranmıştır. Eğitsel müdahale olarak katılımcılara, yüzyüze küçük grup mentörlüğüne dayalı akademik temelli bir program iki dönüm süresince uygulanmıştır. Uygulama öncesinde ve uygulama tamamlandıktan sonra katılımcılardan veri toplanarak uygulanan programın etkililiği sınanmıştır.

Tablo 1.

Eleştirel düşünme gelişimi.

Eleştirel düşünme puanı	X	Ss	t	p	Cohen d
Ön test	28.7	4.86	-7.20	.001	-1.07
Son test	34.3	2.18			

Katılımcıların eğitim sonrasında eleştirel düşünme puan toplamları, eğitim öncesine göre anlamlı derecede yüksek olduğu saptanmıştır ($t_{(44)} = -7.20$, $p = .001$). Cohen d etki büyüklüğü katsayısı (d= 1.07), müdahale programının katılımcıların eleştirel düşünme becerileri toplam puanları üzerinde çok büyük düzeyde ve anlamlı bir etkiye sahip olduğunu ve uygulamanın son test lehinde anlamlı olduğuna işaret etmektedir.

Her ne kadar, bu çalışmanın birincil amacı Vygotskiyan teorik bakış açısının test edilmesi değilse de, bu çalışmada elde edilen bulgular sözkonusu teorik önermeleriyle tutarlılık sergilemektedir. Bir diğer ifadeyle, uygulamaya ilişkin veriler, mentörlük uygulamasına bağlı olarak mentör tarafından mentilere verilen uyaranlar ve grup etkileşimini yönetme biçimine bağlı olarak katılımcıların eleştirel düşünme düzeylerinde bir artış ortaya çıktığını yansıtmaktadır. Dolayısıyla, mentörlerin sesli kendi kendine konuşmaları, mentilerin edindiği bilgileri içselleştirmeleri ve mentörlerin öğrenmede yakınsal gelişim alanını dikkate alarak sundukları destekleyici uyaranların (iskele kurma[scaffolding]) katılımcıların eleştirel düşünme becerilerini geliştirdiği yorumuna varılabilir.

Bu çalışmanın bir takım sınırlılıkları mevcuttur. Bunlardan ilki, müdahale iki farklı uygulayıcı tarafından birbirine paralel oturumlar halinde farklı gruplara yönelik sunulmuştur. İki farklı uygulayıcı arasında uygulama birlikteliği sağlanabilmesi için uygulama öncesinde içeriğin sunumuna ilişkin görüşmeler gerçekleştirilerek eğitim oturumlarının benzerliği kontrollü olarak sağlanmaya çalışılmıştır. Çalışmanın bir diğer sınırlılığı, uygulama süresi ile ilgilidir. Bu çalışma, toplam 120 saat olarak sürdürülmüştür. Özellikle akademik içerikli (Şahin, 2026) mentörlük çalışmalarında eğitim süresine bağlı olarak akademik çıktı kalitesi etkilenebilmektedir. Bu çalışmada, öğrencilerin devamsızlık durumuna ilişkin sınıf kayıtları incelenmiştir. Çalışmanın üçüncü sınırlılığı, mentörlük uygulama modeli olan "akademik temelli, yüzyüze, küçük grup eğitimi" yaklaşımıyla sınırlıdır.

Araştırma sınırlılıkları, yenilikçi bilgi üretmek için alanda ihtiyaç duyulan araştırma konularını ortaya koymak için önemli referans noktaları olarak görülebilir. Bir diğer ifadeyle, bu çalışmanın sınırlılıkları göz önünde bulundurularak bir başka çalışmada, farklı modellerin denendiği uygulamaların yapılması ve sonuçlarının bu çalışma sonuçları ile kıyaslanmasının eleştirel düşünme becerilerini destekleme iyi uygulama örneklerini ortaya koymada anlamlı katkılar sağlayabilir. Örneğin diğer araştırmacılarca eğitim programının sunum biçimi (yüzyüze, online veya hibrit), katılımcı sayısı (bireysel, küçük grup, büyük grup) ve içerik (sosyo-duygusal, akademik temelli, kariyer gelişimi…) konuları göz önünde bulundurularak yeni araştırmalar uygulanabilir ve uygulamalardan elde edilen sonuçlar en etkili uygulama biçimlerine karar vermek için kullanılabilir.

Ayrıca, bir başka çalışmada konuya ilgi duyan araştırmacılar, farlı uygulama sürelerine bağlı olarak mentörlük destekli uygulamaların eleştirel düşünme becerileri gelişimine etkilerini inceleyebilir. Buradan elde edilecek karşılaştırmalı sonuçlarla, optimum uygulama sürelerinin belirlenmesi için bir

referans değer olara göz önünde bulundurulabilir. Konuya ilgi duyan araştırmacılar gelecek araştırmalarda, bu müdahale de elde edilen anlamlı sonuçların etkisinin uzun vadede kalıcılığını incelemek üzere bir izleme çalışması veya boylamsal çalışma yapılabilir. Son olarak bu çalışma ön test-son test kontrol grupsuz desende sürdürülmüştür. Mentörlük sürecinin eleştirel düşünme becerileri gelişimine etkisinin altında yatan temel dinamikler olan menti – mentör eşleşme süreci, etkileşim biçim gibi konular bir başka nitel çalışmada veya karma desen bir araştırmada incelenmesi alan yazına önemli katkılar sağlayacaktır.

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SMART GEOTECHNICAL ENGINEERING FOR BLACK SEA COASTAL RESILIENCE: AN INTEGRATED IOT, EDGE AI, AND DIGITAL TWIN FRAMEWORK

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ABSTRACT

Objectives: This study develops a deployable smart-geotechnical framework for strengthening the resilience of Black Sea coastal slopes and ground-supported infrastructure under interacting rainfall, groundwater, wave, erosion, seismic, and anthropogenic pressures.

Methods: A design-science method was combined with a targeted synthesis of peer-reviewed and authoritative evidence published from 2022 to July 2026. Requirements were derived for observability, local autonomy, data quality, physics-data fusion, uncertainty communication, cybersecurity, human oversight, and staged deployment. The proposed architecture was assessed through requirements traceability and four desk-based stress cases; no field-performance claim is made.

Results: The resulting six-layer architecture links coastal assets, heterogeneous Internet of Things sensing, confidence-aware edge analytics, secure data services, a physics-informed digital twin, and governed decisions. It introduces an explicit state vector, sensor-confidence weighting, Bayesian updating, probabilistic limit-state forecasting, residual-based anomaly screening, and loss-aware action selection. Architectural verification shows that local detection can continue during cloud disconnection, while degraded sensing is represented as an unknown state rather than misclassified as safe.

Conclusions: The framework provides a transparent research and implementation blueprint for interoperable coastal monitoring. Site-specific thresholds, geotechnical models, sensor validation, and prospective field trials remain mandatory before operational safety decisions.

Keywords: Smart geotechnical engineering; Black Sea; coastal resilience; Internet of Things; edge artificial intelligence; digital twin.

INTRODUCTION

Black Sea coastlines support settlements, ports, highways, tourism, energy facilities, and ecological systems, yet their geotechnical condition is governed by coupled processes that are rarely observed together. Rainfall infiltration and groundwater rise can reduce effective stress in coastal slopes; wave attack and shoreline retreat can remove toe support; storm water levels can increase loading and drainage constraints; earthquakes can produce transient deformation or liquefaction demand; and excavation, reclamation, traffic, and poorly controlled drainage can alter an already sensitive ground system. Regional wave-climate projections, cross-shore modelling, and current climate-risk assessments indicate that climate-sensitive marine forcing must be included in long-term coastal engineering decisions rather than treated as a stationary boundary condition (Intergovernmental Panel on Climate Change [IPCC], 2022; Islek et al., 2022; Arı Güner & Başaran, 2024).

Recent events and assessments demonstrate why the land-sea interface must be treated as a connected geotechnical system. A risk-assessment study on the northern Bulgarian Black Sea coast showed the need to link landslide consequences with social, ecological, and cultural exposure (Frantzova et al., 2024). On the eastern Turkish Black Sea coast, the 2024 Kıyıcık event was analysed as a rainfall-

triggered failure in weathered coastal ground whose stability had also been affected by road construction, quarrying, and marine processes (Turoğlu & Duran, 2025). These studies do not imply uniform behaviour around the basin; rather, they show that local geology, morphology, infrastructure interventions, and hydroclimatic forcing must be represented explicitly.

Conventional monitoring generally remains fragmented. Piezometers, inclinometers, rain gauges, survey points, satellite products, maintenance records, and numerical models may be owned by different organisations, sampled at different rates, and interpreted after separate processing steps. A dashboard that merely displays these streams is a digital representation, but not necessarily a functional digital twin. A safety-oriented twin requires two-way state exchange, explicit treatment of uncertainty, model updating, provenance, scenario testing, and a governed path from evidence to action (Naderi & Shojaei, 2022; Wang et al., 2023; Su et al., 2023).

Internet of Things (IoT) instrumentation can improve temporal coverage, but continuous transmission to a remote cloud is not a sufficient reliability strategy for exposed coastlines. Communication may be degraded precisely when storms, slope failures, or power interruptions occur. Edge artificial intelligence (edge AI) moves selected quality-control, fusion, and anomaly-detection functions near the sensors, reducing dependence on continuous connectivity and enabling low-latency local decisions. Evidence from structural health monitoring shows that edge deployment can support real-time inference, although model compression, hardware limits, calibration, and domain shift must be evaluated explicitly (Mishra et al., 2024).

Digital-twin research in geotechnics has advanced from static subsurface models toward continuously updated slope, excavation, tunnel, and ground-performance applications. A slope twin developed by Liu et al. (2022) combined monitoring data with prior slope-performance records, while Piciullo et al. (2025) demonstrated an operational IoT-based slope-stability forecast. Physics-informed Bayesian learning has also shown how sparse investigation data and monitoring observations can be combined while preserving uncertainty (Tian & Wang, 2023). Nevertheless, transferring these advances to Black Sea coastal resilience requires a framework that couples land and marine forcing, distributes intelligence between edge and cloud, and prevents low-confidence data from producing apparently precise warnings.

Accordingly, this paper develops an integrated IoT-edge AI-digital twin framework for Black Sea coastal geotechnical systems. Its contributions are: a Black Sea-oriented hazard-to-observation model; a six-layer architecture with offline edge autonomy; an explicit confidence and uncertainty formulation; a human-governed decision loop; a requirements-traceability assessment; and a staged deployment roadmap. The work is conceptual and design-oriented. It does not present field measurements, train a site-specific model, or claim operational validation.

METHODOLOGY

Research design and evidence base

A design-science approach was used because the research question concerns how existing technical capabilities should be organised into a coherent and testable coastal geotechnical system. Evidence was identified through publisher databases, DOI metadata records, and backward reference chaining. The synthesis was restricted to material published from 2022 to July 2026 and directly relevant to at least one of four domains: Black Sea coastal hazards, geotechnical sensing and early warning, edge intelligence and cyber-physical reliability, or infrastructure and coastal digital twins. Authoritative risk and cybersecurity frameworks were included where they defined governance requirements. The procedure was targeted rather than systematic; therefore, no exhaustive-coverage or publication-count claim is made.

The selected evidence was coded qualitatively against three questions: what physical state or precursor is observable; where should processing occur to meet latency and continuity needs; and what information is required before an engineering action can be justified? Field-based monitoring studies were used to ground sensor and data-quality requirements (Lau et al., 2023; Freddi et al., 2023). Digital-geotechnics and digital-twin studies informed state representation, model updating, and interoperability (Wang & Tian, 2024; Tuhaise et al., 2023). Black Sea studies defined regional hazard pathways without

assuming that one site represents the entire coastline (Islek et al., 2022; Frantzova et al., 2024; Turoğlu & Duran, 2025).

Requirements derivation and architectural verification

Nine design requirements were derived: multi-hazard observability; local continuity during network loss; explicit sensor quality; physics-data fusion; probabilistic uncertainty; explainable and traceable warnings; human authority over consequential actions; secure and interoperable exchange; and scalable implementation. Each requirement was mapped to components, outputs, and verification activities. This mapping is a design traceability exercise, not a substitute for field validation.

The architecture was then challenged using four desk-based stress cases: rapid rainfall and groundwater rise; combined storm-wave and shoreline effects; loss of backhaul communication; and drift or partial loss of sensors. A design response was considered adequate only when the proposed components could identify the state, express confidence, preserve an auditable record, and route the result to an authorised decision-maker. Where evidence was inadequate, the required response was an explicit degraded or unknown state. This conservative rule follows the risk-management principle that absence of trustworthy evidence is not evidence of safety (National Institute of Standards and Technology [NIST], 2023).

BLACK SEA COASTAL GEOTECHNICAL CONTEXT

Coupled hazard pathways

A coastal ground system should be delineated by process pathways rather than by administrative asset boundaries. In steep sectors, the monitored domain may extend from the upslope catchment and tension-crack zone to the shoreline toe. In low-lying or reclaimed sectors, it may extend across fills, buried utilities, quay structures, dunes, and shallow foundations. The external forcing set includes rainfall, groundwater, wave conditions, water level, temperature, and seismic motion. Internal state variables include pore pressure, saturation, deformation, velocity, tilt, vibration response, and indicators of erosion or toe loss. Exposure variables include people, transport continuity, utility service, environmental receptors, and emergency access.

The relevant processes occur on different timescales. Ground acceleration and abrupt deformation require second-to-minute detection. Rainfall infiltration, groundwater response, and progressive movement may evolve over hours to weeks. Shoreline change, weathering, and asset deterioration may require seasonal to multi-year observation. A single sampling rate or analytical model is therefore inappropriate. The architecture must preserve high-frequency local data for event detection while synchronising lower-frequency geospatial and Earth-observation products for state correction and long-term planning.

Table 1 translates the principal hazard pathways into observable evidence. The listed technologies are candidates, not universal prescriptions. Sensor selection must follow a site investigation, failure-mechanism hypothesis, required lead time, maintainability assessment, and an explicit plan for independent confirmation.

Table 1. Hazard-to-observation matrix for a Black Sea coastal geotechnical digital twin

Hazard pathway	Observable precursors or states	Candidate observation modes	Decision relevance
Rainfall-induced slope instability	Rainfall history; soil moisture; pore pressure; groundwater level; displacement; velocity; tilt	Rain gauge; moisture probe; piezometer; GNSS; in-place inclinometer; extensometer; satellite InSAR	Drainage inspection; movement escalation; access restriction; emergency review
Marine erosion and toe loss	Shoreline position; beach or cliff profile; scour depth; wave and water-level descriptors; toe displacement	UAV/photogrammetry; terrestrial or bathymetric survey; wave buoy; tide gauge; camera; InSAR where coherent	Toe protection; survey frequency; structural assessment; adaptation option testing
Settlement or lateral spreading in fills	Surface and subsurface displacement; pore pressure; vibration; differential settlement	GNSS; settlement sensors; inclinometers; piezometers; accelerometers; repeated levelling; InSAR	Load or traffic control; quay/embankment inspection; ground-improvement review
Earthquake or vibration-triggered instability	Ground motion; transient pore-pressure response; permanent deformation; post-event residual movement	Accelerometer; piezometer; GNSS; tilt sensor; rapid visual/UAV inspection	Immediate condition screening; closure or reduced operation; detailed geotechnical inspection
Anthropogenic modification and drainage failure	Excavation geometry; fill placement; blocked drains; leakage; traffic vibration; construction sequence	BIM/GIS records; inspection; cameras; flow sensors; work records; vibration sensors	Work hold point; drainage maintenance; model revision; construction-control action

Source: *Authors' synthesis from Black Sea hazard evidence and monitoring studies reported by Arı Güner and Başaran (2024), Frantzova et al. (2024), Lau et al. (2023), Nikolakopoulos et al. (2023), and Turoğlu and Duran (2025).*

Observability, redundancy, and data fitness

Observability means more than measuring many variables. A monitoring system is observable when the measurements, together with a model, are sufficient to distinguish safety-relevant states within the required time. Displacement alone may reveal movement but not its hydrogeological cause; rainfall alone may indicate forcing but not slope response. Field evidence from Taiwan showed that combining displacement, vibration, groundwater, and rainfall clarified both triggering and continued post-rainfall movement (Lau et al., 2023). Laboratory assessment of an in-place inclinometer chain further demonstrated that system-level validation is necessary because the performance of an assembled measurement chain cannot be inferred solely from individual sensor specifications (Freddi et al., 2023).

Redundancy should therefore be heterogeneous. Two identical sensors sharing the same power supply, enclosure, communication path, and installation defect are not independent. A resilient design combines local subsurface measurements, surface deformation, hydroclimatic forcing, periodic geospatial observations, and physical inspection. Satellite and UAV products can extend spatial coverage, while ground sensors provide higher-frequency local response; their different error structures make them complementary rather than interchangeable (Macchiarulo et al., 2022; Nikolakopoulos et al., 2023; Khalili et al., 2023).

INTEGRATED IOT, EDGE AI, AND DIGITAL TWIN FRAMEWORK

Design principles

The proposed framework is governed by five principles. First, every analytical output must retain a link to the measurement, calibration record, model version, and decision rule that produced it. Second, local safety functions must not depend exclusively on a remote cloud. Third, mechanistic and data-driven models must constrain and challenge each other. Fourth, uncertainty and data degradation must remain

visible to users. Fifth, the system recommends and documents actions but does not displace accountable professional judgement or emergency authority.

These principles distinguish a decision-capable twin from a three-dimensional visualisation. The digital object is continuously reconciled with the physical system; discrepancies are treated as information; forecast confidence affects the permissible action; and interventions generate new evidence for subsequent model updating. This closed-loop interpretation is consistent with recent civil-infrastructure and coastal digital-twin architectures, while the present framework adds an explicit geotechnical state, edge fail-safe logic, and Black Sea hazard mapping (Naderi & Shojaei, 2022; Su et al., 2023; Yu et al., 2026).

Six-layer architecture

Figure 1 presents the architecture. The physical layer contains ground units, water boundaries, protective works, and exposed infrastructure. The IoT layer acquires heterogeneous observations with timestamps, units, coordinates, calibration status, and health metadata. The edge layer performs quality control, time alignment, feature extraction, lightweight inference, and local warning. The communication and data layer synchronises time-series, geospatial, model, inspection, and intervention records through secure interfaces; three-dimensional geological context may be represented through interoperable BIM/GIS and voxel structures where appropriate (Khan et al., 2023). The twin layer maintains geometry, parameters, boundary conditions, estimated states, model versions, and forecast ensembles. The governance layer converts evidence into inspected, authorised, and recorded actions.

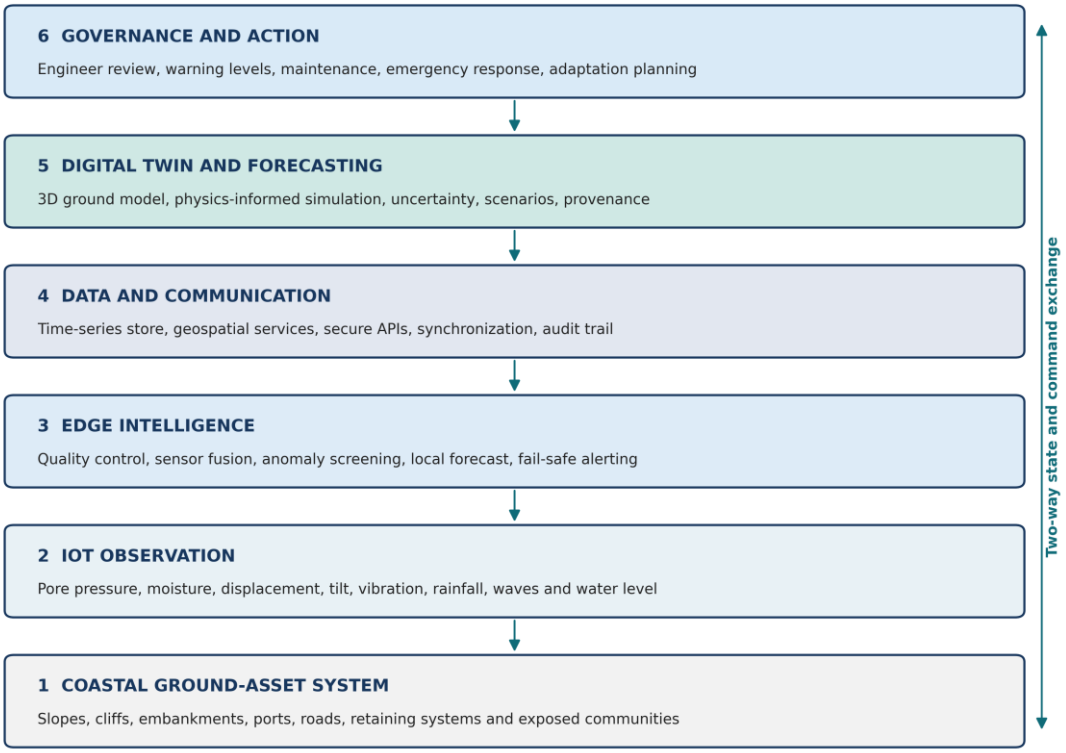

Figure 1. Six-layer architecture for a smart coastal geotechnical digital twin

Source: *Authors' original framework, developed with reference to Naderi and Shojaei (2022), Wang et al. (2023), Tuhaise et al. (2023), and Yu et al. (2026).*

Workload placement follows consequence and latency. Sensor diagnostics, simple threshold checks, data-quality scores, rapid anomaly screening, and a compact local forecast belong at the edge. Computationally intensive finite-element or hydro-mechanical analyses, cross-site learning, long-term

wave and shoreline scenarios, and portfolio optimisation belong in higher-capacity services. The boundary is configurable: a coastal road site with unstable connectivity may retain more functionality locally than an instrumented port with redundant fibre and power.

Table 2. Functional allocation across the proposed architecture

Layer	Primary functions	Minimum persistent outputs	Failure-aware behaviour
Coastal ground-asset system	Defines geometry, materials, boundaries, interventions, exposure, and plausible failure mechanisms	Asset and ground-unit identifiers; baseline condition; inspection record	Physical inspection and manual controls remain available
IoT observation	Measures forcing, internal state, deformation, and device health	Value; unit; time; location; calibration; uncertainty; device health	Flags missing, saturated, implausible, or stale observations
Edge intelligence	Aligns streams, computes features, screens anomalies, and issues local advisories	Quality score; features; inference; model version; local event log	Uses a validated fallback rule and declares degraded confidence
Data and communication	Provides synchronisation, geospatial context, secure access, provenance, and retention	Immutable raw record; transformed record; access and change log	Buffers locally, prevents silent overwriting, and reconciles conflicts
Digital twin	Assimilates evidence, updates state and parameters, simulates scenarios, and quantifies uncertainty	Analysis state; forecast ensemble; residuals; assumptions; model lineage	Freezes stale components and marks results outside validity domain
Governance and action	Supports engineer review, escalation, maintenance, emergency response, and adaptation	Decision; authority; rationale; time; action; outcome	Requires acknowledgement and supports safe manual override

Source: *Authors' synthesis based on civil-infrastructure digital-twin and edge-intelligence requirements in Naderi and Shojaei (2022), Mishra et al. (2024), Moshood et al. (2024), and Wang et al. (2023).*

State representation and confidence-aware fusion

The twin represents a time-dependent analysis state rather than a collection of unrelated sensor values. Following the state-estimation logic used in recent digital-geotechnics and slope-twin studies (Liu et al., 2022; Wang & Tian, 2024; Piciullo et al., 2025), a site-level state vector may be defined as:

$$\mathbf{x}_t = [u_t, \dot{u}_t, \theta_t, p_t, s_t, R_t, a_t, h_t, q_t]^T \quad (1)$$

where u_t is displacement; $\dot{u}_t$ is displacement rate; θ_t is tilt or rotation; p_t is pore-water pressure; s_t is a soil-moisture or saturation descriptor; R_t is a rainfall descriptor over a site-relevant accumulation window; a_t is ground acceleration or vibration; h_t is coastal water level; and q_t is a wave or nearshore forcing descriptor. The vector is adapted for each failure mechanism: for example, a reclaimed quay may add differential settlement and structural demand, whereas a cliff site may add toe-retreat and fracture-opening variables.

Before assimilation, each stream receives a proposed confidence weight. This formulation is an architectural quality-control device, not a universal calibration law. It operationalises the sensor-health, calibration, completeness, and timeliness concerns identified in wireless and geotechnical monitoring research (Ragnoli et al., 2023; Freddi et al., 2023):

$$c_i(t) = \alpha_i \, \kappa_i(t) \, [1 - m_i(t)] \exp\left[-\frac{\Delta t_i(t)}{\tau_i}\right], \qquad 0 \le c_i(t) \le 1 \quad (2)$$

where $c_i(t)$ is the confidence assigned to stream i; α_i is a validated performance factor; $\kappa_i(t)$ represents current calibration and device-health validity; $m_i(t)$ is the missing-data fraction over the decision window; $\Delta t_i(t)$ is data age; and τ_i is the maximum acceptable staleness scale for that variable. Values and tolerances must be established through laboratory calibration, installation acceptance tests, baseline monitoring, and maintenance evidence. A low value does not automatically delete a stream; it limits its influence and triggers inspection or substitution.

Table 3. Core variables and quality metadata required for editable model implementation

Symbol or field	Meaning	Typical unit or representation	Principal evidence source
u_t, $\dot{u}_t$	Displacement and displacement rate	mm; mm/h or site-appropriate rate	GNSS, inclinometer, extensometer, survey, InSAR
θ_t	Tilt or rotation	degrees, radians, or micro-radians	MEMS tilt sensor or inclinometer chain
p_t, s_t	Pore pressure and soil wetness/saturation descriptor	kPa; volumetric water content or index	Piezometer and moisture probe
R_t	Rainfall intensity or accumulated rainfall descriptor	mm/h and/or accumulated mm	On-site gauge and quality-controlled meteorological source
a_t	Ground acceleration or vibration descriptor	m/s², g, or spectral feature	Accelerometer or seismological feed
h_t, q_t	Coastal water level and wave/nearshore forcing	m; wave height/period or model-derived descriptor	Gauge, buoy, camera, hindcast or forecast service
α_i, κ_i, m_i, Δt_i, τ_i	Performance, calibration/health, missingness, age, and staleness tolerance	Dimensionless except time terms	Calibration, device telemetry, data audit, and decision requirements

Source: *Authors' parameterisation based on the monitoring configurations discussed by Lau et al. (2023), Freddi et al. (2023), Ragnoli et al. (2023), and Nikolakopoulos et al. (2023). Units and thresholds remain site-specific.*

Physics-informed updating, forecasting, and anomaly screening

Sensor confidence alone cannot resolve incomplete site knowledge. A probabilistic update combines the prior state with new observations. Consistent with physics-informed Bayesian geotechnical learning (Tian & Wang, 2023), the analysis state is updated as:

$$p(\mathbf{x}_t \mid \mathbf{z}_{1:t}) \propto p(\mathbf{z}_t \mid \mathbf{x}_t, \mathbf{c}_t)\, p(\mathbf{x}_t \mid \mathbf{z}_{1:t-1}) \tag{3}$$

where z_t is the measurement vector, c_t is the vector of stream-confidence values, $p(z_t|x_t,c_t)$ is the confidence-conditioned likelihood, and $p(x_t|z_{1:t-1})$ is the prior state distribution generated from the preceding analysis and process model. The likelihood may be widened when confidence deteriorates, preventing uncertain inputs from generating unrealistically narrow posterior intervals.

A physics model then propagates the posterior state through a forecast horizon Δt. The model may range from a calibrated rainfall-threshold or reduced-order seepage-stability formulation at the edge to a coupled numerical model in the central twin. The probability of entering an adverse limit state is expressed as an integral over the forecast-state distribution, following probabilistic geotechnical and machine-learning principles emphasised by Phoon and Zhang (2023):

$$P_f(t+\Delta t) = \int \mathbb{I}[g(\mathbf{x}_{t+\Delta t}, \boldsymbol{\psi}) \le 0] p(\mathbf{x}_{t+\Delta t} \mid \mathbf{z}_{1:t})\, d\mathbf{x} \tag{4}$$

where P(f) is the forecast probability of the adverse state; $g(\cdot)$ is a site-specific limit-state function; ψ contains model parameters and boundary assumptions; and $I[\cdot]$ is an indicator equal to one when the limit state is violated. For a slope, g may be related to factor of safety minus unity, movement

acceleration, or a combined operational criterion. No universal P(f) warning threshold is proposed because acceptable risk, forecast horizon, model error, and consequences differ among sites.

Model-data disagreement is retained as diagnostic evidence. The innovation statistic below is consistent with residual checking used in state estimation and operational digital twins (Tian & Wang, 2023; Piciullo et al., 2025):

$$J_t = \mathbf{e}_t^T \mathbf{S}_t^{-1} \mathbf{e}_t, \qquad \mathbf{e}_t = \mathbf{z}_t - \hat{\mathbf{z}}_t \tag{5}$$

where e_t is the innovation between observed and predicted measurements, and S_t is its covariance matrix. A persistent increase in J_t can indicate physical change, an inadequate model, a boundary-condition error, or sensor malfunction. The system does not decide among these causes automatically; it creates an explainable diagnostic task and identifies which observations contributed most strongly.

Human-governed decision logic

Warnings must be coupled to actions that are feasible, authorised, and proportionate. Forecast probability alone is insufficient because the consequences of a missed failure and a false alarm differ, as do closure costs, inspection time, and the availability of safe alternatives. In a risk-managed decision layer consistent with NIST (2023) and human-centred digital-twin research (Ye et al., 2023), an advisory action may be selected by:

$$a_t^* = \arg\min_{a \in \mathcal{A}} \{\mathbb{E}[L(a, Y_{t+\Delta t}) \mid \mathbf{z}_{1:t}] + \lambda_o C_o(a) + \lambda_d C_d(a)\} \tag{6}$$

where A is the authorised action set; $Y_{t+}\Delta t$ is the future physical state; L is the consequence of action-state combinations, including missed detection and false alarm; C_o is operational disruption; C(delay) is delay or response cost; and λ_o and λ(delay) are governance weights. The computed a^*_t is advisory. Evacuation, closure, construction stoppage, or return to service requires the authority specified in the site's emergency and asset-management plan.

The advisory should enter a locally approved escalation ladder rather than a single automated alarm. A low-confidence or mildly adverse state may prompt data validation and targeted inspection; corroborated deterioration may justify intensified monitoring, operational restrictions, or emergency coordination. Each transition should record the responsible authority, evidence bundle, uncertainty, action deadline, and acknowledgement. This preserves human oversight while making the decision path auditable and repeatable (NIST, 2023; Ye et al., 2023).

Return-to-service criteria should be defined before an event and should not be treated as the simple reversal of a warning threshold. Reopening may require restored sensor health, confirmatory inspection, stable or improving trends over a site-specific observation period, and an engineer's review of residual risk. Such asymmetric criteria reduce the chance that intermittent data recovery or a short-lived forecast improvement is mistaken for physical stabilisation.

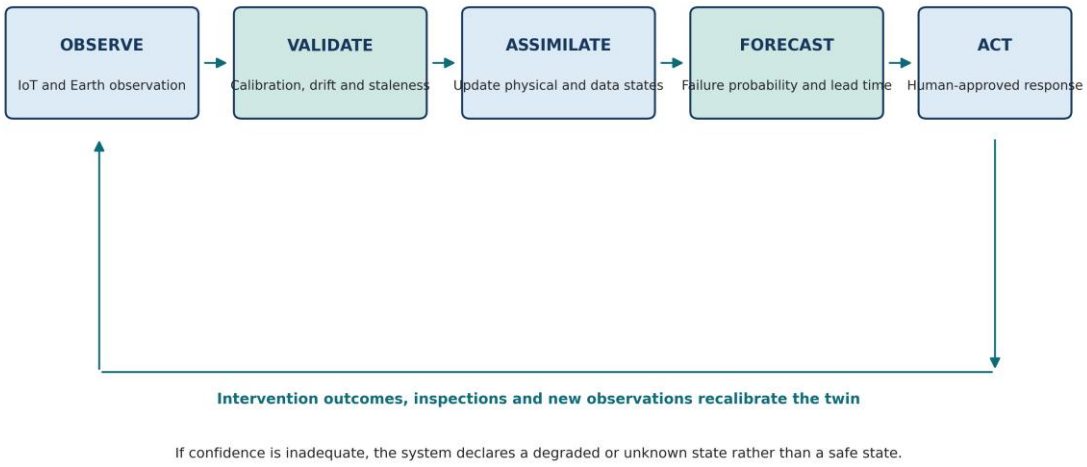

Figure 2. Confidence-aware closed loop from observation to governed action

Source: *Authors' original process model, informed by the operational slope-twin cycle of Piciullo et al. (2025), the digital-twin security and provenance requirements of Wang et al. (2023), and the human-centred principles of Ye et al. (2023).*

Cybersecurity is part of safety because altered timestamps, replayed measurements, compromised calibration records, or unauthorised model changes can affect decisions. The framework therefore requires identity management, least-privilege access, signed or integrity-checked messages where practical, version control, protected time synchronisation, event logging, tested recovery, and separation between monitoring and command functions. These controls follow the govern-identify-protect-detect-respond-recover logic of the NIST Cybersecurity Framework 2.0 and complement digital-twin-specific security concerns (NIST, 2024; Wang et al., 2023).

RESULTS AND DISCUSSION

Principal framework outputs

The principal result is a traceable architecture in which each hazard pathway is connected to observable variables, confidence metadata, a forecast model, an uncertainty statement, and an authorised response. This closes three recurring gaps. First, the land and marine boundaries are represented within the same state rather than in separate coastal and geotechnical analyses. Second, edge and central functions are deliberately partitioned, so the loss of connectivity changes capability and confidence but does not silently terminate local monitoring. Third, a degraded data state cannot be converted into a safe state merely because no threshold has been exceeded.

The state formulation is also extensible. It provides a common interface while allowing site-specific variables and models. A slope, reclaimed port platform, coastal road embankment, and retaining structure can share data-quality, provenance, security, and governance services without sharing an identical constitutive model. This modularity addresses the interoperability problem recognised in recent digital-twin studies (Hu et al., 2022; Opoku et al., 2023; Tuhaise et al., 2023).

Requirements traceability

Table 4 records how the architecture addresses the nine derived requirements and what remains to be verified. It intentionally avoids a binary claim of validation. Design coverage indicates that a mechanism is present; operational adequacy must still be demonstrated with controlled tests and field evidence.

Table 4. Requirements traceability and outstanding verification

Requirement	Architectural coverage	Evidence produced	Verification still required
R1 Multi-hazard observability	Joint ground, hydroclimatic, marine, deformation, and exposure state	Hazard-state-sensor map; coverage register	Site investigation and observability analysis for each failure mode
R2 Local continuity	Edge buffering, local fallback model, and acknowledgement logic	Offline event log; synchronisation record	Power, storage, network-loss, and failover tests
R3 Explicit data quality	Confidence weights, calibration status, missingness, staleness, and drift checks	Per-stream confidence and diagnostic reasons	Laboratory and field calibration; false-diagnostic assessment
R4 Physics-data fusion	Bayesian update and mechanism-specific process model	Posterior state; residuals; model version	Parameter identifiability and out-of-sample field evaluation
R5 Uncertainty communication	Posterior intervals, forecast ensembles, and degraded-state labelling	Probability, interval, confidence, validity domain	User comprehension and decision-threshold studies
R6 Explainability and traceability	Provenance from raw observation to model and action	Immutable lineage and decision rationale	Independent audit and reconstruction exercise
R7 Human authority	Role-based acknowledgement, override, escalation, and return-to-service approval	Named decision, time, rationale, outcome	Emergency exercise with agencies and asset operators
R8 Security and interoperability	Secure interfaces, access control, versioning, and common identifiers	Access/change logs; interface conformance	Threat modelling, penetration testing, backup and recovery drill
R9 Scalable deployment	Tiered sensors, modular services, and shared data contracts	Asset onboarding and capability profile	Lifecycle cost, maintainability, and cross-site transfer assessment

Source: *Authors' design-verification matrix informed by NIST (2023, 2024), Naderi and Shojaei (2022), Wang et al. (2023), and Opoku et al. (2023).*

Desk-based stress-case evaluation

The first stress case considers intense rainfall followed by delayed groundwater rise and accelerating movement. The proposed twin relates rainfall forcing to moisture, pore pressure, and deformation rather than treating a rainfall threshold as sufficient. Edge logic detects rate changes, while the central model updates the forecast distribution. The response is architecturally credible because both forcing and response are observed, but operational lead time cannot be claimed until local hydrogeology, sensor placement, and model error are validated. The time-lag behaviour documented by Lau et al. (2023) illustrates why continued observation after rainfall ceases is necessary.

The second case combines high waves or water levels with shoreline or toe change. The twin can merge rapid marine forcing with slower UAV, survey, or satellite updates and then test altered geometry in a stability model. This case exposes a limitation: remotely sensed shoreline change may not directly reveal subsurface weakening, while a point sensor may not represent spatially distributed erosion. The appropriate design response is multi-resolution evidence and targeted inspection, not forced fusion into a single high-confidence index. Regional wave and cross-shore studies provide boundary scenarios, but local nearshore and ground models remain essential (Islek et al., 2022; Arı Güner & Başaran, 2024).

The third case removes cloud connectivity. Edge nodes continue acquisition, quality checking, buffering, and the validated local warning rule. The last synchronised twin state remains visible but is marked stale; central forecast products are not represented as current. Restoration triggers ordered reconciliation rather than silent replacement. This outcome addresses continuity but depends on tested local power, storage, clock stability, and a deliberately limited edge model.

The fourth case introduces drift in one piezometer and loss of a nearby moisture probe. Confidence weighting reduces their influence, residual checking identifies disagreement, and heterogeneous measurements are used for corroboration. If the remaining evidence cannot resolve the state, the system reports unknown or degraded status and requests inspection. It does not infer stability from the surviving low-variance stream. This behaviour is a design result; the actual sensitivity, detection delay, and false-diagnostic rate require injected-fault testing.

Comparison with less integrated approaches

A sensor dashboard is valuable for visibility but commonly leaves model updating, uncertainty, and action authority outside the digital workflow. A cloud-only analytical platform offers computational scale but is vulnerable to communication and latency constraints. Recent studies have coupled digital-twin representations with deep-learning slope-stability prediction (Chen et al., 2023; Lin et al., 2024), while cross-site evidence shows that no single deep-learning architecture consistently dominates across landslides and behaviours (Nava et al., 2023). A purely mechanistic model, conversely, may be difficult to update when parameters and boundaries are uncertain. The proposed framework combines these approaches without treating any as independently sufficient.

Edge AI is restricted to tasks that can be validated within known hardware, data, and latency limits. It should not host an opaque high-consequence model merely because local execution is possible. The central twin maintains richer physics, uncertainty propagation, scenario comparison, and portfolio context. This division also reduces the pressure to transmit every high-frequency raw signal continuously, while retaining raw event windows and metadata needed for audit and later learning.

The framework's regional value lies in a shared information contract rather than a single basin-wide model. Black Sea coastline countries could exchange schemas for asset identifiers, sensor health, hazard descriptors, model provenance, and warning semantics while retaining national authority and site-specific geotechnical models. A common contract would support comparable evidence without assuming uniform geology, exposure, or risk tolerance.

Staged deployment roadmap

Implementation should begin with a failure-mechanism and decision audit, not with technology procurement. Table 5 proposes five stages with explicit exit criteria. The sequence allows a useful monitoring system to operate before a high-fidelity twin is available, while preventing an unvalidated prototype from being used for consequential automatic control.

Table 5. Staged implementation roadmap for a Black Sea coastal pilot

Stage	Principal activities	Required deliverables	Exit criterion
1. Baseline and governance	Site investigation; historical review; asset/exposure mapping; decision and authority mapping	Ground model; failure hypotheses; data inventory; risk and governance register	Monitoring objectives and accountable decisions are approved
2. Instrumented observatory	Install and calibrate priority sensors; establish inspections and geospatial baselines	Acceptance tests; metadata; maintenance plan; baseline variability	Data fitness and maintainability are demonstrated across a representative period
3. Edge-enabled monitoring	Add local quality control, buffering, fallback rules, and secure synchronisation	Offline test; drift and missing-data tests; alert acknowledgement log	Local continuity and degraded-state behaviour pass controlled tests
4. Operational digital twin	Assimilate data; calibrate physics and reduced-order models; quantify forecast uncertainty	Versioned twin; residual diagnostics; prospective forecast evaluation	Predefined accuracy, calibration, lead-time, and audit criteria are met
5. Multi-site service	Standardise interfaces; compare transferability; integrate emergency and asset-management workflows	Shared data contract; cross-site validation; lifecycle cost and training plan	Independent assurance confirms fitness for each intended use

Source: *Authors' implementation roadmap based on the adoption barriers and lifecycle requirements discussed by Opoku et al. (2023), Moshood et al. (2024), and Wang and Tian (2024).*

Limitations and research agenda

This study has four principal limitations. First, it is an architectural synthesis and has not been deployed on a Black Sea site. Second, a targeted evidence review cannot establish exhaustive coverage. Third, the equations define a transparent integration structure but not calibrated site models or warning thresholds. Fourth, legal authority, data-sharing rules, procurement constraints, and community-warning practices differ among coastline countries and require local institutional design.

A rigorous pilot should therefore proceed prospectively. It should compare edge and central inferences under normal and impaired communication; inject sensor drift, packet loss, clock error, and power interruption; validate the ground model against independent investigation data; and evaluate forecast calibration, not only classification accuracy. Performance measures should include event recall, false-alarm burden, probability calibration, lead time, confidence coverage, system availability, energy use, recovery time, and the proportion of decisions that can be reconstructed from provenance records.

Further research is needed on cross-site transfer without concealing domain shift, reduced-order models suitable for constrained edge hardware, joint wave-seepage-slope assimilation, and methods that explain disagreement between remote sensing and in-ground measurements. Human-factors studies should test whether engineers and emergency managers correctly interpret confidence, uncertainty, and degraded states. The objective is not maximum automation, but dependable augmentation of geotechnical judgement.

CONCLUSION

This paper has developed an integrated IoT, edge AI, and digital twin framework for smart geotechnical management of Black Sea coastal systems. It treats slopes, fills, protective works, infrastructure, hydroclimatic forcing, and exposure as a coupled cyber-physical system. Its six layers connect observation to governed action while retaining calibration, confidence, uncertainty, provenance, and cybersecurity.

The framework's central technical contribution is the explicit combination of a mechanism-oriented state vector, confidence-aware sensing, Bayesian updating, probabilistic limit-state forecasting, residual diagnostics, and loss-aware action selection. The edge-cloud allocation preserves local detection and buffering during communication failure, while the digital twin supports richer simulation and long-term scenarios. Most importantly, insufficient evidence produces a degraded or unknown state rather than an unjustified indication of safety.

The architecture is ready to guide a pilot specification, but not to authorise operational warnings without additional work. Site investigation, calibrated thresholds, independent sensor validation, prospective forecast testing, emergency exercises, cybersecurity assurance, and lifecycle maintenance are prerequisites. Implemented with these safeguards, the framework can provide a shared technical language for more anticipatory, transparent, and locally accountable coastal resilience across the Black Sea region.

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PHYSICS-INFORMED MACHINE LEARNING FOR EARLY WARNING OF RAINFALL-INDUCED LANDSLIDES ALONG THE BLACK SEA COAST

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ABSTRACT

Objectives: This study develops a physics-informed machine-learning framework for early warning of rainfall-induced landslides along the Black Sea coast, where steep terrain, intense rainfall, heterogeneous ground, shoreline processes, and human modification create strongly variable failure conditions. **Methods:** A design-science method and targeted synthesis of peer-reviewed evidence published from 2022 to July 2026 were used to derive a causal model, data specification, editable governing equations, training constraints, uncertainty requirements, validation protocol, and staged deployment plan. The architecture was challenged through requirements traceability and four desk-based stress cases; no field-performance claim is made. **Results:** The proposed workflow connects rainfall observations and forecasts to infiltration, pore-pressure response, effective-stress reduction, slope resistance, probabilistic forecasting, and governed warning. Its composite objective combines labelled-event loss with hydrological residuals, stability consistency, monotonic response, calibration, and regularisation. The framework separates susceptibility, short-horizon hazard, and consequence-based action, and it treats missing or out-of-domain evidence as degraded confidence rather than safety. **Conclusions:** Physics-informed learning can provide a transparent bridge between regional data and geotechnical mechanism, but operational use requires site investigation, event inventories, prospective validation, calibrated uncertainty, sensor assurance, and accountable warning governance.

Keywords: Physics-informed machine learning; rainfall-induced landslide; early warning; Black Sea coast; slope stability; uncertainty.

INTRODUCTION

Rainfall-induced landslides along the Black Sea coast are a coupled hydro-mechanical and societal problem. Intense or prolonged rainfall infiltrates weathered ground, raises moisture and pore-water pressure, reduces matric suction and effective stress, and may accelerate pre-existing movement. The response is conditioned by slope geometry, soil depth, stratigraphy, permeability, vegetation, drainage, road cuts, fills, quarrying, and shoreline modification. Consequently, identical rainfall totals can produce different outcomes at neighbouring slopes, while the same slope can respond differently depending on antecedent wetness and maintenance condition.

Recent evidence from the eastern Black Sea region of Türkiye reinforces this heterogeneity. Akinci (2022) showed the relevance of machine-learning susceptibility analysis in Artvin, whereas the multi-event inventory compiled by Çömert et al. (2025) demonstrated the importance of event-specific rainfall, terrain, lithology, and land-use change. That inventory also reported that spaceborne precipitation products did not capture the intense triggering rainfall adequately for the analysed events. The 2024 Kıyıcık landslide further illustrates how rainfall can interact with weathered coastal ground, road construction, quarrying, and marine influence (Turoğlu & Duran, 2025). On the northern Bulgarian coast, landslide risk is also inseparable from exposed communities, ecosystems, infrastructure, and cultural assets (Frantzova et al., 2024).

Operational early warning therefore cannot be reduced to a single regional rainfall threshold. Thresholds remain useful because they are transparent and inexpensive, but a systematic review identified major variation in rainfall periods, gauge density, geological differentiation, data quality, uncertainty treatment, and performance evaluation (Gonzalez et al., 2024). False alarms and short or non-independent validation periods are particularly consequential because they can erode trust and waste response capacity; recent multi-source validation work shows why warning design must evaluate operational burden as well as discrimination skill (Nocentini et al., 2024).

Purely data-driven machine learning can represent nonlinear interactions among rainfall, terrain, land cover, and historical events. Regional studies have compared random forests, convolutional networks, multilayer perceptrons, and other algorithms for dynamic warning (Kang et al., 2024; Liu et al., 2024; Lee et al., 2025). However, statistical performance alone does not ensure hydro-mechanical plausibility, reliable extrapolation, calibrated probabilities, or sufficient lead time. A model may exploit spatial sampling artefacts, learn the absence of reports rather than the absence of landslides, or assign decreasing risk as pore pressure rises if such behaviour is not constrained.

Physics-informed machine learning (PIML) addresses this weakness by embedding scientific structure in the data pipeline, features, architecture, loss function, sample selection, or post-processing. Recent geotechnical studies have used factor-of-safety calculations, three-dimensional stability models, differentiable hydrological components, and knowledge-guided learning to improve physical consistency and interpretability (Huang, 2023; Liu et al., 2023; Pei et al., 2023; Wang et al., 2024; Yang et al., 2024; Yuan et al., 2025). A rainfall-landslide application has also demonstrated how a differentiable physics model can be coupled to a neural learner (Pei et al., 2025). These advances are promising, but they do not by themselves define an operational early-warning system for the Black Sea coast.

This paper develops a Black Sea-oriented PIML framework that connects observations to mechanism, uncertainty, and authorised action. Its contributions are: a causal rainfall-to-warning model; a minimum data and metadata specification; six editable equations for hydrology, stability, learning, probability, uncertainty, and decision logic; an evaluation protocol that prevents spatial and temporal leakage; four desk-based stress cases; and a staged deployment roadmap. The study is conceptual and design-oriented. It does not present new field measurements, fit a regional model, or claim operational warning performance.

METHODOLOGY

Research design and evidence base

A design-science method was adopted because the research question concerns how verified capabilities should be assembled into a testable warning system. Evidence was identified from publisher databases and DOI metadata and was restricted to work published from 2022 to July 2026. The synthesis prioritised four domains: rainfall-induced landslide inventories and early warning; Black Sea coastal landslide evidence; physics-informed or knowledge-guided geotechnical learning; and monitoring, uncertainty, explainability, and risk governance. The search was targeted rather than systematic, so no exhaustive-coverage claim is made.

The evidence was coded against six questions: what physical state is being predicted; which observations are available before failure; where the physical constraint enters the learner; how uncertainty and data quality are represented; how independent validation is organised; and which authority converts a forecast into action. Recent benchmark and digital-geotechnics studies were used to define reproducibility and validation requirements (Alvioli et al., 2024; Wang & Tian, 2024), while operational forecasting and warning studies informed timing, false-alarm, and communication requirements (Piciullo et al., 2025; Lee et al., 2025; Nocentini et al., 2024).

Requirements derivation and design verification

Ten requirements were derived: causal consistency; separation of susceptibility and short-term hazard; local rainfall representation; explicit antecedent state; ground-response observability; physics-

constrained learning; calibrated uncertainty; spatial-temporal independence in testing; explainable and auditable warnings; and human authority over consequential action. Each requirement was mapped to data fields, equations, model outputs, and a verification activity.

Architectural verification used four desk-based stress cases: an intense local storm missed by a coarse precipitation product; prolonged moderate rainfall that produces delayed pore-pressure response; loss or drift of an in-ground sensor during an event; and application to a coastal sector whose geology and land-use pattern differ from the training region. A design response was considered adequate only when the framework could declare its evidence state, preserve physical constraints, express uncertainty, and route an interpretable result to an authorised reviewer. These are design checks, not field validation.

BLACK SEA RAINFALL-LANDSLIDE WARNING CONTEXT

Causal chain and observable state

Figure 1 defines the causal chain used in this study. Rainfall forcing is transformed by interception, runoff, infiltration, drainage, and evapotranspiration. The resulting water-content and pressure state affects suction, effective stress, shear resistance, and deformation. A PIML model forecasts an adverse state and its uncertainty, but a warning becomes operational only after validation, review, and linkage to a predefined action. The sequence prevents rainfall, susceptibility, probability, warning, and emergency action from being treated as interchangeable terms.

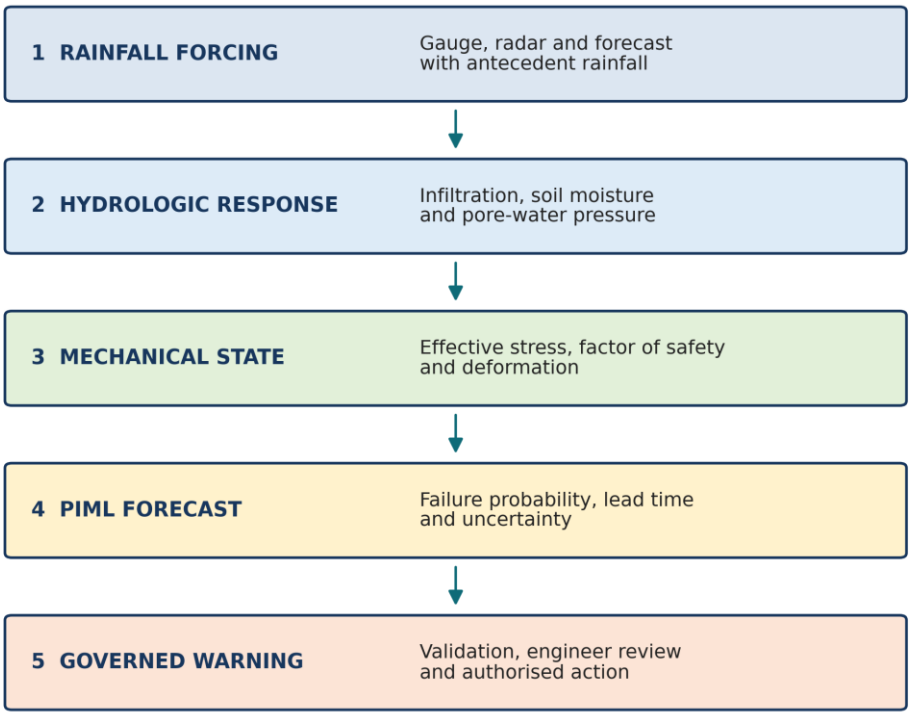

Figure 1. Causal chain from rainfall forcing to a governed landslide warning

Source: *Authors' original framework based on rainfall-threshold limitations reported by Gonzalez et al. (2024), eastern Black Sea event evidence from Çömert et al. (2025), and physics-informed slope modelling by Huang (2023), Yang et al. (2024), and Pei et al. (2025).*

The warning unit must be explicit. At regional scale it may be a slope unit, grid cell, catchment, road corridor segment, or administrative alert zone. A slope unit is physically meaningful for routing and terrain geometry, whereas an operational corridor segment may be more directly connected to closure

and inspection. The framework permits either, provided that rainfall, ground parameters, inventories, forecasts, and decisions use traceable spatial transformations.

Table 1. Hazard-to-observation specification for Black Sea coastal slope units

Process or condition	Observable evidence	Physical interpretation	Warning-system use
Short intense rainfall	Gauge intensity; radar estimate; forecast ensemble; timestamp and quality flag	Rapid infiltration, runoff concentration, or shallow pressure response	Near-term forcing and forecast scenarios
Antecedent wetness	Accumulated rainfall; soil moisture; groundwater or piezometric trend	Reduced storage, reduced suction, and elevated initial pressure	Initial-state estimation and memory
Ground response	Pore pressure; moisture; displacement; tilt; velocity; crack or drainage inspection	Hydrological and mechanical response of the slope	Assimilation, residual checking, and escalation
Static conditioning	Slope angle; curvature; soil depth; lithology; permeability; land cover; drainage; road cuts	Controls routing, storage, resistance, and failure mechanism	Physics parameters and spatial stratification
Coastal and human modification	Toe erosion; seawall or road geometry; fill; excavation; quarrying; maintenance record	Changes boundary condition, loading, drainage, or resistance	Scenario definition and model validity
Exposure and access	Buildings; roads; utilities; population; safe routes; response time	Consequence and feasible intervention	Action level, priority, and communication

Source: *Authors' synthesis from Akinci (2022), Frantzova et al. (2024), Turoğlu and Duran (2025), Çömert et al. (2025), Lau et al. (2023), and Nikolakopoulos et al. (2023).*

Data fitness and event labelling

A landslide inventory is not merely a set of positive pixels. Each event needs a mapped extent, temporal window, confidence class, source, minimum detectable size, and surveyed area. Non-landslide samples must represent observed stable conditions within a known space-time support; they should not be drawn indiscriminately from locations where mapping was absent. Physics-guided negative sampling using factor-of-safety information is one response to this problem (Liu et al., 2023; Wang et al., 2024), while benchmark workflows show the importance of transparent sample construction and geographic transfer tests (Alvioli et al., 2024).

Rainfall data require equally strict metadata. Gauge, radar, satellite, and numerical forecasts have different spatial support, latency, bias, and failure modes. The finding that spaceborne rainfall products missed the intense triggering rainfall in the analysed eastern Black Sea inventories means that a regional model should not assume remote precipitation is locally adequate without comparison against gauges and event evidence (Çömert et al., 2025). Missingness, clock drift, accumulation intervals, quality-control edits, and forecast issue time must be preserved rather than overwritten.

Table 2. Minimum data fields for reproducible PIML development

Data object	Required fields	Quality checks	Leakage control
Rainfall and forecast	Value; interval; location; source; issue time; lead time; quality; uncertainty	Gauge-range checks; radar-gauge comparison; missingness; time alignment	Use only information available at forecast issue time
Ground monitoring	Value; unit; depth; coordinate; calibration; health; sampling rate	Drift, saturation, cross-sensor consistency, maintenance and power status	Do not interpolate future observations into past forecasts
Landslide inventory	Geometry; event window; type; confidence; source; mapped extent; detection limit	Duplicate removal; field or image confirmation; completeness assessment	Hold out complete events and geographic sectors
Terrain and ground model	DEM date; slope unit; soil depth; lithology; parameters; drainage; modifications	Resolution and provenance; parameter ranges; update history	Fit transformations on training regions only
Warning and action log	Probability; interval; alert; rationale; reviewer; time; action; outcome	Acknowledgement, change history, communication latency, retrospective review	Keep operational outcomes separate from model tuning

Source: *Authors' data specification informed by Alvioli et al. (2024), Çömert et al. (2025), Freddi et al. (2023), Ragnoli et al. (2023), and Nocentini et al. (2024).*

PROPOSED PHYSICS-INFORMED MACHINE-LEARNING FRAMEWORK

State definition and hydrological constraint

The model estimates a time-dependent state for each warning unit rather than classifying a static map. A minimal state contains rainfall history, water content or saturation, pressure head, pore-water pressure, slope resistance, and deformation indicators. Where direct pressure observations are sparse, the learner may infer a latent hydrological state, but the inferred trajectory should respect mass balance and plausible boundary conditions.

A convenient physics residual is derived from the mixed form of the Richards equation. The residual is not assumed to be zero in heterogeneous field conditions; instead, it penalises trajectories that are inconsistent with the selected conceptual model (Yuan et al., 2025; Pei et al., 2025):

$$\mathcal{R}_h(\mathbf{s},t) = \frac{\partial \theta(\mathbf{s},t)}{\partial t} - \nabla \cdot [K(h)(\nabla h + \mathbf{e}_z)] - q(\mathbf{s},t) \quad (1)$$

where R_h is the hydrological residual; s is spatial position; t is time; θ is volumetric water content; h is pressure head; K(h) is unsaturated hydraulic conductivity; e_z is the upward vertical unit vector; and q is a source-sink term representing rainfall infiltration, evapotranspiration, drainage, or unresolved exchange according to the adopted sign convention. Boundary conditions, parameter ranges, and the mapping from rainfall to infiltration must be site-specific. When the conceptual hydrology is inadequate, the residual should be reported rather than forced to zero.

Stability consistency and differentiable response

For shallow translational failure, an infinite-slope expression provides an interpretable stability constraint. It is not a universal model for deep-seated, structurally controlled, or complex coastal failures; those cases require an alternative mechanistic component. In its simplest effective-stress form, the factor of safety is:

$$FS_t = \frac{c' + [\gamma z \cos^2\beta - u_t]\tan\phi'}{\gamma z \sin\beta \cos\beta} \quad (2)$$

where FS_t is factor of safety at time t; c' is effective cohesion; φ' is effective friction angle; γ is unit weight; z is soil thickness measured normal to the slope in the adopted formulation; β is slope angle; and u_t is pore-water pressure acting on the potential failure plane. The model encodes the expected reduction of resistance as pressure rises, while allowing learned corrections for unresolved spatial heterogeneity. Recent knowledge-guided and hybrid studies demonstrate several ways to couple stability calculations with machine learning without claiming that a simplified physical model is exact (Huang, 2023; Pei et al., 2023; Cui et al., 2024; Yang et al., 2024).

Composite learning objective

Figure 2 shows the operational architecture. Rainfall, ground response, and terrain data enter a learner that is constrained by hydrological and stability relations. The system produces both a probabilistic forecast and diagnostic evidence. These outputs converge in an engineer-reviewed warning rather than an autonomous emergency command.

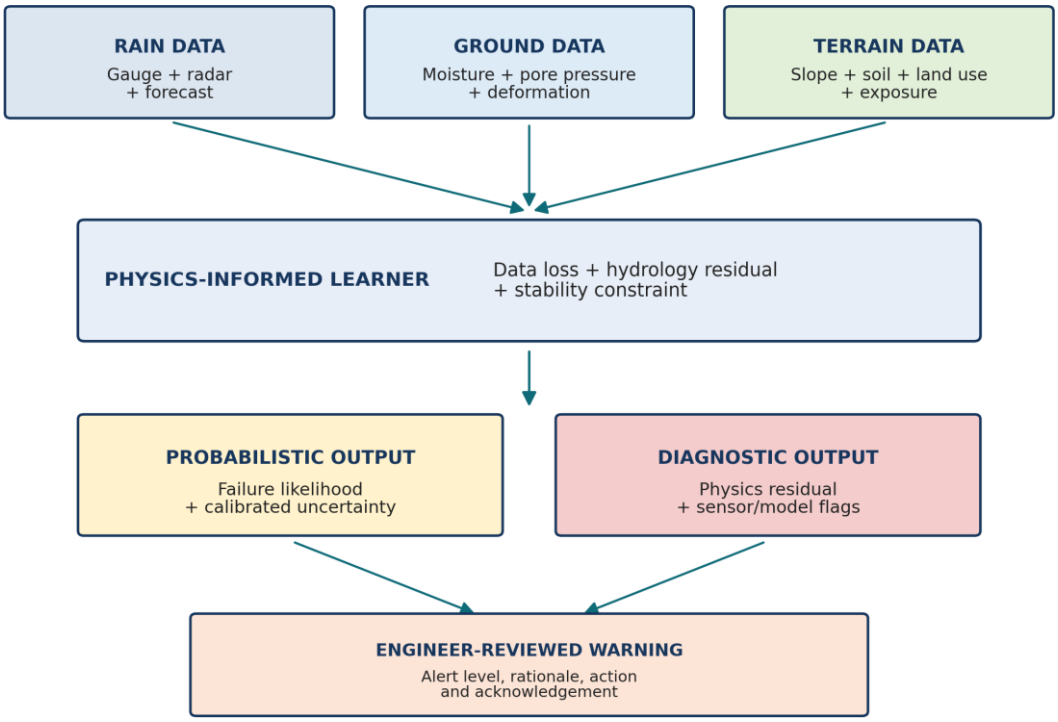

Figure 2. Operational architecture of the proposed physics-informed learning and warning system

Source: *Authors' original architecture informed by Yuan et al. (2025), Pei et al. (2025), Liu et al. (2023), Wang et al. (2024), Yang et al. (2024), and NIST (2023).*

Physics can enter through derived features, constrained sample selection, a differentiable process layer, a residual penalty, monotonicity requirements, or a post-processing feasibility screen. The appropriate level depends on data density and model fidelity. A composite objective that makes these roles explicit is:

$$\mathcal{L} = \lambda_d \mathcal{L}_{data} + \lambda_h \|\mathcal{R}_h\|_2^2 + \lambda_s \mathcal{L}_{FS} + \lambda_m \mathcal{L}_{mono} + \lambda_c \mathcal{L}_{cal} + \lambda_r \|\mathbf{w}\|_2^2 \quad (3)$$

where L is total training loss; the data-loss term measures event or state prediction error; $\|R_h\|^2$ is the hydrological residual penalty; the stability-loss term penalises inconsistency with the selected stability

relation; the monotonicity term penalises specified non-physical response directions within the declared validity domain; the calibration term measures probability miscalibration; and w contains trainable parameters. The six non-negative coefficients weight the data, hydrology, stability, monotonicity, calibration, and regularisation terms. They are modelling choices to be tuned by nested validation and sensitivity analysis. Excessive physics weight can reproduce a biased process model, whereas negligible weight reduces the framework to ordinary machine learning (Yuan et al., 2025).

Table 3. Physics-informed components and their verification requirements

Component	Intended constraint	Evidence required	Failure indicator
Hydrology residual R_h	Water-state evolution follows the adopted infiltration and drainage model	Rainfall, moisture or pressure observations; boundary assumptions; parameter ranges	Persistent structured residual or implausible storage
Stability-loss term	Pressure, strength, geometry, and resistance interact consistently	Ground model, strength ranges, failure mechanism and monitoring	High probability with mechanically stable state, or the reverse
Monotonicity term	Specified response directions hold within a declared domain	Expert-reviewed constraints and counterexample search	Violation under controlled perturbation
Calibration term	Forecast probabilities correspond to observed frequencies	Independent events with sufficient positives and negatives	Reliability-curve deviation or poor proper score
Domain and quality gate	Out-of-domain or degraded inputs reduce confidence	Training-domain descriptors, sensor health, rainfall-product comparison	Confident output beyond validated domain
Explanation record	Warnings retain data, physics, uncertainty, and model-version rationale	Immutable input and decision lineage	Warning cannot be reconstructed

Source: *Authors' synthesis based on physics-informed geotechnical learning in Pei et al. (2023), Liu et al. (2023), Wang et al. (2024), Pei et al. (2025), and Yuan et al. (2025), with explainability considerations from Pradhan et al. (2023).*

Probabilistic forecast and uncertainty

The forecast target should be defined as an event within a spatial unit and a time horizon, not simply as susceptibility. Let $y_{(i,t+\Delta)}$ indicate whether the specified adverse state occurs for unit i during the horizon Δ. A calibrated probability can be written as:

$$p_{i,t}^{(\Delta)} = \Pr\left(y_{i,t+\Delta} = 1 \mid \mathbf{x}_{i,1:t}, \mathbf{g}_i, \mathcal{M}\right) = \sigma\left[f_{\mathbf{w}}\left(\mathbf{x}_{i,1:t}, \mathbf{g}_i\right)\right] \quad (4)$$

where $p_{i,t}^{\wedge}(\Delta)$ is the event probability; $x_{i,1:t}$ is the time-indexed rainfall and monitoring history available at issue time; g_i contains static ground, terrain, land-use, and exposure information; M denotes the adopted physical model and assumptions; f is the constrained predictor parameterised by w; and σ maps its output to the unit interval. The horizon must correspond to an actionable lead time, and forecast rainfall must be distinguished from observations. Recent dynamic warning studies demonstrate the importance of time-indexed susceptibility, event-based assessment, and operational update cycles (Ahmed et al., 2023; Ren et al., 2024; Kang et al., 2024; Lee et al., 2025).

Predictive uncertainty contains at least aleatory variability and epistemic uncertainty from data, parameters, architecture, and domain shift. An ensemble or Bayesian approximation may decompose total variance using the law of total variance:

$$\mathrm{Var}(Y \mid \mathbf{x}) = \mathbb{E}_{\mathbf{w}}[\mathrm{Var}(Y \mid \mathbf{x}, \mathbf{w})] + \mathrm{Var}_{\mathbf{w}}[\mathbb{E}(Y \mid \mathbf{x}, \mathbf{w})] \quad (5)$$

where Y is the forecast outcome, x is the available evidence, and w represents uncertain model parameters or ensemble members. The first term reflects conditional outcome variability and the second

reflects model uncertainty. This decomposition is only useful when accompanied by calibration, coverage, and domain-shift tests. A narrow interval from an unfamiliar geology, failed gauge, or extrapolated rainfall regime should be rejected by the domain and data-quality gate rather than treated as high confidence (Phoon & Zhang, 2023; Wang & Tian, 2024; NIST, 2023).

Warning and human decision logic

An alert is a managed decision, not a probability label. The optimal advisory depends on the consequences of missed failure, false alarm, delayed response, repeated alert switching, and the feasibility of inspection, closure, evacuation, or drainage intervention. A transparent decision rule is:

$$a_t^* = \arg\min_{a \in \mathcal{A}} \left\{ \mathbb{E}[C(a, Y_{t+\Delta}) \mid \mathcal{D}_t] + \lambda_q Q(a, \mathcal{D}_t) + \lambda_{sw} \mathbb{I}(a \neq a_{t-1}) \right\} \quad (6)$$

where A is the authorised advisory set; a^*_t is the recommended action; C is the consequence of action-outcome combinations; D_t is the evidence available at issue time; Q penalises inadequate data quality or unresolved diagnostic conditions; the first coefficient weights the quality penalty; the switching coefficient penalises unjustified movement between adjacent warning states; and I(·) is an indicator. The switching term supports hysteresis but must not delay a necessary escalation. All costs and weights require local governance, and the computed action remains advisory. Risk-tolerance research and the NIST AI risk framework support explicit context, accountability, and human oversight rather than universal thresholds (Sim et al., 2022; NIST, 2023).

RESULTS AND DISCUSSION

Principal framework outputs

The first result is a traceable distinction among five products: static susceptibility, observed hydrological state, short-horizon hazard probability, warning confidence, and authorised action. A slope can be highly susceptible without an imminent event; conversely, an extreme storm can produce concern at a moderate-susceptibility location if drainage or land use has changed. Keeping these products separate reduces category errors and clarifies which evidence can update each component.

The second result is an explicit allocation of responsibility between physics and learning. The physical model defines state variables, directions of response, boundary assumptions, and plausibility checks. Machine learning estimates unresolved parameters, spatial corrections, temporal dependencies, and nonlinear interactions. Neither component is treated as automatically correct. Model-data disagreement is retained as a diagnostic output that can indicate a wrong boundary condition, a failed sensor, an unrepresented intervention, or a changing failure mechanism.

The third result is a warning architecture that remains useful under incomplete evidence. Missing rainfall or ground data do not become zeros; coarse precipitation is not accepted without local comparison; an out-of-domain unit is not assigned ordinary confidence; and a probability is not converted directly into evacuation. This fail-explicit behaviour is particularly important for Black Sea coastal sectors where terrain, geology, drainage, land use, and instrumentation density vary substantially.

Validation protocol and performance measures

A credible evaluation must reproduce the information actually available at warning time. Randomly splitting pixels or time steps can leak spatial neighbours, repeated storm information, terrain derivatives, or future observations into the test set. The primary tests should therefore hold out complete rainfall events, geographic sectors, and later time periods. Nested validation is needed for model and loss-weight selection, followed by a locked prospective test.

Table 4. Validation matrix for a pre-operational Black Sea pilot

Validation question	Required split or test	Minimum reported measures	Acceptance principle
Does the model discriminate events?	Held-out storms and complete mapped areas	Event recall; precision; area under precision-recall curve; warning-area fraction	Performance must exceed transparent threshold and unconstrained ML baselines
Are probabilities reliable?	Independent events by probability bin	Brier score; log score; reliability diagram; interval coverage	Calibration is assessed, not inferred from accuracy
Does it transfer spatially?	Leave-one-sector or leave-one-catchment-out	Skill change; calibration change; domain distance; error map	No confident deployment outside validated domain
Does it provide useful lead time?	Replay with original issue times and data latency	Lead-time distribution; missed events; late alerts; update stability	Only information available at issue time is used
Is physics helpful?	Ablation of each physical term and physics-only baseline	Skill; constraint violations; residual pattern; uncertainty	A constraint is retained only when it improves reliability or diagnostic value
Is it operationally tolerable?	Prospective shadow operation and exercises	False alarms; alert duration; acknowledgement time; action completion; user comprehension	Decision burden and human factors are explicit

Source: *Authors' validation protocol informed by Alvioli et al. (2024), Nocentini et al. (2024), Pradhan et al. (2023), Piciullo et al. (2025), Lee et al. (2025), and NIST (2023).*

Accuracy and receiver-operating-characteristic area alone are insufficient when landslides are rare and warning areas are imbalanced. Precision-recall behaviour, proper probability scores, calibration, spatial extent, event recall, lead time, and false-alarm burden should be reported together. Explainability should also be evaluated: an explanation is useful only when a reviewer can connect it to rainfall, ground response, physical residuals, model domain, and a feasible action (Pradhan et al., 2023; Shao et al., 2025).

Desk-based stress-case evaluation

In the first stress case, a local gauge records an intense storm while a coarse satellite product underestimates it. The data-quality layer detects disagreement, increases reliance on the validated local source, widens uncertainty where spatial coverage is weak, and prevents the coarse product from suppressing the warning. This response is supported by the eastern Black Sea inventory evidence, but its quantitative thresholds require local gauge-radar-event analysis (Çömert et al., 2025).

The second case involves prolonged moderate rainfall followed by delayed pore-pressure rise. An intensity-only threshold may de-escalate too early. The proposed state model retains antecedent wetness and continues assimilation after rainfall weakens; the hydrology residual tests whether the inferred pressure trajectory is consistent with storage and drainage. The alert can remain elevated when the mechanical state is worsening even though current rainfall has declined.

The third case introduces drift in one piezometer and loss of a moisture probe. Cross-sensor checks, residual structure, and device-health metadata reduce their influence and label the state as degraded. The model does not infer stability from the remaining low-variance channels. Where evidence cannot resolve a disagreement, the warning package requests inspection and reports the contribution of sensor and model uncertainty.

The fourth case applies the model to a coastal sector with different lithology, slope-unit geometry, land use, and drainage modification. The domain gate compares the new sector with the training support. If

similarity is inadequate, the system restricts the model to exploratory or shadow use, falls back to a validated transparent rule, and requires local investigation and recalibration. This response addresses transfer risk without claiming that physics alone eliminates domain shift.

Comparison with alternative warning approaches

A rainfall threshold offers transparency, low computational cost, and clear communication, but may not distinguish antecedent state, ground response, or local mechanism. A physics-only regional model offers causal structure but requires spatially dense parameters and can be biased by simplified geometry or boundary conditions. A purely data-driven model can capture complex interactions but may exploit inventory artefacts and violate known response directions. PIML is valuable only when it demonstrates a better trade-off among calibration, physical consistency, transfer, lead time, and diagnostic usefulness than these baselines.

Recent studies illustrate complementary forms of hybridisation: physics-guided sample selection (Liu et al., 2023; Wang et al., 2024), knowledge-guided slope prediction (Huang, 2023; Pei et al., 2023), coupling TRIGRS with random forest (Yang et al., 2024), probabilistic physically based assessment (Cui et al., 2024), and differentiable rainfall-landslide learning (Pei et al., 2025). The proposed framework incorporates these ideas but adds an operational separation between model output, confidence, warning, and authorised action.

Staged implementation roadmap

Deployment should begin with inventory and decision governance, not neural-network selection. Table 5 proposes five stages. Advancement requires explicit exit evidence so that an attractive prototype is not mistaken for a safety system.

Table 5. Staged implementation roadmap for a Black Sea coastal pilot

Stage	Principal activities	Required deliverables	Exit criterion
1. Ground and decision baseline	Select pilot units; investigate failure mechanisms; map exposure, authority, and response time	Ground model; event schema; decision and governance register	Warning objectives and accountable actions are approved
2. Data and observatory	Reconcile inventories; install priority gauges and ground sensors; establish inspections	Quality-controlled data contract; calibration and maintenance plan	Data fitness and event completeness are characterised
3. Transparent baselines	Implement rainfall thresholds, physics-only model, and unconstrained ML benchmark	Replay results; error taxonomy; calibration and lead-time report	Baselines are reproducible and independently reviewed
4. PIML shadow operation	Train constrained model; conduct ablation, transfer, fault, and domain tests	Locked model; model card; residual and uncertainty dashboard	Prospective shadow criteria are met without operational control
5. Controlled service	Integrate engineer review, exercises, cybersecurity, maintenance, and periodic recalibration	Operating procedure; audit trail; training; independent assurance	Authority confirms fitness for each intended decision

Source: *Authors' implementation roadmap based on Piciullo et al. (2025), Lee et al. (2025), Nocentini et al. (2024), Yuan et al. (2025), and NIST (2023).*

Limitations and research agenda

This study has four principal limitations. First, it is an architectural synthesis and has not been deployed along the Black Sea coast. Second, the targeted evidence search cannot establish exhaustive coverage. Third, the hydrology and infinite-slope equations are transparent reference structures, not universal models for every coastal landslide. Fourth, no numerical warning threshold, lead time, loss weight, or acceptance criterion can be transferred responsibly without site-specific evidence and governance.

A rigorous pilot should compare gauges, radar, satellite precipitation, and forecasts at event times; quantify inventory completeness; instrument representative slope units; measure pressure and deformation response; test alternative failure mechanisms; and operate prospectively through multiple wet seasons. Controlled fault injection should examine missing packets, clock errors, sensor drift, saturated readings, forecast revisions, and power interruption. Model evaluation should include calibration, event recall, false-alarm burden, alert stability, lead time, energy and communication availability, and the proportion of decisions that can be reconstructed from the audit record.

Research is also needed on cross-country data standards, privacy and liability, transfer learning under geological heterogeneity, differentiable models for deep-seated or toe-eroded coastal slopes, and human interpretation of residuals and uncertainty. The objective is not maximum automation. It is a dependable augmentation of geotechnical and emergency judgement with evidence that is timely, physically intelligible, and explicit about its limits.

CONCLUSION

This paper has developed a physics-informed machine-learning framework for early warning of rainfall-induced landslides along the Black Sea coast. The framework represents warning as a causal sequence from rainfall forcing through hydrological response and mechanical state to probabilistic forecast and governed action. It integrates local and remote rainfall, ground monitoring, terrain and ground information, event inventories, and exposure within a traceable spatial-temporal data contract.

The technical contribution is an explicit set of editable hydrology, stability, learning, probability, uncertainty, and decision equations. These equations show where scientific assumptions enter the learner and where model-data disagreement becomes diagnostic evidence. The framework also separates susceptibility from imminent hazard, probability from confidence, and model output from authorised warning. Missing, conflicting, or out-of-domain evidence therefore produces a degraded state rather than an unjustified indication of safety.

The architecture is ready to guide a pilot specification, but it is not an operational warning model. Site investigation, complete event inventories, local rainfall validation, calibrated sensors, mechanism selection, independent spatial-temporal testing, prospective shadow operation, emergency exercises, and accountable governance remain prerequisites. With these safeguards, PIML can provide a transparent bridge between regional data and geotechnical mechanism for more anticipatory and locally defensible landslide risk management around the Black Sea.

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EXPLAINABLE AI AND SATELLITE INSAR FOR COASTAL SUBSIDENCE MAPPING AND GEOTECHNICAL RISK ASSESSMENT IN BLACK SEA CITIES

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ABSTRACT

Objectives: This study develops an explainable satellite-interferometry framework for mapping coastal subsidence and assessing geotechnical risk in Black Sea cities without treating remotely sensed motion as a verified cause or an automatic risk decision. **Methods:** A design-science method and targeted synthesis of peer-reviewed evidence published from 2022 to July 2026 were used to derive a measurement chain, geotechnical feature specification, editable equations, explainability protocol, validation matrix, and staged deployment plan. The framework was examined through requirements traceability and four desk-based stress cases; no new field dataset or performance claim is presented. **Results:** The proposed workflow connects ascending and descending InSAR observations with stable referencing, GNSS or levelling, ground investigation, groundwater and loading records, spatially blocked machine learning, mapped explanations, differential-deformation indicators, exposure, vulnerability, and accountable engineering review. It separates observation, interpretation, forecast, and risk action, while low coherence, reference instability, domain shift, and disagreement between evidence sources remain visible as diagnostic states. **Conclusions:** Explainable AI can make InSAR-based screening more auditable, but SHAP values are model explanations rather than causal proof. Operational use requires local calibration, mechanism testing, prospective validation, and governed decisions.

Keywords: Explainable artificial intelligence; InSAR; coastal subsidence; geotechnical risk; Black Sea cities; spatial validation.

INTRODUCTION

Coastal subsidence is a compound geotechnical and urban-risk problem. Vertical or three-dimensional ground motion can alter relative sea level, reduce drainage gradients, damage foundations and buried services, increase differential deformation across structures, and amplify the consequences of coastal flooding. The observed displacement may arise from natural consolidation, groundwater withdrawal, reclamation and fill settlement, construction loading, excavation, tunnelling, deep-seated slope movement, tectonic motion, or combinations of these processes. A velocity map is therefore an important observation, but it is not a mechanism map and it is not, by itself, a risk map.

Satellite interferometric synthetic aperture radar (InSAR) offers repeated, spatially extensive measurements of line-of-sight motion. Contemporary processing can produce dense point time series across built environments, while the European Ground Motion Service provides an important continental-scale reference for consistent Sentinel-1 products (Thiéblemont et al., 2024; Vradi et al., 2023). Global and coastal-city studies have shown that spatially variable subsidence is widespread and that local motion can materially modify exposure to sea-level rise (Wu et al., 2022). These strengths make InSAR valuable for screening Black Sea urban coasts, but coverage, reference stability, atmospheric artefacts, decorrelation, viewing geometry, temporal sampling, and the distinction between vertical and slope-parallel movement remain consequential.

Black Sea evidence supports a deliberately local interpretation. Erkoç et al. (2025) integrated tide-gauge, GNSS, satellite-altimetry, and InSAR observations at Black Sea coastal stations and documented that vertical coastal motion differs among locations. Their station-based evidence should not be extended to unmeasured urban districts. At Istanbul Airport on the Black Sea coast, persistent-scatterer time series have been used to assess surface stability and to investigate machine-learning forecasting with explainability (Yagmur et al., 2022; Yagmur Aydin et al., 2026). These studies establish methodological relevance, not a general subsidence rate for Black Sea cities.

Machine learning can relate InSAR time-series behaviour to terrain, land use, hydrology, geological proxies, and infrastructure conditions. It can also classify motion patterns, estimate susceptibility, or forecast a measured series (Alesheikh et al., 2024; Mirmazloumi et al., 2022; Yagmur et al., 2024). Yet geospatial models are vulnerable to spatial leakage, biased sampling, non-stationarity, and explanations that are visually persuasive but physically ambiguous. Explainable artificial intelligence (XAI) can expose which inputs influence a fitted model, although feature attribution does not prove that a variable caused the observed deformation (Li, 2024; Qiao et al., 2024; Roussel, 2024).

The purpose of this paper is to develop a transparent framework that joins InSAR, geodetic control, geotechnical evidence, spatial machine learning, XAI, and consequence-based risk assessment. Its contributions are: a six-stage measurement-to-decision chain; four claim classes that prevent inferential overreach; a minimum data specification; seven editable equations; a spatially explicit explanation protocol; a validation matrix; four desk-based stress cases; and a staged deployment roadmap. The study is conceptual and design-oriented. It does not process new Sentinel-1 scenes, estimate motion for a particular city, fit an operational model, or claim predictive performance.

METHODOLOGY

Research design and evidence base

A design-science method was adopted because the research question concerns how existing observations and analytical methods should be organised into a testable geotechnical decision system. A targeted evidence synthesis covered peer-reviewed publications and authoritative guidance issued from 2022 to July 2026. The evidence was selected for direct relevance to coastal or urban subsidence, Sentinel-1 time-series analysis, Black Sea ground motion, geospatial XAI, spatial validation, geotechnical mechanism attribution, infrastructure deformation, or risk governance. The search was targeted rather than systematic, and no exhaustive-coverage claim is made.

Each source was coded against five questions: what quantity was observed or predicted; at what spatial and temporal support; how the InSAR reference and uncertainty were handled; which independent evidence was used for interpretation or validation; and whether the analytical explanation was treated as association or causation. Requirements were then mapped to inputs, equations, outputs, failure modes, and verification activities. Four desk-based stress cases were used to challenge the proposed logic. These checks establish internal traceability, not field validity.

Claim discipline and design requirements

The framework distinguishes observation, interpretation, forecast, and risk decision. This distinction is central to scientific defensibility. A coherent persistent-scatterer time series may support an observation of relative line-of-sight motion. A consolidation explanation additionally requires plausible ground, loading, and hydrogeological evidence. A forecast requires temporally independent testing and calibrated uncertainty. A risk decision requires exposure, vulnerability, consequence, authority, and an actionable response. Table 1 defines the permitted claims and the evidence needed to advance between them.

Table 1. Claim classes for defensible InSAR–XAI geotechnical assessment

Claim class	Permitted statement	Minimum supporting evidence	Statement that remains prohibited
Observation	A referenced target shows LOS displacement or a time-series pattern over a defined period.	Processing provenance; reference definition; coherence or quality; uncertainty; acquisition geometry.	The point is undergoing vertical subsidence caused by a named mechanism.
Interpretation	The motion is consistent with a specified mechanism under stated alternatives.	Observation plus ground model, water or loading records, geometry, and independent checks.	The XAI attribution establishes physical causation.
Forecast	A locked model estimates a future measured state within a defined horizon and domain.	Temporal and spatial holdout; calibration; baseline comparison; domain and quality diagnostics.	The forecast is operationally reliable outside the validated domain.
Risk or advisory	A reviewed evidence package supports a prioritised inspection or locally authorised action.	Hazard probability; exposure; vulnerability; consequence; uncertainty; accountable authority.	A universal threshold automatically proves safety, closure, or structural failure.

Source: *Authors' framework informed by the InSAR interpretation cautions of Qiao et al. (2024), geospatial XAI guidance of Roussel and Böhm (2023), and risk-governance principles of NIST (2023).*

Eleven design requirements were derived: traceable SAR processing; stable and documented referencing; viewing-geometry awareness; explicit measurement uncertainty; independent geodetic control; geotechnical mechanism tests; spatially independent model evaluation; local and global explanations; exposure and vulnerability separation; visible degraded states; and human accountability for consequential decisions. A requirement is satisfied only when its evidence can be reconstructed from the retained records.

BLACK SEA COASTAL SUBSIDENCE CONTEXT

What InSAR observes

An interferogram measures phase change between radar acquisitions. After removing topographic, orbital, atmospheric, and other non-deformation components as far as the selected method permits, the deformation phase can be expressed as line-of-sight displacement. Under the stated sign convention, the relationship is:

$$d_{\mathrm{LOS}} = \frac{\lambda}{4\pi}\Delta\phi_{\mathrm{def}} \tag{1}$$

where dLOS is displacement along the satellite-to-ground line of sight; λ is radar wavelength; and Δφdef is the phase component attributed to deformation after processing. The equation is a measurement conversion, not a guarantee that all residual phase is deformation. Atmospheric delay, unwrapping error, reference instability, thermal effects, vegetation, snow, construction change, and low coherence can contaminate a time series. Quality information must therefore accompany every mapped value (Qiao et al., 2023; Vradi et al., 2023).

For acquisition geometry k, the observed velocity is a projection of the three-dimensional velocity vector:

$$v_{\mathrm{LOS},k} = \mathbf{l}_k^{\mathrm{T}}[v_E \quad v_N \quad v_U]^{\mathrm{T}} + \epsilon_k \tag{2}$$

where vLOS,k is the LOS velocity for geometry k; l_k is the unit look vector; vE, vN, and vU are east, north, and up velocity components; and ε_k collects measurement and model error. A single viewing geometry cannot uniquely recover all components. Ascending and descending observations improve east-up separation, but the north component commonly remains weakly constrained; GNSS, levelling, terrain direction, or a defensible movement assumption may be required. On coastal slopes, a LOS trend interpreted automatically as vertical subsidence can therefore be misleading.

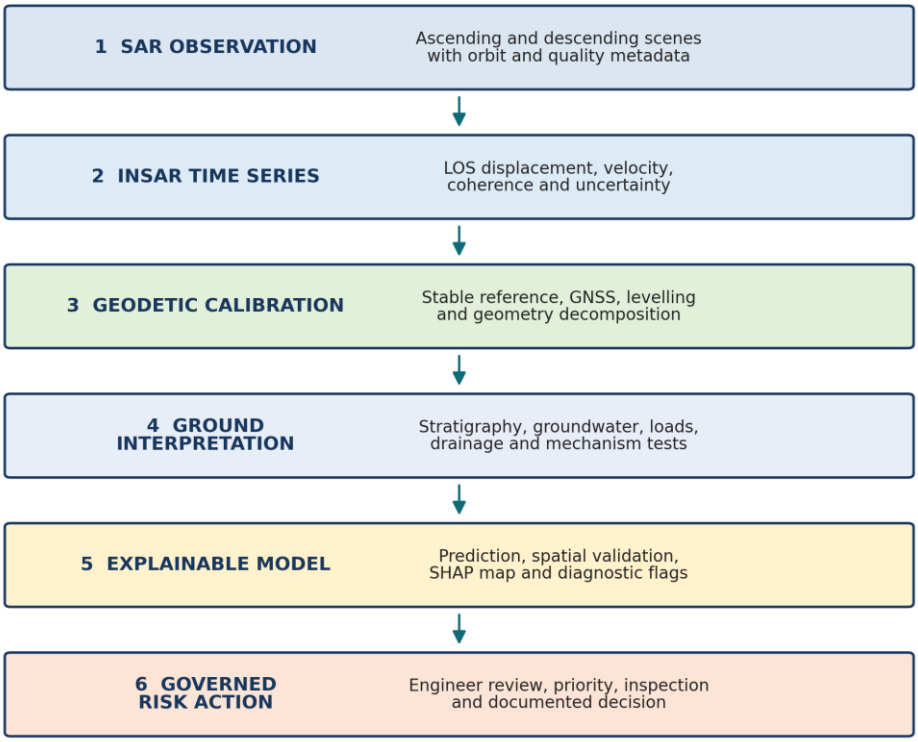

Figure 1. Traceable measurement-to-risk chain for Black Sea coastal cities

Source: *Authors' original framework based on InSAR quality and geometry requirements discussed by Vradi et al. (2023), Qiao et al. (2023), and Thiéblemont et al. (2024); XAI interpretation guidance from Roussel (2024) and Qiao et al. (2024); and governed-risk principles from NIST (2023).*

Why mechanism attribution is difficult

Urban coastal motion is rarely controlled by one variable. Compressible Holocene sediments, reclamation fill, seasonal groundwater fluctuations, dewatering, leaking utilities, construction surcharge, excavation, tunnelling, slope creep, shoreline erosion, and regional tectonic motion can overlap in space and time. Similar surface patterns may arise from different causes, while a single mechanism may produce different patterns depending on stratigraphy, drainage, and structural load. Cavalié et al. (2023), Cigna and Tapete (2022), and Medici et al. (2024) demonstrate the value of combining long InSAR histories with local geological, hydrogeological, and development evidence rather than inferring mechanism from velocity alone.

A simplified one-dimensional settlement check can be written as:

$$\Delta H = \sum_{m=1}^{M} H_m \; m_{v,m} \, \Delta\sigma'_m \tag{3}$$

where ΔH is estimated settlement; M is the number of compressible layers; H_m is the thickness of layer m; $m_{v,m}$ is its constrained coefficient of volume compressibility over the relevant stress range; and $\Delta\sigma'_m$

is the change in vertical effective stress. Equation (3) is an interpretable screening relation for a compatible consolidation hypothesis, not a universal model. It requires appropriate parameters, drainage conditions, stress history, and loading or pore-pressure evidence. It is unsuitable as a sole explanation for tectonic motion, lateral spreading, landslide displacement, sinkhole processes, or complex three-dimensional interaction.

Differential deformation may be more relevant to infrastructure than a spatially uniform absolute rate. For two observation or asset locations i and j, a transparent angular-distortion screening indicator is:

$$\beta_{ij} = \frac{|s_i - s_j|}{L_{ij}} \tag{4}$$

where β_{ij} is the magnitude of differential settlement per unit separation; s_i and s_j are compatible vertical-settlement estimates or validated proxies at the two locations; and L_{ij} is their horizontal separation. The locations must belong to a comparable reference frame and support. Equation (4) must not be applied directly to unrelated LOS values from different viewing geometries. Asset-specific tolerances require structural and geotechnical assessment; no universal damage threshold is proposed (Cigna et al., 2025).

Data contract for urban coastal assessment

A defensible pilot needs a shared geospatial and temporal data contract. Raw and processed SAR records must retain acquisition identifier, orbit direction, incidence angle, reference area, processing version, quality metrics, and uncertainty. Geodetic observations require monument stability, datum, survey method, coordinate epoch, and maintenance history. Ground and asset information requires provenance, spatial support, update date, and confidence. Table 2 summarises the minimum fields.

Table 2. Minimum data objects and quality fields for a Black Sea city pilot

Data object	Required content	Principal quality checks	Role in decision chain
SAR and InSAR	Scene IDs; orbit; geometry; dates; method; reference; LOS series; coherence or precision; processing version.	Coverage; unwrapping; atmospheric residual; temporal consistency; reference sensitivity.	Observation and uncertainty.
Geodetic control	GNSS or levelling coordinates; epoch; datum; monument; instrument; covariance; operator.	Monument stability; network closure; time alignment; independent processing.	Calibration, decomposition, and reference verification.
Ground model	Geomorphology; fill; strata; thickness; parameters; boreholes; groundwater; drainage; uncertainty.	Depth and location support; laboratory or field method; representativeness; update history.	Mechanism hypotheses and counterfactual tests.
Loads and boundaries	Buildings; reclamation; excavation; tunnels; pumping; tide; rainfall; shoreline and drainage changes.	Issue time; completeness; units; spatial linkage; operational records.	Temporal attribution and scenarios.
Assets and consequences	Footprints; foundations; roads; utilities; occupancy; criticality; redundancy; inspection history.	Ownership; positional accuracy; current condition; consequence classification.	Exposure, vulnerability, priority, and action.

Source: *Authors' specification informed by Vradi et al. (2023), Cuervas-Mons et al. (2024), Qiao et al. (2024), Cigna et al. (2025), and Erkoç et al. (2025).*

PROPOSED INSAR–XAI–GEOTECHNICAL FRAMEWORK

InSAR processing, referencing, and calibration

The workflow begins with an intended-use statement: screening, condition assessment, deformation forecasting, or support to an inspection decision. The choice determines the required spatial resolution, latency, historical depth, uncertainty, and independent evidence. Persistent-scatterer or small-baseline time-series processing may then be selected according to target density, coherence, motion rate, and environmental conditions. The original processing records and quality layers are retained so that later models cannot detach a velocity value from its measurement context.

Reference stability is tested by repeating the solution with alternative stable areas and by comparison with available GNSS or levelling. Ascending and descending geometries are examined separately before decomposition. Temporal changes in scatterer population, construction, vegetation, or snow are flagged. The European Ground Motion Service can support regional screening and methodological consistency, but local decisions still require an assessment of measurement-point density, visibility, reference, and local validation (Thiéblemont et al., 2024; Vradi et al., 2023; Cuervas-Mons et al., 2024).

Geotechnical feature stack and mechanism hypotheses

The feature stack is organised by mechanism rather than convenience. Static variables describe geomorphology, reclaimed land, compressible-layer thickness, foundation type, slope, and infrastructure. Dynamic variables describe groundwater, pumping, tide, rainfall, construction loading, excavation, drainage condition, and prior displacement. Measurement-quality variables describe coherence, temporal gaps, viewing geometry, point density, distance to control, and reference sensitivity. This separation helps the model distinguish evidence about the physical system from evidence about the reliability of the observation.

Table 3. Candidate feature families and their permitted geotechnical interpretation

Feature family	Examples	Testable hypothesis	Required caution
Ground and landform	Fill extent; soil unit; compressible thickness; elevation; slope; distance to shoreline.	Spatial variation in material and geometry is associated with different motion responses.	Mapped class is a proxy until confirmed by investigation.
Water and drainage	Groundwater level; pumping; tide; rainfall; drainage defects; leakage records.	Changes in pore pressure or effective stress are temporally consistent with motion.	Correlation and SHAP attribution do not establish hydraulic causation.
Loading and construction	Building age; surcharge; reclamation phase; excavation; tunnel or utility work.	Loading or stress relief precedes a compatible deformation response.	Dates, depth, and spatial influence must be independently verified.
InSAR quality	Coherence; precision; point density; geometry; gaps; reference sensitivity.	Apparent patterns partly reflect observation reliability.	Quality variables must diagnose data fitness, not mask physical motion.
Asset condition	Cracks; serviceability reports; settlement survey; foundation type; repair history.	Observed deformation is consistent with independent condition evidence.	Absence of a report is not evidence of absence of damage.

Source: *Authors' synthesis from Cavalié et al. (2023), Cigna and Tapete (2022), Medici et al. (2024), Alesheikh et al. (2024), and Qiao et al. (2024).*

Explainable spatial machine learning

For analysis unit i, a supervised regression model can be written as:

$$\hat{y}_i = f_{\boldsymbol{\theta}}(\mathbf{x}_i) \tag{5}$$

where $\hat{y}_i$ is the predicted response, such as a future LOS increment, a validated vertical-motion proxy, or a susceptibility score; f is the fitted model; θ is its parameter vector; and x_i is the feature vector available at the forecast or assessment issue time. The response must be named precisely. A model trained on LOS velocity does not automatically predict settlement, vertical land motion, structural damage, or failure.

Randomly splitting neighbouring points can produce optimistic performance because nearby observations share geology, land use, atmosphere, and processing artefacts. Spatial blocks, held-out districts, leave-one-zone-out tests, and temporally later periods are therefore required. Spatial+ or comparable methods should be considered when conventional cross-validation permits spatial dependence to leak between training and testing (Wang et al., 2023). Transparent linear and tree baselines remain necessary, and any complex model must justify its additional value in calibration, spatial transfer, uncertainty, or diagnostic usefulness.

For an additive SHAP explanation, the prediction for unit i is represented as:

$$\hat{y}_i = \phi_0 + \sum_{j=1}^{p} \phi_{ij} \tag{6}$$

where φ_0 is the model's baseline prediction over the defined background dataset; p is the number of model features; and φ_{ij} is the contribution assigned to feature j for unit i under the selected SHAP implementation and background distribution. Positive and negative values describe changes in the model output relative to φ_0. They do not establish that changing the feature would physically change the ground response. Collinearity, feature construction, training distribution, and spatial context can redistribute attributions (Li, 2024; Roussel, 2024; Wang et al., 2024).

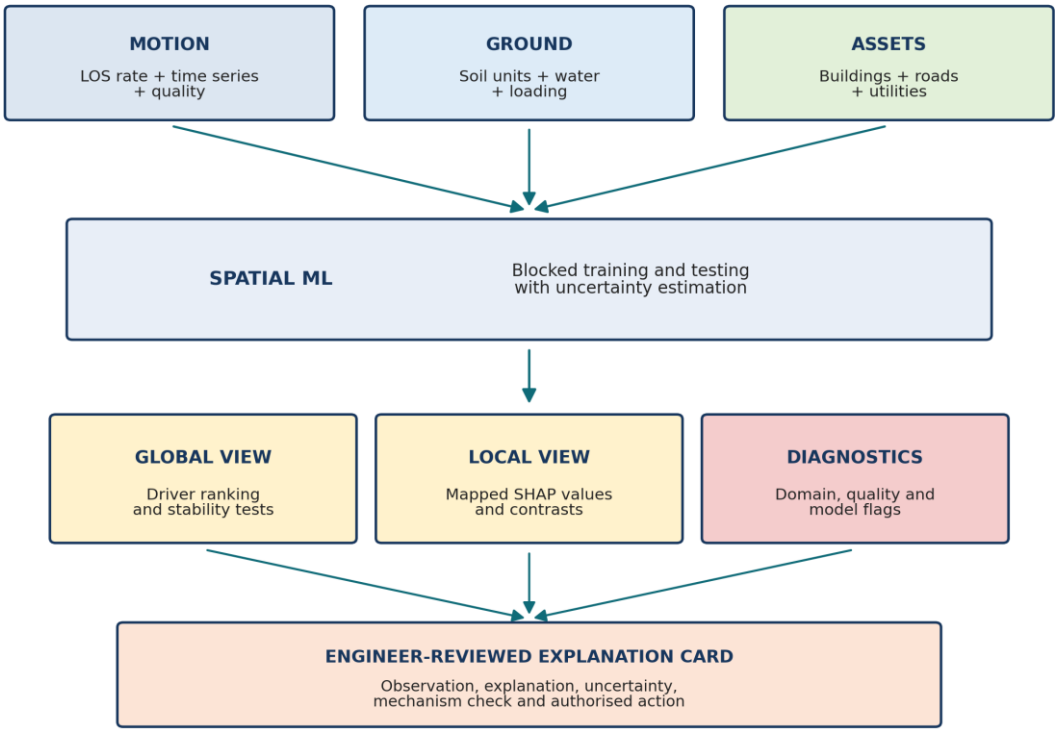

Figure 2. Architecture of an engineer-reviewed spatial explanation card

Source: *Authors' original framework based on geospatial XAI requirements from Roussel and Böhm (2023), Roussel (2024), Li (2024), and Wang et al. (2024), with InSAR application cautions from Qiao et al. (2024).*

Figure 2 converts model output into an explanation card rather than a single colour map. The card records the observation period and geometry, reference and quality, prediction and interval, dominant local contributions, global feature stability, nearest spatial holdout performance, domain similarity, alternative mechanism tests, and the reviewer-approved action. Local explanation maps are inspected for abrupt boundaries that coincide with data tiles, acquisition geometry, administrative mapping, or missingness. Global rankings are tested across folds, model classes, background datasets, and plausible feature perturbations.

From mapped motion to governed risk

Risk is kept separate from the displacement model. For analysis unit i and consequence class c, an auditable screening expression is:

$$R_i = \sum_{c=1}^{C} P\left(H_i = c \mid \mathcal{D}\right) E_i \, V_i \, C_{i,c} \tag{7}$$

where R_i is a comparative risk score or expected-loss quantity, depending on locally defined units; C is the number of mutually exclusive hazard or damage classes; $P(H_i = c \mid D)$ is the probability of class c given evidence D; E_i represents the exposed asset, population, service, or value; V_i is vulnerability conditional on the relevant mechanism and asset characteristics; and C_i,c is the consequence associated with class c. Probability, exposure, vulnerability, and consequence must be defined without double counting. Locally approved weights and tolerability criteria are required; Equation (7) does not supply a universal risk threshold.

The operational output is a prioritised evidence package. A high mapped velocity with low exposure may warrant mechanism investigation, while moderate differential motion across a hospital access route

or buried utility may warrant earlier inspection. Conversely, a model can be highly confident about a measured trend and still have low confidence in its cause. The decision record should distinguish these uncertainties and preserve the reviewer, rationale, action, deadline, acknowledgement, and outcome.

RESULTS AND DISCUSSION

Design result and information products

The principal result is a traceable architecture in which each risk statement can be reconstructed through six stages: SAR observation, InSAR time series, geodetic calibration, geotechnical interpretation, explainable modelling, and governed action. The architecture prevents a common collapse of categories. Motion is not labelled as subsidence until geometry and reference are addressed; an XAI driver is not labelled as a cause until mechanism evidence is tested; and a predicted response is not labelled as risk until exposure, vulnerability, and consequence are added.

The framework produces five complementary information products. The first is a measurement layer containing LOS values, time series, geometry, reference, quality, and uncertainty. The second is a mechanism layer containing competing ground-response hypotheses and the evidence for or against each. The third is a model layer containing predictions, intervals, spatial holdout results, and domain flags. The fourth is an explanation layer containing mapped local contributions, global stability tests, and counterfactual checks. The fifth is a risk register linking reviewed evidence to assets, consequences, authorities, and actions.

Validation and assurance matrix

Validation must occur at every link rather than only at the final classifier. Table 4 defines the minimum assurance questions. Passing one layer does not compensate for failure in another: excellent predictive discrimination cannot correct an unstable InSAR reference, and agreement with GNSS does not prove a groundwater mechanism.

Table 4. Validation matrix for InSAR–XAI coastal subsidence assessment

Layer	Validation question	Evidence and metrics	Failure response
Measurement	Is the mapped motion stable to processing and reference choices?	Alternative references; asc/desc consistency; residual inspection; precision, coherence, and point density.	Reprocess, qualify, or suppress unsupported values.
Geodetic	Does independent control support magnitude, direction, and temporal pattern?	GNSS or levelling comparison with coordinate, epoch, covariance, and spatial-support analysis.	Report disagreement; review geometry, datum, monument, and scale.
Predictive	Does the locked model transfer in space and time?	Spatial blocks; later-period holdout; baseline comparison; calibration; error by district and ground unit.	Restrict domain, simplify model, recalibrate, or return to shadow use.
Explanation	Are attributions stable and spatially meaningful?	Fold and model stability; background sensitivity; collinearity review; explanation maps; perturbation tests.	Mark explanation unstable and prohibit causal wording.
Mechanism	Does independent ground evidence distinguish plausible causes?	Boreholes; groundwater; loads; deformation surveys; inspections; temporal precedence; alternative hypotheses.	Retain multiple hypotheses and commission targeted investigation.

Layer	Validation question	Evidence and metrics	Failure response
Risk and governance	Can a reviewer understand and act on the evidence within authority?	Exposure and vulnerability audit; consequence review; exercises; decision reconstruction; acknowledgement time.	Revise procedures, roles, thresholds, communication, or intended use.

Source: *Authors' validation framework informed by Wang et al. (2023), Roussel (2024), Qiao et al. (2024), Cigna et al. (2025), and NIST (2023).*

Desk-based stress-case evaluation

The first stress case is an apparent high subsidence rate in a district visible only from one acquisition geometry. The framework keeps the result as LOS motion, compares ascending and descending coverage, tests terrain direction, inspects reference sensitivity, and seeks GNSS or levelling before vertical interpretation. Where decomposition is underdetermined, the explanation card reports the unresolved component instead of converting the value automatically to subsidence.

The second case is a coherent urban cluster for which groundwater depth has the largest positive SHAP contribution. The framework states that groundwater strongly influenced the fitted prediction for the selected background distribution. It then requires temporal precedence, pumping or piezometric records, compatible stratigraphy, settlement calculations, and comparison with construction loading and other hypotheses. Until these tests discriminate the mechanism, the word cause is not used.

The third case is sparse measurement coverage over reclaimed land and critical utilities. A smooth interpolated map could conceal unsupported areas. The architecture preserves point density, distance to observation, coherence, and interpolation uncertainty, and it prevents the XAI model from presenting extrapolated zones as equally observed. The risk register may still prioritise the zone because consequences are high, but the corresponding action is targeted ground investigation or monitoring rather than a claim of confirmed deformation.

The fourth case is a model trained in one coastal city and applied to another with different geology, construction history, and InSAR visibility. Spatial holdout performance in the source city does not establish transfer. The domain gate compares feature support, ground classes, acquisition geometry, and error structure. If the destination lies outside the validated domain, predictions remain exploratory, explanations are labelled non-operational, and a local baseline and calibration programme are required.

Comparison with alternative approaches

A velocity-threshold map is transparent and inexpensive, but it may conflate noise, uniform translation, differential settlement, and structural consequence. A geotechnical investigation provides direct subsurface evidence but is spatially sparse and may miss evolving regional patterns. Pure machine learning can integrate many variables but may exploit spatial autocorrelation and proxy relationships. A purely physical model supplies causal structure but depends on geometry, parameters, boundaries, and forcing that may be uncertain at city scale. The proposed architecture uses each method for the question it can answer and requires disagreement to remain visible.

Recent work demonstrates complementary capabilities: machine-learning classification of InSAR series (Mirmazloumi et al., 2022), susceptibility mapping from InSAR and environmental variables (Alesheikh et al., 2024), time-series forecasting in Istanbul (Yagmur et al., 2024), spatially mapped SHAP analysis (Wang et al., 2024), and infrastructure-oriented subsidence-risk screening (Cigna et al., 2025). The present contribution is not a new algorithm. It is a disciplined integration and assurance structure for Black Sea coastal applications.

Black Sea deployment roadmap

A regional programme should share data and evidence standards while retaining local ground models and decision authority. Station evidence from Erkoç et al. (2025), coastal airport studies by Yagmur et al. (2022) and Yagmur Aydin et al. (2026), eastern Black Sea landslide inventories from Çömert et al. (2025), and northern Bulgarian coastal-risk research from Frantzova et al. (2024) show why a single

basin-wide model would be inappropriate. Table 5 proposes staged progression for a city or infrastructure corridor.

Table 5. Staged implementation roadmap for a Black Sea coastal-city pilot

Stage	Principal activities	Required deliverables	Exit criterion
1. Intended use and baseline	Select district and assets; define decisions; review geology, history, tide, groundwater, and prior surveys.	Ground model; claim register; authority map; data inventory; monitoring objectives.	Intended use and accountable decisions are approved.
2. InSAR and geodetic assurance	Process or acquire time series; test references; assess density and quality; establish GNSS or levelling control.	Versioned motion products; uncertainty layers; comparison report; gap plan.	Measurement fitness is independently reviewed.
3. Mechanism and transparent baselines	Investigate priority ground units; assemble water, load, and asset records; fit interpretable baselines.	Competing hypotheses; evidence matrix; baseline and spatial-validation report.	Model target and permitted interpretation are defensible.
4. XAI shadow assessment	Fit locked models; test spatial and temporal transfer; map explanations; conduct fault and sensitivity tests.	Model card; explanation card; domain gate; uncertainty and error taxonomy.	Prospective shadow criteria are met without operational control.
5. Controlled risk service	Integrate inspections, risk register, roles, exercises, cybersecurity, maintenance, and periodic review.	Operating procedure; audit trail; training; independent assurance; review schedule.	Authority confirms fitness for each intended decision.

Source: *Authors' roadmap based on NIST (2023), Thiéblemont et al. (2024), Qiao et al. (2024), Cigna et al. (2025), and Erkoç et al. (2025).*

Limitations and research agenda

This study has five principal limitations. First, it is a conceptual framework and has not been deployed in a Black Sea city. Second, the targeted evidence synthesis cannot establish exhaustive coverage. Third, Equations (1)–(7) are transparent integration structures, not calibrated local models. Fourth, InSAR visibility and error differ by surface, climate, geometry, and processing choice. Fifth, local geology, asset vulnerability, decision authority, data rights, and tolerable risk differ among cities and countries.

Research priorities include multi-geometry decomposition supported by dense geodetic control; uncertainty propagation from phase and reference through explanation and risk; explanation methods that account for spatial dependence and feature collinearity; separation of consolidation, groundwater, loading, tectonic, and slope-movement signatures; and prospective evaluation across construction and hydrological cycles. Field studies should publish negative and contradictory findings, not only visually compelling motion clusters.

Human-factors research is also required. Engineers, planners, asset operators, and emergency managers should be tested on whether they understand LOS geometry, uncertainty, local versus global explanation, and the difference between model contribution and physical cause. An explanation is successful only when it improves an appropriately authorised decision without creating unwarranted certainty.

CONCLUSION

This paper has developed an explainable InSAR–geotechnical framework for coastal subsidence mapping and risk assessment in Black Sea cities. The framework connects satellite observations to time-series processing, stable referencing, geodetic calibration, mechanism-oriented ground evidence, spatial machine learning, mapped explanations, differential-deformation screening, exposure and vulnerability, and accountable engineering action.

Its central contribution is claim discipline. LOS motion is not automatically vertical subsidence; a SHAP value is not causal proof; a forecast is not a risk decision; and absence of a reliable measurement is not evidence of stability. Editable equations and tables make these boundaries explicit and provide a traceable basis for local implementation, validation, and review.

The framework is ready to guide a pilot specification, but not to authorise operational decisions without further evidence. Local InSAR quality assessment, independent geodetic control, site investigation, mechanism testing, spatial-temporal validation, prospective shadow operation, asset-vulnerability analysis, exercises, and governance remain prerequisites. With these safeguards, satellite InSAR and explainable AI can support more transparent, spatially informed, and professionally accountable coastal geotechnical risk management around the Black Sea.

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DIGITAL TWINS FOR REAL-TIME MONITORING OF PORT FOUNDATIONS AND COASTAL GEOTECHNICAL INFRASTRUCTURE IN THE BLACK SEA REGION

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ABSTRACT

Objectives: This study develops a digital-twin framework for real-time monitoring of port foundations and coastal geotechnical infrastructure in the Black Sea region while preventing monitoring data from being misrepresented as verified safety decisions. **Methods:** A design-science method and targeted synthesis of peer-reviewed evidence published from 2022 to July 2026 were used to define the asset scope, minimum data contract, editable state-estimation and risk equations, service classes, validation controls, and staged implementation roadmap. Requirements traceability and four desk-based stress cases were applied; no new field dataset, deployed port case, or performance claim is presented. **Results:** The proposed six-layer architecture connects port foundations, quay structures, reclaimed ground, coastal slopes, marine boundaries, heterogeneous sensing, edge quality control, information integration, calibrated numerical and data-driven models, and engineer-governed action. It distinguishes measurements, latent state, forecast, and decision; propagates data freshness and uncertainty; exposes model–measurement residuals; and converts missing or contradictory evidence into degraded or unknown status rather than a declaration of safety. **Conclusions:** A port digital twin can support transparent inspection and maintenance planning only after site-specific calibration, prospective validation, cybersecurity assurance, and definition of accountable operating authority.

Keywords: Digital twin; port foundations; coastal geotechnics; structural health monitoring; Black Sea; risk-informed maintenance.

INTRODUCTION

Ports are coupled geotechnical, structural, marine, and operational systems. A pile-supported wharf transfers crane, cargo, berthing, and environmental actions through its superstructure and foundations; an anchored sheet-pile quay depends on wall stiffness, anchors, backfill, pore pressure, and toe support; a caisson quay or breakwater depends on foundation contact, seabed stability, and resistance to sliding, overturning, settlement, and scour. Reclaimed yards, coastal embankments, access roads, utilities, dredged slopes, and nearby natural slopes interact with these waterfront structures. Monitoring only a visible structural component can therefore miss the ground and boundary changes that control serviceability or stability.

A digital twin is often proposed as the integrating mechanism for these observations. In a defensible engineering use, however, the twin is not merely a three-dimensional model or dashboard. It is a maintained digital representation of an identified physical asset, linked to observations and models for a stated decision purpose, with explicit synchronization, uncertainty, provenance, and governance. Reviews of civil-infrastructure and port applications show rapid progress but also inconsistent terminology, weak interoperability, limited validation, and a tendency to label static digital models as twins (Naderi & Shojaei, 2022; Neugebauer et al., 2024; Wang et al., 2023).

Recent port studies establish the technical feasibility of more rigorous implementations. Bi et al. (2024) integrated geospatial, sensor, and oceanic information for long-term terminal monitoring. Jayasinghe et

al. (2024) developed a port-structure twin in which an artificial-neural-network surrogate reproduced the response of a validated finite-element model for near-real-time use. Lee et al. (2025) addressed online anomaly detection for long-term monitoring of caisson quay walls, while Shin et al. (2024) combined multiple sensors to recognise events affecting a quay wall. These results are application-specific. They demonstrate useful design patterns but do not supply performance values, alarm thresholds, or foundation conditions for Black Sea ports.

The Black Sea adds regional reasons for integration without supporting a single regional model. Wave climate, water-level behaviour, coastal morphology, sediment movement, local geology, reclamation history, ageing, construction practice, and operational loading vary among ports. Published studies document changing wave characteristics and cross-shore profile response, location-dependent coastal motion, and slope–infrastructure interaction along parts of the Black Sea coast (Arı Güner & Başaran, 2024; Erkoç et al., 2025; Islek et al., 2022; Turoğlu & Duran, 2025). These findings justify local monitoring and regional information compatibility; they do not justify transferring a constitutive model or limit state from one site to another.

This paper develops a design-science framework for digital twins of port foundations and associated coastal geotechnical infrastructure. The contribution is a traceable six-layer architecture, an asset–mechanism–observation matrix, a minimum data contract, seven editable equations, four decision-latency service classes, a validation and assurance matrix, four stress-tested operational scenarios, and a staged implementation roadmap. The paper deliberately reports no new field measurements and makes no claim that the framework is deployed at a Black Sea port. Its purpose is to specify what must be observed, modelled, validated, and governed before a twin can support real decisions.

METHODOLOGY

Research design and evidence base

A design-science method was selected because the research question concerns the construction and evaluation of an engineering information system rather than estimation from a newly collected dataset. A targeted evidence synthesis covered peer-reviewed work published from 2022 to July 2026. Sources were selected for direct relevance to port digital twins, quay-wall and harbour monitoring, geotechnical sensing, state estimation, physics-informed learning, civil-infrastructure interoperability, anomaly detection, coastal digital-twin architecture, Black Sea coastal processes, or risk and cybersecurity governance. The search was targeted rather than systematic, and exhaustive bibliographic coverage is not claimed.

Evidence was coded against six questions: what physical asset and failure mechanism were represented; what was directly measured; what model converted measurements into an estimated state; how uncertainty and data quality were handled; how the proposed output was validated; and who was authorised to act. The resulting requirements were mapped to the architecture, equations, tables, and validation activities. Four desk-based stress cases—sensor conflict, construction loading, severe marine conditions, and communication loss—were then used to test whether the design fails explicitly. This evaluation supports logical completeness and traceability, not field effectiveness.

Intended use, twin maturity, and design principles

The intended use is to support condition awareness, targeted inspection, engineering assessment, and maintenance planning for an identified port asset. The framework does not assume that a twin may automatically close a berth, reduce a crane load, or declare a foundation safe. Automation is limited to acquisition, quality checks, state updating, diagnostics, and communication unless a port has separately validated and authorised a narrowly defined control action. Human authority, decision validity, escalation, and follow-up remain part of the twin specification.

Three maturity levels are distinguished. A digital record or model contains asset information but has no maintained connection to the physical system. A digital shadow receives synchronized observations and can describe or diagnose the monitored state. An operational digital twin adds calibrated models, prediction, uncertainty, and governed feedback from inspections and interventions. Bidirectional

information does not require unconstrained physical actuation; an approved work order, inspection result, or changed operating envelope can provide the feedback needed to update the digital representation (Hu et al., 2022; Klar et al., 2023; Neugebauer et al., 2024; Su et al., 2023).

The design principles are asset identity, mechanism relevance, time synchronization, uncertainty visibility, model pluralism, fail-explicit operation, interoperability, cybersecurity, and accountable decisions. “Real time” is defined relative to the latest time at which evidence can still support the intended decision. A local vibration event and a consolidation trend have different useful latencies. The framework therefore uses decision-linked service classes rather than a universal sampling interval or response time.

PORT ASSET AND OBSERVATION MODEL

Asset–mechanism–observation matrix

The twin boundary must include the load path, supporting ground, hydraulic boundaries, and observable consequences of deterioration. For each asset, the project team prepares a mechanism register before selecting instruments. The register states plausible serviceability and ultimate limit states, expected precursors, confounding effects, decision lead time, and required independent confirmation. Table 1 provides a generic starting point; it is not a substitute for site investigation or asset-specific design records.

Table 1. Asset–mechanism–observation–decision matrix for port geotechnical infrastructure

Asset system	Mechanisms to represent	Complementary observations	Decision supported
Pile-supported wharf	Axial or lateral pile response; group interaction; deck–pile deformation; seabed change; fatigue or impact effects.	Survey and tilt; pile or deck strain; acceleration; joint movement; loads; bathymetry; inspection.	Targeted inspection, load review, repair planning, and model recalibration.
Anchored or sheet-pile quay	Wall bending; anchor demand; backfill settlement; pore-pressure rise; toe movement; corrosion-related stiffness loss.	Inclinometer; anchor or strain response; pore pressure; settlement; water level; visual and underwater inspection.	Drainage check, anchor assessment, excavation or surcharge control, and intervention design.
Caisson quay or breakwater	Foundation settlement; sliding or rotation; joint opening; bearing response; overtopping effects; scour or undermining.	Geodetic movement; tilt; joint gauges; acceleration; wave and water level; bathymetry; sonar inspection.	Stability assessment, seabed protection, maintenance priority, and operating-envelope review.
Reclaimed platform and yard	Primary or secondary settlement; differential movement; cyclic densification; drainage change; pavement distress.	Levelling or GNSS; surface displacement; pore pressure; groundwater; loads and stack history; pavement inspection.	Yard-use planning, drainage maintenance, resurfacing, and ground-improvement assessment.
Coastal embankment or slope	Rainfall infiltration; groundwater rise; toe erosion; progressive movement; construction-induced stress change.	Piezometers; inclinometers; surface survey; rainfall; drainage state; shoreline or toe survey; inspection.	Access restriction, drainage or toe works, investigation, and emergency planning.
Seabed, dredged slope, and toe	Scour; sedimentation; dredging-induced geometry change; loss of support; slope instability.	Multibeam or sonar survey; dredging records; currents and waves; turbidity; diver or remotely operated inspection.	Dredging control, scour protection, foundation review, and navigation maintenance.

Source: *Authors' synthesis informed by port-monitoring and quay-wall studies by Bi et al. (2024), Lee et al. (2025), Negi et al. (2024), Ruggeri et al. (2024), and Shin et al. (2024).*

The monitored state should be concise enough to estimate, yet rich enough to represent the intended decisions. A generic port geotechnical state vector is:

$$\mathbf{x}_t = [s_t, \dot{s}_t, \theta_t, \varepsilon_t, N_t, u_t, h_t, q_t, a_t, T_t]^{\mathrm{T}} \quad (1)$$

where x_t is the monitored state at time t; s_t and $\dot{s}_t$ are displacement or settlement and its rate; θ_t is rotation or tilt; ε_t is strain; N_t is a relevant pile, anchor, or structural-force descriptor inferred through a validated model; u_t is pore-water pressure; h_t is water level; q_t represents site-defined wave, current, surcharge, cargo, or other boundary/load descriptors; a_t is acceleration or vibration; and T_t is temperature used to interpret environmental effects. Equation (1) is a schema, not a demand that every project estimate every term. The selected components must follow the mechanism register and sensor capability (Bi et al., 2024; Negi et al., 2024; Ruggeri et al., 2024; Shin et al., 2024).

Data quality and the minimum information contract

A digital twin depends on associations among observations, assets, locations, models, and decisions. Every observation therefore requires an immutable source identifier, asset and sensor identity, position and orientation, unit, timestamp and time basis, calibration record, acquisition and processing version, quality status, uncertainty, and responsible owner. The twin must retain raw evidence or a governed link to it, because a processed indicator alone cannot support later forensic review.

A transparent stream-confidence indicator can support data triage:

$$c_i(t) = \alpha_i \, \kappa_i(t)[1 - m_i(t)]\exp\left[-\frac{\Delta t_i(t)}{\tau_i}\right] \quad (2)$$

where $c_i(t)$ is the current confidence assigned to stream i; α_i is a site-approved baseline reliability factor based on installation and calibration; $\kappa_i(t)$ is a bounded quality-test result; $m_i(t)$ is a missing-data indicator between zero and one; $\Delta t_i(t)$ is data age; and τ_i is a decision-specific ageing constant. Equation (2) is an architectural rule for exposing deterioration in evidence, not a universal reliability law. Values and tests must be established from instrument behaviour and decision requirements. A low confidence suppresses unsupported conclusions; it does not prove physical instability or safety (Chen et al., 2024; Freddi et al., 2023).

Table 2. Minimum information contract for a port-foundation digital twin

Information object	Required fields	Quality and provenance controls	Twin use
Asset, geometry, and identity	Unique asset and component IDs; coordinates and datum; dimensions; materials; foundation type; construction and modification history.	Survey date; source model; level of detail; revision status; owner approval; geometric uncertainty.	Spatial linkage, model mesh, inspection location, and decision scope.
Ground and foundation model	Strata; bathymetry; fill and reclamation phases; groundwater; parameters; tests; foundation records; uncertainty ranges.	Investigation method; depth and coverage; laboratory or field standard; sample date; interpretive author.	Mechanism definition, parameter updating, and counterfactual analysis.
Sensor and geodetic time series	Sensor ID; channel; position and orientation; unit; time basis; sample or survey epoch; value; uncertainty; status.	Calibration; drift and range checks; synchronization; missingness; firmware and processing version.	State estimation, anomaly diagnosis, and trend assessment.
Marine, meteorological, and hydraulic boundary	Water level; waves; currents; rainfall; temperature; drainage or pumping state; source and forecast horizon.	Station representativeness; datum; latency; gap handling; forecast issue time and revision.	Load and boundary definition, event attribution, and scenario forecast.

Information object	Required fields	Quality and provenance controls	Twin use
Operations and construction	Berthing; cargo and crane configuration; traffic; dredging; piling; excavation; surcharge; restricted area; work permit.	Authoritative system; start and end time; location; responsible party; completeness; later corrections.	Load attribution, confounder control, and intervention learning.
Inspection, intervention, and decision	Finding; image or scan; location; severity basis; repair; work order; decision; authority; validity; follow-up.	Inspector competency; method; evidence link; approval; closure record; superseded status.	Validation, maintenance planning, and auditable feedback.
Model, forecast, and provenance	Purpose; version; equations or algorithm; parameters; training or calibration set; domain; output; uncertainty; residual.	Independent review; code and data hash; validation result; change approval; retirement rule.	Reproducible state update, forecast, comparison, and governance.

Source: *Authors' data specification derived from interoperable SHM and digital-twin requirements discussed by Chen et al. (2024), Jost et al. (2025), Naderi and Shojaei (2022), Neugebauer et al. (2024), and Wang et al. (2023).*

Semantic interoperability is as important as communication interoperability. “Settlement” must state direction, datum, reference, spatial support, and whether it is directly measured or model-derived. “Load” must distinguish applied action from inferred response. “Alarm” must name the rule, version, authority, and required action. Regional exchange should therefore use shared identifiers and metadata while preserving local coordinate reference systems, geotechnical classification, legal responsibilities, and operating procedures.

PROPOSED DIGITAL-TWIN FRAMEWORK

Six-layer architecture

Figure 1 presents the proposed architecture. The physical layer includes the port structure, foundations, supporting ground, nearby slopes, seabed, and environmental and operational boundaries. The observation layer combines geotechnical, structural, geodetic, marine, operational, and inspection evidence. Edge quality control synchronizes time, rejects impossible values without erasing the raw record, detects drift or staleness, and buffers essential data during communication loss. The information layer associates observations with asset and ground-model objects. The twin layer updates state and uncertainty using competing physical and data-driven models. The action layer exposes evidence to authorised engineers and records the resulting decision and follow-up.

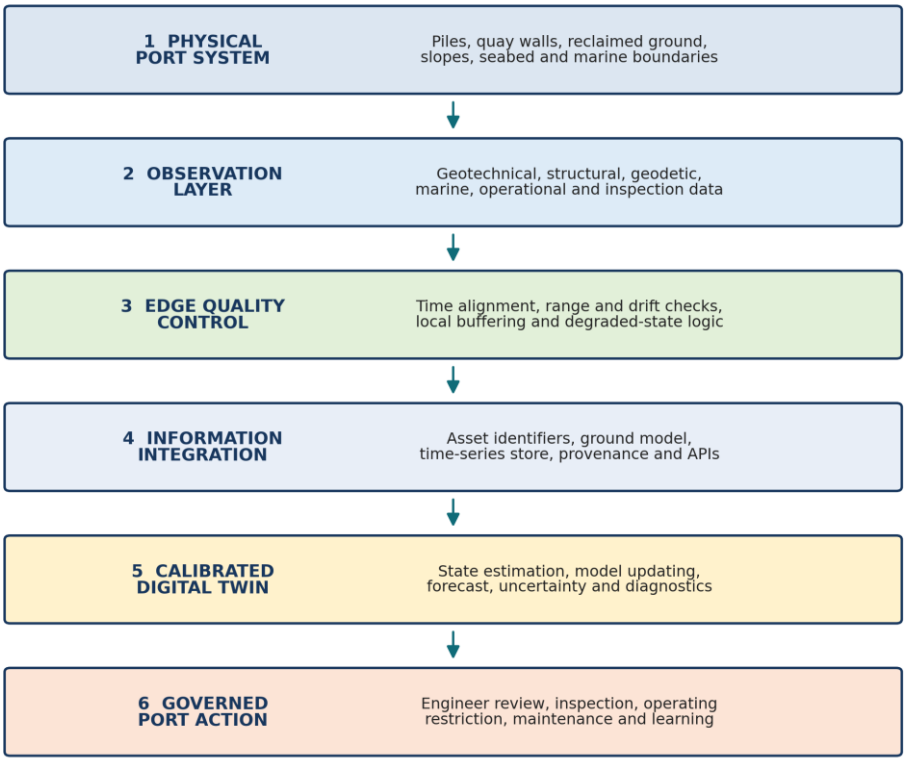

Figure 1. Six-layer architecture for a port-foundation and coastal-infrastructure digital twin

Source: *Authors' original framework synthesising port digital-twin concepts from Bi et al. (2024), Jayasinghe et al. (2024), Klar et al. (2023), and Neugebauer et al. (2024), with interoperable sensing and assurance principles from Chen et al. (2024) and Wang et al. (2023).*

No single model should be forced to explain all port behaviour. A finite-element or reduced-order geotechnical model may represent stress, deformation, pore-pressure coupling, and soil–structure interaction. Statistical baseline models can capture seasonal or operational response. Machine-learning surrogates can reduce computational latency after they have been trained against a valid model or dataset and tested within a defined domain. Underwater point clouds and imagery can support geometry and damage tracking. The twin should compare these evidence sources rather than obscure disagreement behind a composite score (Hake et al., 2022; Jayasinghe et al., 2024; Jost et al., 2025).

State transition, observation, and Bayesian updating

The latent geotechnical–structural state evolves under operational and environmental boundaries according to:

$$\mathbf{z}_t = \mathcal{M}(\mathbf{z}_{t-1}, \mathbf{b}_t, \boldsymbol{\vartheta}) + \mathbf{w}_t \tag{3}$$

where z_t is the latent state at time t; M is a selected physical, reduced-order, or hybrid transition model; b_t contains observed or forecast loads and boundary conditions; ϑ contains model parameters; and w_t represents process error and unresolved mechanisms. Parameters may include stiffness, permeability, consolidation properties, interface response, damping, or support conditions, but only those that the available observations can meaningfully identify should be updated. Equation (3) follows physics-informed digital-geotechnics practice; it must be specialised and calibrated for the asset (Tian & Wang, 2023; Wang & Tian, 2024).

Measurements are linked to the latent state through an observation model:

$$\mathbf{y}_t = \mathcal{H}_t(\mathbf{z}_t) + \mathbf{v}_t \tag{4}$$

where y_t is the vector of synchronized measurements; H_t maps the latent state to the locations, directions, and quantities actually observed; and v_t represents measurement error. The operator can contain a survey projection, a strain–response mapping, a pore-pressure observation, or a numerical-model output. Equation (4) prevents direct comparison of incompatible quantities—for example, seabed change and deck tilt—without an explicit model (Bi et al., 2024; Jayasinghe et al., 2024).

The probability distribution of the state is updated as evidence arrives:

$$p(\mathbf{z}_t \mid \mathcal{D}_t) \propto p(\mathbf{y}_t \mid \mathbf{z}_t)\, p(\mathbf{z}_t \mid \mathcal{D}_{t-1}) \tag{5}$$

where D_t is the evidence available through time t; $p(y_t|z_t)$ is the likelihood defined by the observation model and quality information; and $p(z_t|D_{t-1})$ is the prior state distribution propagated from earlier evidence. Equation (5) expresses Bayesian updating and does not prescribe a particular filter. Particle, ensemble, variational, or other methods may be appropriate according to nonlinearity, computational resources, and validation. Quality confidence from Equation (2) should influence the likelihood or exclusion logic transparently rather than silently reweighting evidence (Tian & Wang, 2023).

Forecast, limit state, and diagnostic residual

A useful forecast is tied to a defined state, horizon, scenario, and decision. For a limit-state function g, the conditional probability of entering an adverse domain is:

$$P_f(t, \Delta) = P[g(\mathbf{z}_{t+\Delta}, \mathbf{r}) \leq 0 \mid \mathcal{D}_t] \tag{6}$$

where $Pf(t,\Delta)$ is the conditional probability over forecast horizon Δ; $z_{t+}\Delta$ is the forecast state; r contains resistance, capacity, or tolerance variables and their uncertainty; and g is a locally defined serviceability or ultimate limit-state function, with values at or below zero representing the adverse domain under the adopted convention. Equation (6) does not provide a universal intervention threshold. Decision criteria must account for consequence, lead time, redundancy, model validity, and the port's approved risk process (Mahmoodian et al., 2022; Wang & Tian, 2024).

Model–measurement disagreement is itself important evidence. A normalized innovation statistic is:

$$J_t = \mathbf{r}_t^{\mathsf{T}} \mathbf{S}_t^{-1} \mathbf{r}_t, \qquad \mathbf{r}_t = \mathbf{y}_t - \hat{\mathbf{y}}_t \tag{7}$$

where J_t is the normalized innovation measure; r_t is the residual between the observation y_t and the model-predicted observation $\hat{y}_t$; and S_t is the residual covariance. A large or persistent innovation may indicate physical change, an unmodelled operational event, sensor drift, incorrect boundary data, or model inadequacy. It is a diagnostic trigger, not proof of damage. Thresholds must be calibrated against validated normal and abnormal behaviour and reviewed when the model or operating domain changes (Lee et al., 2025; Tian & Wang, 2023).

Evidence-to-decision package

Figure 2 shows how ground and foundation evidence, structural response and load, and marine and operational boundaries are brought into the twin update. The output is deliberately separated into state and forecast, quality and residual, and risk and response options. The engineer receives all three views. A favourable forecast cannot override missing critical evidence, and an anomaly score cannot bypass a mechanism review. The decision record states the evidence used, uncertainty, responsible authority, period of validity, and required confirmation.

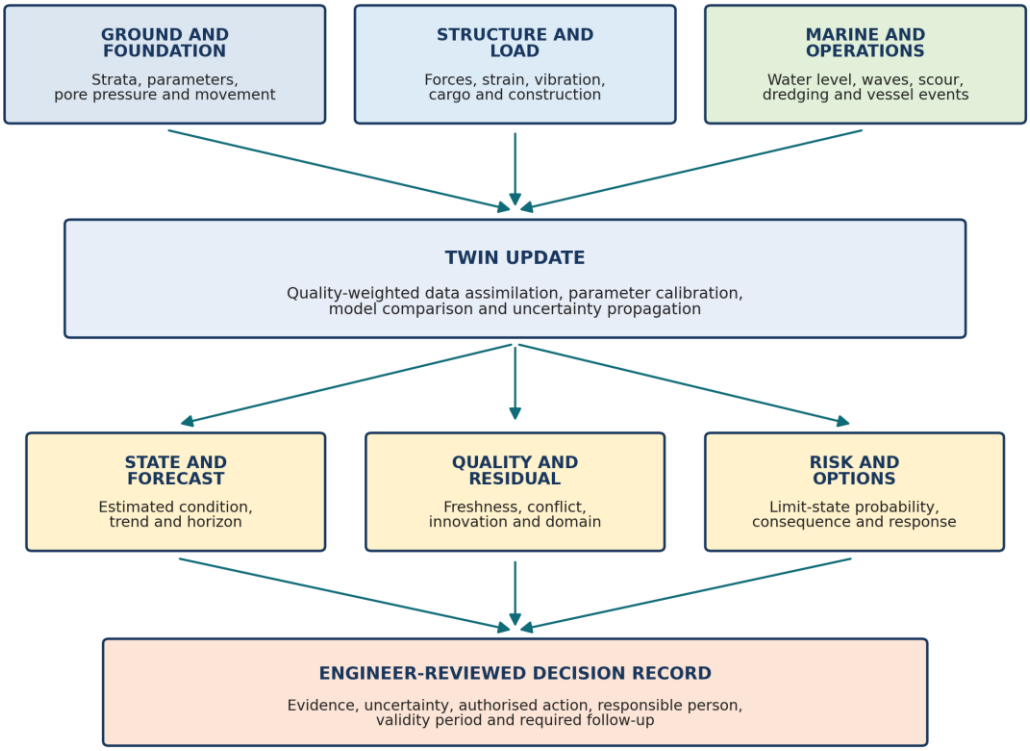

Figure 2. Evidence-to-decision package for governed port digital-twin operation

Source: *Authors' original design informed by probabilistic updating in Tian and Wang (2023), online quay-wall diagnostics in Lee et al. (2025), port-structure response modelling in Jayasinghe et al. (2024), and infrastructure risk governance in the National Institute of Standards and Technology (NIST, 2023).*

The explanation accompanying a forecast should identify the dominant current loads and boundaries, the observations that materially changed the state estimate, the parameters updated, disagreement among models, data outside the validated domain, and feasible actions. Explanations based on feature attribution may support diagnosis, but they remain descriptions of a fitted model unless tested against physical mechanisms. A counterfactual—such as recomputing the state without a suspect sensor or under an alternative groundwater boundary—can be more informative than a single importance ranking.

Real-time service classes and fail-explicit operation

The required update rate follows the decision, not a generic technology claim. Table 3 defines four service classes without inventing universal time limits. Each port must translate the class into validated latency, availability, and fallback requirements. Data delivery slower than the site-approved horizon is stale for that decision even if it would be timely for a longer-term engineering assessment.

Table 3. Decision-linked real-time service classes for port digital twins

Service class	Intended decision	Update evidence	Safe degraded mode
Local safety event	Recognise a short-duration impact, vibration, rapid movement, or instrumented event requiring immediate local review.	Edge timestamp; local sensor fusion; event trigger; health status; buffered raw record; authorised notification.	Local alarm or conservative operating rule remains available when central communication fails.

Service class	Intended decision	Update evidence	Safe degraded mode
Operational watch	Review behaviour during berthing, cargo handling, dredging, piling, excavation, severe weather, or changed drainage.	Synchronized operational, environmental, geotechnical, and structural streams with quality and baseline comparison.	Declare incomplete evidence; apply pre-approved conservative controls; request inspection or confirmation.
Engineering assessment	Update condition, parameters, scenarios, and intervention options for an identified asset or mechanism.	Quality-controlled monitoring, surveys, inspections, ground data, model version, uncertainty, and independent check.	Freeze the last valid model, identify what is missing, and return the question for investigation.
Lifecycle planning	Prioritise investigation, maintenance, renewal, adaptation, and data investment across an asset portfolio.	Validated long-term trends, inspection and intervention history, consequence, deterioration assumptions, and cost evidence.	Retain uncertainty ranges and avoid ranking assets with materially incomparable evidence as if equivalent.

Source: *Authors' service classification based on edge-enabled infrastructure monitoring in Chen et al. (2024) and Mishra et al. (2024), and port digital-twin decision contexts reviewed by Klar et al. (2023) and Neugebauer et al. (2024).*

Fail-explicit logic is mandatory. Missing, stale, conflicting, drifting, or out-of-domain evidence produces a named degraded or unknown state. The system must state which decision is affected and which services remain valid. Redundancy is functional rather than merely numerical: an inclinometer, pore-pressure response, survey displacement, and visual inspection provide different evidence about a quay mechanism. Replicating the same vulnerable sensor does not establish independent confirmation.

RESULTS AND DISCUSSION

Design evaluation and requirements traceability

The design evaluation produced five principal results. First, the twin boundary expands from the visible waterfront structure to include foundations, supporting ground, seabed, environmental boundaries, and relevant operations. Second, the data contract distinguishes a measured quantity from a model-derived state and records the transformation between them. Third, Equations (2)–(7) make quality, dynamics, observation, updating, forecast, and residual diagnosis explicit. Fourth, service classes connect latency to an authorised decision. Fifth, every consequential output ends in an evidence package and decision record rather than an unexplained dashboard status.

These are design outcomes, not measured performance outcomes. They show that the proposed components address the stated requirements and that common failure modes have explicit controls. Field validity still depends on whether instruments, models, and decision procedures perform under the site's geology, marine exposure, construction, ageing, and operational variability. Table 4 defines the evidence needed to progress from component testing to operational assurance.

Table 4. Validation and assurance matrix for a port-foundation digital twin

Assurance layer	Question to verify	Evidence and test	Acceptance basis
Sensor and communication	Are observations accurate, synchronized, available, and recoverable under expected conditions?	Calibration; drift and temperature tests; clock audit; controlled gaps; communication-loss and buffer-recovery test.	Project-specific metrological and availability requirements linked to intended decisions.

Assurance layer	Question to verify	Evidence and test	Acceptance basis
Geodetic and geotechnical observation	Do measurements represent the stated location, direction, depth, datum, and mechanism?	Independent survey; installation records; datum closure; ground investigation; repeatability; plausibility across sensors.	Agreement within stated uncertainty or documented explanation of discrepancy.
Physical and numerical model	Does the model represent relevant load paths, boundaries, soil behaviour, and parameter uncertainty?	Benchmark problems; sensitivity; mesh and timestep checks; calibration; competing models; independent review.	Fit for the named scenario and domain, not general correctness.
Surrogate or data-driven model	Does the model reproduce required outputs within the validated input domain and expose extrapolation?	Held-out events; temporal and asset separation; baseline comparison; calibration; domain-shift and perturbation tests.	Predefined error and reliability criteria for the intended output and horizon.
Forecast and diagnosis	Are uncertainty, residuals, false alarms, missed events, and lead time understood prospectively?	Shadow operation; event replay; synthetic fault injection; prospective prediction; threshold sensitivity.	Site-approved balance of consequences, evidence, and response capacity.
Decision and governance	Can authorised users interpret the output, apply controls, and reconstruct the decision?	Scenario exercise; role test; explanation review; audit-trail reconstruction; override and expiry tests.	Competent authority approves use, limitations, escalation, and review cycle.
Cybersecurity and continuity	Can the system preserve trustworthy evidence and essential service during attack or component failure?	Identity and access review; integrity test; backup restoration; segmentation; incident exercise; dependency inventory.	Risk treatment and recovery objectives approved under the port's security governance.

Source: *Authors' assurance matrix informed by civil-infrastructure twin reviews (Naderi & Shojaei, 2022; Neugebauer et al., 2024), sensing validation (Chen et al., 2024; Freddi et al., 2023), and NIST governance guidance (NIST, 2023, 2024).*

Desk-based stress cases

Stress case 1 concerns conflicting observations at an anchored quay. A wall inclinometer indicates increasing movement while a nearby surface survey remains stable and pore pressure is unchanged. The framework does not average the evidence into a safe composite. It checks instrument orientation, depth, calibration, survey support, time alignment, wall temperature, construction or surcharge records, and the predicted spatial deformation mode. The output is a conflict diagnostic, a bounded set of mechanism hypotheses, and a targeted confirmation plan. This case demonstrates the value of Equations (2), (4), and (7).

Stress case 2 concerns pile installation or other construction near an operating quay. Time-stamped works, vibration, anchor strain, wall movement, and geodetic observations are associated with the same asset and work zone. The twin compares the response with the approved construction-stage model and pre-work baseline. Evidence from monitored quay works shows why wall-top displacement, inclinometer profiles, and anchor measurements should be interpreted together (Ruggeri et al., 2024). The framework can support review of the construction sequence, but it cannot infer structural safety from vibration alone.

Stress case 3 concerns a severe marine event accompanied by missing underwater geometry. Water level, waves, structural acceleration, tilt, and joint response are available, but the latest bathymetric or sonar survey predates the event. The twin may update short-term structural response within its validated domain while declaring scour-dependent foundation conclusions unknown. A post-event survey or underwater inspection becomes a required action. This separates a valid monitored response from an unsupported foundation claim.

Stress case 4 concerns loss of the central data service during a local event. The edge layer retains its health checks, event recognition, raw-data buffer, and pre-approved notification route. Central forecasting and portfolio functions are marked unavailable. On reconnection, records are transferred with their original timestamps and integrity metadata; the twin is replayed and reconciled before the central state is treated as current. The case confirms that local continuity and later auditability can coexist without pretending that all services remained active.

Across the four cases, the architecture remained logically consistent because uncertainty and availability are attributes of each decision service, not a single system-wide traffic light. The most important outcome is negative capability: the framework can state what is not known. This is preferable to a high-resolution visualisation that obscures missing boundary data, model inadequacy, or conflicting evidence.

Black Sea applicability and regional interoperability

Black Sea ports operate across different geological settings, tidal and non-tidal water-level influences, wave exposures, sediment regimes, seismic contexts, construction histories, and governance systems. Regional studies indicate spatially and temporally variable waves, profile response, and coastal motion (Arı Güner & Başaran, 2024; Erkoç et al., 2025; Islek et al., 2022). The Kıyıcık case further demonstrates that coastal infrastructure and slope processes can interact, although its evidence cannot be transferred to a port without local investigation (Turoğlu & Duran, 2025).

The appropriate regional objective is therefore a shared information contract, not a uniform physical model. Ports can agree on asset identifiers, time and coordinate metadata, sensor-health states, model provenance, uncertainty representation, decision records, and exchange interfaces. Each site retains its local ground model, boundary conditions, limit states, maintenance authority, and legal requirements. A coastal-zone information architecture can link port twins with shoreline, hydrometeorological, environmental, and urban systems while maintaining these boundaries (Yu et al., 2026).

Regional learning should use transfer tests rather than assumed similarity. A model developed for one quay type or operational regime must be evaluated against the new asset's geometry, materials, ground, loads, sensors, and decision horizon. Where raw data cannot be shared, ports can exchange schemas, benchmark cases, validated model components, and documented failure modes. Such cooperation has scientific value even when a model is found not to transfer.

Governance, cybersecurity, and human factors

A port twin connects operational technology, sensor networks, geospatial systems, engineering models, inspection records, and maintenance workflows. This increases the potential consequence of corrupted timestamps, substituted sensor values, unauthorised model changes, unavailable dependencies, or misleading dashboards. Security controls must therefore include asset and dependency inventory, authenticated devices and users, least privilege, network segmentation, encrypted communication where appropriate, integrity-protected records, logging, backups, recovery exercises, and governed model release. Security evidence belongs in the twin provenance rather than in a separate compliance archive (NIST, 2024; Wang et al., 2023).

Governance must identify the asset owner, data steward, model owner, system operator, competent engineer, cybersecurity authority, and decision authority. It must define who can change sensor status, accept a calibration, release a model, alter a threshold, acknowledge an advisory, impose an operational control, and close an action. Every advisory requires a validity period because boundary conditions, data availability, and operations change.

Human-centred testing is necessary. Users should be able to distinguish a measured quantity from an estimated state, a residual from damage, a conditional probability from a frequency, and a low-confidence status from a safe status. Exercises should include contradictory evidence and unavailable services, not only obvious simulated failures. The twin succeeds when it improves an authorised decision and its reasoning can be reconstructed, not when it produces the most detailed visual model.

Staged implementation roadmap

Implementation should progress through evidence gates. A port should first select a bounded asset and decision with an identifiable owner, rather than digitising the entire estate without a testable purpose.

Each stage in Table 5 produces a reviewable deliverable and can stop if the next level is not justified. Existing monitoring and information systems should be reused when their provenance and interfaces are adequate.

Table 5. Staged roadmap for a Black Sea port-foundation digital twin

Stage	Principal work	Required deliverable	Gate to proceed
1. Intended use and failure model	Select asset, decision, authority, mechanisms, consequences, lead time, and current evidence.	Twin purpose statement; asset boundary; mechanism register; responsibility map; gap analysis.	Asset owner and competent engineer approve a bounded, valuable, and testable use.
2. Baseline and monitoring design	Compile records; investigate ground and foundations; survey geometry; select complementary observations; establish baselines.	Approved ground–asset model; monitoring plan; data contract; calibration and maintenance plan.	Observability and evidence quality are adequate for the intended claim.
3. Synchronized digital shadow	Connect time series, operations, boundaries, inspections, and asset identifiers; implement quality and degraded states.	Traceable dashboard and archive; sensor-health logic; replay; access controls; continuity test.	Users can reconstruct observations and limitations without predictive claims.
4. Calibrated twin in shadow operation	Implement competing physical and data-driven models; update state; quantify uncertainty; test residuals and forecasts prospectively.	Locked model versions; validation report; domain definition; forecast and failure-mode log.	Independent review confirms fitness for a named advisory under controlled conditions.
5. Controlled operational service	Integrate engineer review, inspection, work orders, authorised advisories, cyber response, training, and periodic revalidation.	Operating procedure; decision record; exercises; maintenance and model-change process; assurance schedule.	Competent authority accepts residual risk, limitations, escalation, and withdrawal criteria.
6. Portfolio and regional exchange	Scale only validated patterns; harmonise metadata; compare assets; share benchmarks and lessons; test transfer explicitly.	Interoperability profile; portfolio evidence map; transfer tests; governance agreements.	Shared information improves decisions without erasing local models or responsibilities.

Source: *Authors' roadmap synthesising infrastructure twin implementation and adoption findings from Mahmoodian et al. (2022), Moshood et al. (2024), Neugebauer et al. (2024), Opoku et al. (2023), and Tuhaise et al. (2023).*

Limitations and research agenda

This study has six principal limitations. It is a conceptual design and has not been deployed at a Black Sea port. The evidence synthesis is targeted rather than systematic. Equations (1)–(7) are integration structures, not calibrated asset models. No universal sensor layout, latency, threshold, failure probability, or maintenance action is proposed. Cybersecurity requirements are architectural and require local threat and dependency assessment. Finally, the framework cannot compensate for absent foundation records or inadequate ground investigation.

Research priorities include long-term open datasets that synchronize geotechnical, structural, marine, operational, inspection, and intervention evidence; methods for updating soil–structure interaction without creating unidentifiable parameter sets; trustworthy surrogates that expose extrapolation; assimilation of underwater geometry and damage observations; uncertainty propagation from instruments to operational decisions; and prospective evaluation of alarms and missed detections. Studies should report negative transfer results and periods in which the twin was degraded.

Black Sea research would particularly benefit from comparable pilot protocols across different quay types and geological settings. Shared benchmark definitions could specify asset geometry, boundary

data, observation metadata, prediction horizons, uncertainty scoring, and decision tasks while allowing each port to protect sensitive operational data. The scientific question should be whether the twin improves a defined engineering decision relative to a documented baseline, not whether it can display more data.

CONCLUSION

This paper has developed a digital-twin framework for real-time monitoring of port foundations and coastal geotechnical infrastructure in the Black Sea region. It links piles, quay walls, caissons, reclaimed ground, slopes, seabed, and marine and operational boundaries with complementary observations, edge quality control, an interoperable information layer, calibrated state estimation, forecast and diagnosis, and engineer-governed action.

The framework's central contribution is evidence discipline. Measurements are not treated as latent state; a fitted model is not treated as verified mechanism; an innovation is not treated as damage; and a forecast is not treated as a safety decision. Data freshness, uncertainty, domain, residuals, conflicting observations, and unavailable services remain visible. Editable equations, tables, and original figures provide a reproducible basis for local specification and review.

The proposed architecture is ready to guide a bounded pilot, but not to authorise port operations without site evidence. Ground investigation, foundation records, calibrated monitoring, independent validation, prospective shadow operation, decision exercises, cybersecurity assurance, and competent authority remain prerequisites. With these safeguards, digital twins can become transparent instruments for inspection, maintenance, adaptation, and learning rather than high-resolution substitutes for engineering judgement.

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MULTI-SENSOR DATA FUSION FOR EARTHQUAKE-INDUCED LIQUEFACTION EARLY WARNING IN BLACK SEA COASTAL SETTLEMENTS

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ABSTRACT

Objectives: This study develops a multi-sensor data-fusion framework for earthquake-induced liquefaction early warning in Black Sea coastal settlements while preventing earthquake detection, susceptibility mapping, or a single sensor response from being misrepresented as proof of liquefaction or safety. **Methods:** A design-science method and targeted synthesis of peer-reviewed and authoritative evidence published from 2022 to July 2026 were used to define the intended use, six-layer architecture, minimum data contract, editable fusion equations, evidence ladder, assurance controls, and staged implementation roadmap. Requirements traceability and four desk-based stress cases were applied. No new field dataset, deployed system, universal warning threshold, or performance claim is presented. **Results:** The framework combines site-characterisation priors, regional earthquake information, local strong-motion and pore-pressure measurements, groundwater and sea-level context, ground-deformation observations, remote sensing, and inspection evidence. Quality and freshness weights, physics-informed demand–capacity screening, Bayesian state updating, and loss-aware action selection preserve uncertainty and convert missing or contradictory evidence into a degraded or unknown status. **Conclusions:** A liquefaction warning service should be implemented as an evidence progression from susceptibility through triggering and manifestation to consequence. Site-specific calibration, prospective validation, communication testing, cybersecurity assurance, and competent engineering authority are prerequisites for operational use.

Keywords: Liquefaction; earthquake early warning; multi-sensor fusion; coastal settlements; Black Sea; geotechnical risk.

INTRODUCTION

Earthquake-induced soil liquefaction is a time-dependent loss of strength and stiffness in susceptible saturated granular ground under cyclic loading. Its engineering consequences can include settlement, lateral spreading, bearing failure, flotation of buried infrastructure, ground cracking, quay-wall movement, and disruption of roads, water, energy, and communication networks. In a coastal settlement, these consequences may interact with water bodies and damaged flood defences. Observations after the 2023 Kahramanmaraş earthquake sequence showed that liquefaction-related deformation can contribute to cascading coastal flooding, illustrating why consequence assessment must extend beyond a binary triggering label (Bassal et al., 2024; Cetin et al., 2025; Toprak et al., 2025).

The phrase “liquefaction early warning” requires precision. Earthquake early-warning systems detect an earthquake after rupture has begun and estimate the likely arrival and intensity of shaking at downstream locations; they do not predict the earthquake. Depending on source–site geometry, detection speed, network density, communication, and the action being protected, useful warning time may be short or absent. Recent reviews and operational developments show that distributed ground-motion sensing, node-level processing, onsite models, and mobile devices can expand detection coverage, but they also

expose trade-offs in latency, magnitude estimation, false alarms, and public communication (Allen & Stogaitis, 2022; Allen et al., 2025; Chandrakumar et al., 2022; Prasanna et al., 2022; Wang et al., 2022).

Liquefaction is more difficult to warn for than shaking because the phenomenon depends on the combination of event-specific cyclic demand and local soil, groundwater, stress, and drainage conditions. A susceptibility map is a pre-event prior, not an event diagnosis. A strong-motion record describes demand but does not prove pore-pressure generation. A pore-pressure transducer provides direct evidence only at its installation depth and location. Surface deformation, ejecta, and remote-sensing signatures may confirm manifestation, but often after the most time-critical protective actions have passed. Reliable decision support therefore depends on multi-sensor evidence that is fused according to physical meaning, time, quality, uncertainty, and the action horizon.

This distinction matters in the Black Sea region. A Europe-wide susceptibility study identified Black Sea beach deposits as one macro-unit in which liquefaction has been observed, while also making clear that continental-scale mapping is a screening product rather than a local site assessment (Meisina et al., 2022). Eastern Black Sea investigations demonstrate spatial variability in seismicity, stiffness, resistivity, weathering, and groundwater conditions and show the benefit of integrating seismic and electrical geophysical methods (Karslı et al., 2024). Coastal-motion research further demonstrates the value of combining in-situ and satellite observations around the basin (Erkoç et al., 2025). These studies justify local evidence and regional data compatibility; they do not support one transferable Black Sea-wide liquefaction threshold.

This paper develops a design-science framework for a multi-sensor liquefaction warning service. Its contributions are a six-layer architecture, an observation-and-limitations matrix, a minimum data contract, seven editable equations, an evidence ladder that separates susceptibility, triggering, manifestation, and consequence, a validation and assurance matrix, four desk-based stress cases, and a staged roadmap for Black Sea coastal settlements. No field campaign, deployed warning service, measured performance, or universal threshold is reported. The framework specifies the evidence and governance needed before operational claims can be made.

METHODOLOGY

Research design and evidence base

A design-science method was adopted because the research objective is to construct and logically evaluate an engineering warning architecture rather than infer site performance from a new dataset. A targeted synthesis was undertaken using peer-reviewed and authoritative sources published from 2022 to July 2026. Evidence was selected for direct relevance to liquefaction susceptibility and triggering, probabilistic and interpretable assessment, earthquake early warning, low-cost sensing, laboratory pore-pressure observation, satellite and geospatial manifestation mapping, coastal consequences, sensor fusion, edge processing, social communication, artificial-intelligence governance, and cybersecurity. The synthesis is targeted and does not claim the exhaustive coverage of a systematic review.

Each source was interrogated against five questions: what state or phenomenon was observed; at what spatial and temporal scale; what assumptions connected the observation to liquefaction; what uncertainty or failure mode remained; and what decision could reasonably use the evidence. Requirements were then traced to architecture components, equations, data fields, warning states, and assurance activities. Four hypothetical but technically plausible stress cases were used to determine whether the proposed service exposes uncertainty and fails explicitly. The cases test design behaviour only and are not simulations of named Black Sea settlements.

Intended use and claim discipline

The intended use is to provide time-qualified evidence for emergency managers, infrastructure operators, and competent geotechnical engineers to prioritise protective action and inspection. The service may support pre-event readiness, immediate earthquake and shaking advisories, local triggering watches, rapid impact screening, and post-event confirmation. The exact action set is owned locally and

may include checking critical valves, pausing vulnerable operations where lead time permits, restricting access, dispatching inspection teams, or maintaining an unknown status until evidence is restored.

The service is not authorised by this conceptual study to declare ground safe, automate evacuation, close infrastructure, or replace a site-specific liquefaction assessment. Any such use requires local legal authority, validated trigger logic, consequence analysis, communication testing, and an auditable operating procedure. The same evidence can justify different actions because the cost of false alarm, missed detection, and delay differs among a fuel terminal, hospital access road, residential district, and buried utility corridor.

LIQUEFACTION WARNING PROBLEM IN COASTAL SETTLEMENTS

Susceptibility, triggering, manifestation, and consequence

A warning system should maintain four distinct propositions. Susceptibility asks whether local ground can liquefy under appropriate loading. Triggering asks whether a particular earthquake has imposed demand sufficient to generate damaging pore-pressure response. Manifestation asks whether ground deformation or ejecta has occurred. Consequence asks how that deformation affects people, buildings, networks, and coastal hazards. Conflating these propositions creates avoidable error. For example, a high-susceptibility map cell can remain unaffected in a modest event, while an unrecognised fill pocket within a lower-resolution cell can develop damaging deformation.

Recent geospatial models combine global, continental, regional, and event-specific information, but their agreement and error vary with input data and scale (Asadi et al., 2024). Machine-learning reviews likewise show useful predictive capability while identifying sensitivity to database construction, feature definitions, class imbalance, validation practice, and interpretability (Jas & Dodagoudar, 2023). Bayesian approaches can integrate SPT and CPT evidence and express probability, while rule-based interpretable learning can expose conditional patterns (Han et al., 2024; Torres & Dungca, 2024). These tools are appropriate as calibrated components, not as substitutes for ground models or independent event observations.

Black Sea coastal context and transfer limits

Black Sea coastal settlements include natural beach deposits, deltas, alluvial plains, reclaimed waterfronts, ports, embankments, buried utilities, and dense urban development. Their seismic sources, soil fabric, fines content, age, stress history, groundwater regime, drainage, and foundation systems differ. Sea-level and groundwater variations can alter saturation and effective stress, but no single hydraulic proxy represents the three-dimensional pore-pressure field. Regional screening can identify where investigation is most valuable; local boreholes, CPT or SPT, shear-wave velocity, laboratory interpretation, groundwater observation, and engineering records are required for site decisions.

The proposed regional strategy is consequently interoperability without physical homogenisation. Participating settlements can share common event identifiers, time standards, coordinate reference systems, sensor-health vocabularies, uncertainty fields, provenance, warning semantics, and exercise protocols. Each jurisdiction retains its ground model, sensor layout, trigger criteria, consequence functions, language, communication channels, and accountable authority. This arrangement supports comparison and mutual learning without treating a model developed for one coast, deposit, or infrastructure system as locally validated elsewhere.

Multi-sensor observability

Sensor selection follows the causal chain rather than a desire for maximum data volume. Baseline observations characterise susceptibility and saturation. Regional networks provide source and ground-motion information. Local accelerometers observe shaking at or near the site. In-place piezometers observe excess pore pressure at selected depths. GNSS, tiltmeters, settlement points, and extensometers indicate movement. Optical, radar, unmanned-aerial-vehicle, and field observations can locate surface manifestations and infrastructure effects. Table 1 summarises what these observations contribute and, equally importantly, what they cannot establish alone.

Table 1. Sensor and observation roles in a liquefaction warning service

Observation family	Primary contribution	Important limitation	Quality and corroboration need
CPT, SPT, laboratory and shear-wave-velocity baseline	Defines stratigraphy, index or resistance measures, stress conditions, and site-specific susceptibility priors.	Spatial sampling is incomplete; empirical methods and corrections have defined domains.	Record method, depth, coordinates, datum, groundwater condition, corrections, version, and interpretive uncertainty.
Regional or distributed earthquake detection	Estimates event origin, magnitude or evolving size, expected arrival, and spatial shaking demand.	Detection occurs after rupture begins; useful lead time and early magnitude accuracy are event- and site-dependent.	Preserve update history, latency, network geometry, uncertainty, and whether the message is regional or onsite.
Local strong-motion accelerometer	Measures site motion and supports event-specific cyclic-demand and duration descriptors.	Motion alone does not prove saturation, pore-pressure generation, or deformation.	Check orientation, timing, clipping, mounting, noise, calibration, and agreement with neighbouring stations.
In-place pore-pressure transducer	Directly observes total pore-pressure change at an instrumented location and depth.	A point response may not represent nearby lenses; drift, air, installation disturbance, and sensor range can mislead.	Use baseline effective stress, barometric or tidal context where relevant, metrology, redundancy, and plausibility checks.
Groundwater and sea-level observation	Constrains hydraulic boundary and saturation prior before and after an event.	Water level is not equivalent to transient excess pore pressure within every susceptible layer.	Reference a common datum; record sampling, wells, tidal influence, seasonal range, and sensor status.
GNSS, tilt, settlement and extensometry	Detects permanent or progressive movement that may indicate manifestation or consequence.	Movement can arise from structural response, slope movement, thermal effects, settlement, or monument instability.	Use stable reference control, uncertainty, direction, event time, independent inspection, and mechanism comparison.
Optical, SAR, UAV and field inspection	Maps ejecta, cracking, lateral spreading, subsidence, inundation, and asset disruption over wider areas.	Availability may be delayed or obstructed; remote signatures are indirect and can be confused with other processes.	Preserve acquisition geometry and time, resolution, processing lineage, confidence, and field confirmation.

Source: *Authors' synthesis based on Albano et al. (2024), Bojadjieva et al. (2022), Chandrakumar et al. (2022), Esposito et al. (2024), Freddi et al. (2023), Karslı et al. (2024), and Taftsoglou et al. (2023).*

PROPOSED MULTI-SENSOR FUSION FRAMEWORK

Six-layer architecture

Figure 1 presents the proposed architecture. The baseline ground model provides a spatial prior and identifies exposed assets. The earthquake-detection layer maintains a versioned event estimate and expected shaking. Local observations capture motion, hydraulic response, and deformation. A quality-aware fusion layer time-aligns streams, evaluates health and freshness, enforces physical constraints, and updates uncertainty. Consequence assessment distinguishes triggering likelihood from observed deformation and infrastructure effects. The final layer produces governed advisories and actions with named authority, validity, and follow-up.

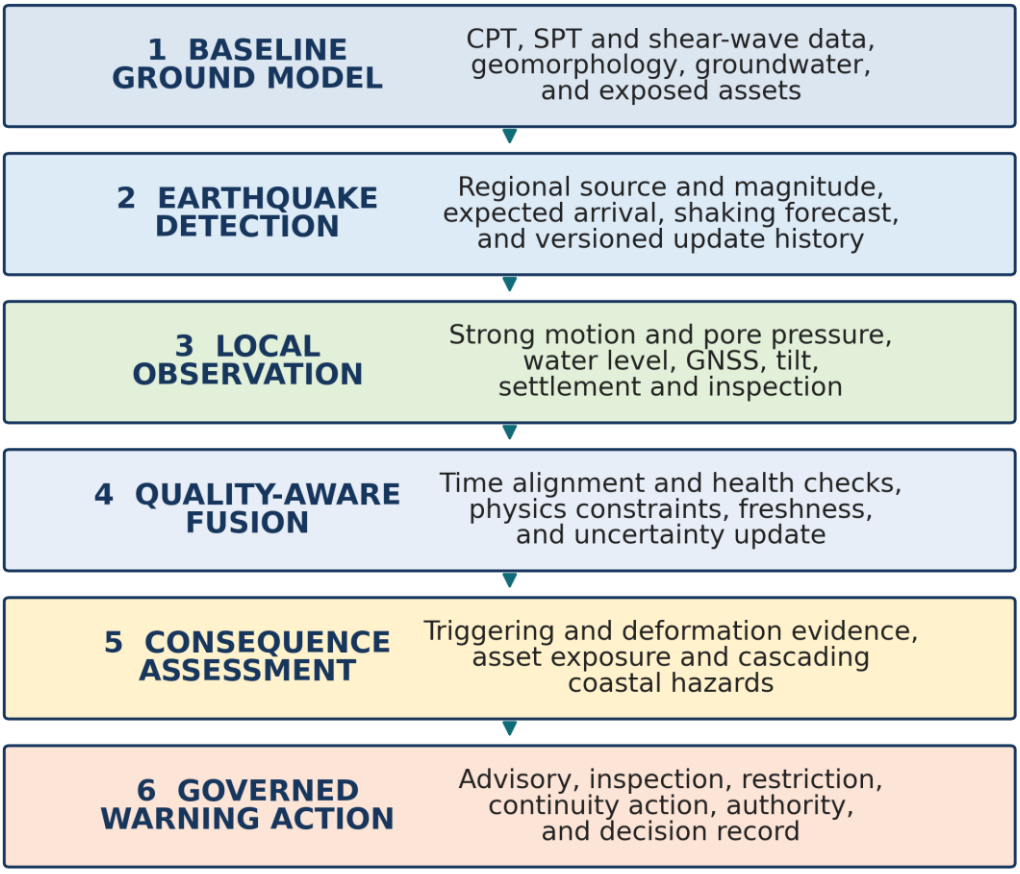

Figure 1. Six-layer architecture for multi-sensor liquefaction early warning

Source: *Original framework developed by the authors from evidence in Allen and Stogaitis (2022), Han et al. (2024), Meisina et al. (2022), Taftsoglou et al. (2023), and Tan et al. (2022).*

The architecture deliberately separates the data pathway from authority. A model may update automatically, but a high-consequence action is governed by an approved rule or competent person. Every displayed state identifies its evidence time, spatial support, model version, uncertainty, and data-quality status. When a critical stream is absent, stale, saturated, or contradictory, the system declares a degraded or unknown condition. It does not infer safety from silence.

Observation vector and minimum data contract

For spatial cell or asset k, the available time-indexed measurements can be represented by the observation vector in Equation (1). The vector is a schema rather than a requirement that every site install every sensor.

$$\mathbf{y}_{k,t} = \left[a_{k,t},\, v_{k,t},\, d_{k,t},\, \Delta u_{k,t},\, h_{k,t},\, \theta_{k,t},\, \varepsilon_{k,t}\right]^{\mathrm{T}} \tag{1}$$

In Equation (1), a, v, and d are acceleration, velocity, and displacement descriptors; Δu is excess pore-pressure change; h is groundwater or sea-level context referenced to a declared datum; θ is tilt; ε is a strain, settlement, or extensometer proxy; k identifies the spatial cell or asset; t is the observation time; and T denotes transpose. Only physically meaningful, calibrated terms are populated. Laboratory and field monitoring studies support combining motion, pore-pressure, and deformation measurements, but they also demonstrate that the observations have different spatial support and error processes (Bojadjieva et al., 2022; Freddi et al., 2023).

Fusion requires more than matching column names. Table 2 defines the minimum contract needed to reconstruct how an advisory was produced. Raw data, derived features, model inputs, and decision

outputs remain distinguishable. All timestamps use a declared standard, all locations use a recorded coordinate reference system, and all vertical measurements identify their datum and sign convention.

Table 2. Minimum data contract for traceable multi-sensor fusion

Record class	Required fields	Purpose in warning and audit
Spatial unit and asset	Unique identifier; geometry; coordinate reference system; elevation datum; land use; owner; critical dependencies.	Prevents observations and actions from being assigned to the wrong ground unit, structure, or network.
Ground and hydraulic baseline	Stratigraphy; CPT/SPT/Vs and laboratory records; stress and groundwater assumptions; susceptibility method; date; uncertainty; version.	Defines the prior and the domain within which event-specific evidence is interpreted.
Sensor stream	Device and channel ID; location and depth; orientation; unit; sampling; timestamp; calibration; range; quality flags; maintenance status.	Supports synchronisation, metrological traceability, health assessment, and reproducible feature calculation.
Earthquake and shaking	Event ID; source provider; origin and update times; location; magnitude estimate; arrival or shaking estimate; uncertainty; latency; local recording link.	Maintains the evolving event hypothesis and separates source updates from observed site motion.
Hydraulic boundary	Groundwater and sea level; datum; barometric or tidal context where relevant; acquisition time; spatial support; uncertainty.	Constrains saturation and effective-stress assumptions without treating a boundary sensor as a pore-pressure profile.
Manifestation observation	Observation type; acquisition time; footprint; resolution; interpreter; confidence; image or field record; alternative explanation.	Supports rapid mapping while preserving the difference between inferred and confirmed deformation.
Model and provenance	Model ID and version; features; parameters; training or calibration data; validation domain; uncertainty method; software; release approval.	Allows a probability or classification to be reproduced and withdrawn when its domain is exceeded.
Advisory and decision	State; evidence time; location; confidence; limitations; action; authority; issue and expiry times; recipients; acknowledgement; follow-up.	Connects technical evidence to an accountable, time-bounded response and learning record.

Source: *Authors' data contract informed by Chen et al. (2024), NIST (2023, 2024), Tan et al. (2022), and Tiggeloven et al. (2025).*

Quality, freshness, and sensor conflict

Each observation receives a time-varying weight before it contributes to fusion. Equation (2) defines a transparent conceptual rule; production systems may use a validated alternative, but they should preserve the same meanings.

$$w_i(t) = \alpha_i \, \kappa_i(t)[1 - m_i(t)]\exp\left[-\frac{\Delta t_i(t)}{\tau_i}\right] \qquad (2)$$

In Equation (2), wi(t) is the usable weight of stream i; αi is a verified baseline reliability coefficient; κi(t) is a dimensionless quality factor derived from calibration, range, timing, and plausibility checks; mi(t) equals one when the observation is unusable and zero otherwise; Δti(t) is its age at the fusion time; and τi is a decision-specific freshness scale. The equation is not a universal calibration and does not make heterogeneous quantities commensurate by itself. It ensures that stale or invalid values cannot silently receive full influence, consistent with quality-aware sensing and edge-processing practice (Chen et al., 2024; Esposito et al., 2024; Mishra et al., 2024).

Conflict is retained as evidence. A regional estimate of strong shaking combined with a healthy local sensor reporting weak motion may indicate spatial variability, an event-location update, or a sensor

problem. A rapid pore-pressure rise without compatible motion may reflect drift, hydraulic disturbance, timing error, or local vibration. The fusion layer therefore stores residuals, health tests, neighbouring-station comparisons, and alternative explanations. It may lower confidence, request corroboration, or move the service to an unknown state; it does not average incompatible observations until the contradiction disappears.

Physics-informed triggering update

Where a piezometer is installed in a susceptible layer, the excess pore-pressure ratio in Equation (3) provides a physically interpretable indicator of local response.

$$r_u(z,t) = \frac{\Delta u(z,t)}{\sigma'_{v0}(z)} \tag{3}$$

In Equation (3), ru(z,t) is the excess pore-pressure ratio at depth z and time t; Δu(z,t) is the measured increase from a documented pre-event baseline; and σ′v0(z) is the initial vertical effective stress at the instrumented point. Installation conditions, datum, transducer range, drift, baseline stability, and the representativeness of the instrumented lens must be verified. A local ratio is not a universal threshold for surface manifestation or safety. Controlled liquefaction experiments show why synchronised motion, pressure, and deformation observations are preferable to a single channel (Bojadjieva et al., 2022).

For event-specific screening, the simplified cyclic stress ratio can be updated from local strong-motion evidence using Equation (4). It is an engineering demand descriptor and must be applied within the domain of the selected assessment procedure.

$$CSR(z,t) = 0.65\,\frac{a_{\max}(t)}{g}\,\frac{\sigma_{v0}(z)}{\sigma'_{v0}(z)}\,r_d(z) \tag{4}$$

In Equation (4), CSR(z,t) is cyclic stress ratio; amax(t) is the adopted peak horizontal acceleration from a quality-controlled local record or explicitly identified estimate; g is gravitational acceleration; σv0(z) and σ′v0(z) are initial total and effective vertical stresses; and rd(z) is a depth-reduction factor defined by the selected method. Magnitude, duration, multidirectional loading, sloping-ground, and procedure-specific corrections are not concealed inside this expression; they must be documented separately. Recent probabilistic and machine-learning studies emphasise that method, feature, and database choices govern interpretation (Han et al., 2024; Jas & Dodagoudar, 2023; Torres & Dungca, 2024).

The corresponding factor-of-safety screening is written in Equation (5).

$$FS_L(z,t) = \frac{CRR(z)}{CSR(z,t)} \tag{5}$$

In Equation (5), FSL(z,t) is a liquefaction-triggering factor-of-safety descriptor; CRR(z) is cyclic resistance ratio derived using a named, site-appropriate procedure and its corrections; and CSR(z,t) is the demand from Equation (4). Neither a single value of FSL nor an empirical classifier is treated as proof of safety or manifestation. Parameter uncertainty, method uncertainty, spatial variability, and the consequences of the decision must be propagated. Bayesian assessment provides one structured way to retain these uncertainties rather than collapse them prematurely (Han et al., 2024).

Probabilistic fusion and action selection

The evidence for a liquefaction state can be updated sequentially as measurements arrive. Equation (6) expresses the Bayesian structure for a spatial cell or asset.

$$P\left(L_{k,t} = 1 \mid \mathcal{D}_t\right) \propto P\left(\mathbf{y}_{k,t} \mid L_{k,t} = 1\right) P\left(L_{k,t} = 1 \mid \mathcal{D}_{t-1}\right) \tag{6}$$

In Equation (6), Lk,t is the defined liquefaction state for unit k at time t; $\mathcal{D}$t is all accepted evidence available by t; yk,t is the current observation vector; P(yk,t|Lk,t = 1) is the likelihood under the specified

sensor and mechanism model; and P(Lk,t = 1|$\mathcal{D}$t−1) is the previous posterior or pre-event prior. The state definition must specify whether it denotes triggering at depth, surface manifestation, or an asset-relevant consequence. The likelihood must represent sensor dependence and missingness. Equation (6) is an integration structure, not a calibrated Black Sea model (Asadi et al., 2024; Han et al., 2024; Tian & Wang, 2023).

A warning state is useful only when connected to an authorised decision. Equation (7) gives a loss-aware decision structure.

$$a_t^* = \operatorname{argmin}_{a \in \mathcal{A}} \sum_j P\left(S_{j,t} \mid \mathcal{D}_t\right) C\left(a, S_j\right) \tag{7}$$

In Equation (7), a-star at time t is the selected action; $\mathcal{A}$ is the locally authorised action set; Sj,t is a defined physical or operational state; P(Sj,t|$\mathcal{D}$t) is its posterior probability given available evidence; and C(a,Sj) is the locally approved consequence or loss of taking action a when state Sj occurs. Costs are not universal and include life safety, service disruption, cascading hazards, false alarm, missed detection, and reversibility. Governance and human-centred warning research require that uncertainty, authority, message meaning, and action feasibility be designed together (NIST, 2023; Tan et al., 2022; Tiggeloven et al., 2025).

Event-time evidence progression and warning ladder

Figure 2 organises the service in event time. The pre-event stage maintains ground, groundwater, exposure, and instrument readiness. After earthquake detection, source and expected-shaking information are communicated with update time and uncertainty. As local data arrive, cyclic demand and pore-pressure evidence support a triggering watch. Permanent-motion measurements, imagery, and inspections then support rapid impact checking and confirmation. Recovery observations and engineering decisions update the baseline rather than disappearing into a separate incident archive.

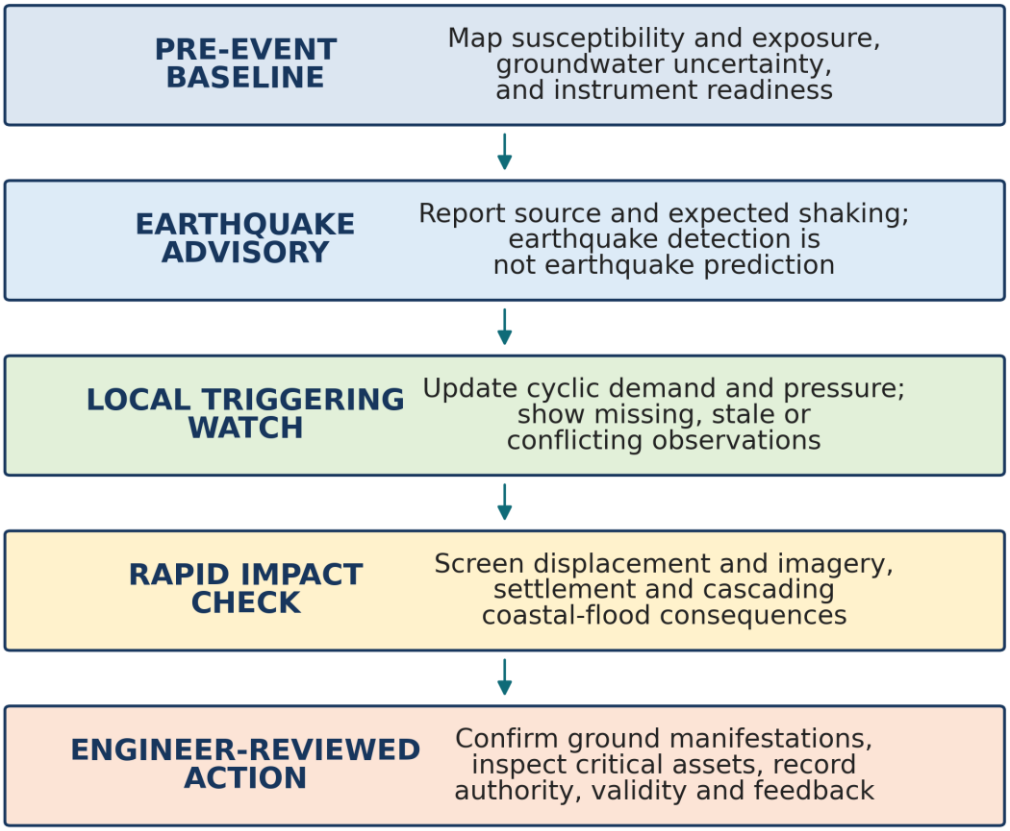

Figure 2. Event-time progression from susceptibility evidence to engineer-reviewed action

Source: *Original event-time synthesis developed by the authors from Allen and Stogaitis (2022), Bassal et al. (2024), Taftsoglou et al. (2023), and Toprak et al. (2025).*

Table 3 translates this progression into an evidence ladder. The terms are deliberately descriptive rather than numerical. A project may assign colours or levels only after local users demonstrate that the labels are understood, accessible, and consistently connected to feasible actions. No level below confirmed manifestation proves that liquefaction occurred, and no absence of evidence proves that it did not.

Table 3. Evidence ladder for liquefaction warning and response

Evidence state	Minimum evidence	Permissible interpretation	Typical governed response
Baseline susceptibility	Versioned ground and groundwater model; mapped exposure; known uncertainty; instrument-readiness status.	Liquefaction could occur under suitable loading; no event-specific triggering claim.	Investigation, mitigation planning, instrument maintenance, exercise, and prioritisation.
Earthquake advisory	Detected event with provider, update history, expected arrival or shaking, uncertainty, and communication status.	Potential event-specific demand exists; earthquake detection is not earthquake prediction or liquefaction confirmation.	Execute pre-authorised seconds-scale actions where feasible; prepare inspection and continuity teams.

Evidence state	Minimum evidence	Permissible interpretation	Typical governed response
Local triggering watch	Quality-controlled local motion and/or pore-pressure evidence linked to a susceptible layer; missing and conflicting data shown.	Triggering is plausible or increasingly supported at defined locations and depths; manifestation remains unconfirmed.	Protect personnel, restrict selected operations or access under local procedure, and request corroboration.
Probable manifestation	Permanent movement, mapped surface signature, multiple consistent sensors, or credible reports with location and time.	Liquefaction-related ground deformation is probable, while alternative mechanisms and footprint remain under review.	Prioritise critical assets and routes, conduct rapid inspection, isolate hazards, and update public or operator messages.
Confirmed impact and engineering assessment	Competent inspection and engineering interpretation of ground manifestation, asset condition, and residual hazards.	Observed impact is attributable within stated confidence and boundaries; serviceability and safety require asset-specific assessment.	Maintain or change restrictions, implement emergency works, plan recovery, preserve evidence, and recalibrate models.
Degraded or unknown	Critical evidence is absent, stale, clipped, contradictory, outside model domain, or communication is unverified.	The service cannot support the intended claim; unknown is not equivalent to low risk.	Use conservative fallback procedure, restore evidence, verify recipients, and record the period of degraded service.

Source: *Authors' warning ladder synthesising technical and social evidence from Allen and Stogaitis (2022), Tan et al. (2022), Tiggeloven et al. (2025), and NIST (2023).*

RESULTS AND DISCUSSION

Design evaluation and requirements traceability

The design-science result is an internally traceable specification, not an estimate of field accuracy. The susceptibility–triggering–manifestation–consequence distinction is implemented in the architecture, posterior state definition, event-time sequence, and evidence ladder. The requirement for multi-physics observability is implemented in Equation (1) and Table 1. Data freshness and health are explicit in Equation (2) and the minimum contract. Effective-stress and cyclic-demand logic are visible in Equations (3)–(5). Uncertainty updating and action consequences are visible in Equations (6) and (7). Missingness is carried into a degraded state rather than replaced by a default value.

This traceability addresses several recurrent failure modes. A continental or satellite model cannot silently become a parcel-scale decision layer because its footprint and validation domain are recorded. A regional earthquake estimate cannot overwrite a local record without retaining both sources and their time histories. A pore-pressure threshold cannot be copied between sites because depth, initial effective stress, installation, and ground unit remain part of the observation. A machine-learning probability cannot be presented without model version, input availability, domain, and calibration evidence. Finally, a warning cannot remain indefinitely valid because issue and expiry times are mandatory.

Table 4 defines how each component should be validated before controlled use. Validation is prospective wherever the proposed output is time-dependent. Historical replay is valuable for debugging and comparative analysis, but it does not expose all operational problems, including clock drift, packet loss, maintenance gaps, changing ground conditions, user interpretation, or communications under load.

Table 4. Validation and assurance matrix for an operational liquefaction warning service

Component	Evidence and test	Acceptance basis	Failure response
Baseline susceptibility and ground model	Independent review of investigation, stratigraphy, groundwater, method domain, spatial resolution, uncertainty, and change control.	Fitness for the named spatial unit and screening or design purpose; no unsupported extrapolation.	Restrict domain, commission investigation, widen uncertainty, or withdraw the affected prior.
Earthquake detection and message pathway	Historical replay, live exercises, timing audit, update sequencing, coverage analysis, and recipient acknowledgement.	Documented latency and reliability for the intended action; clear distinction between detection, estimate, and local observation.	Declare advisory channel degraded and invoke local or official fallback communication.
Sensor metrology and installation	Calibration, orientation and depth survey, clock test, range and clipping test, baseline stability, maintenance, and redundancy review.	Traceable measurement uncertainty and verified operation under expected environmental and seismic conditions.	Quarantine channel, reduce weight, use corroborating evidence, and dispatch maintenance or inspection.
Fusion and feature processing	Unit and sign tests, synthetic missingness, time-offset and conflict injection, independent code review, and reproducible event replay.	Correct handling of quality flags, dependence, latency, missingness, uncertainty, and alternative explanations.	Freeze or roll back model, expose unknown state, and preserve raw evidence and logs.
Triggering and manifestation models	External event data, spatial holdout, probability calibration, sensitivity, domain-shift test, benchmark against transparent baselines.	Performance meets predeclared metrics for a named claim, horizon, ground domain, and consequence; uncertainty is calibrated.	Limit claim, require engineer interpretation, retrain only under change control, or withdraw model.
Warning decision and human factors	Scenario exercise with ambiguous and conflicting evidence; accessibility, language, action feasibility, expiry, and authority tests.	Recipients understand meaning and uncertainty, can act within available time, and can reconstruct responsibility.	Revise message, action set, training, or authority; do not compensate with a lower technical threshold alone.
Cybersecurity and continuity	Asset inventory, authentication and access review, segmentation, integrity test, backups, incident exercise, offline buffering, and recovery test.	Essential evidence and fallback service remain available or fail visibly under credible dependency loss.	Isolate affected components, use approved fallback, issue degraded status, recover from trusted state, and document the incident.

Source: *Authors' assurance matrix informed by NIST (2023, 2024), Chandrakumar et al. (2022), Esposito et al. (2024), Tan et al. (2022), and Torres and Dungca (2024).*

5.2 Desk-based stress cases

Stress case 1 considers a strong regional earthquake advisory while local groundwater and saturation evidence are incomplete. The architecture may communicate expected shaking and execute pre-

authorised earthquake actions, but it cannot claim local liquefaction triggering. The posterior retains the mapped susceptibility prior and a wider uncertainty range. The dashboard identifies the missing hydraulic evidence, and the inspection plan prioritises susceptible and consequence-critical locations. This response prevents regional shaking information from being treated as a site diagnosis.

Stress case 2 considers a rapid pore-pressure increase while the collocated accelerometer is clipped or fails a timing check. The pore-pressure observation is not discarded, but Equation (2) reduces or removes the unusable motion channel. Neighbouring ground-motion records, hydraulic context, instrument range, and time synchronisation are checked. Until the conflict is resolved, the system can escalate a local triggering watch and request inspection without presenting a precise cyclic-demand calculation. This behaviour preserves potentially important evidence while avoiding false numerical confidence.

Stress case 3 considers quality-controlled strong motion and permanent ground movement while satellite imagery is delayed. The service does not wait for imagery if local multi-sensor evidence and consequences justify protective action. It marks the spatial footprint as provisional, prioritises critical access routes and utilities, and requests field confirmation. When imagery becomes available, it is fused as a new observation with its acquisition time and resolution. Rapid satellite studies following recent earthquakes demonstrate substantial value for mapping, but also show why imagery belongs to a broader evidence chain rather than the seconds-scale trigger pathway (Taftsoglou et al., 2023).

Stress case 4 considers loss of the central communication service during strong shaking. Edge nodes continue acquisition, timestamping, local quality checks, and buffering. Only a narrowly validated local advisory can continue autonomously; the central map and cross-site fusion display an explicit communication-loss state. After reconnection, buffered observations are reconciled without rewriting their original arrival times. Edge processing can improve resilience and latency, but it also creates configuration, model-version, security, and maintenance responsibilities that must be assured (Mishra et al., 2024; Prasanna et al., 2022).

Across all four cases, the logical result is consistent: the service preserves valid observations, identifies unavailable evidence, prevents unsupported inferences, and links any action to an authorised fallback. These outcomes demonstrate requirement coverage, not empirical reliability. Field trials must still measure warning latency, availability, probability calibration, false and missed alerts, user comprehension, action completion, and recovery behaviour.

Model roles, interpretability, and remote sensing

Data-driven models can contribute at three different stages. Before an event, they can support susceptibility screening from geotechnical and geospatial features. During an event, they can estimate shaking or classify time-series patterns. After an event, they can identify candidate manifestations from imagery or deformation fields. These models should not share an undifferentiated “liquefaction probability.” Their targets, labels, spatial units, horizons, and validation domains differ. Rule-based models may improve local interpretability, while Bayesian networks can represent conditional dependence and uncertainty, but neither removes the need for representative data and explicit physical definitions (Han et al., 2024; Torres & Dungca, 2024).

Satellite soil-moisture information can help construct broad saturation priors, especially where ground observations are sparse, but pixel-scale surface estimates cannot replace the groundwater and pore-pressure conditions of a buried susceptible layer (Farahani & Ghayoomi, 2024). Similarly, InSAR can detect post-event consolidation subsidence over appropriate surfaces and time intervals, yet it cannot provide the seconds-scale local pore-pressure response required for triggering warning (Albano et al., 2024). Each remote-sensing product must retain acquisition time, geometry, coherence or quality, resolution, processing lineage, and the physical state it is permitted to inform.

Physics-informed fusion provides a practical middle path. Equations (3)–(5) preserve effective-stress and cyclic-demand meaning, while Equation (6) permits calibrated data to update uncertainty. Physics can constrain implausible model behaviour and improve interpretability, but an incorrect ground model can also impose incorrect constraints. Multiple models, residual analysis, domain checks, and independent observations are therefore preferable to a single authoritative predictor. Work on physics-

informed Bayesian learning in geotechnics illustrates how sparse investigation and monitoring can be combined while retaining uncertainty (Tian & Wang, 2023).

Black Sea implementation and interoperability

A practical Black Sea programme would begin with a bounded pilot in a settlement where susceptible ground, critical exposure, available investigation, and responsible institutions justify the effort. The pilot might focus on an access corridor, port backland, reclaimed district, utility crossing, or emergency-service route. Site selection should be based on consequence and observability, not only on the highest regional susceptibility class. Existing national seismic networks and official warning channels remain authoritative inputs; a local project should complement, not obscure, their roles.

Regional interoperability can be built around the data contract in Table 2 and evidence meanings in Table 3. Common schemas allow a neighbouring jurisdiction or basin-level coordination centre to understand when an advisory was issued, what it means, what evidence is missing, and when it expires. Shared benchmark events can test message translation, cross-border data latency, coordinate and datum consistency, model provenance, and mutual aid. The common service should exchange uncertainty and degraded states as readily as alerts.

The regional evidence reviewed here also supports restraint. Europe-wide susceptibility mapping offers useful screening at a coarse scale (Meisina et al., 2022). Eastern Black Sea geophysical results show that near-surface properties and groundwater indicators vary among sites (Karslı et al., 2024). Coastal-motion observations demonstrate the need to connect in-situ and space-based records carefully (Erkoç et al., 2025). These findings support a federation of locally calibrated services with shared information semantics, not a single basin-scale model.

Human factors, governance, and cybersecurity

Warning effectiveness depends on whether recipients receive, understand, trust, and can act on a message within the available time. Earthquake early-warning research shows that social context, prior education, message design, accessibility, and feasible protective actions are as consequential as technical detection (Tan et al., 2022). For liquefaction, the message must also distinguish shaking from ground-failure evidence. A concise advisory should state location, evidence state, uncertainty, issued and expiry times, authorised action, unavailable data, and the source for updates.

Governance assigns an owner to the ground model, each sensor stream, the fusion model, the warning service, communications, cybersecurity, and operational decisions. Only approved personnel can change sensor status, effective-stress assumptions, model versions, warning logic, recipient lists, or expiry rules. Model changes are tested in shadow operation and recorded. Exercises include ambiguous data and false or missed triggers, because a system tested only on obvious events will not reveal how people handle uncertainty.

Cybersecurity is integral because manipulated timestamps, event identities, calibration values, model files, or recipient lists can alter risk decisions. Controls should include asset and dependency inventory, authenticated devices and users, least privilege, network segmentation, integrity-protected records, encrypted communication where appropriate, monitoring, backups, trusted recovery, and tested offline procedures. The NIST AI Risk Management Framework and Cybersecurity Framework provide general governance structures, but local threat analysis and infrastructure requirements remain necessary (NIST, 2023, 2024).

Staged implementation roadmap

Table 5 proposes an evidence-gated roadmap. A project advances only when its current claims are supported. An information-rich baseline can provide value even if a real-time triggering service is not yet justified. Conversely, adding more sensors does not justify escalation if ownership, calibration, communication, or action protocols are absent.

Table 5. Staged roadmap for a Black Sea coastal liquefaction warning pilot

Stage	Principal work	Required deliverable	Gate to proceed
1. Intended use and responsibility	Select spatial unit, exposed assets, decisions, users, authority, action horizon, false-alarm and missed-event consequences.	Purpose and claim statement; responsibility map; communication and fallback concept.	Named authority approves a bounded, feasible, and testable service objective.
2. Baseline microzonation and investigation	Compile geology, CPT/SPT/Vs, groundwater, historical manifestations, assets, dependencies, and uncertainty; identify data gaps.	Versioned ground and exposure model; susceptibility map with scale and domain; investigation plan.	Competent review confirms that the prior is adequate for monitoring design, not merely regional screening.
3. Instrumented pilot and data contract	Install complementary motion, pressure, hydraulic and deformation sensors at representative locations; integrate official event feeds.	Surveyed and calibrated network; metadata and maintenance plan; synchronized archive; health and degraded-state logic.	Metrology, timing, communication, security, and spatial representativeness meet predeclared requirements.
4. Shadow fusion and prospective validation	Run physics and statistical models without operational authority; replay events; inject missingness and conflicts; conduct exercises.	Locked model versions; calibration and validation report; domain and limitation register; human-factors findings.	Independent review confirms fitness for a named advisory and identifies withdrawal criteria.
5. Controlled warning service	Authorise limited actions; train users; test acknowledgement, expiry, inspection, continuity, cyber response, and evidence preservation.	Operating procedure; decision log; exercise evidence; maintenance and model-change process; periodic assurance schedule.	Authority accepts residual risk and can suspend the service when evidence or dependencies fail.
6. Settlement portfolio and regional federation	Scale validated patterns; harmonise metadata and warning semantics; test transfer; share benchmarks and lessons.	Interoperability profile; cross-border exercise; transfer-test report; governance and data-sharing agreement.	Shared information improves decisions without replacing local ground models or accountable authority.

Source: *Authors' roadmap synthesising implementation requirements from Chandrakumar et al. (2022), Chen et al. (2024), NIST (2023, 2024), Tan et al. (2022), and Tiggeloven et al. (2025).*

Limitations and research agenda

This study has six principal limitations. It is a conceptual design without a deployed Black Sea case. Its evidence synthesis is targeted rather than systematic. The seven equations are integration structures and require local calibration or replacement. No sensor spacing, sampling rate, lead time, pore-pressure ratio, factor of safety, probability, or warning threshold is prescribed. The framework does not establish that all settlements have sufficient telecommunications or institutional capacity. Finally, logical stress testing cannot quantify field reliability or public benefit.

Research should therefore develop openly documented multi-sensor datasets that synchronise earthquake source updates, local strong motion, pore pressure, groundwater, deformation, imagery, inspection, and infrastructure consequences. Field and centrifuge or 1-g experiments should report sensor placement, metrology, timing, saturation, density, stress, drainage, and negative results. Model studies should use spatial and event holdouts, probability calibration, transparent baselines, uncertainty decomposition, and domain-shift tests rather than random record splits alone.

Prospective pilots should compare the warning service with the existing decision process. Evaluation should measure end-to-end latency, availability, message receipt, user comprehension, action completion, false and missed advisories, spatial accuracy, uncertainty calibration, inspection prioritisation, downtime avoided or added, and recovery quality. Distributed sensing innovations—including low-cost MEMS and mobile devices—deserve evaluation as complementary detection infrastructure, but their benefits must be assessed together with mounting, timing, noise, coverage, maintenance, and privacy limitations (Allen et al., 2025; Esposito et al., 2024).

Further work should examine whether emerging rapid source-characterisation methods can improve the event-demand pathway for large earthquakes without creating false precision. For example, elastogravity research explores very rapid tracking of earthquake growth, yet operational integration would require independent validation, network availability, and clear communication of uncertainty (Licciardi et al., 2022). The research objective is not to maximise technological complexity, but to improve a defined decision while preserving the boundary between observation, inference, and authority.

CONCLUSION

This paper has developed a multi-sensor data-fusion framework for earthquake-induced liquefaction early warning in Black Sea coastal settlements. It connects site-characterisation priors, earthquake detection, local strong motion, excess pore pressure, groundwater and sea-level context, deformation observations, remote sensing, and inspections through quality-aware fusion, physics-informed screening, probabilistic updating, consequence assessment, and governed action.

The central contribution is evidence discipline. Susceptibility is not triggering; triggering is not manifestation; manifestation is not automatically an infrastructure safety decision. Earthquake early warning is detection after rupture begins, not prediction. A point sensor does not represent an entire deposit, and a map or machine-learning probability does not replace local ground evidence. Missing, stale, clipped, contradictory, or out-of-domain information produces a degraded or unknown state rather than an unsupported declaration of safety.

The architecture is suitable for specifying and reviewing a bounded pilot, but it does not authorise operational warnings by itself. Local ground investigation, calibrated sensing, prospective validation, independent review, human-centred communication tests, cybersecurity and continuity exercises, and competent authority remain prerequisites. A federated Black Sea approach should share data contracts, warning semantics, benchmark events, and lessons while preserving local models and responsibility. With these safeguards, multi-sensor fusion can support faster and more transparent protective decisions without overstating what the available evidence can prove.

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FEDERATED LEARNING FOR CROSS-BORDER LANDSLIDE RISK INTELLIGENCE ACROSS BLACK SEA COASTLINE COUNTRIES

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ABSTRACT

Objectives: This study develops a federated-learning framework for cross-border landslide risk intelligence among Black Sea coastline countries while preserving local data custody, model accountability, and warning authority. **Methods:** A design-science method and targeted synthesis of peer-reviewed and authoritative evidence published from 2022 to July 2026 were used to specify a six-layer architecture, semantic contract, editable learning and decision equations, threat controls, validation matrix, and staged implementation roadmap. Requirements traceability and four desk-based stress cases were applied. No multinational dataset, operational consortium, deployed model, universal threshold, privacy guarantee, or performance result is claimed. **Results:** The framework retains landslide inventories, terrain, rainfall, soil-state, monitoring, exposure, and action records at participating nodes and exchanges controlled model updates or derived statistics. It separates susceptibility from time-dependent hazard and risk, addresses non-independent data through local baselines and personalisation, and treats label conflict, anomalous updates, missing clients, and domain shift as explicit degraded states. Secure aggregation, privacy controls, robust update screening, provenance, and human review are assigned distinct functions. **Conclusions:** Federation can support regional learning without centralising raw records, but it does not itself establish confidentiality, fairness, transferability, or warning reliability. Operational use requires locally calibrated models, prospective validation, cybersecurity assurance, explicit agreements, and accountable national or municipal decision authority.

Keywords: Federated learning; landslide risk; Black Sea; cross-border intelligence; geospatial artificial intelligence; early warning.

INTRODUCTION

Landslides along the Black Sea coast arise in varied combinations of steep terrain, weathered and weak materials, rainfall and snowmelt, groundwater change, shoreline and river erosion, earthquakes, excavation, road construction, drainage alteration, and urban development. The relative importance of these controls changes across catchments and seasons. A recent investigation of the Kıyıcık landslide in Artvin, Türkiye, for example, associated a December 2024 failure with the interaction of coastal-road construction, drainage and geomorphological conditions; it is a documented local case, not a template for every Black Sea slope (Turoğlu & Duran, 2025). Eastern Black Sea geophysical research likewise demonstrates meaningful site-to-site variation in near-surface properties and groundwater indicators (Karslı et al., 2024).

Risk intelligence is broader than a susceptibility map. Susceptibility describes where slope failure is more or less likely under relevant conditions. Time-dependent hazard adds triggering state, timing and intensity. Risk additionally requires exposed people, buildings, roads, ports, utilities and response capacity. An early-warning decision must also account for uncertainty, communication, feasible action and the consequences of false, missed or late alerts. Recent landslide-warning research emphasises

hydrological state, spatial representativeness and locally tested thresholds rather than rainfall alone (Mirus et al., 2025; Palazzolo et al., 2023; Patton et al., 2023; Wicki et al., 2023).

The six Black Sea littoral states—Bulgaria, Georgia, Romania, Russia, Türkiye and Ukraine—hold landslide information in different institutional, technical and linguistic settings. Inventories, rainfall archives, ground investigations, remote-sensing products, warning records and exposure data may be distributed among national agencies, municipalities, universities and infrastructure operators. Centralising all raw records may be infeasible because of legal responsibilities, security concerns, data licences, organisational capacity, technical incompatibility or legitimate reluctance to transfer sensitive asset and location information.

Federated learning offers a different collaboration pattern. Each participating client trains or evaluates a model using local records and communicates controlled model updates or derived statistics to a coordinating process. Raw training records can remain with their custodian. This arrangement may reduce unnecessary data movement, but it is frequently overstated. Model updates can leak information; clients can submit poisoned or backdoored updates; a global model can perform poorly for a minority geography; and secure communication does not correct inconsistent landslide labels or invalid local measurements (Chen et al., 2022; Gosselin et al., 2022; Li et al., 2023; Xia et al., 2023). Federated learning therefore changes the data pathway; it does not prove privacy, security, fairness or scientific validity.

Spatial data intensify these challenges. Adjacent cells are correlated, observation density follows roads and settlements, mapping practices vary by institution, and train–test leakage can occur when nearby samples are split randomly. Landslide prevalence is also strongly imbalanced, and absence labels may mean either stable terrain or unobserved failure. Research on spatial federated learning and federated remote sensing identifies coordinate systems, scale, spatial dependence, heterogeneous sensors and non-independent data as first-order design issues (Graser et al., 2022; Moreno-Álvarez et al., 2024). A single basin-wide model or warning threshold would conceal these differences.

This paper develops a design-science framework for cross-border landslide risk intelligence rather than reporting an operational federation. Its contributions are a six-layer architecture; a data, label and role matrix; a minimum semantic contract; seven editable equations; privacy and security controls; an evidence-gated lifecycle; a validation matrix; four desk-based stress cases; and a staged roadmap. No participating institutions, data-sharing agreements, multinational dataset, deployed system, model accuracy, privacy budget or warning threshold is asserted. The objective is to define what must be made compatible, validated, protected and governed before regional learning can support local decisions.

METHODOLOGY

Design-science approach and evidence base

A design-science method was adopted because the research problem is to construct and logically evaluate an information architecture in the absence of a supplied multinational dataset. A targeted synthesis of peer-reviewed and authoritative literature published from 2022 to July 2026 was used. The evidence covers federated-learning systems, remote sensing, spatial data science, statistical and system heterogeneity, personalisation, secure aggregation, privacy and poisoning risks, landslide susceptibility, uncertainty and interpretability, regional rainfall warning, hydrological monitoring, artificial-intelligence governance, cybersecurity and Black Sea geotechnical context. The synthesis is purposeful and does not claim the exhaustive coverage of a systematic review.

Evidence was analysed through six questions: what phenomenon and prediction target were defined; what spatial and temporal unit was used; how labels and missing observations were constructed; which data remained local and which information was exchanged; how performance, calibration and uncertainty were evaluated; and what decision could reasonably follow. The answers were translated into requirements, architecture elements, data-contract fields, equations, assurance tests and withdrawal conditions. Recent remote-sensing federations demonstrate technical feasibility for distributed scene classification, while reviews show that heterogeneity, communication, security and governance remain application-specific (Ben Youssef et al., 2024; Liu, Lv, et al., 2024; Moreno-Álvarez et al., 2024).

Four hypothetical stress cases were then applied to the framework: domination by a large client, a changed or incompatible label ontology, an anomalous or malicious update, and loss of a client or coordinator. The cases test whether the design exposes uncertainty, preserves provenance and fails explicitly. They are not numerical experiments, representations of named countries, or evidence of field reliability. Results are therefore requirements-traceability and logical-behaviour results only.

Intended use and claim boundaries

The intended use is to support participating custodians in improving locally owned models and in comparing regional patterns without routinely transferring raw records. Permitted outputs may include a shared feature representation, a candidate susceptibility model, calibrated local probability estimates, indicators of domain shift, common benchmark metrics and versioned risk-intelligence summaries. The framework can also support mutual learning about observation gaps, uncertainty and warning practice.

The framework does not authorise an automated warning, evacuation, road closure or declaration of safety. A participating authority remains responsible for its local observations, model validation, thresholds, exposure data, messages and actions. Cross-border coordination cannot convert a model that fails local validation into an acceptable operational model. A regional product must state whether it is intended for research, screening, preparedness, advisory support or time-critical warning; these uses require different evidence.

CROSS-BORDER LANDSLIDE INTELLIGENCE PROBLEM

Distributed evidence and heterogeneous labels

Landslide intelligence draws on several evidence families that are not interchangeable. Inventories provide event locations, types and dates but can be incomplete or biased toward visible and accessible failures. Terrain, geology, land cover, drainage and infrastructure describe conditioning factors. Rainfall, soil moisture, groundwater, snowmelt and earthquakes provide dynamic triggers. Inclinometers, pore-pressure sensors, GNSS, extensometers, optical imagery and radar observations provide local or spatially extensive state evidence. Exposure and loss records connect hazard to consequence. Table 1 identifies the principal contribution, source of heterogeneity and permitted role of each family.

Table 1. Cross-border landslide data, label and decision-role matrix

Evidence family	Contribution	Heterogeneity or confounding	Federation treatment and prohibited inference
Landslide inventories	Failure location, geometry, type, date, trigger and confidence; basis for labels and event-based validation.	Mapping scale, detection opportunity, terminology, duplicate events, positional error and unrecorded non-events differ.	Map local classes to a versioned ontology and retain confidence. Never treat unmapped terrain as confirmed stable ground.
Conditioning factors	Terrain, lithology, soils, structures, land cover, drainage, erosion and human modification.	Resolution, age, sensor, classification and causal relevance differ; adjacent pixels are spatially dependent.	Exchange feature definitions and domain summaries. Never assume an identically named layer has the same meaning or quality.
Dynamic triggers and state	Rainfall, antecedent wetness, soil moisture, groundwater, snowmelt, river or wave erosion, and earthquake shaking.	Gauge density, interpolation, sampling, bias correction, depth support and climatology differ.	Retain observation time, support and uncertainty. Never transfer a rainfall or moisture threshold without local validation.

Evidence family	Contribution	Heterogeneity or confounding	Federation treatment and prohibited inference
Slope monitoring	Displacement, velocity, tilt, pore pressure, cracks, vibration and sensor health at instrumented locations.	Installation geometry, calibration, noise, maintenance, missingness and local representativeness differ.	Use quality-controlled features and explicit missing states. Never infer regional stability from silent or failed sensors.
Earth observation	Spatially extensive change, deformation, surface moisture or land-cover information.	Orbit, viewing geometry, atmosphere, cloud, coherence, resolution, revisit and processing chain differ.	Federate compatible derived features only where licensing permits. Never equate a remote signature with a confirmed mechanism.
Exposure and consequence	People, buildings, transport, ports, utilities, service dependencies and potential loss.	Currency, valuation date, occupancy, confidentiality, network topology and social vulnerability differ.	Keep sensitive asset details local where required; exchange aggregated metrics. Never call hazard probability a risk estimate without exposure.
Warnings, actions and outcomes	Issued state, recipients, acknowledgement, protective action, inspection, impact and post-event learning.	Authority, language, warning levels, feasible actions and reporting culture differ.	Map semantics and record provenance. Never import another jurisdiction's action threshold as if authority and consequences were identical.

Source: *Authors' synthesis based on Achu et al. (2023), Mirus et al. (2025), Palazzolo et al. (2023), Patton et al. (2023), Tuia et al. (2025), and Wicki et al. (2023).*

Label harmonisation is the first scientific gate. A binary landslide label can conceal rockfall, debris flow, rotational slide, shallow translational failure, slow-moving deep-seated movement and reactivation. The relevant prediction horizon also changes the label: long-term susceptibility, event occurrence within a day, threshold exceedance within hours and observed displacement are different targets. Each client must retain its original classification and document the mapping to a common ontology. Ambiguous and unmapped records remain explicit rather than being forced into a convenient binary class.

Non-independent and spatially dependent data

Federated clients will not be independent and identically distributed. Geology, slope morphology, climate, land use, sensor networks, mapping effort, infrastructure and event prevalence vary across and within countries. One client may hold dense rainfall-triggered shallow-slide records, another sparse deep-seated movement monitoring, and another predominantly remote-sensing observations. A model that minimises average loss across all records can therefore favour the largest or easiest client and degrade a smaller high-consequence domain. Personalised and cross-silo federated-learning research demonstrates why a shared representation may need local adaptation under statistical and system heterogeneity (Qin et al., 2023; Yang et al., 2024).

Spatial dependence also invalidates naive validation. Random pixel splits can place neighbouring locations from the same slope in both training and test sets, thereby overstating generalisation. Evaluation should hold out spatial blocks, complete events, time periods and, where scientifically justified, entire clients. Performance must be reported per client, landslide class, season, terrain domain and decision horizon. Average accuracy is insufficient for a rare-event warning problem; discrimination, probability calibration, false-alert burden, missed events, lead time and action consequences all matter (Achu et al., 2023; Le et al., 2024; Han & Semnani, 2025).

Data custody, sovereignty and accountability

Local retention of raw data can support legitimate custody constraints, but it does not remove the need for an explicit agreement. Participants must define the controller or custodian of each dataset; the permitted purpose; lawful access; retention; model and update ownership; incident notification; publication; withdrawal; and responsibility for erroneous outputs. National security, critical infrastructure, personal information and commercial licences may require separate treatments. The

technical protocol must enforce the approved information flow rather than assuming that every feature, gradient or model can be exchanged.

The coordinating role also requires definition. It may be performed by one institution, rotated, divided hierarchically or implemented through a consortium service, but no arrangement is presumed here. The coordinator should not have unilateral power to change the target, client eligibility, aggregation rule or operational interpretation. Each training round records who participated, what code and model versions were used, which checks were applied, what was excluded and why, and which clients accepted the resulting model for local evaluation.

PROPOSED FEDERATED-LEARNING FRAMEWORK

Six-layer architecture

Figure 1 presents the proposed architecture. Local hazard systems retain inventories, terrain and geology, dynamic triggers, monitoring, exposure and decisions. A common semantic contract defines what a spatial unit, label, feature, time, quality flag and model output mean. Each client trains and validates locally before creating a controlled update. The exchange layer authenticates parties, protects communication and may apply secure aggregation. The federation layer checks eligibility, anomaly indicators, provenance and the declared aggregation rule. The resulting shared model or representation is returned for local personalisation, validation and governed use.

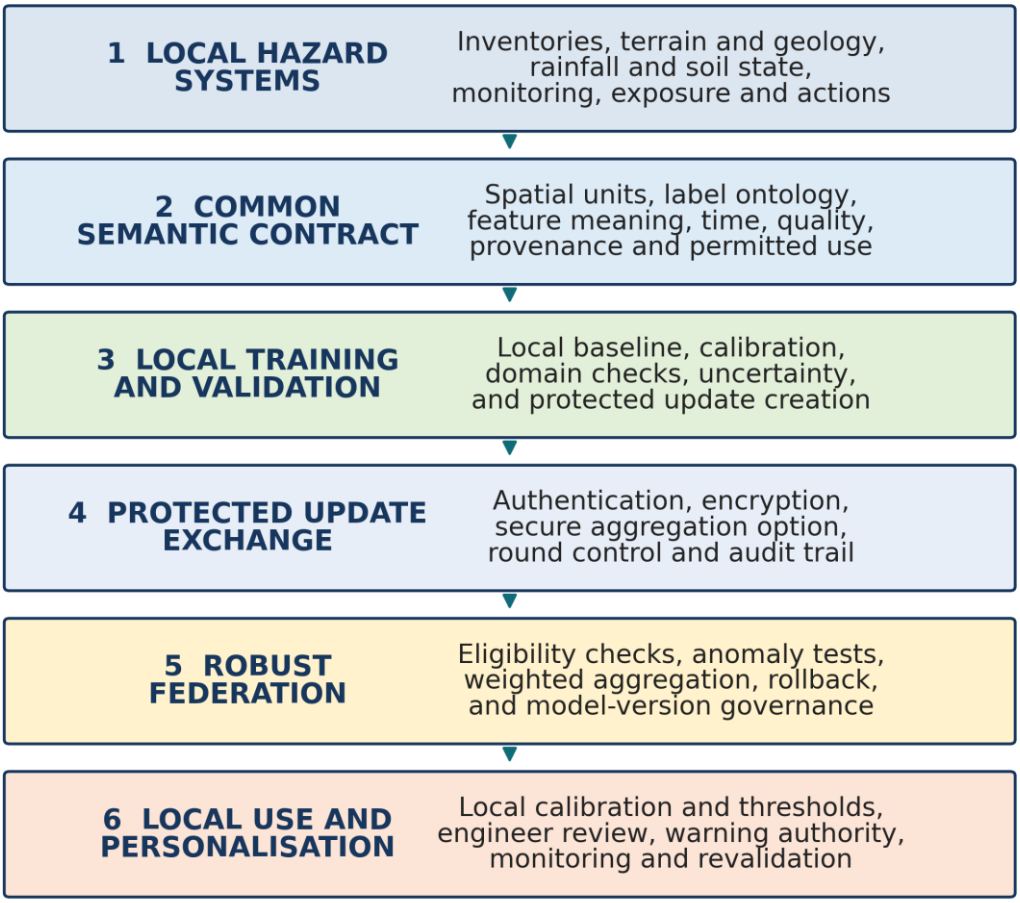

Figure 1. Six-layer architecture for cross-border federated landslide risk intelligence

Source: *Original framework developed by the authors from Graser et al. (2022), Gosselin et al. (2022), Li et al. (2023), Moreno-Álvarez et al. (2024), and NIST (2023, 2024).*

Two separations are essential. First, the common semantic layer precedes model exchange because encryption cannot repair inconsistent meanings. Second, the global model is not the warning service. It is a candidate knowledge product that must be compared with the local baseline, calibrated and approved for a named purpose. A client may reject, personalise or restrict the shared model while remaining a participant in benchmark and metadata work.

Local objective and baseline requirement

For client k with nk locally eligible records, a supervised local objective can be written as Equation (1). The equation is deliberately general because the model class and loss must match the defined task.

$$F_k(\mathbf{w}) = \frac{1}{n_k} \sum_{i=1}^{n_k} \ell\left(f_{\mathbf{w}}(\mathbf{x}_{k,i}), y_{k,i}\right) \tag{1}$$

In Equation (1), Fk is the empirical local objective; w is the model-parameter vector; nk is the number of locally eligible training records; xk,i is the feature vector for record i at client k; yk,i is the versioned target label; f is the prediction function; and ℓ is the predeclared loss. Eligibility includes the label ontology, observation period, spatial unit, quality rules and exclusion logic. Equation (1) is cited here as the local learning component of the broader federated systems described by Li et al. (2023) and Liu, Lv, et al. (2024); it is not evidence that a particular landslide model is suitable.

Before federation, every client develops a transparent local baseline using only information that would have been available at the prediction time. A complex federated model should not proceed if it cannot improve a predeclared decision-relevant metric, calibration or uncertainty characterisation without unacceptable harm to important subgroups or terrain domains. Recent landslide studies show that uncertainty and interpretability can materially change how susceptibility models are evaluated (Achu et al., 2023; Le et al., 2024; Xu et al., 2024).

Federated aggregation and participation record

A standard sample-size-weighted aggregation for training round r is shown in Equation (2). It provides a reproducible baseline against which more robust or personalised strategies can be tested.

$$\mathbf{w}^{(r+1)} = \sum_{k \in \mathcal{K}_r} \frac{n_k}{\sum_{j \in \mathcal{K}_r} n_j} \mathbf{w}_k^{(r+1)} \tag{2}$$

In Equation (2), w(r+1) is the aggregated parameter vector; Kr is the set of eligible clients participating in round r; wk(r+1) is the locally updated parameter vector; and nk is the declared number of eligible local training records. The denominator includes only eligible participants in that round. The equation does not justify weighting a client solely by record count when labels, prevalence, quality and geographic domains differ. It is used as an auditable benchmark consistent with modern federated-learning system descriptions, while its limitations must be tested under non-IID data (Li et al., 2023; Qin et al., 2023).

A participation record accompanies every aggregation. It includes client and coordinator identifiers, model and code hashes, ontology and feature-schema versions, local training interval, declared sample count, data-quality summary, validation metrics, update norm, anomaly flags, privacy mechanism, cryptographic status, acceptance decision and rollback point. The record contains no raw landslide location or personal data unless the agreement specifically permits it.

Communication-efficient federation can reduce the size or frequency of exchanged model information, but compression and knowledge-distillation choices can also change model behaviour under heterogeneous data. Published cross-silo results therefore motivate an option for bandwidth-constrained participants; they do not establish an acceptable accuracy–communication trade-off for landslide intelligence without local tests (Wu et al., 2022).

Quality- and domain-aware aggregation

Where simple sample-size weighting is demonstrably unsuitable, a predeclared quality- and domain-aware weight can be tested using Equation (3). The variables must be derived from auditable rules established before the round.

$$\omega_k^{(r)} = \frac{n_k q_k^{(r)} d_k}{\sum_{j \in \mathcal{K}_r} n_j \, q_j^{(r)} d_j}, \qquad \mathbf{w}^{(r+1)} = \sum_{k \in \mathcal{K}_r} \omega_k^{(r)} \, \mathbf{w}_k^{(r+1)} \tag{3}$$

In Equation (3), ωk(r) is the normalised aggregation weight; qk(r) is an independently computed round-specific quality and protocol-compliance factor; dk is a predeclared domain-relevance factor for the target evaluation; and all other terms retain the meanings defined for Equation (2). A zero value excludes a client from that round and requires a recorded reason. Quality weighting is not a mechanism for politically or institutionally preferred participation, and domain relevance must not be selected after observing which model performs best. The equation is a conceptual governance aid informed by statistical-heterogeneity and client-selection research, not a validated Black Sea aggregation rule (Qin et al., 2023; Yang et al., 2024).

Robust aggregation cannot be reduced to one formula. Median, trimmed, similarity-based, validation-based and anomaly-aware approaches make different assumptions, and attackers may adapt to the chosen rule. A defensible service combines authenticated participation, bounded update norms, local and cross-client validation, anomaly investigation, secure logging, rate limits, rollback and incident response. Poisoning surveys show that no single defence covers all data and model attacks (Chen et al., 2022; Xia et al., 2023).

Local personalisation under non-IID conditions

Local personalisation retains useful shared information while limiting forced convergence toward an unsuitable global model. A proximal formulation is shown in Equation (4).

$$\mathbf{w}_k^* = \arg\min_{\mathbf{w}} \left[F_k(\mathbf{w}) + \frac{\mu_k}{2} \left\| \mathbf{w} - \mathbf{w}_g \right\|_2^2 \right] \tag{4}$$

In Equation (4), wk* is the locally personalised parameter vector; Fk is the local objective from Equation (1); wg is the candidate global parameter vector; μk is a locally validated regularisation strength; and ||·||2 is the Euclidean norm. A larger μk constrains the local model more strongly toward the global model, whereas a smaller value permits greater local adaptation. The value must be selected using local validation and not treated as transferable. Cross-silo personalisation research supports this general approach to heterogeneous clients, but published benchmark results do not establish performance for landslide warning (Qin et al., 2023; Yang et al., 2024).

Personalisation can also occur through local calibration, a local output head, a shared representation, client clustering or multi-task learning. The choice depends on whether heterogeneity lies mainly in features, labels, prevalence, sensor response or decision costs. A client with a different landslide process should not be grouped merely because its update vector is numerically similar over a short period. Geotechnical and hydrological interpretation remains necessary.

Protected update exchange and residual privacy risk

Secure aggregation is one mechanism for preventing the coordinator from reading an individual client's update when a sufficient eligible group participates. Its masking principle can be represented by Equation (5).

$$\sum_{k \in \mathcal{K}_r} (\Delta \mathbf{w}_k + \mathbf{m}_k) = \sum_{k \in \mathcal{K}_r} \Delta \, \mathbf{w}_k, \qquad \sum_{k \in \mathcal{K}_r} \mathbf{m}_k = \mathbf{0} \tag{5}$$

In Equation (5), Δwk is client k's model update; mk is a protocol-generated mask; and the masks cancel only in the authorised aggregate. The expression illustrates a required property rather than specifying a production cryptographic protocol. Dropout recovery, collusion assumptions, key management, minimum cohort size, verification and implementation security must be defined separately. Secure aggregation hides individual updates from a qualifying aggregator view; it does not detect poisoning, guarantee anonymity, protect an insecure client or prevent every inference from the final model (Gosselin et al., 2022; Li et al., 2023).

Differential privacy can bound certain information disclosures by adding calibrated randomness and maintaining a privacy account, but the chosen mechanism, clipping rule, privacy parameters and cumulative budget affect both privacy and utility. No privacy parameter is proposed because no dataset, threat model or operational task was supplied. Encryption in transit, access control, secure aggregation, differential privacy, update validation and data minimisation address different threats and should not be presented as interchangeable guarantees.

Probability calibration and local decision logic

A landslide probability used in risk intelligence should be calibrated for the local prediction horizon and domain. The Brier score in Equation (6) is one transparent probability metric among several.

$$BS_k = \frac{1}{m_k}\sum_{i=1}^{m_k}\left(\hat{p}_{k,i} - y_{k,i}\right)^2 \tag{6}$$

In Equation (6), BSk is the local Brier score on an independent evaluation set; mk is the number of eligible evaluation records; p-hat-k,i is the predicted probability for the defined target and horizon; and yk,i is the observed binary outcome under the same ontology. Lower values indicate smaller mean squared probability error, but the score should be accompanied by reliability diagrams, discrimination, class-specific errors and uncertainty intervals. Spatial and event holdouts are required. Calibration evidence from one client cannot be assigned to another without transfer testing (Achu et al., 2023; Le et al., 2024).

Risk-informed action additionally depends on consequences. Equation (7) expresses a local expected-cost decision rule rather than a universal warning threshold.

$$a^*_{k,t} = \arg\min_{a \in \mathcal{A}_k} \sum_j P\left(S_{j,k,t} \mid \mathcal{D}_{k,t}\right) C_k\left(a, S_j\right) \tag{7}$$

In Equation (7), ak,t* is the locally selected action at client k and time t; Ak is the authorised action set; Sj is a defined hazard or consequence state; Dk,t is the time-qualified local evidence, including any federated model output; P is the locally calibrated state probability; and Ck(a,Sj) is the locally approved consequence or cost of action a if state Sj occurs. Costs can be ordinal where monetary estimates are inappropriate. The equation makes authority and consequence explicit; it does not permit the federation coordinator to impose an action. Human-centred early-warning research and current AI governance guidance support this separation between model evidence and accountable decision (NIST, 2023; Tiggeloven et al., 2025).

Minimum semantic and governance contract

Table 2 defines the minimum contract required before a client can exchange an update. It addresses meanings, provenance and authority rather than only network compatibility. A federation can operate with a narrower feature set, but it cannot omit the definition of its target, spatial unit or permitted use.

Table 2. Minimum contract for federated landslide intelligence

Contract element	Required content	Acceptance condition
Intended use and authority	Research, screening, preparedness, advisory or warning purpose; users; decisions; responsible authority; prohibited uses.	All participants accept the bounded purpose and can reject a model for local operational use.
Spatial and temporal unit	Geometry, coordinate reference system, vertical datum, support, map scale, prediction time, horizon and update frequency.	Transformation is reproducible and does not create false precision or spatial leakage.
Label ontology	Landslide type, activity, certainty, date precision, trigger, negative-label rule, mapping and ontology version.	Original labels are retained; ambiguous or unmapped classes are not silently coerced.
Feature schema	Name, physical meaning, unit, source, resolution, sampling, processing, uncertainty, missing code and permitted transformation.	Local tests confirm that nominally common features are physically and statistically comparable.
Eligibility and quality	Inclusion and exclusion criteria, duplicate handling, outlier review, sensor health, inventory confidence and minimum sample rule.	The eligible count and quality summary can be audited without disclosing prohibited raw records.
Model and update	Architecture, objective, hyperparameters, random seed policy, software, code and model hashes, update form, norm and round.	A local run is reproducible and the received artefact matches the approved version.
Validation and uncertainty	Local baseline, spatial/event/time holdouts, metrics, calibration, uncertainty, subgroup and domain-shift tests.	Predeclared acceptance and withdrawal criteria are met for the named local use.
Privacy and security	Threat model, data classification, permitted exchange, authentication, encryption, aggregation, privacy account, logging and incident process.	Residual risks, assumptions and failure procedures are approved; no mechanism is described as an absolute guarantee.
Decision record	Output meaning, evidence time, local calibration, limitations, action authority, issue and expiry, acknowledgement and feedback.	A recipient can reconstruct what informed the action and who was accountable.

Source: *Authors' contract informed by Graser et al. (2022), Moreno-Álvarez et al. (2024), NIST (2023, 2024), and Tuia et al. (2025).*

Evidence-gated federation lifecycle

Figure 2 prevents a technically functioning training round from being mistaken for operational readiness. The lifecycle begins with intended use and client eligibility, then aligns semantics, establishes local baselines, and runs federation in shadow mode. Only a model that passes cross-site and local validation can enter controlled local use. Monitoring, event replay, drift detection, privacy reassessment and user exercises continue throughout its life. Failure at any gate restricts the claim, returns the system to an earlier stage or suspends the model.

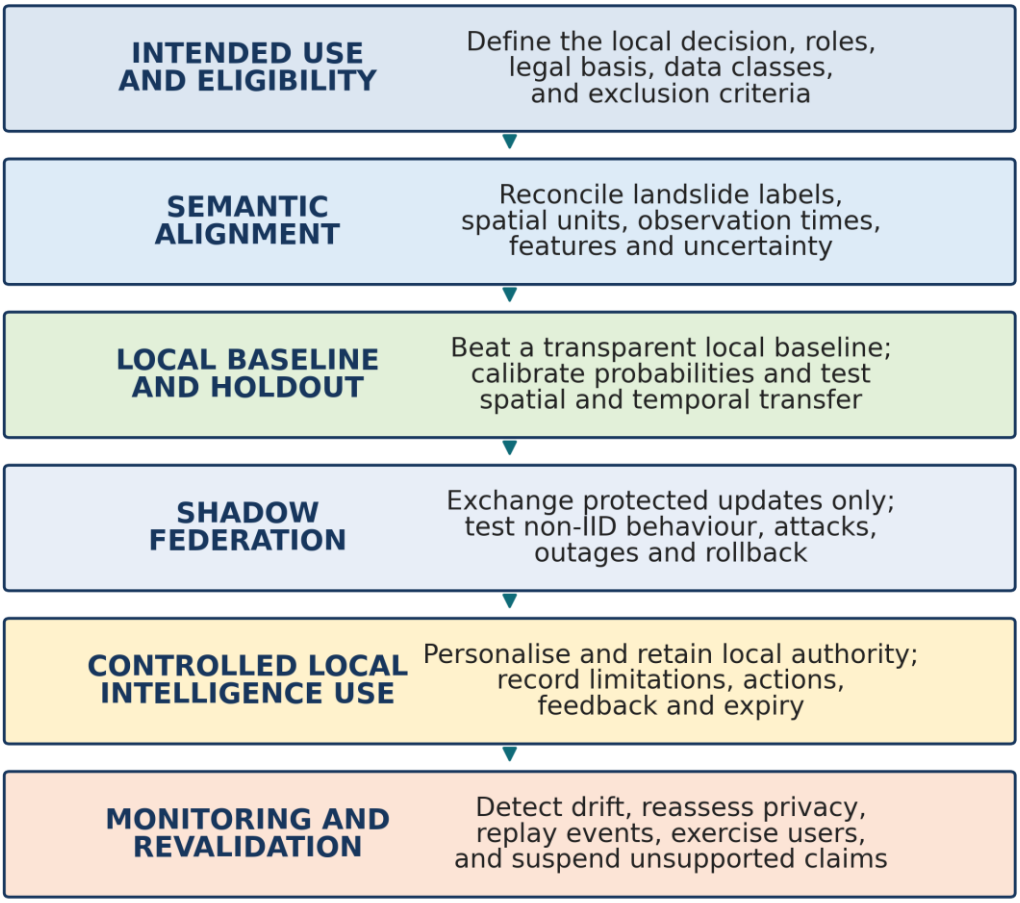

Figure 2. Evidence-gated lifecycle from eligibility to controlled local use

Source: *Original framework developed by the authors from NIST (2023, 2024), Tiggeloven et al. (2025), and current federated-learning assurance evidence in Chen et al. (2022), Gosselin et al. (2022), and Li et al. (2023).*

The gate structure also supports partial value. A consortium that cannot justify federated model training may still improve risk intelligence through a shared ontology, metadata profile, benchmark event set and uncertainty vocabulary. Conversely, a high-performing research model does not bypass governance, communication or human-factors tests.

RESULTS AND DISCUSSION

Requirements traceability and assurance

The design exercise produced a traceable relationship between principal failure modes and controls. Table 3 records the threat or failure, the observable evidence, the preventive or detective safeguard, and the required system response. The result is architectural completeness against the selected evidence, not a measured reduction in risk. Each control still requires implementation and independent testing.

Table 3. Federated-learning threat and failure-control matrix

Threat or failure	Detectable evidence	Safeguards	Required response
Label or schema mismatch	Ontology hash differs; unexpected class proportions, units, ranges, missing codes or spatial support.	Versioned contract, schema validation, physical plausibility checks and mapping review.	Reject or quarantine the update; preserve original mapping; resume only after approved reconciliation.
Non-IID degradation	Global average improves while one or more clients, classes, seasons or terrain domains degrade.	Per-client reporting, local baseline, spatial/event holdouts, personalisation and domain-specific acceptance.	Retain or restore local model, reduce claim, cluster only with geotechnical justification, and investigate transfer.
Inventory bias or false negatives	Performance changes with mapped-area masks, survey effort, accessibility or event completeness.	Confidence fields, positive–unlabelled sensitivity, event-based review and explicit negative-label rules.	Widen uncertainty, relabel, limit domain and avoid interpreting unmapped terrain as stable.
Poisoned or backdoored update	Unusual norm, direction, validation behaviour, targeted class response, provenance or participation pattern.	Authentication, bounded updates, robust aggregation tests, validation, anomaly investigation and rollback.	Exclude the update, freeze release, preserve evidence, notify participants and initiate incident response.
Inference or model leakage	Privacy test exceeds approved bound; small cohort, repeated queries or exposed intermediate artefacts.	Data minimisation, access control, secure aggregation, privacy accounting, cohort policy and query limits.	Stop exchange, rotate credentials or keys, assess disclosure, notify under the agreement and revise mechanism.
Client dropout or network interruption	Missing heartbeat, incomplete round, stale model or failed secure-aggregation recovery.	Eligibility threshold, bounded waiting, local continuity, signed checkpoints and retry policy.	Abort or complete only under the approved protocol; never impute a silent client's approval or data.
Coordinator compromise or failure	Invalid signature, unapproved code or rule, divergent logs, unavailable service or suspicious model release.	Separation of duties, signed artefacts, replicated logs, independent verification, backups and tested recovery.	Suspend rounds, reject release, recover from trusted checkpoint and require multi-party approval.
Concept or infrastructure drift	Feature, prevalence, calibration or residual distributions change; new construction, drainage or events alter slope behaviour.	Drift monitoring, event replay, periodic field review, model expiry and change-controlled retraining.	Declare out-of-domain or degraded state, revert to baseline and revalidate before renewed use.

Source: *Authors' assurance matrix based on Chen et al. (2022), Gosselin et al. (2022), Li et al. (2023), Xia et al. (2023), and NIST (2023, 2024).*

The matrix shows why privacy, robustness and scientific validity cannot be collapsed into one assurance claim. Secure aggregation may protect an individual update from the coordinator yet prevent direct inspection of an anomalous contribution. Robust aggregation may reduce some poisoned updates yet still favour a majority domain. Differential privacy may reduce certain disclosure risks yet worsen

calibration for rare events. The assurance case must therefore state which threat each control addresses, which assumptions remain and how failure becomes visible.

Desk-based stress cases

Stress case 1 considers a client with substantially more mapped samples than all other participants. Under Equation (2), its update dominates the weighted average. The framework does not assume that this is correct: it compares the global candidate against each client's local baseline, class and terrain performance, and calibration. Equation (3) may be tested only with predeclared quality and domain rules. If smaller clients degrade, the release is rejected for those clients or locally personalised under Equation (4). The logical result is that sample volume cannot substitute for geographic relevance.

Stress case 2 considers a participant that changes from event polygons to point-centroid labels or reclassifies debris flows as shallow slides without updating the contract. The ontology or schema hash differs, and distribution and geometry checks identify the change. The update is quarantined before aggregation. Historical models remain reproducible because the original ontology version is retained. The framework therefore fails visibly rather than interpreting a mapping-policy change as a new landslide pattern.

Stress case 3 considers a compromised or faulty client that submits a bounded update designed to increase a particular road corridor's apparent safety. Authentication alone does not detect the attack. Cross-client and local validation, targeted class and geographic tests, update-similarity analysis, provenance and rollback controls provide multiple opportunities for detection. If the anomaly cannot be resolved, the release is frozen and the previous approved local model remains in service. This response is consistent with the layered defence required by federated poisoning research (Chen et al., 2022; Xia et al., 2023).

Stress case 4 considers communication loss during a training round or loss of the coordinator during a rainfall emergency. Model training and operational warning are decoupled. Each local authority continues its approved local warning procedure and does not wait for a global update. The incomplete training round is aborted or completed only if its dropout and secure-aggregation conditions were met. After recovery, signed checkpoints and logs are reconciled. The absence of a federated update is shown as stale or unavailable, never as evidence of low hazard.

Across the four cases, the framework preserves local continuity, exposes unsupported assumptions and prevents a regional average from overriding local evidence. These are logical properties of the design, not observations from participating countries. Quantitative reliability can be established only through implementations, prospective data and controlled exercises.

Validation and assurance matrix

Table 4 defines the minimum validation package. A single random holdout and global accuracy score cannot support a cross-border risk-intelligence claim. The evaluation must compare local-only, central benchmark where lawfully possible, and federated candidates; preserve spatial and temporal separation; and report uncertainty and operational behaviour.

Table 4. Validation and assurance matrix for a federated landslide model

Assurance domain	Required test	Evidence to report	Failure action
Local baseline and target validity	Transparent local model; label audit; leakage review; sensitivity to inventory confidence and negative-label rule.	Target definition, eligible counts, data periods, spatial units, baseline metrics, calibration and limitations.	Correct labels or restrict purpose; do not federate an invalid local task.

Assurance domain	Required test	Evidence to report	Failure action
Cross-client generalisation	Leave-one-client-out where justified; spatial, event and temporal holdouts; terrain and season strata.	Per-client and subgroup discrimination, calibration, false alerts, misses and uncertainty.	Reject global claim; personalise, cluster with physical justification or keep local-only model.
Federation benefit	Compare federated candidate with the approved local baseline under identical evaluation data and decision horizon.	Absolute and relative metric change, uncertainty, computation and communication burden.	Retain baseline where benefit is absent, unstable or operationally irrelevant.
Probability and decision calibration	Reliability analysis, Brier score, threshold or action sensitivity, cost scenarios and warning lead-time review.	Calibration curves, confidence intervals, action consequences and local acceptance rationale.	Recalibrate, change claim or withhold time-critical use.
Robustness and security	Malformed, stale, extreme, targeted and colluding update tests; dropout; coordinator loss; replay and rollback.	Detection coverage, false positives, recovery time, residual attack paths and incident evidence.	Freeze release, improve controls and repeat independent test.
Privacy and data protection	Threat-model review, update leakage tests, cohort and query analysis, secure-aggregation verification and privacy accounting where used.	Exchanged fields, assumptions, privacy parameters, cumulative exposure, access and incident logs.	Reduce exchange, revise mechanism or stop federation; notify as required by the agreement.
Human and organisational use	Scenario exercises with uncertainty, contradiction, stale models, multilingual messages and responsibility handover.	Comprehension, acknowledgement, action feasibility, decision record and lessons.	Revise message, authority, action set or training; a model metric cannot compensate for unusable advice.

Source: *Authors' validation matrix informed by Achu et al. (2023), Han and Semnani (2025), Le et al. (2024), NIST (2023, 2024), and Tiggeloven et al. (2025).*

Black Sea applicability and interoperability

The Black Sea is an appropriate region for shared learning because neighbouring coasts experience transboundary meteorological systems, transport and energy interdependencies, and common satellite coverage, while retaining strong geotechnical and institutional diversity. Remote-sensing models can be trained across distributed holdings, and modern Earth-observation research provides tools for multimodal and adaptive analysis (Ben Youssef et al., 2024; Moreno-Álvarez et al., 2024; Tuia et al., 2025). These capabilities support common observation and benchmark practices; they do not demonstrate one transferable landslide model.

A regional federation should begin with semantics and local baselines, not with a presumption that all countries will contribute the same data. One node may participate through validated inventory and terrain features; another through model evaluation only; another through aggregated rainfall or satellite-derived features. Participation can be asymmetric if the permitted contribution, scientific limitations and aggregation rule are explicit. A client should also be able to withdraw from future rounds without invalidating the provenance of models already approved under the agreement.

Regional interoperability is most valuable when it reveals transfer limits. For example, a model trained on shallow rainfall-induced failures may appear accurate in aggregate yet be irrelevant for a monitored deep-seated coastal landslide. The Kıyıcık case demonstrates how construction and drainage can be

central to a specific failure (Turoğlu & Duran, 2025). Eastern Black Sea geophysical variability likewise supports local subsurface evidence (Karslı et al., 2024). A regional model should therefore carry a domain statement identifying landslide types, terrain, observation period, scale and excluded mechanisms.

Rainfall warning studies also caution against threshold transfer. Multi-layer soil moisture can improve hydrometeorological interpretation, topography affects the representativeness of soil-wetness observations, and thresholds in data-sparse regions require explicit uncertainty (Palazzolo et al., 2023; Patton et al., 2023; Wicki et al., 2023). Comparative machine-learning results from one region cannot be treated as operational evidence for another (Liu, Ma, et al., 2024). The federation should share methods and uncertainty while preserving locally calibrated trigger logic.

Governance, human factors and cybersecurity

Governance begins with a responsibility map. Each participant names owners for inventory quality, sensor and remote-sensing products, feature engineering, local training, validation, privacy, cybersecurity, model release, warning interpretation and incident response. The coordinating organisation maintains the protocol and audit trail but does not acquire local decision authority by technical convenience. Model cards and data statements record the intended use, data period, domain, excluded classes, known limitations, validation and expiry.

Human review is not a decorative final step. Engineers and warning authorities must be able to distinguish a federated susceptibility score from an observed slope movement or time-dependent warning. A message should state spatial support, evidence time, model version, probability or category meaning, uncertainty, unavailable inputs, validity period and locally authorised action. Multilingual communication must preserve these meanings rather than translating only the warning colour.

Cybersecurity covers clients, coordinator, identity services, model registry, communication, software supply chain, monitoring and recovery. Controls include an asset and dependency inventory; strong authentication; least privilege; encrypted channels; integrity-protected artefacts; signed code and models; network segmentation; anomaly monitoring; backups; independent logs; incident exercises; and trusted rollback. The NIST Cybersecurity Framework provides a general governance structure, while the AI Risk Management Framework helps organise validity, transparency and accountability concerns (NIST, 2023, 2024). Neither framework replaces the participating organisations' laws, sector requirements or threat model.

Staged implementation roadmap

Table 5 translates the architecture into six evidence-gated stages. The first deliverable is a bounded use case and governance agreement; the first technical deliverable is a semantic profile and local baseline. Model exchange is deliberately delayed until participants can evaluate whether the same target and feature meanings are being learned.

Table 5. Staged roadmap for Black Sea federated landslide intelligence

Stage	Principal work	Required deliverable	Gate to proceed
1. Purpose, partners and authority	Define use, clients, coordinator, decisions, responsibilities, lawful basis, prohibited uses, withdrawal and incident process.	Signed governance and information-flow specification; responsibility and risk register.	Every participant accepts a bounded purpose and retains local authority.
2. Semantic and geospatial alignment	Map inventories, landslide types, spatial units, time, features, units, uncertainty, quality and missingness.	Versioned ontology, feature schema, transformation tests and unresolved-difference register.	Common fields are physically meaningful; incompatible data remain excluded or separate.

Stage	Principal work	Required deliverable	Gate to proceed
3. Local baselines and benchmark protocol	Audit labels, construct spatial/event/time holdouts, fit transparent baselines and define metrics and calibration.	Per-client baseline report, evaluation package and predeclared acceptance criteria.	The local task is valid, reproducible and relevant to a named decision.
4. Shadow federation and protection	Implement authenticated rounds, protected exchange, provenance, robust-update tests, privacy assessment, dropout and rollback.	Reproducible federation run, security and privacy test report, signed checkpoints and incident exercise.	Scientific and technical failures are detected and recoverable without operational consequences.
5. Controlled local intelligence use	Personalise and calibrate; compare with local baseline; exercise users; limit outputs to approved research or advisory roles.	Independent validation, model card, operating procedure, expiry and withdrawal criteria.	Local authority accepts residual risk for the exact use; no unsupported regional threshold is adopted.
6. Regional expansion and maintenance	Add clients gradually; test transfer; monitor drift; replay events; review agreements, security and model performance.	Cross-client assurance report, change history, recurring exercise record and revalidation schedule.	Expansion improves defined outcomes without degrading clients or obscuring accountability.

Source: *Authors' roadmap synthesising Graser et al. (2022), Li et al. (2023), Moreno-Álvarez et al. (2024), NIST (2023, 2024), and Tiggeloven et al. (2025).*

Limitations and research agenda

This study has seven principal limitations. It is a conceptual architecture without a participating consortium or new dataset. The literature synthesis is targeted rather than systematic. No legal analysis of the six countries is offered. Equations (1)–(7) are editable design structures, not calibrated Black Sea models. The threat matrix does not prove implementation security. Logical stress testing cannot quantify prediction skill, privacy leakage, warning lead time or social benefit. Finally, the framework does not establish that a shared model will outperform strong local baselines.

Research should first develop a documented benchmark protocol rather than a central raw-data repository. Each client can run identical containerised evaluation code on local data and return privacy-reviewed aggregate metrics. Benchmark tasks should distinguish long-term susceptibility, event-based occurrence, short-horizon warning and post-event mapping. Inventories should report landslide type, geometry, date precision, trigger evidence, confidence, survey footprint and mapping opportunity. Negative and unlabelled terrain require separate treatment.

Methodological studies should compare local-only, simple federated averaging, robust aggregation and personalised approaches using spatial, event, temporal and leave-client-out evaluation. They should report per-client discrimination and calibration, uncertainty, class-specific errors, false-alert burden, missed events, communication cost, training stability and sensitivity to incomplete inventories. Published susceptibility research demonstrates the importance of uncertainty and interpretable features; these properties should be evaluated rather than assumed to follow from federation (Achu et al., 2023; Le et al., 2024; Xu et al., 2024).

Security and privacy research should use explicit adversary models and red-team exercises. Tests should include membership and property inference, gradient or update reconstruction where applicable, malicious labels, targeted backdoors, model replacement, colluding clients, coordinator compromise, dropout and replay. The evaluation should measure both attack success and the scientific cost of

defences, particularly for rare landslide classes and small clients. Privacy controls that remove useful minority information can create a safety-relevant disparity even while reducing disclosure risk.

Prospective pilots should begin in shadow mode and compare federated outputs with current expert and operational practice. Evaluation should measure timeliness, calibration, domain shift, message comprehension, action feasibility, inspection prioritisation, continuity and post-event learning. Hydrologic early-warning research shows that useful systems connect rainfall and soil-state observations to locally understood slope processes (Mirus et al., 2025; Piciullo et al., 2022; Roman Quintero et al., 2023). The purpose of federation is to improve that local evidence, not to detach prediction from physical process.

CONCLUSION

This paper has developed a federated-learning framework for cross-border landslide risk intelligence across Black Sea coastline countries. The framework links locally retained landslide inventories, conditioning factors, dynamic triggers, monitoring, Earth observation, exposure and decision records through a common semantic contract, local training and validation, protected update exchange, robust federation, personalisation and accountable local use.

The central contribution is disciplined separation. Retaining raw data locally is not a privacy guarantee. Secure aggregation is not poisoning defence. A global average is not evidence of performance for every coast. Susceptibility is not time-dependent hazard, and a model probability is not an authorised warning action. Label conflict, missing clients, anomalous updates, drift and out-of-domain predictions must become visible degraded states rather than being hidden by automatic aggregation.

The proposed architecture can guide a bounded pilot and independent review, but it does not authorise an operational regional service. Implementation requires explicit participating institutions and agreements, a versioned landslide ontology, locally valid baselines, prospective and spatial validation, a defined privacy and security threat model, incident and continuity exercises, interpretable communication, and competent national or municipal authority. A successful Black Sea federation would share evidence and learning while preserving local geotechnical meaning and responsibility.

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SMART BIO-ENGINEERED SLOPE STABILIZATION WITH EMBEDDED SENSORS FOR CLIMATE-RESILIENT BLACK SEA COASTLINES

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ABSTRACT

Objectives: This study develops a smart bio-engineered framework for climate-resilient stabilization and performance verification of Black Sea coastal slopes.

Methods: A design-science method and targeted synthesis of peer-reviewed evidence published from 2022 to July 2026 were used to specify a six-layer architecture, editable mechanics and data-quality equations, intervention and sensor matrices, assurance controls, and an evidence-gated roadmap. Requirements traceability and four desk-based stress cases were applied. No site investigation, treatment trial, field dataset, measured improvement, climate projection, deployment, or universal threshold is claimed.

Results: The framework separates ecological soil bioengineering from microbially or enzyme-induced mineralisation and combines either only where site qualification supports its mechanism. Embedded rainfall, soil-water, pore-pressure, strain, displacement, temperature, and conductivity observations verify loads, slope response, vegetation condition, and treatment durability. Quality and freshness weighting, explicit degraded states, mechanism-based factor-of-safety updating, and human-authorised actions prevent sensor silence or biological decline from being interpreted as safety.

Conclusions: Bio-engineered stabilization can contribute to coastal resilience when integrated with drainage, erosion control, conventional reinforcement where necessary, ecological safeguards, and long-term maintenance. Operational use requires site-specific species selection, constitutive calibration, environmental assessment, prospective monitoring, and accountable geotechnical authority.

Keywords: Soil bioengineering; slope stabilization; embedded sensors; biocementation; climate resilience; Black Sea coast.

INTRODUCTION

Black Sea coastal slopes occur in markedly different geological, geomorphological, climatic, ecological and urban settings. Their instability may involve rainfall infiltration, loss of matric suction, groundwater rise, progressive weathering, surface runoff, gullying, toe erosion, wave attack, river incision, earthquakes, excavation, drainage alteration and added structural load. These processes do not act uniformly around the basin. The documented December 2024 Kıyıcık landslide in Artvin, Türkiye, illustrates a local interaction among coastal-road construction, drainage and geomorphology rather than a basin-wide template (Turoğlu & Duran, 2025). Eastern Black Sea geophysical investigations similarly show why near-surface materials and water conditions must be resolved locally (Karslı et al., 2024).

Climate resilience in this setting cannot be reduced to planting a slope. Vegetation can intercept rainfall, promote evapotranspiration, alter infiltration and suction, reduce surface erosion and reinforce shallow soil through roots. Its contribution depends on species, root architecture, soil, establishment, season, drought, disease, management and failure depth. Reviews of hydro-mechanical vegetation effects and their representation in slope-stability models identify substantial parameter and validation uncertainty,

especially for time-dependent reinforcement and climates outside well-studied domains (Lann et al., 2024; DiBiagio et al., 2024). Herbaceous vegetation can be valuable for surface protection and shallow root networks, but its engineering role remains species- and site-specific (Gong et al., 2024).

The term bio-engineered also covers mineralisation techniques that are physically different from vegetation. Microbially induced carbonate precipitation (MICP) and enzyme-induced carbonate precipitation (EICP) can create calcium-carbonate bonding and modify erosion resistance or strength. Recent laboratory and field research demonstrates promising applications on slopes, sandy coastal materials and beaches, but also highlights treatment uniformity, reagent transport, durability, scale, chemistry and environmental by-products (He et al., 2023; Imran et al., 2022; Wu et al., 2024; Zhang et al., 2024). It is therefore inaccurate to treat biocementation as an automatically sustainable substitute for conventional stabilization.

Embedded sensors add a further layer of engineering intelligence. Rain gauges, soil-moisture and suction sensors, piezometers, temperature and electrical-conductivity probes, fibre-optic strain sensing, inclinometers, tilt meters, extensometers and GNSS can observe loading, hydrological state, deformation and treatment condition. Reviews show that monitoring value depends on installation, scale, calibration, data quality, maintenance and interpretation, not simply on network density (Alam et al., 2024; Anjana et al., 2024). Smart geosynthetics may combine reinforcement and sensing, while operational Internet of Things implementations demonstrate the potential for near-real-time slope state assessment (Abedi et al., 2023; Piciullo et al., 2025).

Sensors do not stabilize a slope, prove root reinforcement, demonstrate mineralisation durability or authorise a warning. They provide observations that must be connected to a ground model, failure mechanism, intervention mechanism and decision process. A falling soil-moisture reading could indicate drying, a failed sensor or loss of contact. Stable surface coordinates can coexist with rising pore pressure at depth. Healthy above-ground vegetation can conceal inadequate root depth, while a mineralised surface crust can mask untreated or weakened soil beneath it. A smart system must distinguish evidence, inference and decision.

This paper proposes a design-science framework for smart bio-engineered stabilization of Black Sea coastal slopes. The contributions are a six-layer architecture; a differentiated intervention matrix; seven editable equations; an embedded-sensor and observability matrix; a climate-stress response matrix; an evidence-gated lifecycle; assurance and maintenance requirements; four desk-based stress cases; and a staged implementation roadmap. No named site, field installation, species prescription, treatment recipe, sensor performance, stabilization gain, climate projection or warning threshold is reported. The result is a transparent design and validation blueprint to be populated by competent local investigations.

METHODOLOGY

Design-science approach and evidence base

A design-science method was selected because the research objective is to construct and logically evaluate an integrated stabilization-and-verification architecture without a supplied site or dataset. A targeted synthesis of peer-reviewed research published from 2022 to July 2026 was conducted across vegetation–soil mechanics, ecological slope protection, MICP and EICP, coastal nature-based solutions, climate-adaptive geotechnics, slope monitoring, distributed fibre-optic sensing, Internet of Things systems and Black Sea geotechnical context. The synthesis is purposeful and does not claim the exhaustive search, screening or meta-analysis of a systematic review.

Evidence was interpreted through seven questions: which failure mechanism is addressed; what physical or biological mechanism provides resistance; at what depth and time scale it acts; what environmental boundary conditions limit it; which observation can verify it; what maintenance or renewal preserves it; and what claim must be withdrawn if validation fails. Laboratory, pilot, field, review and guidance evidence were not treated as equivalent. Coastal evidence from other regions was used to derive transferable principles, not to prescribe non-native ecosystems or assume identical wave, sediment or ecological conditions.

The framework was translated into components, information flows, equations, tables and assurance gates. Four hypothetical stress cases were then used to test logical behaviour: intense rainfall combined with blocked drainage; vegetation dieback following drought or salinity stress; erosion or loss of a mineralised surface layer; and sensor or communication loss during a coastal storm. These are structured thought experiments, not simulations or observations of a Black Sea site. The reported results are consequently requirements-traceability and failure-response results only.

Intended use and claim discipline

The intended use is preliminary design, pilot planning, instrumentation design, performance verification and adaptive maintenance of coastal soil or weathered-ground slopes. The framework can organise evidence for planted slopes, live fascines or brush layers, vegetated geogrids, drainage-supported bioengineering, qualified MICP or EICP surface zones, and hybrid measures that include structural reinforcement or toe protection. It is not a design standard, species catalogue, treatment specification, emergency procedure or replacement for site investigation.

Operational claims are bounded. A vegetation measure cannot be credited with root cohesion until root distribution, tensile contribution, seasonal condition and relevant slip depth are supported. Mineralisation cannot be credited until chemistry, distribution, engineering properties, by-products and durability are tested for the actual ground and exposure. A sensor record cannot be treated as representative until its support volume, location, calibration and failure modes are understood. Any claimed factor of safety, service life, alarm level or ecological benefit remains a local engineering result.

BIO-ENGINEERED COASTAL SLOPE PROBLEM

Coupled climate, coastal and geotechnical processes

A coastal slope is a coupled atmosphere–vegetation–groundwater–soil–shoreline system. Short intense rainfall may generate surface runoff and erosion before a deep response becomes visible. Prolonged rainfall can reduce suction and raise pore pressure. Dry periods may increase apparent suction while also causing cracking, vegetation stress and preferential flow during the next storm. Wet–dry cycles can change aggregation and treatment bonds; freeze–thaw is relevant only where local exposure supports it. Toe erosion can steepen a slope or remove passive support, while drainage blockage redirects water into vulnerable zones.

Recent reviews link climate change to altered slope-stability drivers but also document substantial uncertainty in translating climate information into local ground response (Tetteh et al., 2025). Climate-adaptive geotechnical design therefore requires an explicit chain from climate variable to boundary condition, ground process, limit state, consequence and adaptation decision (Insana et al., 2025). Machine-learning projections cannot repair a poorly defined causal chain, and future-condition evaluation must address non-stationarity, extrapolation and spatial bias (Han & Semnani, 2025).

Coastal natural and nature-based features are most credible when their functions, performance limits, monitoring and adaptive management are explicit (Bridges et al., 2022). A recent meta-analysis found that hybrid engineering–natural coastal defences can offer adaptation and mitigation advantages across the reviewed evidence base, but that finding does not imply that every hybrid measure or site will perform better (Huynh et al., 2024). For slopes, the corresponding principle is to combine biological and conventional functions according to the governing failure mechanism rather than by a fixed preference hierarchy.

Ecological soil bioengineering

Ecological soil bioengineering uses living plants or live plant material as functional engineering components. Candidate measures include seeded or planted cover, deep- and shallow-rooted native assemblages, live staking, brush layering, fascines, vegetated crib systems, coir or biodegradable erosion-control materials and vegetated geogrids. The mechanism may be surface armouring, runoff interruption, root reinforcement, moisture extraction, roughness, sediment capture or a combination. A review of sustainable slope reinforcement emphasises that living systems should be selected in relation

to soil, climate, slope geometry and maintenance rather than as generic landscaping (Sujatha et al., 2023).

Roots do not provide a uniform cohesion layer. Root density and orientation vary with depth and distance from the plant; root–soil interaction changes with moisture and soil structure; and mature performance may require years. Herbaceous cover can reduce raindrop impact and surface wash while deeper-rooted shrubs or trees may offer different reinforcement and hydrological effects. Large woody vegetation can also add wind loading, create preferential pathways, interfere with drainage or become hazardous when uprooted. The planting design must therefore map desired functions to zones and life stages.

Coastal dunes provide a useful but bounded analogy. Fine roots have been shown experimentally to influence erosion during wave collision in vegetated dune systems (Figlus et al., 2022). That evidence supports explicit attention to root architecture and erosion processes, but it does not establish an identical response for cohesive bluffs, engineered fills or weathered rock around the Black Sea. Native biodiversity, invasive-species risk, habitat continuity, establishment water and long-term land management must be assessed with local ecological expertise.

Biogeotechnical mineralisation and environmental limits

MICP commonly promotes carbonate precipitation through microbial activity, whereas EICP uses free enzymes to catalyse reactions. Both can increase particle bonding or surface resistance when treatment reaches the intended zone under suitable chemical, hydraulic and thermal conditions. Experiments have examined wave-erosion protection of sandy slopes, fibre-assisted EICP protection of clay slopes and rainfall-runoff erosion mitigation (He et al., 2023; Li et al., 2022). A 2024 field trial investigated EICP on a beach slope, and a separate field study examined MICP mitigation of rainfall erosion in a gravelly clay slope (Wu et al., 2024; Zhang et al., 2024). These studies demonstrate feasibility domains, not universal design values.

Treatment performance can be spatially non-uniform because fluids follow preferential paths, react near injection points or fail to penetrate low-permeability zones. Cementation can reduce permeability, which may be beneficial for surface erosion yet adverse if it traps water or redirects infiltration. Carbonate bonds and fibres can be affected by wet–dry, freeze–thaw, dissolution, abrasion and wave action. Published durability work confirms that exposure cycling must be tested rather than assumed (Huang et al., 2022; Imran et al., 2022).

Environmental qualification is part of engineering validity. Ureolytic biocementation can generate ammonium by-products, and rinse strategies have been investigated for their removal (Lee & Gomez, 2024). Reagent sourcing, water use, embodied impacts, energy, transport, effluent, pH change, salinity interaction, microbial ecology and worker exposure require assessment. Life-cycle studies show that sustainability depends on the treatment pathway and system boundary rather than on a biological label (Raymond et al., 2025). MICP or EICP should be rejected or redesigned where ecological or water-quality constraints cannot be met.

Intervention selection and verification

Table 1 separates intervention families by mechanism, suitable domain, limitations and verification. The table is a screening structure; it is not a catalogue of approved measures. Every selected measure must be traced to the site failure model and consequence class.

Table 1. Bio-engineered and hybrid intervention screening matrix

Intervention family	Principal mechanism and possible domain	Material limits and adverse effects	Verification evidence
Native herbaceous and mixed cover	Raindrop interception, surface roughness, erosion resistance and shallow-root reinforcement on erodible surface zones.	Establishment delay, seasonal dieback, drought, fire, trampling, shallow roots, invasive-species risk and irrigation demand.	Coverage, vitality, root depth and density, erosion pins or surveys, moisture response and seasonal inspection.

Intervention family	Principal mechanism and possible domain	Material limits and adverse effects	Verification evidence
Deep-rooted shrubs or selected woody plants	Potential reinforcement of deeper shallow-soil zones, evapotranspiration and interception where geometry and ecology permit.	Wind loading, surcharge, uprooting, preferential flow, root–drain interaction, ageing and mismatch with failure depth.	Species and rooting survey, pull-out or root tests where justified, water balance, wind exposure and arboricultural review.
Live stakes, fascines and brush layers	Near-surface reinforcement, runoff interruption and erosion control with living structural elements.	Survival and rooting depend on species, moisture, installation season and construction quality; not a deep-slip remedy.	Installation record, survival and rooting checks, alignment, settlement, runoff behaviour and replacement rate.
Vegetated geogrids, geocells or erosion mats	Immediate manufactured reinforcement or confinement combined with developing vegetation and surface protection.	Interface pull-out, ultraviolet exposure, clogging, fire, polymer durability, drainage interaction and end-of-life impacts.	Product qualification, as-built geometry, strain or deformation, drainage function, cover integrity and vegetation establishment.
MICP or EICP qualified treatment zone	Carbonate bonding or surface crust for erosion resistance or locally calibrated strength improvement.	Non-uniform treatment, pore clogging, by-products, pH or salinity effects, abrasion, dissolution and exposure-cycle degradation.	Chemistry, carbonate and uniformity tests, strength and permeability, effluent monitoring, durability cycling and inspection.
Drainage-supported bioengineering	Pore-pressure control plus surface and root functions; suitable where water is a governing trigger.	Blocked outlets, root intrusion, maintenance failure, concentrated discharge and false confidence from healthy vegetation.	Piezometric response, flow and outlet checks, camera or physical inspection, moisture transects and maintenance records.
Hybrid toe, structural and biological system	Toe erosion resistance or structural capacity combined with ecological surface functions and monitoring.	Interface scour, reflected erosion, constructability, visual and habitat effects, differential deformation and access needs.	Toe and bathymetric survey where applicable, structural inspection, deformation sensing, habitat monitoring and event review.

Source: *Authors' synthesis based on Bridges et al. (2022), DiBiagio et al. (2024), Gong et al. (2024), He et al. (2023), Huynh et al. (2024), Imran et al. (2022), and Sujatha et al. (2023).*

PROPOSED SMART BIO-ENGINEERED FRAMEWORK

Six-layer architecture

Figure 1 presents the six-layer architecture. A site and consequence model establishes the failure mechanisms and assets before any measure is chosen. A climate and coastal envelope translates relevant rainfall, drying, cycling, runoff, wave and toe conditions into boundary cases. The hybrid intervention package assigns biological, hydraulic, mineralisation and structural functions by zone. Embedded observations then verify loads, states and intervention condition. Mechanism-aware assessment converts quality-controlled evidence into a bounded engineering interpretation. Governed action covers inspection, maintenance, repair, access control, redesign and withdrawal of unsupported claims.

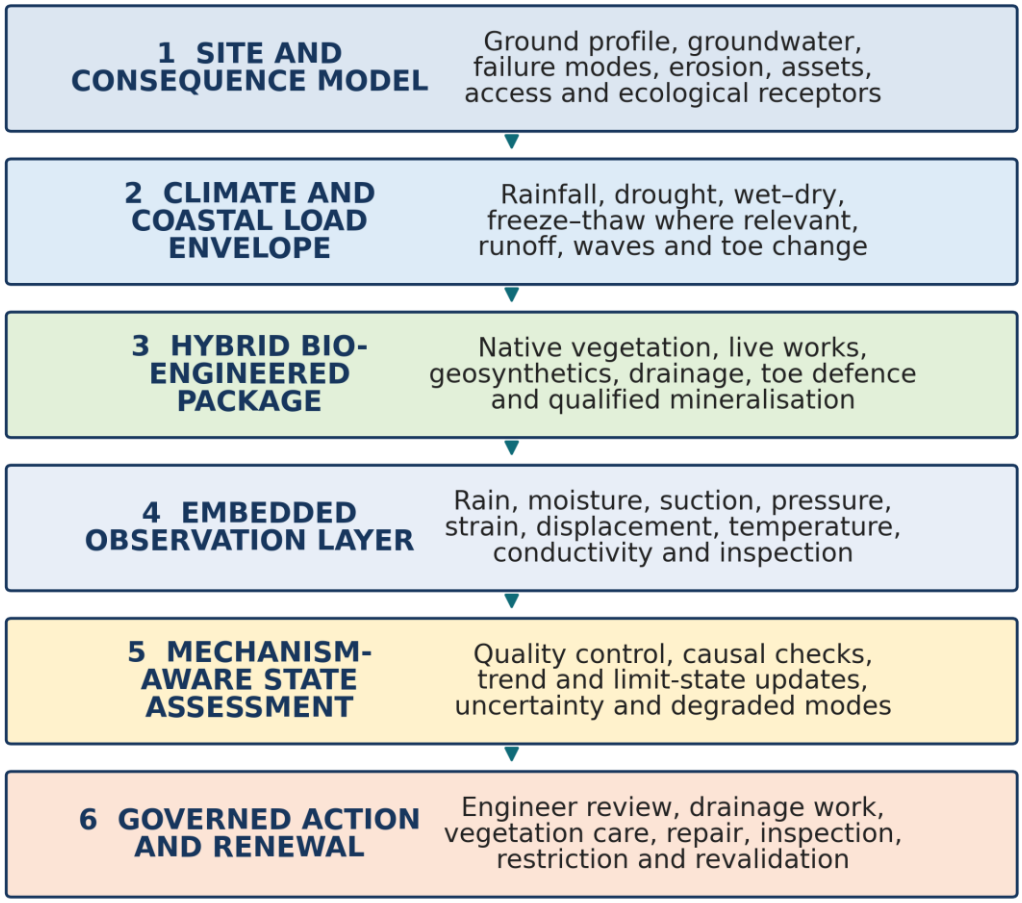

Figure 1. Six-layer architecture for smart bio-engineered coastal slope stabilization

Source: *Original framework developed by the authors from Abedi et al. (2023), Alam et al. (2024), Bridges et al. (2022), DiBiagio et al. (2024), Piciullo et al. (2025), and Raymond et al. (2025).*

The architecture is deliberately hybrid. Biological measures can be the primary system only where their establishment time, resistance, durability and uncertainty are compatible with the consequence and failure mode. Drainage, toe protection, anchors, retaining systems, grading or access restrictions remain available when demanded by the ground model. The presence of vegetation or biocement must never reduce the investigation or design standard for a high-consequence slope.

The observation layer is mechanism-led rather than technology-led. A pore-pressure-driven slip requires pressure and groundwater observations at relevant depths, not only surface moisture. An erosion-dominated slope requires topographic change, runoff and toe evidence. A vegetated geogrid requires deformation and connection checks in addition to plant vitality. A mineralised surface requires chemistry, integrity and beneath-layer response. Instrument locations should be selected from competing failure hypotheses and sensitivity analysis.

Effective stress and unsaturated vegetated strength

The starting point is effective stress. For a saturated idealisation, Equation (1) expresses the normal effective stress carried by the soil skeleton. It is cited here as a constitutive reminder rather than a complete coastal-slope model.

$$\sigma' = \sigma - u_w \tag{1}$$

In Equation (1), σ′ is normal effective stress, σ is total normal stress and u_w is pore-water pressure. The equation shows why rainfall, drainage blockage, groundwater or wave-related boundary change can

reduce available shear resistance even when surface vegetation appears healthy. Site models may require transient unsaturated flow, seepage forces, spatial variability and stress-dependent behaviour (Lann et al., 2024; Tetteh et al., 2025).

A transparent screening representation of unsaturated shear strength with a separate root term is given in Equation (2). It prevents plant contribution from being hidden inside an unexplained fitted cohesion.

$$\tau_f = c' + c_r + (\sigma - u_a)\tan\phi' + (u_a - u_w)\tan\phi_b \quad (2)$$

In Equation (2), τ_f is shear strength on the considered plane; c′ is effective soil cohesion; c_r is the validated root-reinforcement contribution; u_a is pore-air pressure; u_w is pore-water pressure; φ′ is the effective friction angle; and φ_b is a fitted parameter representing the rate of strength increase with matric suction over a stated range. The expression is a conceptual engineering form, not a universal constitutive law. Root effects may be anisotropic, strain-dependent and non-additive, while φ_b may change with suction. Parameters must be obtained for the relevant soil, vegetation state and stress path (DiBiagio et al., 2024; Gong et al., 2024).

Time-dependent root contribution

Living reinforcement changes during establishment, seasonal cycles, disturbance, maturity and decline. Equation (3) makes this time dependence explicit rather than crediting permanent nominal root cohesion.

$$c_r(z,t) = c_{r,0}(z)\, v(t)\, d(t) \quad (3)$$

In Equation (3), c_r(z,t) is the credited root contribution at depth z and time t; c_{r,0}(z) is a site-calibrated reference profile; v(t) is a bounded vitality factor between zero and one; and d(t) is a bounded development-and-durability factor between zero and one. The factors are not directly observable universal constants. They must be linked to root survey, vegetation condition, moisture stress, disturbance and conservative engineering rules. A design may set the contribution to zero during establishment or after unverified mortality. The formulation follows the need for time-dependent vegetation parameterisation identified by DiBiagio et al. (2024) and Lann et al. (2024).

Qualified biocement contribution

Where biocementation is included, its contribution should be separated from untreated soil and reduced when distribution or durability is uncertain. Equation (4) is a bounded bookkeeping relation for a locally calibrated resistance parameter, not a chemical law.

$$c_b(t) = c_{b,0}\, \eta_c(t)\, g_T(t)\, g_S(t)\, g_E(t) \quad (4)$$

In Equation (4), c_b(t) is the credited biocement contribution at time t; c_{b,0} is the reference contribution demonstrated for the actual treatment and ground; η_c(t) is a verified spatial-uniformity and carbonate-retention factor; g_T(t) represents temperature-domain qualification; g_S(t) represents salinity and chemical-domain qualification; and g_E(t) represents exposure durability under relevant wet–dry, freeze–thaw, runoff, abrasion or wave conditions. Each multiplier is bounded from zero to one and must be conservatively assigned from tests and monitoring. The form reflects reported needs for field verification, exposure testing and environmental control (Huang et al., 2022; Imran et al., 2022; Zhang et al., 2024).

Electrical conductivity, temperature and pH can help interpret treatment delivery and changing chemistry, but they do not directly measure cementation strength. Verification may require cores, penetration or shear testing, carbonate measurements, hydraulic conductivity, imaging and controlled coupons. Ammonium or other relevant effluent must be measured where the chosen reaction pathway can produce it. A system that cannot verify treatment depth and ecological acceptability should not credit Equation (4).

4.5 Embedded observations and data contract

Equation (5) defines a minimum observation vector for mechanism-aware monitoring. It does not require every sensor at every location; it requires that omitted variables be justified against the site failure and intervention model.

$$\mathbf{y}_t = [r, \theta, \psi, u_w, \epsilon, \delta, T, EC]^T \quad (5)$$

In Equation (5), r is rainfall or relevant water input; θ is volumetric water content; ψ is matric suction or pressure head according to the adopted convention; u_w is pore-water pressure; ε is strain in a reinforcement, geosynthetic, fibre or soil-coupled sensor; δ is displacement or tilt-derived movement; T is temperature; and EC is electrical conductivity. The superscript T denotes vector transpose. Each observation is stored with time, location and depth, unit, sensor identifier, calibration, sampling and aggregation method, quality flag, uncertainty, maintenance event and provenance (Alam et al., 2024; Anjana et al., 2024; Piciullo et al., 2025).

Table 2 maps observations to mechanisms and limitations. It is cited here to emphasise that redundancy should be functional: independent measurements should challenge the same causal hypothesis through different physical principles. Correlated duplicates on the same failed power supply are not true redundancy.

Table 2. Embedded sensor and observability matrix

Observation	Mechanism or intervention verified	Installation and interpretation limits	Complementary evidence
Rainfall, throughfall and runoff	External water loading, canopy modification, event duration and surface-flow concentration.	Wind undercatch, blockage, spatial variability and mismatch between rainfall and infiltration.	Weather records, inspection, flow measurement, erosion survey and nearby gauges.
Volumetric water content	Wetting front, drying, storage change and vegetation water use at the sensor support volume.	Soil-specific calibration, salinity, temperature, air gaps, stones and limited spatial representativeness.	Suction, pore pressure, gravimetric checks, electrical methods and soil profile.
Matric suction or pressure head	Unsaturated strength state and wetting/drying response above the water table.	Measurement range, cavitation, contact, hysteresis and sensor response time.	Water content, rainfall, soil-water characteristic curve and tensiometer maintenance.
Pore pressure and water level	Transient groundwater, perched water, drainage effectiveness and hydraulic trigger state.	Filter response, installation seal, barometric effects, depth placement and clogging.	Drain flow, neighbouring piezometers, borehole log, moisture and seepage inspection.
Fibre-optic or geosynthetic strain	Distributed deformation, reinforcement load transfer and potential shear localisation.	Cable–ground coupling, temperature compensation, strain transfer, survivability and spatial resolution.	Inclinometer, survey, extensometer, connection inspection and event records.
Tilt, inclinometer, extensometer or GNSS	Slope deformation, rate change, surface and subsurface movement geometry.	Reference stability, installation orientation, noise, depth support and episodic motion.	Fibre strain, cracks, terrestrial or aerial survey and geotechnical interpretation.
Temperature, EC and pH where relevant	Sensor correction, treatment delivery, chemical-domain change and possible leakage or dilution.	Non-unique relation to mineralisation; electrode drift, fouling and soil-contact effects.	Laboratory chemistry, carbonate, effluent, strength, permeability and ecological tests.
Vegetation and surface inspection	Coverage, vitality, root-zone disturbance, erosion, drainage condition and visible treatment damage.	Observer variability, seasonal appearance, surface bias and incomplete access.	Fixed photography, multispectral data where justified, root survey and maintenance record.

Source: *Authors' synthesis based on Abedi et al. (2023), Acharya and Kogure (2025), Alam et al. (2024), Anjana et al. (2024), and Piciullo et al. (2022, 2025).*

Sensor quality, freshness and disagreement

A numerical value should contribute only in proportion to its validity and freshness. Equation (6) provides a transparent sensor weight for fusion or review. It is a governance mechanism, not a claim that heterogeneous observations can be averaged directly.

$$w_i(t) = \alpha_i \, \kappa_i(t) \, [1 - m_i(t)] \exp[-\Delta t_i(t)/\tau_i] \tag{6}$$

In Equation (6), w_i(t) is the weight assigned to observation i at time t; α_i is a predeclared relevance factor for the monitored mechanism; κ_i(t) is a zero-to-one calibration and plausibility factor; m_i(t) is a missing-or-invalid indicator equal to one when the observation must be excluded and zero otherwise; Δt_i(t) is its age; and τ_i is the permitted freshness time constant for that variable and decision. A weight of zero means unavailable evidence, not a safe condition. The exponential term makes stale data visibly decay. Sensor-specific thresholds and quality rules require field validation (Alam et al., 2024; Piciullo et al., 2025).

Disagreement is retained as information. If soil moisture rises while suction and pore pressure remain unchanged, the system tests sensor depth, response time, local infiltration and calibration rather than forcing consensus. If deformation accelerates without a measured hydrological change, it considers toe loss, construction, deeper groundwater, sensor coverage and non-hydrological mechanisms. A conflict flag prompts review and may increase inspection priority. Automatic substitution is permitted only when equivalence and uncertainty have been established.

Mechanism-based stability updating

Equation (7) expresses an auditable decomposition of time-dependent factor of safety. It can organise a more detailed limit-equilibrium, finite-element or probabilistic model, but it is not itself a calculation procedure.

$$FS(t) = \frac{R_g(t) + R_r(t) + R_b(t) + R_s(t)}{D_g(t) + D_w(t) + D_e(t)} \tag{7}$$

In Equation (7), FS(t) is factor of safety at time t; R_g is resistance from the untreated ground; R_r is validated living-root or live-work resistance; R_b is qualified biocement resistance; R_s is structural, geosynthetic, drainage-related or toe-support resistance represented consistently with the adopted method; D_g is gravity and imposed-load demand; D_w is water-related demand, including pore pressure or seepage effects; and D_e is erosion, toe-loss, degradation or other exposure demand. Terms must be derived without double counting. For example, drainage effects should not be credited both as additional resistance and reduced water demand unless the formulation supports that separation. This decomposition is an authors' design representation informed by vegetation-mechanics and climate-adaptive design evidence (DiBiagio et al., 2024; Insana et al., 2025).

The equation supports explicit withdrawal. Vegetation mortality reduces or removes R_r; unverified mineralisation degradation reduces R_b; blocked drainage changes the water term and may remove credited drainage resistance; and observed toe erosion changes D_e and geometry. A calculated safety margin cannot remain frozen while its supporting biological, hydraulic or coastal conditions change. Climate-adaptive design should predefine which observations trigger reanalysis and what evidence is required before a contribution is restored (Insana et al., 2025).

Actions are selected by competent authorities using consequence, uncertainty and feasibility. Possible actions include targeted inspection, clearing or repairing drainage, temporary runoff control, vegetation care, replanting, treatment sampling, toe survey, access restriction, conventional reinforcement or complete redesign. An algorithm may prioritise evidence, but it does not possess legal authority or local situational awareness. High-consequence actions require corroboration and an auditable human decision path.

Evidence-gated lifecycle

Figure 2 defines the evidence-gated lifecycle. It begins with intended use and exclusion criteria, then requires ground and ecological characterisation before laboratory or pilot qualification. Shadow observation establishes seasonal and event behaviour without operational reliance. Controlled installation proceeds by verified zones, and long-term monitoring includes maintenance, renewal and withdrawal. Failure at a gate leads to redesign, a conventional measure or a narrower claim; it does not become a reason to lower the gate.

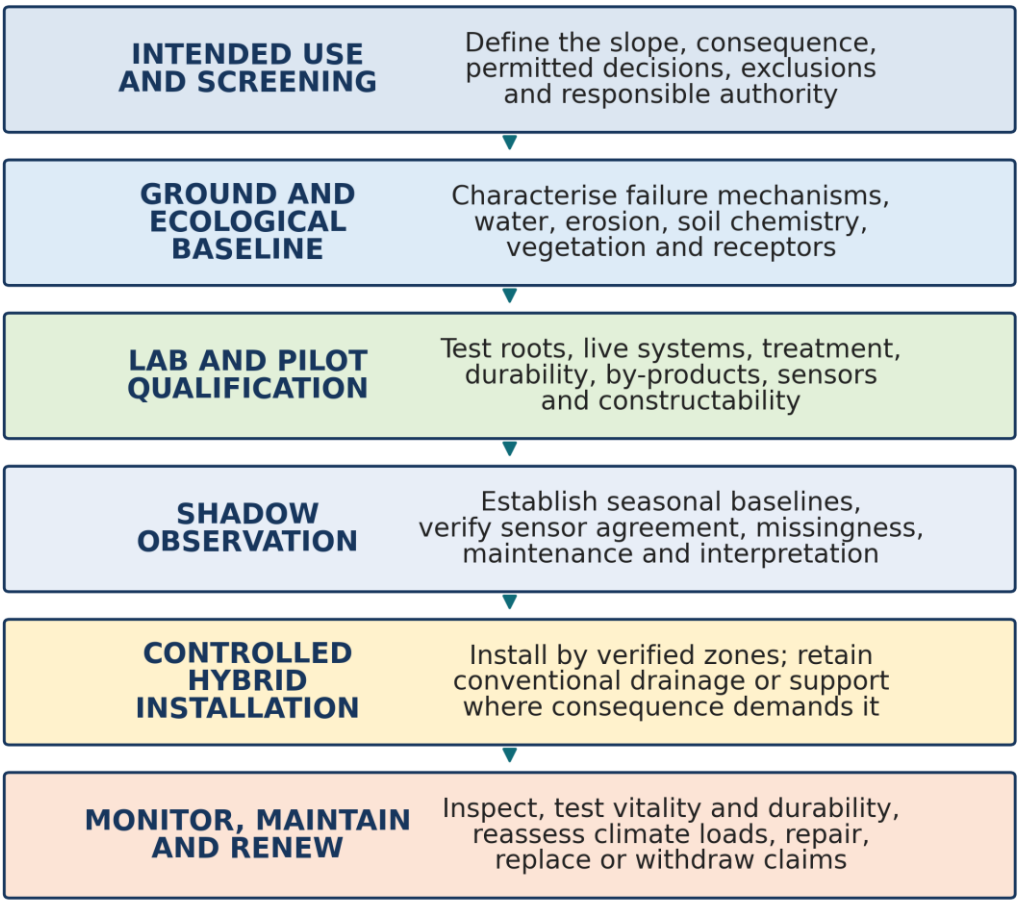

Figure 2. Evidence-gated lifecycle for a bio-engineered and sensor-verified slope

Source: *Original framework developed by the authors from Bridges et al. (2022), Insana et al. (2025), Lee and Gomez (2024), Piciullo et al. (2025), and Raymond et al. (2025).*

RESULTS AND DISCUSSION

Requirements traceability

The principal design result is traceability from hazard and intervention mechanism to observation, decision and failure response. Table 3 summarises this result. The framework does not pass a requirement merely because a sensor or bio-based material is present; it passes only when the relevant mechanism can be verified and an unsupported claim can be withdrawn.

Table 3. Requirements traceability for the proposed framework

Requirement	Framework implementation	Evidence or acceptance test	Explicit degraded response
Failure-mechanism relevance	Site model precedes measure selection; each intervention is assigned to a depth, process and zone.	Ground investigation, alternative hypotheses, sensitivity analysis and independent geotechnical review.	Remove the measure from resistance credit or redesign when the mechanism or depth is unsupported.
Living-system performance	Root contribution is time-, depth- and vitality-dependent through Equation (3).	Establishment, root and vitality observations across seasons and disturbance states.	Set living contribution conservatively to zero or a reduced value; inspect and restore vegetation.
Mineralisation qualification	Equation (4) separates reference contribution, uniformity, environment and exposure durability.	Actual-ground trials, chemistry, distribution, strength, permeability, durability and ecological testing.	Withhold credit, isolate treatment, manage effluent, sample, repair or select another technique.
Hydrological observability	Rain, water content, suction, pore pressure, drainage and runoff are related to the conceptual model.	Event response, depth coverage, cross-sensor consistency and drain inspection.	Unknown hydrological state; increased inspection and conservative action rather than safe classification.
Deformation observability	Surface and subsurface movement plus distributed or local strain are selected to cover likely shear zones.	Stable reference, installation verification, repeatability, independent survey and event replay.	Treat unobserved zones and sensor failure explicitly; restrict reliance or install independent coverage.
Data fitness and continuity	Equation (6) applies calibration, plausibility, missingness and freshness; raw and derived data retain provenance.	Drift, outage, time-sync, power, communication and recovery tests; signed maintenance records.	Decay or zero affected weights; preserve last-known time and issue a data-unavailable state.
Climate and coastal adaptation	Boundary envelopes cover locally relevant rainfall, drying, cycling, runoff, wave and toe scenarios.	Periodic load review, post-event survey and updated stability analysis.	Suspend outdated design credit; strengthen, repair, restrict use or redesign.
Accountable action	Decision rights, inspection, maintenance, warning and closure roles remain with named authorities.	Operating procedure, exercise, audit trail, response time and post-event review.	Manual fallback, escalation and withdrawal from operational use if responsibility or capacity is absent.

Source: *Authors' requirements analysis based on DiBiagio et al. (2024), Insana et al. (2025), Mirus et al. (2025), Piciullo et al. (2022, 2025), and Raymond et al. (2025).*

The traceability result exposes a common category error: performance of the intervention and performance of the monitoring system are different. A well-monitored ineffective measure remains ineffective. A mechanically adequate system with poor monitoring may still be safe under a conventional design and inspection regime, but it cannot claim smart adaptive verification. The integrated system must satisfy both the geotechnical limit state and the information-assurance case.

A second result is temporal asymmetry. Drainage or structural support may provide immediate capacity, whereas vegetation develops over time. Mineralisation may provide an early effect that later degrades under exposure. Sensor quality may decline between maintenance visits. Design stages must therefore use time-indexed resistance and observation assumptions rather than a single mature-state diagram. Equations (3), (4), (6) and (7) make these changes reviewable.

Desk-based stress cases

Stress case 1 considers intense or prolonged rainfall while a drain outlet is blocked. Rainfall and near-surface moisture rise; the vegetation remains green; a deeper piezometer shows pressure increase; and outlet flow is absent. The framework identifies a hydraulic degradation, reduces the credited drainage function, updates D_w in Equation (7), and prioritises safe inspection and drainage response. It prohibits treating surface vitality or one dry sensor as evidence of stability. Hydrologic warning research supports integrating subsurface state and recognising observation representativeness (Mirus et al., 2025; Wicki et al., 2023).

Stress case 2 considers vegetation dieback after drought, salinity stress, disease or maintenance failure. Pore pressure may remain low during the dry period, so a hydrological dashboard alone appears favourable. The vitality factor v(t) in Equation (3) declines, root contribution is reduced conservatively, erosion exposure is re-inspected and the establishment or replanting plan is activated. The framework also checks whether desiccation cracking has created preferential infiltration paths. It does not infer root condition solely from a short above-ground image sequence.

Stress case 3 considers abrasion, wet–dry cycling or storm erosion that damages a mineralised surface layer. Conductivity or pH values may remain within prior ranges even though physical continuity is lost. Surface change, coupons, cores or strength and permeability checks challenge η_c and g_E in Equation (4). The credited biocement contribution is reduced or removed, and the slope is assessed using remaining ground, root, structural and drainage components. Published durability and coastal-erosion studies justify this explicit exposure gate (Huang et al., 2022; Imran et al., 2022; Wu et al., 2024).

Stress case 4 considers loss of power or communication during a coastal storm. Equation (6) decays stale weights and sets failed observations to zero. The system reports the last valid time and unavailable variables; it does not carry forward a green status. Local recording, independent visual or survey checks and predefined manual inspection provide continuity where safe. The result is an unknown or degraded monitoring state, with action determined by consequence and remaining evidence. Operational IoT slope work demonstrates the need to connect sensing, modelling and procedures rather than relying on connectivity alone (Piciullo et al., 2022, 2025).

Across the four cases, the framework behaves conservatively without pretending that every anomaly predicts failure. It identifies which assumption is no longer supported, which evidence can resolve the uncertainty and who must decide. These are logical assurance results. They do not quantify lead time, false alerts, factor-of-safety change, vegetation recovery, treatment loss or field reliability.

Climate and coastal stress matrix

Table 4 connects climate and coastal stresses to plausible degradation pathways, observations and responses. Its purpose is to prevent a monitoring plan from focusing only on rainfall while overlooking drought, cycling, toe change or biological condition. Applicability must be screened for each site.

Table 4. Climate and coastal stress–failure–response matrix

Stress	Potential degradation pathway	Primary observations	Engineering and maintenance response
Short intense rainfall	Runoff concentration, surface erosion, shallow wetting, gully initiation and overloaded drains.	Rain intensity, runoff, surface moisture, erosion survey, drain flow and inspection.	Clear and resize drainage where justified, dissipate flow, repair cover and reassess erosion resistance.
Prolonged or repeated rainfall	Loss of suction, perched or deep pressure rise, progressive deformation and weakened interfaces.	Cumulative rain, suction, water content, piezometry, displacement and strain.	Hydraulic reanalysis, drainage repair, intensified observation, access control or structural support.
Drought and heat	Vegetation stress or mortality, shrinkage cracks, loss of root credit and preferential later infiltration.	Vitality, root-zone moisture and suction, cracks, temperature and maintenance record.	Species and water-management review, replanting, temporary protection and conservative root credit.

Stress	Potential degradation pathway	Primary observations	Engineering and maintenance response
Wet–dry cycling	Soil structure change, crack development, interface degradation and biocement bond loss.	Moisture cycles, suction, cracks, strain, coupons or samples, strength and permeability.	Durability requalification, crack and drainage treatment, repair or removal of unsupported contribution.
Freeze–thaw where locally relevant	Heave, thaw weakening, root and treatment damage, blocked drainage and surface disintegration.	Temperature profile, moisture, deformation, drainage, surface and treatment integrity.	Cold-region qualification, seasonal restrictions, insulation or drainage measures and post-thaw inspection.
Wave, river or storm toe erosion	Geometry change, loss of passive support, scour, undercutting and accelerated slope deformation.	Toe and shoreline survey, water or wave conditions, imagery, displacement and cracks.	Emergency inspection, toe protection review, erosion repair, setback or structural redesign.
Salinity, sea spray or chemical change	Plant stress, sensor bias, reaction-domain change, carbonate dissolution or ecological impact.	EC, pH, plant condition, soil and water chemistry, carbonate and sensor checks.	Species or treatment requalification, corrosion and sensor correction, effluent control or technique change.

Source: *Authors' synthesis based on Huang et al. (2022), Imran et al. (2022), Insana et al. (2025), Lann et al. (2024), Tetteh et al. (2025), and Zhang et al. (2024).*

Validation and assurance

Table 5 defines an assurance matrix for the ground, vegetation, mineralisation, sensors, analytical model and organisation. Acceptance criteria are written before results are known and are scaled to consequence. A pilot is not successful merely because vegetation survives, carbonate is detected or a dashboard displays data.

Table 5. Validation and assurance matrix

Assurance domain	Minimum evidence	Acceptance focus	Withdrawal or corrective condition
Ground and failure model	Topography, stratigraphy, groundwater, properties, erosion, history, loads, alternatives and uncertainty.	Model explains credible failure modes and supports instrument and intervention zones.	Unexpected layer, water response, deformation geometry or toe change invalidates the adopted mechanism.
Vegetation and live works	Native suitability, establishment, root profile, seasonal vitality, interaction with drains and ecological review.	Required function develops at the credited depth without unacceptable ecological or asset effects.	Mortality, shallow or sparse rooting, invasive behaviour, root–asset conflict or persistent maintenance failure.
MICP or EICP treatment	Reagent and organism or enzyme specification, delivery, chemistry, carbonate, uniformity, properties, effluent and cycling.	Intended zone meets engineering and environmental criteria under representative exposure.	Non-uniformity, adverse by-products, clogging, ecological impact, rapid abrasion, dissolution or property loss.
Sensors and communications	Calibration, installation, coupling, timing, power, telemetry, local storage, drift, redundancy and recovery tests.	Observations resolve required mechanism with known uncertainty and recover from credible outages.	Unquantified drift, common-mode failure, stale data, unstable reference or unobservable critical zone.

Assurance domain	Minimum evidence	Acceptance focus	Withdrawal or corrective condition
Mechanics and state model	Parameter provenance, sensitivity, calibration period, independent events, alternative models and uncertainty.	Model represents observed hydrological and deformation behaviour without double counting resistance.	Persistent residuals, out-of-domain loads, unexplained motion or failure to outperform a simpler transparent model.
Decision and maintenance system	Named roles, response procedures, access, spares, inspections, ecological care, incident exercises and budget.	Responsible teams can interpret degraded states and complete actions within the required time.	Unassigned authority, missed maintenance, inaccessible instruments, untested fallback or unaffordable renewal.

Source: *Authors' assurance synthesis based on Alam et al. (2024), DiBiagio et al. (2024), Lee and Gomez (2024), Piciullo et al. (2025), Raymond et al. (2025), and Zhang et al. (2024).*

Validation should progress from material and component tests to pilot zones, seasonal baselines, representative event response and independent review. Vegetation trials should include survival, rooting, water use, erosion function and ecological compatibility. Mineralisation trials should use actual ground and water chemistry where possible and should measure untreated controls, spatial variation, mechanical and hydraulic properties, effluent and exposure degradation. Sensor acceptance should include installation effects, not only factory calibration.

Monitoring models should be evaluated against transparent baselines. A mechanistic model that is imperfect but interpretable may be preferable to an opaque predictor with higher retrospective fit if the latter cannot recognise changed vegetation, treatment loss or missing sensors. Event and seasonal holdouts are preferable to random sample splits. Performance reporting should include detection, calibration, false and missed escalation, lead time, data availability, maintenance burden and the consequences of acting or not acting.

Black Sea applicability and transfer limits

The framework is applicable around the Black Sea only at the level of common engineering questions. The littoral includes different soils and rocks, landslide types, rainfall and temperature regimes, shoreline energy, salinity exposure, habitats, land uses, regulations, maintenance capacities and security contexts. A measure qualified for a Turkish eastern-coast cut slope cannot be transferred directly to a Romanian bluff, Georgian urban slope, Bulgarian dune, Ukrainian coast or another setting without local evidence.

Regional value lies in a common reporting structure: failure mechanism, intervention mechanism, species or treatment domain, sensor support, climate and coastal loads, validation, maintenance and withdrawal conditions. Shared protocols can enable comparable pilot evidence without imposing one material, species or threshold. Black Sea institutions could exchange anonymised performance definitions, test methods, sensor-quality flags and post-event lessons while retaining site authority and sensitive asset information.

Coastal evidence must also be interpreted by landform. Dunes, beaches, engineered fills, soft cliffs, weathered rock and deep-seated landslides require different mechanics. Fine-root dune evidence is informative for erosion processes but not a direct design model for a cohesive slope (Figlus et al., 2022). Hybrid coastal-defence evidence supports integration, yet the ecological and sediment consequences of toe works, planting or hard structures remain site-dependent (Huynh et al., 2024; Jordan & Fröhle, 2022).

Ecological, human and information governance

Ecological governance begins before species or treatment selection. The design should record native status, genetic and habitat considerations, establishment resources, invasive potential, protected receptors, seasonal work restrictions and the consequences of long-term maintenance. A technically successful planting that damages a protected community or requires unsustainable irrigation is not a

resilient solution. Similarly, carbonate precipitation with uncontrolled effluent or chemical impacts cannot be described as environmentally preferable solely because microbes or enzymes are involved.

Human governance assigns responsibility for the ground model, ecological design, treatment, sensors, analysis, inspection, maintenance and public-safety decision. Dashboard language should distinguish observation, model state, confidence and authorised action. Operators must see missing inputs, the last valid time, conflicts and the assumptions supporting resistance credit. Training should include cases where vegetation looks healthy while groundwater rises, or where sensors function while the intervention degrades.

Information security matters because connected monitoring can expose asset condition, location and operational procedures. Minimum controls include authenticated devices and users, least privilege, encrypted communication, protected configuration, time synchronisation, signed updates, audit logs, backup, local buffering, vulnerability management and tested recovery. Cybersecurity does not correct a bad sensor or model, but a compromised device can create false evidence. The engineering safety case should therefore document both physical and digital failure paths.

Staged implementation roadmap

Table 6 converts the framework into six evidence-gated stages. The roadmap delays resistance credit and operational reliance until the relevant mechanism, environmental boundary and observation quality have been demonstrated.

Table 6. Staged roadmap for Black Sea smart bio-engineered slopes

Stage	Principal work	Required deliverable	Gate to proceed
1. Intended use and screening	Define site, consequence, decisions, failure hypotheses, ecological receptors, ownership, access and exclusions.	Bounded use statement, responsibility map, risk register and preliminary monitoring objectives.	Competent authority accepts the scope and confirms that bio-engineering is a candidate, not a predetermined answer.
2. Ground, coastal and ecological baseline	Investigate geometry, materials, groundwater, drainage, erosion, loads, vegetation, chemistry and seasonal conditions.	Conceptual ground model, consequence model, climate/coastal envelope and baseline data-quality report.	Credible mechanisms, sensitive zones and unresolved uncertainties are explicit.
3. Laboratory and pilot qualification	Test plants or live works, root development, erosion function, mineralisation recipe, by-products, durability and sensors.	Controlled results with untreated comparators, spatial variability, environmental review and provisional parameters.	The proposed function is demonstrated for representative ground and exposure without unacceptable impact.
4. Shadow observation and model calibration	Install representative sensors, collect seasonal and event data, verify coupling, missingness and model residuals.	Baseline hydrological and deformation model, sensor assurance report and maintenance procedure.	Critical states are observable and degraded data are detected before operational reliance.
5. Controlled hybrid installation	Construct by verified zones, record as-built details, retain drainage, toe or structural measures where required.	As-built model, material and ecological acceptance, updated stability case and response plan.	Independent review accepts resistance credit and residual risk for the exact service condition.

Stage	Principal work	Required deliverable	Gate to proceed
6. Adaptive operation and renewal	Inspect, maintain vegetation and drainage, test treatment and sensors, review loads, replay events and renew components.	Performance history, post-event reports, revalidation schedule, budget and withdrawal criteria.	Continued use depends on current evidence; outdated, degraded or unmaintained components lose credit.

Source: *Authors' roadmap synthesising Bridges et al. (2022), Insana et al. (2025), Piciullo et al. (2025), Raymond et al. (2025), and Wu et al. (2024).*

Limitations and research agenda

This study has seven principal limitations. It is a conceptual framework without a site, new experiment or operational deployment. The evidence synthesis is targeted rather than systematic. Equations (1)–(7) are editable design structures and not calibrated Black Sea models. The desk stress cases are logical tests and cannot quantify field performance. No species, treatment concentration, sensor layout, service life or warning threshold is prescribed. Legal and ecological requirements of individual countries are not analysed. Finally, the framework does not demonstrate that a bio-engineered option will outperform a conventional alternative at any specific site.

Research should begin with paired pilot zones that compare strong conventional baselines, biological or mineralisation measures and hybrids under the same monitored exposure. Designs should predeclare the failure mechanism, expected function, parameter pathway, environmental acceptance and stopping rules. Vegetation studies need multi-season root and water observations, not only surface biomass. Biocement studies need treatment distribution, strength, permeability, by-products, durability and life-cycle evidence at field-relevant scale.

Sensor research should focus on observability and uncertainty. Distributed fibre systems require quantified cable–ground coupling and temperature compensation; moisture and suction networks require soil-specific calibration and topographic coverage; chemical proxies require confirmation against actual mineralisation and environmental measures. Smart geosynthetic research is promising, but sensing and reinforcement functions should be validated separately before combined credit is assigned (Abedi et al., 2023; Acharya & Kogure, 2025).

Climate research should propagate uncertainty from climate and coastal forcing through hydrology, vegetation, treatment durability, erosion and slope mechanics. Scenarios should test sequences such as drought followed by extreme rainfall, repeated moderate storms, toe erosion combined with saturation, and sensor outage during an event. The objective is not a precise distant forecast but a robust design domain, monitoring trigger and adaptation pathway (Insana et al., 2025; Tetteh et al., 2025).

Prospective evaluation should measure engineering safety, ecological condition, availability, maintainability, resource use, user comprehension and social consequences. Post-event review should compare observed load and response with the conceptual model, update resistance credit and record whether actions were feasible. Successful learning will come from documented failures, maintenance and withdrawn assumptions as well as from stable slopes.

CONCLUSION

This paper has developed a smart bio-engineered framework for climate-resilient stabilization of Black Sea coastal slopes. It separates ecological soil bioengineering from MICP and EICP mineralisation, then combines either with drainage, erosion control, geosynthetics, toe protection or structural support only when the site mechanism and consequence justify the package. Embedded observations verify external loads, water state, deformation, vegetation condition, treatment domain and maintenance; they are not treated as stabilizing elements.

The central contribution is an auditable chain from mechanism to evidence. Effective stress, unsaturated strength, time-dependent root credit, qualified biocement contribution, a defined observation vector, sensor quality and freshness, and decomposed factor of safety are expressed in seven editable equations. Six editable tables establish intervention selection, observability, requirements traceability, climate stresses, validation and staged implementation. The two original figures show the architecture and evidence gates without implying field performance.

No operational Black Sea deployment or measured stabilization gain is claimed. Implementation requires a site-specific ground and ecological model, locally relevant climate and coastal loads, native and maintainable vegetation, actual-ground mineralisation trials where proposed, environmental and life-cycle assessment, calibrated and redundant monitoring, independent validation, and named authority for decisions. A climate-resilient slope is not one that merely contains living material or connected sensors; it is one whose resistance, degradation and maintenance remain observable and whose unsupported assumptions are withdrawn in time.

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REMOTE SENSING AND EDGE AI FOR DETECTING EROSION-INDUCED FOUNDATION INSTABILITY IN BLACK SEA COASTAL INFRASTRUCTURE

A MULTI-SENSOR METHODOLOGICAL FRAMEWORK

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ABSTRACT

Erosion-induced loss of ground support can progress beneath coastal roads, ports, retaining structures and buildings before visible structural distress becomes sufficiently pronounced to trigger intervention. This problem is particularly important around the Black Sea, where rapidly changing sandy, deltaic, cliffed and urbanized shorelines coexist with dense transport and utility infrastructure. This paper develops a reproducible multi-sensor framework that combines optical and synthetic-aperture-radar Earth observation, time-series interferometric SAR, targeted unmanned-aerial-vehicle surveys, low-cost geotechnical and structural sensors, and edge artificial intelligence for early detection of foundation instability. The framework converts shoreline position, erosion-buffer loss, surface-deformation velocity, moisture change, tilt, vibration and pore-pressure measurements into an uncertainty-aware asset risk score. A lightweight inference layer is positioned at the edge to reduce communication demand, maintain operation during intermittent connectivity and preserve an auditable local alert history. The proposed workflow includes sensor selection, data harmonization, feature engineering, site-based model training, quantization, latency and memory benchmarking, field validation, uncertainty calibration, and post-deployment drift monitoring. No site-specific performance values are claimed; the study is intentionally presented as a methodological and deployment design to prevent unverified empirical conclusions. Its principal contribution is the explicit coupling of coastal-change indicators with foundation-response indicators, rather than treating shoreline retreat and structural health as separate monitoring tasks. The resulting architecture is suitable for staged pilot implementation on Black Sea coastal infrastructure and provides a defensible basis for subsequent field validation and operational threshold setting.

Keywords: Black Sea, coastal erosion, edge artificial intelligence, foundation instability, InSAR, remote sensing, structural health monitoring.

INTRODUCTION

Coastal foundation instability is rarely governed by a single observable process. Shoreline retreat may reduce the horizontal distance between an asset and the active erosion front; wave attack may remove supporting sediment; saturation and repeated drawdown may weaken near-surface soils; and differential settlement or rotation may develop within the structure. Conventional inspection often detects the consequence only after cracks, distortion or serviceability loss has become visible. A more preventive strategy requires observation of both the coastal process and the asset response, at compatible spatial and temporal scales. The Black Sea is an appropriate setting for such an integrated approach because its coast contains deltas, sandy barriers, cliffs, ports, revetments, urban waterfronts and transportation corridors exposed to spatially variable erosion and accretion. Recent basin-scale work combining optical and SAR imagery demonstrated that coastal change is heterogeneous around the Black Sea and that multi-sensor observation is more robust than dependence on one image type alone (Jiang et al., 2025). Local studies near Black Sea and Azov Sea ports similarly show that satellite images can support repeated analysis of shore dynamics around engineered coastlines (Kuprin and Kantargi, 2024). In

parallel, regional sea-level-monitoring networks provide valuable forcing and validation information, although differences in latency, quality control and data availability remain important operational constraints (Pérez Gómez et al., 2022).

Current shoreline-extraction research has progressed from fixed thresholding toward automated sub-pixel and deep-learning methods. Multispectral approaches can distinguish water and land efficiently, but their accuracy depends on shoreline type, atmospheric conditions, water level, waves and image resolution (McAllister et al., 2022; Pucino et al., 2022). Deep segmentation models and new benchmark datasets improve the treatment of narrow, irregular and engineered coastal features (Seale et al., 2022; Feng et al., 2024; Scala et al., 2024). SAR provides complementary all-weather and day-night capability, although speckle, rough water and complex port geometries require careful segmentation and quality control (Ciecholewski, 2024).

A second research stream concerns ground and infrastructure deformation. Time-series InSAR has become an operationally relevant technique for mapping subsidence and differential motion over large areas (Raspini et al., 2022). Applications to coastal airports and coastal high-rise development have demonstrated that satellite deformation measurements can reveal spatially variable settlement affecting critical assets (An et al., 2023; Aziz Zanjani et al., 2024). These studies are important, but deformation mapping alone cannot determine whether movement is driven by erosion, compressible ground, loading, groundwater change or another mechanism. Mechanistic interpretation therefore requires fusion with shoreline, hydrometeorological, geotechnical and structural information.

Edge AI offers a practical means of performing this fusion near the monitored asset. Instead of continuously transmitting raw imagery and high-frequency sensor records to a central server, an edge node can calculate features, run a compact model and transmit only summaries, anomalies and selected evidence. This architecture can reduce latency and communication demand and can continue operating during intermittent network access, provided that models are designed for constrained memory, power and computation (Singh and Gill, 2023). For civil infrastructure, the edge layer must also support traceability, conservative uncertainty handling and human confirmation because false reassurance is more serious than a minor reduction in nominal model accuracy.

This study addresses three questions: (1) how can regional remote sensing and local asset sensors be combined into a coherent monitoring chain; (2) which features are most directly linked to erosion-induced loss of foundation support; and (3) how should an edge AI system be validated before it is used for maintenance decisions? The objective is not to report unverified field results. Instead, the paper presents a technically explicit framework, editable equations and operational tables that can be implemented and tested at selected Black Sea pilot sites.

BLACK SEA COASTAL SETTING AND MONITORING REQUIREMENTS

Hazard chain from shoreline change to foundation response

The relevant hazard chain begins with a change in coastal morphology and ends with a change in structural performance. The intermediate steps are asset-specific. On a sandy coast, repeated storm erosion can reduce the protective beach width and expose a buried toe or shallow foundation. At a cliff or bluff, toe erosion can steepen the slope and activate retrogressive failure. Around ports and seawalls, reflected waves and concentrated currents may produce local scour that is not represented by a basin-scale shoreline trend. At reclaimed or compressible coastal ground, erosion may act together with consolidation, groundwater variation and construction loading.

Accordingly, a monitoring system should not equate shoreline retreat with foundation failure. Shoreline change is an exposure indicator; surface deformation, tilt and vibration are response indicators; and subsurface moisture, pore pressure and soil condition are mechanism indicators. A credible alert requires agreement among several indicator families, persistence through time, or independent field confirmation. Figure 1 presents the resulting multi-scale architecture.

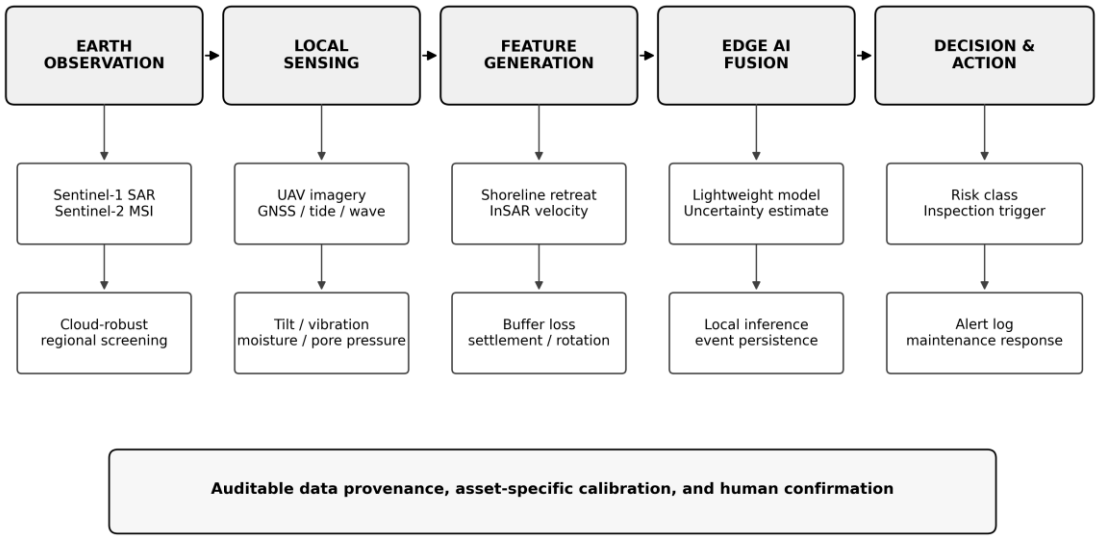

Figure 1. Multi-scale monitoring architecture linking Earth observation, local sensing, feature generation, edge AI and maintenance action. Source: authors' original synthesis based on Jiang et al. (2025), An et al. (2023), Ahmed et al. (2023) and Singh and Gill (2023).

Observation scales and minimum information set

Regional screening should identify coastal sectors where the erosion front, deformation field or hydrodynamic forcing is changing. Asset-scale monitoring should then determine whether the change affects a specific foundation. The minimum information set therefore includes: a georeferenced asset footprint; foundation type and approximate depth; a shoreline or erosion-front time series; a surface-deformation time series; local water-level or wave context where available; and at least one independent structural or geotechnical confirmation channel. Additional variables improve diagnosis but should not be prerequisites for an initial pilot.

Table 1. Recommended sensing sources and their roles in the proposed framework.

Source	Primary variables	Principal contribution	Key limitation
Sentinel-2 or equivalent optical imagery	Water/land boundary, wetness, exposed sediment, post-storm morphology	Broad-area shoreline screening; interpretable spectral information	Cloud, haze, sun glint, wave run-up and water-level dependence
Sentinel-1 or equivalent SAR imagery	All-weather water/land contrast, backscatter change, coherence and InSAR deformation	Day/night acquisition; regional change and deformation monitoring	Speckle, rough-water ambiguity, geometric distortion and decorrelation
UAV photogrammetry or terrestrial imaging	High-resolution orthomosaic, DSM, scarp position, local volume change	Targeted validation and detailed post-event survey	Requires flight access, ground control, consistent acquisition and safe operation
Tide, wave and meteorological observations	Water level, storm timing, wave forcing and rainfall	Separates transient waterline movement from persistent morphological change	Station spacing, data latency and gaps may limit local representativeness

Source	Primary variables	Principal contribution	Key limitation
Geotechnical and structural sensors	Tilt, acceleration, crack opening, pore pressure, moisture and local settlement	Direct evidence of asset response and potential mechanism	Sensor drift, damage, power demand and maintenance requirements
Inspection and asset records	Foundation configuration, observed distress, repair history and exposure conditions	Essential labels and engineering interpretation	Records may be incomplete, inconsistent or subjective

Source: synthesized from McAllister et al. (2022), Pucino et al. (2022), Ciecholewski (2024), Raspini et al. (2022), Ahmed et al. (2023) and Pérez Gómez et al. (2022).

MATERIALS AND METHODS

Study design and scope

The study is a methodological synthesis and system-design investigation. It specifies the data model, equations, feature set, edge architecture, validation plan and decision logic required for a future field deployment. It does not use invented measurements, simulated performance values presented as observations, or unverified claims of accuracy. All operational thresholds are to be calibrated from a pilot dataset for the selected asset and coastal setting.

A staged implementation is recommended. Stage 1 establishes a basin or national screening layer from open Earth-observation data. Stage 2 selects assets according to exposure, criticality and data availability. Stage 3 adds local sensors and engineering records. Stage 4 develops and validates the edge model using event- and site-separated data. Stage 5 begins supervised operation in which alerts support inspection rather than automatically closing or restricting infrastructure.

Image preprocessing and shoreline extraction

Optical images should be atmospherically corrected, co-registered to a common reference, cloud-masked and filtered for unacceptable wave or sun-glint conditions. A water index provides a transparent baseline and can also be used as an input channel to a learned segmentation model. The normalized difference water index used in recent automated shoreline workflows can be written as Equation (1), where ρG and ρNIR are surface reflectance in the green and near-infrared bands, respectively (McAllister et al., 2022; Abdelhady et al., 2022).

$$\mathrm{NDWI} = (\rho G - \rho \mathrm{NIR}) / (\rho G + \rho \mathrm{NIR}) \quad (1)$$

Equation (1) is a standard water-index formulation used here as a transparent baseline; attribution and recent shoreline applications are discussed by McAllister et al. (2022) and Abdelhady et al. (2022).

The water/land mask should be converted to a vector shoreline and cleaned using topology rules that preserve engineered features relevant to the asset. Where the coast contains ports, detached breakwaters, river mouths or enclosed water bodies, a simple longest-contour rule may be insufficient. Deep segmentation can improve boundary continuity, but predictions must remain linked to image quality and uncertainty. Recent studies demonstrate the value of benchmark datasets, edge-sensitive loss functions, attention mechanisms and multi-scale feature fusion for this purpose (Seale et al., 2022; Feng et al., 2024; Lv et al., 2024; Scala et al., 2024).

Shoreline position should be intersected with stable, asset-oriented transects. The endpoint rate in Equation (2) provides a simple measure over an interval, where d1 and d2 are signed shoreline positions on a transect at times t1 and t2. Negative values should be defined consistently as retreat toward the asset. More robust regression rates can be used where a sufficient number of observations exists, but the endpoint rate remains useful for transparent event-to-event change assessment (McAllister et al., 2022; Bergsma et al., 2024).

$$\mathrm{EPR} = (\mathrm{d2} - \mathrm{d1}) / (\mathrm{t2} - \mathrm{t1}) \quad (2)$$

Equation (2) follows commonly used shoreline-change notation; the sign convention must be documented for each site. Recent automated and sub-pixel shoreline workflows are described by McAllister et al. (2022) and Bergsma et al. (2024).

SAR change detection and time-series InSAR

SAR amplitude change can support shoreline mapping when optical data are obscured, while coherence change may indicate altered surface conditions. For deformation analysis, persistent-scatterer or small-baseline time-series processing should be selected according to temporal sampling, coherence and the density of stable targets. The line-of-sight displacement associated with an unwrapped interferometric phase change can be expressed by Equation (3), where λ is radar wavelength and $\Delta\varphi$ is the displacement-related phase term. The sign and geometric projection must follow the adopted processing convention (Raspini et al., 2022; An et al., 2023).

$$\mathrm{dLOS} = (\lambda / 4\pi)\, \Delta\varphi \quad (3)$$

Equation (3) states the standard phase-to-line-of-sight displacement relationship. Interpretation should follow the processing convention and viewing geometry described in the time-series InSAR workflow (Raspini et al., 2022; An et al., 2023).

A deformation anomaly is more informative when it is spatially associated with the asset footprint and temporally associated with erosion or a high-energy event. The framework therefore stores the deformation velocity, acceleration, seasonal amplitude, coherence quality and distance to the foundation. Abrupt decorrelation is not automatically treated as movement because surface moisture, vegetation and construction activity can also reduce coherence.

Asset-referenced feature engineering

The central methodological step is conversion from environmental change to asset-referenced features. For each foundation or structural segment, the shoreline buffer B(t) is defined as the shortest stable-plan distance from the monitored erosion front to the relevant foundation boundary. The Coastal Foundation Exposure Index proposed in Equation (4) measures the fractional loss of the initial buffer B0, subject to truncation between zero and one. It is a screening indicator, not a factor of safety.

$$\mathrm{CFEI}(t) = \min[1, \max(0, (\mathrm{B0} - \mathrm{B}(t)) / \mathrm{B0})] \quad (4)$$

Equation (4) is proposed in this study as an asset-referenced exposure indicator. It is conceptually informed by recent multi-temporal shoreline monitoring and coastal infrastructure deformation studies (Jiang et al., 2025; An et al., 2023).

Features should be calculated over several windows so that the model distinguishes chronic retreat from a short-lived waterline excursion. The feature vector can include current CFEI, buffer-loss rate, event-scale shoreline displacement, InSAR velocity and acceleration, coherence, soil-moisture proxy, tilt, vibration-energy change, pore-pressure deviation, rainfall, water-level anomaly and inspection flags. Each feature should carry a quality indicator and time stamp.

Table 2. Feature groups and their engineering interpretation.

Feature group	Examples	Engineering interpretation
Erosion exposure	CFEI; shoreline-buffer loss; erosion-front persistence	Progressive reduction in protective ground between active coast and foundation
Surface deformation	LOS velocity; acceleration; differential displacement across asset	Settlement, lateral movement or rotation requiring geometric interpretation

Feature group	Examples	Engineering interpretation
Hydrologic condition	Moisture anomaly; pore-pressure deviation; rainfall and water-level context	Saturation, loss of suction, seepage or storm-related transient loading
Structural response	Tilt; crack opening; vibration-feature drift; visual distress flag	Direct evidence that environmental change is affecting asset behaviour
Data quality	Cloud fraction; SAR coherence; georegistration error; sensor health	Prevents low-quality observations from being interpreted as physical change
Asset context	Foundation type; depth; setback; protection works; criticality	Controls susceptibility, consequences and the required inspection urgency

Source: authors' synthesis based on An et al. (2023), Aziz Zanjani et al. (2024), Cha et al. (2024), Jiang et al. (2025) and Ahmed et al. (2023).

PROPOSED EDGE AI ARCHITECTURE

Model structure and data fusion

The edge model should be deliberately smaller than the cloud-based development model. A practical architecture has two branches. The first branch processes slowly changing geospatial features derived from satellite and UAV products. The second branch processes local time-series features from tilt, vibration, moisture or pore-pressure sensors. A late-fusion layer combines the branch outputs with asset metadata and quality indicators. Late fusion is preferred for an initial deployment because each sensing branch can be tested independently and missing channels can be handled explicitly.

The output is a calibrated probability of an instability state or a conservative anomaly score. For a supervised model, the fused probability can be written in the logistic form of Equation (5), where xi are standardized features and βi are coefficients or the final learned representation weights. More complex neural models may be used, but this expression preserves interpretability and provides a benchmark against which additional complexity must be justified.

$$\text{pinst} = 1 / \{1 + \exp[-(\beta 0 + \Sigma\, \beta i\, xi)]\} \quad (5)$$

Equation (5) is the transparent probabilistic baseline proposed for the fusion layer. More complex models should demonstrate a reproducible benefit over this baseline and should be evaluated under the edge constraints summarized by Singh and Gill (2023) and the SHM considerations reviewed by Cha et al. (2024).

Uncertainty must influence the alert logic. Let μp be the mean predicted probability across an approved ensemble or stochastic inference set and σp its uncertainty. Equation (6) defines a conservative decision score using a calibration coefficient κ selected from validation data. The score is clipped to the interval from zero to one. This formulation prevents a highly uncertain prediction from being treated as reassuring merely because its mean value is moderate.

$$\text{Salert} = \min[1, \mu p + \kappa\, \sigma p] \quad (6)$$

Equation (6) is proposed in this study as an uncertainty-adjusted decision score. The coefficient κ must be calibrated from field-validation data and approved by the asset owner; it is not a universal constant.

Edge optimization and operational constraints

Candidate models should be compared using accuracy, calibration and engineering resource metrics. Quantization can reduce memory and inference time, but it may alter sensitivity to small changes. Pruning or knowledge distillation may reduce model size, while a rule-based fallback should remain available if the learned model, sensor health or data quality fails. The edge device should retain the input feature vector, quality flags, model version, prediction, uncertainty, alert state and operator response in an immutable or access-controlled log.

Table 3. Edge model options and deployment considerations.

Model option	Strength	Limitation	Recommended role
Regularized logistic model	Small memory; transparent coefficients; rapid inference	May miss nonlinear interaction unless engineered explicitly	Required baseline and fallback
Gradient-boosted trees	Handles nonlinearities and mixed feature scales; strong tabular performance	Larger model and less smooth calibration; careful conversion needed	Suitable for feature-level fusion
Compact temporal CNN or gated network	Learns short temporal patterns from sensor windows	Requires representative event labels and careful drift testing	Useful for vibration, tilt and pore-pressure sequences
Lightweight segmentation network	Local processing of UAV or fixed-camera imagery	Higher compute and memory demand than feature-level models	Use only where local image inference is operationally necessary
Hybrid rules plus learned score	Embeds engineering limits and sensor-health checks	Rules require maintenance and asset-specific governance	Preferred operational architecture

Source: authors' synthesis informed by Singh and Gill (2023), Cha et al. (2024) and recent lightweight coastal-segmentation studies (Feng et al., 2024; Scala et al., 2024).

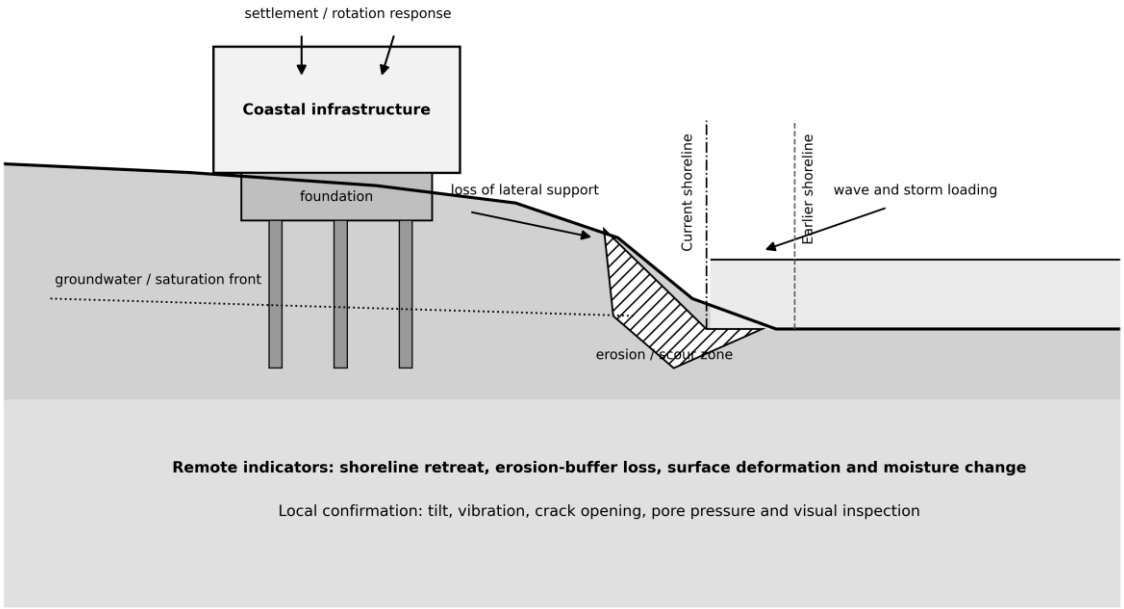

Figure 2. Conceptual mechanism linking shoreline retreat and local scour to loss of foundation support, settlement and rotation. Source: authors' original engineering schematic informed by An et al. (2023), Aziz Zanjani et al. (2024) and Jiang et al. (2025).

Communications, resilience and cybersecurity

The system should use store-and-forward communication. Routine messages may contain a time stamp, sensor-health summary, feature statistics, risk score and model version. Raw data or image chips should be transmitted when an alert is issued, during scheduled quality assurance, or when an engineer requests evidence. This approach reduces bandwidth without preventing forensic review.

Operational resilience requires local time synchronization, watchdog processes, safe restart, encrypted communication, signed model packages and controlled model rollback. A missing data stream must lower confidence rather than silently producing a normal classification. The interface should therefore distinguish four conditions: normal evidence, elevated risk, insufficient evidence and device or sensor fault.

FRAMEWORK OUTPUTS AND VALIDATION PROTOCOL

Expected outputs

The framework produces five engineering outputs rather than a single opaque score: (1) a map of shoreline and erosion-front change; (2) an asset-level buffer and exposure history; (3) a deformation map and time series with quality indicators; (4) a local structural and geotechnical anomaly summary; and (5) an uncertainty-aware alert state with supporting evidence. The separation is intentional. An engineer must be able to determine whether an alert is caused by increasing exposure, measured movement, local sensor response, data-quality deterioration or a combination of these factors.

The principal methodological result is the coupling of exposure and response. A sector with rapid shoreline retreat but no nearby asset may remain a coastal-management priority without becoming a foundation-instability alert. Conversely, an asset with significant settlement but stable shoreline may require geotechnical investigation for consolidation, leakage or construction loading rather than erosion control. The combined framework supports this distinction.

Ground truth and data splitting

Validation labels should be created from engineering evidence, not image interpretation alone. Positive or elevated-risk periods may be defined by surveyed settlement, verified rotation, exposure of foundation elements, scour survey, crack progression, emergency repair, or an engineer-confirmed instability episode. Normal periods should include representative storms, seasonal water-level changes and sensor disturbances so that the model learns difficult negative cases. Data must be split by site and event, not by randomly mixing adjacent time windows, because random splitting would overstate generalization.

Table 4. Validation matrix for the proposed monitoring system.

Component	Independent reference	Primary metrics	Required qualification
Shoreline extraction	UAV/GNSS shoreline or high-resolution orthomosaic	Median absolute shoreline distance; 90th-percentile distance; completeness	Evaluate separately for sandy, cliffed and engineered coast
InSAR deformation	Levelling, GNSS, total station or stable local sensor	Bias; RMSE; temporal correlation; spatial consistency	Report geometry and coherence limits
Instability classification	Engineer-confirmed event and normal periods	Recall; precision; AUCPR; false alerts per month; calibration error	Prioritize recall subject to manageable false-alert burden
Edge performance	Target hardware under field power and temperature	Inference latency; peak RAM; storage; energy per inference	Measure after quantization and packaging

Component	Independent reference	Primary metrics	Required qualification
Operational utility	Inspection and maintenance records	Alert lead time; confirmation rate; action time; missed-event review	Conduct supervised pilot before autonomous use

Source: authors' validation design, informed by Pucino et al. (2022), Raspini et al. (2022), An et al. (2023), Singh and Gill (2023) and Cha et al. (2024).

Alert classes and action logic

Risk classes should be derived from site-calibrated percentiles and persistence rather than universal fixed values. The following table defines a governance structure using the calibrated decision score Salert, the quality state and evidence persistence. P50, P75 and P90 denote percentiles of the validated reference distribution for the specific asset or asset class. An alert may be escalated immediately when direct structural evidence exceeds an approved engineering limit, even if the fused score has not persisted.

Table 5. Proposed site-calibrated alert classes and actions.

Class	Decision condition	Minimum action
Normal	Salert below P50; acceptable data quality; no direct-response exceedance	Routine automated logging and scheduled review
Watch	Salert between P50 and P75, or isolated low-confidence anomaly	Increase sampling; verify sensor health; inspect recent imagery
Warning	Salert between P75 and P90 with persistence, or agreement of exposure and response indicators	Targeted engineering inspection; UAV/ground survey; review access and loading
Critical	Salert above P90 with persistence, or engineer-approved direct limit exceeded	Immediate responsible-engineer notification; restrict activity where warranted; initiate emergency assessment
Insufficient evidence	Major sensor failure, unacceptable image quality or unresolved model fault	Do not report normal status; restore sensing and apply manual inspection plan

Source: proposed in this study. Percentiles and persistence durations must be set from pilot validation and approved by the responsible infrastructure authority; they are not universal thresholds.

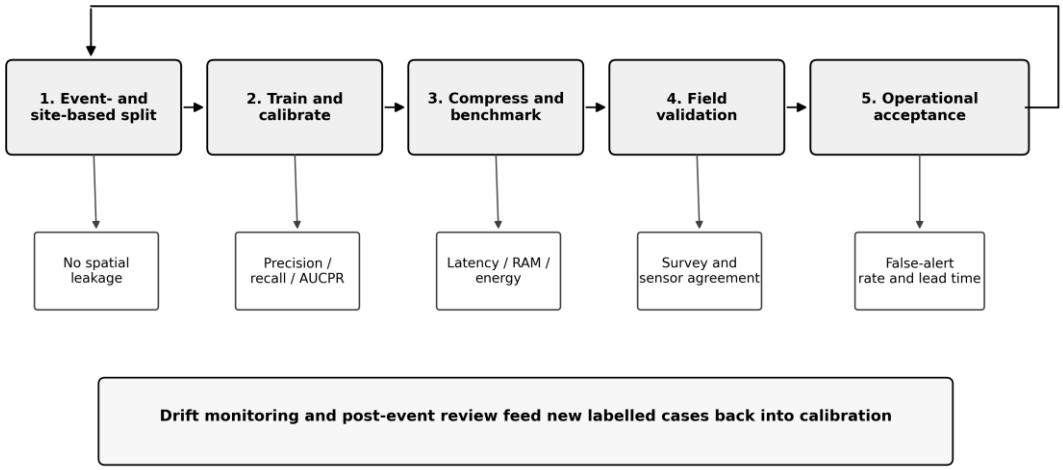

Figure 3. Validation and model-governance cycle for field deployment. Source: authors' original diagram based on validation principles in Pucino et al. (2022), Singh and Gill (2023) and Cha et al. (2024).

DISCUSSION

Advantages of the integrated approach

The framework improves on single-sensor monitoring in three ways. First, it links a basin-scale view to the exact asset location. Satellite imagery can identify where the coast is changing, while the asset buffer determines whether the change is approaching a foundation. Second, it separates exposure from response. Shoreline retreat without movement is treated differently from deformation without erosion, reducing the risk of an incorrect causal conclusion. Third, edge processing supports timely local decisions while preserving the cloud or central platform for retraining, long-term storage and regional analysis.

The use of both optical and SAR observations is particularly relevant around the Black Sea. Optical imagery offers intuitive spectral discrimination and detailed context, whereas SAR can provide observations when clouds or darkness prevent optical analysis. The recent Black Sea multi-sensor coastline study by Jiang et al. (2025) supports this complementary use. Time-series InSAR adds a third dimension by detecting movement of the ground or infrastructure, as demonstrated in coastal infrastructure studies outside the basin (An et al., 2023; Aziz Zanjani et al., 2024).

Limitations and failure modes

The main limitation is causal ambiguity. A model may detect that shoreline exposure and settlement are increasing together, but this association does not by itself prove that erosion caused the settlement. Engineering investigation remains necessary to examine foundation details, soil stratigraphy, drainage, scour, protection works and loading. The framework is therefore designed for screening and early warning, not automatic diagnosis.

Remote-sensing uncertainty is also scale dependent. A ten-metre optical pixel can support regional monitoring but may not resolve a narrow scour hole beside a foundation. Sub-pixel shoreline methods improve positional estimation but remain sensitive to water level, waves and shoreline type (Pucino et al., 2022; Bergsma et al., 2024). InSAR can measure deformation only where coherent targets and appropriate viewing geometry exist. Horizontal motion and rapid movement may be difficult to interpret, while atmospheric artefacts and decorrelation can mimic change if quality control is weak (Raspini et al., 2022).

Edge models introduce their own failure modes. Quantization can change output calibration; local sensors can drift; data distributions can change after coastal protection or construction; and a model trained on sandy beaches may not transfer to cliffs or armoured waterfronts. These risks justify site-based data splitting, supervised pilot operation, explicit uncertainty, periodic drift review and model rollback.

Implementation pathway for Black Sea pilot sites

A practical pilot should begin with two or three contrasting asset types, for example a coastal road on an eroding sandy sector, a port or quay with engineered shoreline geometry, and a building or utility corridor on compressible coastal ground. The initial year should focus on data quality and engineering labels rather than on maximizing model complexity. Monthly or event-driven shoreline products, routine InSAR updates, and a small set of reliable local sensors are preferable to a large sensor network that cannot be maintained.

The pilot should include at least one independent survey after a significant storm and one period of normal seasonal variability. The first model should use transparent features and a regularized logistic or tree-based baseline. A compact temporal network should be added only when the baseline fails to capture repeatable time-dependent patterns. Acceptance should be based on missed-event analysis, false-alert burden, calibration, edge latency and the quality of the evidence presented to engineers.

CONCLUSION

This paper presented a multi-sensor methodological framework for detecting erosion-induced foundation instability in Black Sea coastal infrastructure. The proposed system combines optical shoreline mapping, SAR-based coastal change, time-series InSAR deformation, targeted UAV surveys, local geotechnical and structural sensing, and edge AI. Its defining feature is the asset-referenced coupling of coastal exposure with structural response.

The framework is intentionally conservative. It does not claim site-specific accuracy without field data, and it does not treat shoreline retreat as proof of foundation failure. Instead, it provides an auditable chain from observation to feature, uncertainty, alert and engineering action. Editable equations define shoreline change, InSAR displacement, coastal foundation exposure and uncertainty-adjusted decision scoring. The tables specify sensor roles, feature interpretation, model options, validation requirements and action classes.

Future work should implement the framework at selected Black Sea pilot sites, establish engineer-verified labels, quantify the value of optical-SAR fusion, validate InSAR against local surveys, benchmark edge models under field constraints, and determine asset-specific alert persistence. Only after this staged validation should the system progress from inspection support to operational early warning.

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THE NECESSITY OF URBAN SQUARES IN THE CONTEXT OF URBAN CLIMATE RESILIENCE: AN ECOLOGICAL APPROACH TO THE CASE OF ERZURUM PALANDOKEN

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ABSTRACT

Rapid urbanization increases human pressure on natural ecosystems, making cities more vulnerable to climate change impacts. Rising temperatures, the urban heat island effect, and biodiversity loss highlight the need to reconsider public open spaces not only as social areas but also as ecologically functional environments. In this context, ecological design offers a strategic approach through green infrastructure, sustainable materials, and nature-based solutions to enhance urban resilience and improve microclimatic conditions. Accordingly, this study aims to develop ecological design scenarios for a strategically located urban area in the Yenişehir district of Erzurum, considering its harsh continental climate and future climate risks.

The material of the study consists of a selected site located in the Yenişehir district of Erzurum, which is currently characterized by low-density old building stock and lacks a qualified urban square identity. The methodology is based on identifying the current environmental problems of the site, analyzing microclimatic comfort parameters, and designing resilient interventions based on these data. In this process, technical assessments that measure the climatic performance of the physical structure of the selected area are utilized.

The findings expected to be obtained from the research aim to present a unique model that maximizes the climate adaptation capacity of the site in the context of Erzurum. The proposed model is expected to contribute to enhancing environmental resilience and improving microclimatic comfort conditions in urban squares under harsh continental climates. In this respect, it is anticipated to serve as an implementation guide for local authorities and to provide a substantial academic foundation for the sustainable transformation of urban voids with similar morphological characteristics.

Keywords: Ecological Design, Climate Change Adaptation, Urban Square, Erzurum-Palandöken, Microclimatic Comfort, Green Infrastructure.

INTRODUCTION

Climate change is generally defined as “statistically significant variations in the mean state of the climate or in its variability, persisting for decades or longer periods” (Türkeş, 2008). This phenomenon, whose importance has been increasing over time, has also led to greater emphasis on concepts such as vulnerability, resilience, and urban resilience. In the formation of urban resilience, design, planning, and governance elements come to the forefront. Each of these fields brings about various debates in terms of their relationships with policy dimensions (Kavanoz, 2020).

Cities are among the areas most affected by climate change due to their unique environmental, social, and economic structures. Climate change causes significant problems in urban areas such as rising temperatures, floods, heat waves, and droughts. Although the type and severity of these impacts vary from city to city, climate change constitutes a serious threat to cities and urban populations in general. Therefore, it is of great importance for cities affected by climate change to develop appropriate and effective adaptation strategies (Kaya, 2018).

Cities are not only contributors to climate change but also among the most affected settlements by this process. This situation demonstrates that climate change and urban planning processes cannot be considered separately. In recent years, sustainability-oriented urban policies have been developed, and the importance given to mitigation and adaptation strategies has increased. Within this scope, practices such as promoting the use of renewable energy, improving waste management systems, reducing environmental degradation and resource consumption, and lowering greenhouse gas emissions have been implemented in cities. Examples of such practices include Hamburg in Germany, Arizona in the USA, Linz in Austria, Copenhagen in Denmark, Eco-Viikki in Finland, Nantes in France, Malmö in Sweden, and Stockholm in Switzerland (Koçan & Alp, 2021).

As environmental challenges faced by cities have increased, international organizations, local governments, and central authorities have placed greater emphasis on policy development and preventive measures (Kavanoz, 2020). In parallel with these developments, the concept of urban resilience has emerged as a means to adapt to climate change and reduce its adverse impacts. Rapid population growth, unplanned urbanization, and disasters limit the capacity of cities to respond to emerging needs. Consequently, the concept of resilient cities, which aims to prevent the decline in quality of life, has become an important issue on a global scale (Erdoğan et al., 2022).

Within the framework of urban climate change and adaptation, a resilience-oriented approach enables practitioners to evaluate innovations and anticipate changes that facilitate recovery from stress and shocks. In complex socio-ecological systems characterized by high uncertainty and dynamism, resilience development offers various advantages over traditional management approaches as a strategic framework (Walker et al., 2006).

The criteria and impacts of urban resilience are generally examined under three main dimensions: social, environmental, and economic. The social dimension includes elements such as social cohesion, sense of place, street life, active mobility, diversity, social interaction, and public space use; the environmental dimension covers high-quality green design, integration of natural and built environments, increased biodiversity, and improved air quality; and the economic dimension includes accessibility, increases in land value, energy efficiency, economic growth, and support for small and local businesses (Soofi-Siavash, 2016).

Landscape and design practices in public open spaces should support users both physically and psychologically by fostering evolving social interactions. However, the success of these spaces depends on their ability to adapt to user needs, transform over time, and respond to expectations (Alpak & Düzenli, 2018). In this way, it becomes possible to create more qualified and vibrant urban spaces.

With the development of urbanization, urban squares have also evolved in parallel with the growth of cities. As an essential component of urban life, people have historically created gathering spaces for social interaction and public use. Although these spaces have been referred to by different names in different periods, they have maintained their fundamental functions and have been shaped according to the social structures of societies. Today, however, due to rapid urbanization, population growth, dense construction, traffic, and technological advancements, many urban squares have undergone functional transformation or have become integrated into transportation systems, turning into intersections. This situation has led to a decline in both the functional and qualitative characteristics of these spaces and a gradual loss of their public value. Nevertheless, urban squares continue to play a significant role in preserving the spatial identity of cities (Abacıoğlu Gitmiş, 2021).

This transformation is not only a general trend but can also be observed at the local scale. In the Palandöken district of Erzurum province, particularly in areas at risk of losing their function due to urban transformation processes and physical deterioration, the lack of public open spaces and the need for urban squares are becoming increasingly evident. In this context, the study area has been addressed

within the framework of identifying existing environmental problems, analyzing microclimatic comfort in spatial terms, and developing resilience-based design proposals based on the obtained findings.

PURPOSE AND SIGNIFICANCE OF THE STUDY

• The aim of this research is to examine the function of public open spaces within urban life and to reveal the spatial, social, and functional necessity of urban squares. In this context, the environmental impacts of climate change on cities and their implications for user needs have been evaluated together. The study area selected is a region located in the Palandöken district of Erzurum province, characterized by a predominance of old, single-story buildings and lacking the qualities of an urban square.

• In this study, the existing land use patterns, user expectations, and spatial characteristics of the area were examined through field observations and user surveys. Based on the findings obtained, the microclimatic performance of the area was assessed comprehensively using ENVI-met software, SVF analyses, thermal camera data, and various field measurements.

• This research aims to identify the insufficiency of public open spaces and to develop a design proposal for a qualified urban square that can respond to user expectations. In this regard, it seeks to contribute to the creation of more functional, accessible, and user-centered public spaces within the city.

RESEARCH PROBLEM AND CURRENT SİTUATİON

- **Microclimatic Heating and Thermal Comfort Deficiency**

The widespread use of hard surfaces and the inadequacy of shading elements in the study area lead to increased surface temperatures during the summer period and a noticeable decline in microclimatic comfort levels.

- **Irregular Wind Movements and Thermal Stress Issues in Winter**

Under Erzurum’s severe climatic conditions, the building form, which has a limited capacity to guide wind, leaves the open space exposed and negatively affects pedestrian comfort due to increased wind speeds during the winter months.

- **Insufficiency of Green Infrastructure and Ecological Components**

The lack of vegetation and permeable surfaces limits the area’s capacity to provide ecosystem services and reduces its environmental performance.

- **Ecological and Spatial Inadequacy of the Existing Building Stock**

This area, composed largely of old, single-story buildings that have lost their function, results in the inefficient use of a valuable space in the city center. The existing built environment remains inadequate in terms of energy efficiency, spatial productivity, and ecological performance.

- **User Experience and Loss of Social Function**

Microclimatic challenges, the dominance of hard surfaces, and the lack of shading elements reduce social use and user comfort, preventing the area from acquiring a functional public space identity.

- **Insufficiency of Urban Squares in the Palandöken District**

The Palandöken district lacks a qualified urban square where users can gather, encourage social interaction, and organize public life.

MATERIAL

The study area is situated in the Solakzade Neighborhood, located within the boundaries of Palandöken district, one of the central districts of Erzurum province in the Eastern Anatolia Region of Türkiye (URL-1). The study area has a total size of 30.4 hectares.

Its proximity to the city center positions the neighborhood as an important transportation and residential zone (URL-1). Public transportation routes along the Yakutiye–Palandöken corridor enhance accessibility, while the residential fabric predominantly consists of medium- and high-density apartment blocks (URL-1). Moreover, the inclusion of the area within the scope of an urban transformation project through the Official Gazette decision dated August 27, 2025, indicates that more extensive spatial interventions are likely to take place in the future (URL-2).

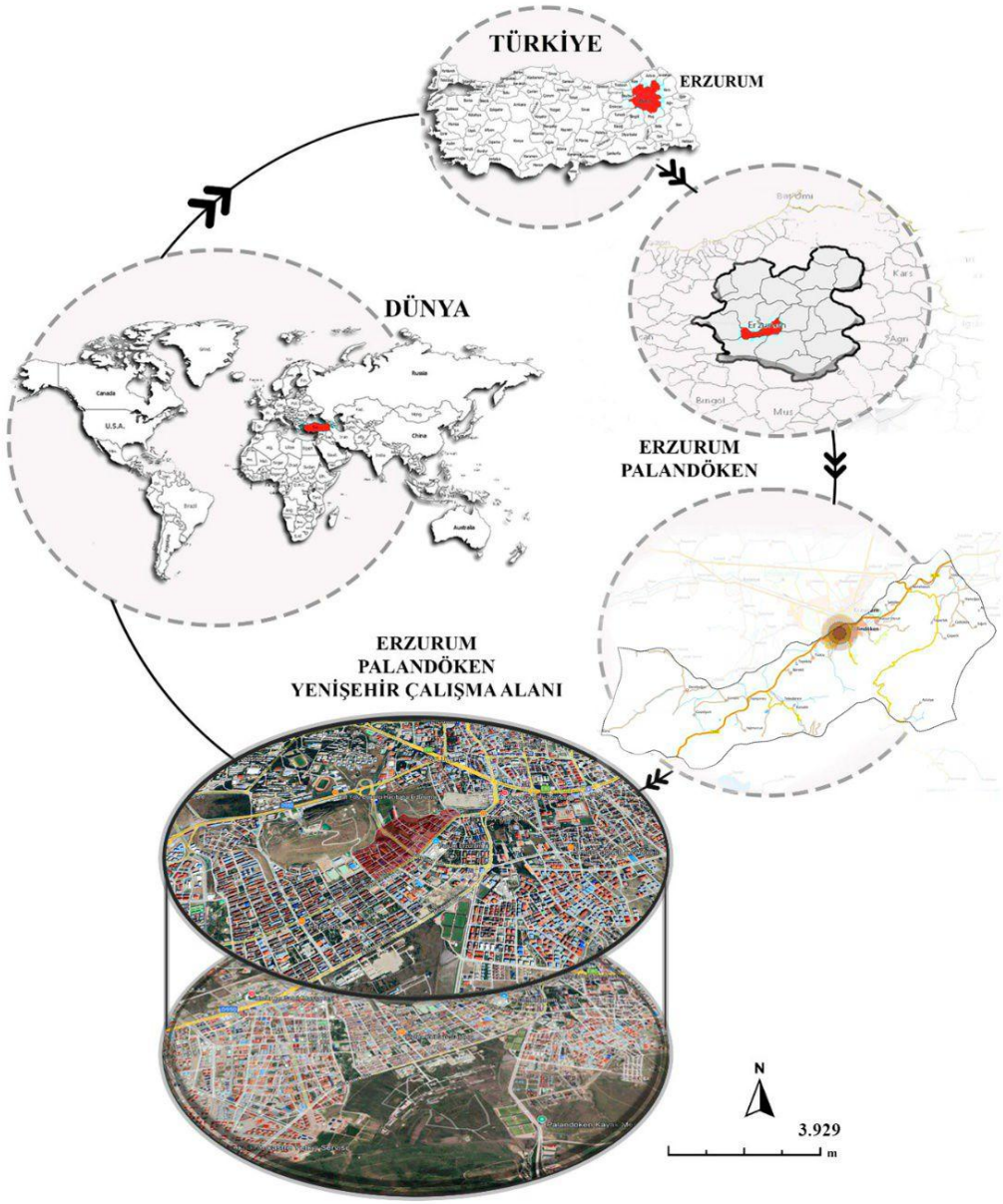

Figure 1. Location map of the study area (prepared by the author).

Table 1. Material and Program Inventory

Code	Item name	Product image	Parameters	Status
D5200	Nikon D5200 camera		video and image	new
PIX connection	ProHD lens		video and image	new
PIX connection	Optris PI thermal camera		video and image	new
5,7,2	ASUS computer and ENVI-met simulation software		Air temperature, wind speed and direction, and surface temperature.	good
	Hygrometer		Humidity	new
AM-4206M	Anemometer (AM-4206M)		Wind speed	new
	Microsoft Excel		input	good
D-79085	RayMAN Pro		Meteorological data	good



Figure 2. Study area.

METHODOLOGY

- **Field Surveys**

The existing physical structure, usage intensity, and environmental characteristics of the area were evaluated through on-site surveys.

- **Survey Implementation**

Structured questionnaires were conducted to identify users' perceptions and requirements regarding the space. The collected data were analyzed using Microsoft Excel through frequency, percentage, and mean values, and were supported with graphical representations.

- **Microclimatic Assessments**

To determine the microclimatic performance of the area, measurements were carried out between 12:00 and 13:00, the hottest period of the day. SVF analyses were performed, and thermal camera data along with field measurements were collected, with the findings supported by ENVI-met and RayMAN software.

- **Data Processing and Evaluation**

Based on the collected data, the environmental comfort conditions and spatial performance of the area were examined through a multidimensional approach.

- **Design Proposal**

In line with the analysis findings, the proposed urban square design for the area was presented through visual materials, and its spatial usage potential was evaluated.



Figure 3. Field Equipment and Measurement Applications

- The nearby station will use the data both daily and annually.
- According to the measurements taken, the current PET value of the area is 31.5.

- **Data Collection Technique**

The research data were obtained through a structured questionnaire. The questionnaire consists of three main sections: demographic attributes, usage habits, and spatial perception assessment. In the spatial perception section, a closed-ended scale including the options "Yes," "No," and "Undecided" was employed to determine participants' level of need for urban squares. In addition, multiple-choice

questions were included to identify the purposes for which users utilize urban squares and their opinions regarding the spatial components that should be present.

- **Population and Sample**

The population of this study comprises individuals who use the urban open space examined within the scope of the research. The sample consists of a total of 89 participants who use this area and voluntarily took part in the study. The sample group was determined using the convenience sampling method.

The collected data were evaluated using quantitative analysis techniques. In this context, frequency distributions, percentage calculations, and mean values were determined. The findings were interpreted based on the perceptual evaluations of the participants and visualized through graphs.

The data were analyzed using frequency (f) and percentage (%) distributions. The following formula was used to calculate percentages:

$$\%= f / N \times 100$$

Here, f represents the number of participants who selected the relevant option, and N represents the total number of participants (N = 89). The data were evaluated using descriptive statistical methods and supported with graphical representations.

FİNDİNGS

A) Individual Characteristics of Participants

- **Demographic Attributes of Participants**

Women constitute 62.9% of the participants, while 37.1% are men. This indicates that the sample group is predominantly female.
When the age distribution is examined, the largest group of participants falls within the 26–35 age range (47.2%), followed by the 18–25 age group (28.1%).
In terms of occupational distribution, 66.3% of the participants are students, 21.3% are employed in the public sector, and 12.4% work in the private sector.

- **Identification of the Need for a Public Square in the Area**

A vast majority of participants (93.3%) responded “Yes” to the question. Meanwhile, 2.2% answered “No,” and 4.5% selected “Undecided.”
These findings indicate that the general tendency among participants is strongly positive.

- **Land Use Tendencies**

In this multiple-choice question, participants stated that they most frequently use open spaces for “relaxation” (100%), “social interaction” (80.9%), and “activities” (73.0%). The “transitional space” option was selected by 64.0%, whereas only 2.2% indicated “I would not use it.”

- **Participants’ Design Preferences**

Participants identified the most important elements in open space design as “tree planting and green areas” (100%), “wind protection” (100%), and “seating areas” (100%). In addition, “water features” were preferred by 92.1% and “shading” by 76.4%.
The findings presented in Figure 4 reveal that participants attach a high level of importance to natural components and comfort-enhancing design features in open spaces.

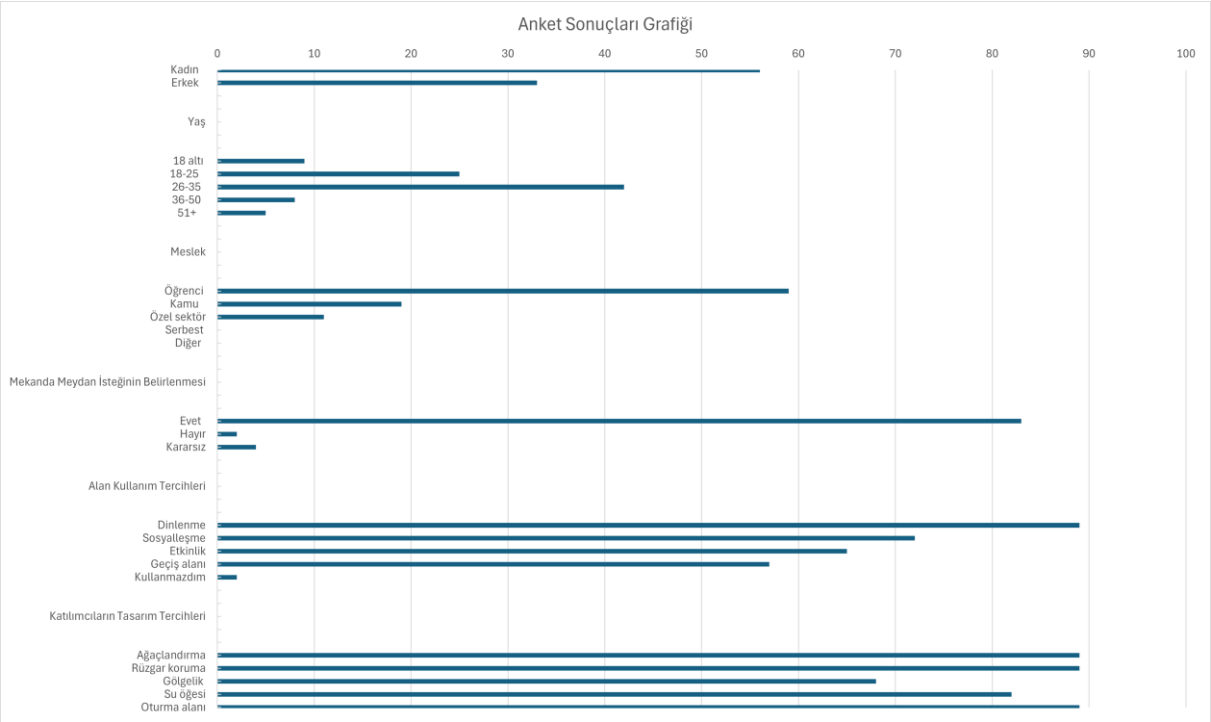

Figure 4. Survey Results

B) Microclimatic Findings

Thermal camera data reveal noticeable variations in temperature values across different points. In particular, surface temperatures reach higher levels in open areas with hard surfaces (e.g., Area 4), whereas temperatures decrease considerably in shaded zones or areas with vegetation (as shown in Figure 5, e.g., Area 2). This clearly indicates the significant influence of surface materials and shading elements on microclimatic comfort.

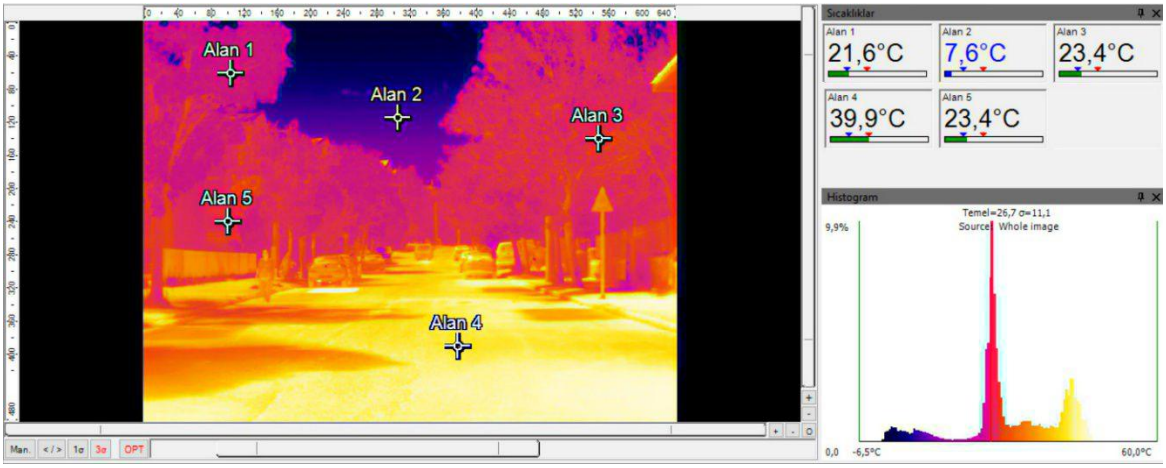

Figure 5. Thermal camera image.

The visuals presented in Figure 6 further demonstrate the influence of shading elements, vegetation arrangements, and surface covering choices on thermal comfort in urban open space design. Measurements conducted particularly during the hottest period of the day (around 13:00) indicate that controlling sky view exposure and reducing impermeable surfaces are necessary to enhance user comfort.

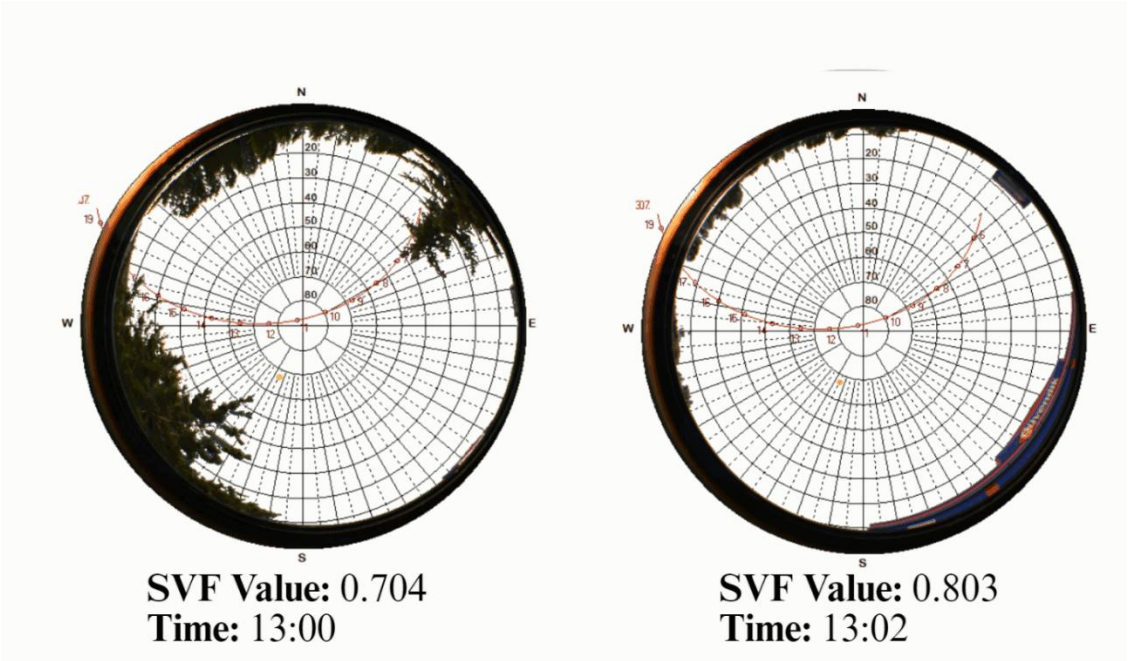

Figure 6. SVF images.

As illustrated in Figure 7, surface temperatures are noticeably higher in areas with hard surfaces that are exposed to direct solar radiation (e.g., Areas 4 and 6). In contrast, temperatures are considerably lower in areas shaded by trees or partially covered with vegetation (Areas 2 and 3). This finding clearly demonstrates the effectiveness of shading in reducing surface temperatures.

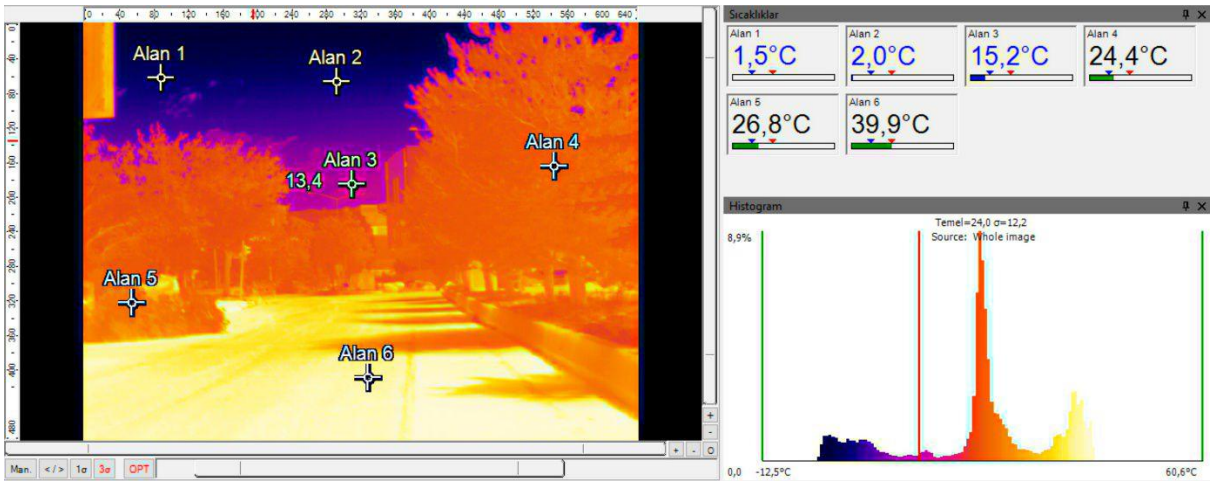

Figure 7. Thermal camera image.

In areas with high SVF (Sky View Factor) values, the sky is perceived as more open and unobstructed. Consequently, more solar radiation reaches the area, leading to increased heating of the environment.

In areas with low SVF values, trees or structures create shading effects. This condition limits solar radiation and helps maintain a cooler environment (Figure 8).

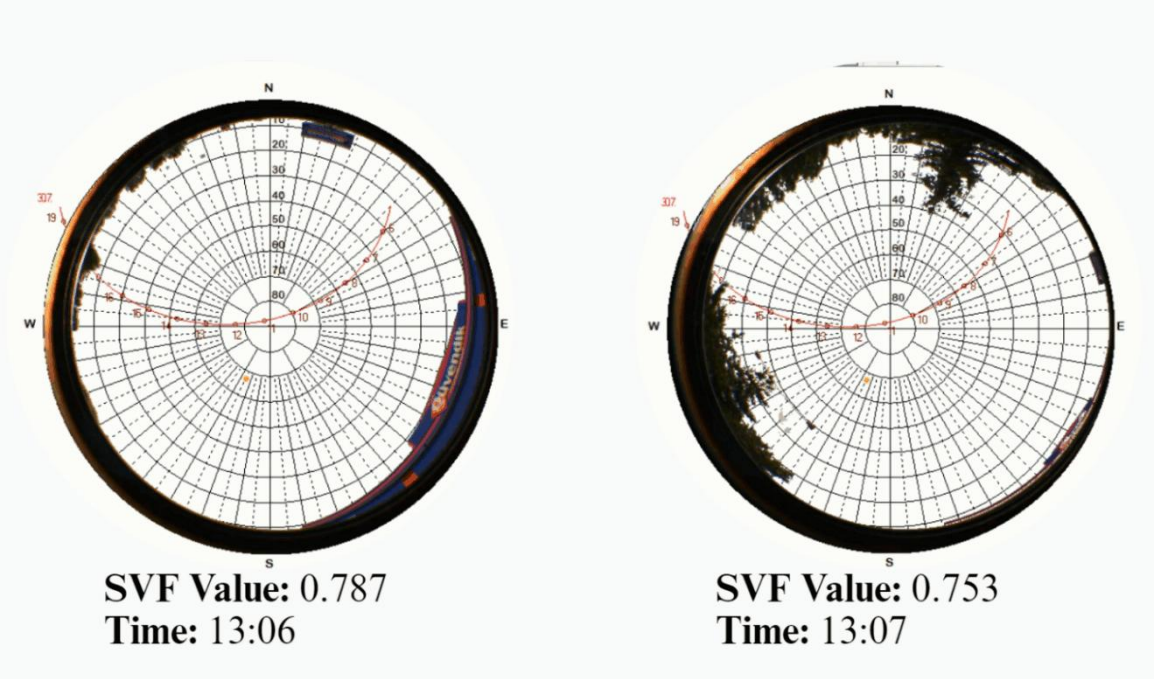

Figure 8. SVF images

Figure 9 demonstrates that temperatures reached very high levels (approximately 43°C) in areas exposed to open and direct solar radiation (particularly Area 7 and its surroundings). In contrast, temperatures were observed to be noticeably lower in areas influenced by tree shade (Area 3, Area 4, and partially Area 5). This finding indicates that vegetation cover plays a significant role in reducing surface temperatures.

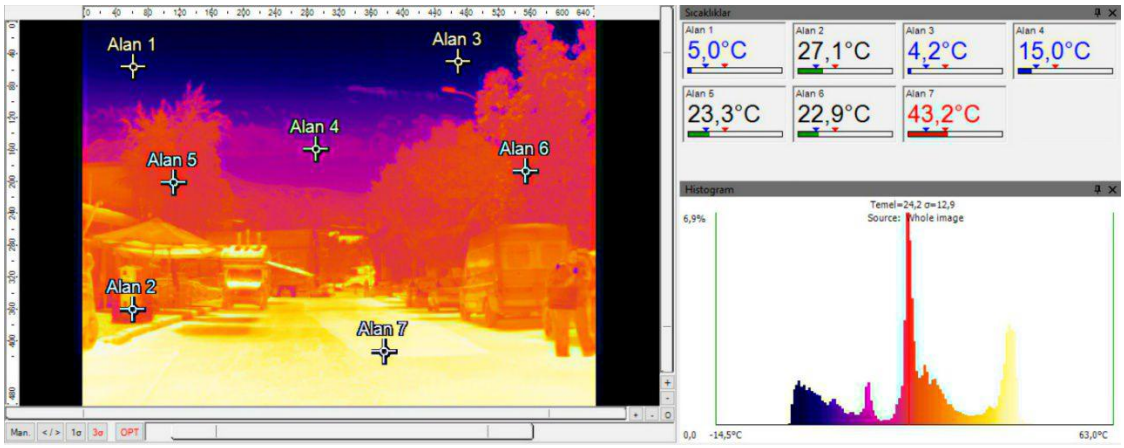

Figure 9. Thermal camera image.

Figure 10 indicates that measurements conducted between 13:12 and 13:15 reveal the pronounced effect of shading on the microclimate, even during the hottest period of the day. Accordingly, measurements taken between 13:00 and 13:15 showed that SVF values ranged between 0.542 and 0.803. While surface temperatures remained within approximately 15–25°C in shaded areas with low SVF values, temperatures in open areas with high SVF values reached 39–43°C. This finding demonstrates that surface temperatures increase significantly as sky openness increases.

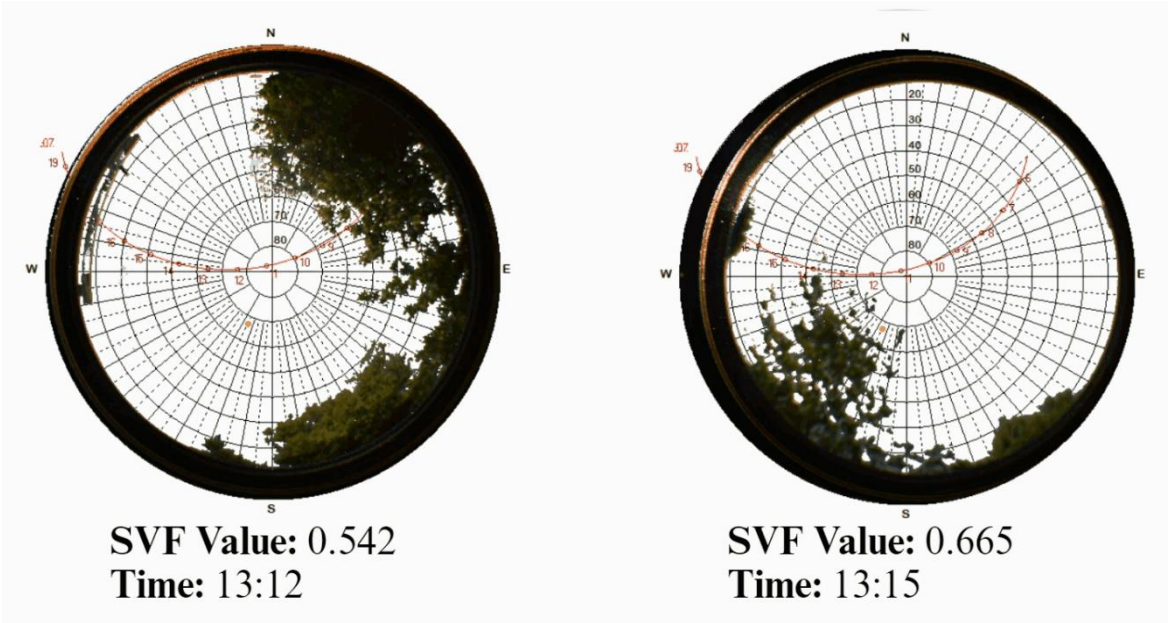

Figure 10. SVF images

DISCUSSION AND CONCLUSION

This study examined the demographic structure, spatial usage tendencies, and microclimatic performance of users of urban open spaces in the Yenişehir neighborhood of the Palandöken district in Erzurum province. The conducted measurements and analyses revealed that surface temperature, sky view factor (SVF), wind impact, and shade distribution are directly influential in determining comfort conditions within the area. Measurements carried out between 13:00 and 13:15 indicated that SVF values varied between 0.542 and 0.803. It was observed that surface temperatures in shaded areas with low SVF values remained within the range of approximately 15–25°C, whereas in open areas with high SVF values, temperatures increased up to 39–43°C. The findings suggest that high surface temperatures and insufficient shading negatively affect thermal comfort during the summer period, while wind constitutes a significant limiting factor for user comfort in the winter season.

The results show that the majority of participants consist of women and young adults. According to the research data, users predominantly prefer open spaces for relaxation and social interaction. In addition, the study demonstrates that increasing green areas, providing wind protection, creating shaded spaces, and incorporating water features and seating units are essential components in open space design.

Overall, it is understood that participants attach considerable importance to natural elements and design features that enhance comfort. This indicates that environmental comfort and naturalness should be among the primary criteria in the design of urban open spaces in the Yenişehir district. However, the inadequacy of the existing physical characteristics and the limited usability of the area necessitate a reconsideration of the space. In this context, considering the transformation potential of the existing structure shown in Figure 11, it is concluded that redesigning the area as an urban square would provide a more functional and sustainable solution and contribute to the creation of a public space that better responds to diverse user needs and is used more efficiently.

The obtained results are consistent with studies in the literature. Kaya (2018) emphasizes that cities have become more vulnerable to climate-related risks due to their environmental, social, and economic characteristics, and that this directly influences urban planning approaches. Similarly, Kavanoz (2020) states that urban design and planning processes should be reconsidered in a way that adapts to changing environmental conditions.

On the other hand, it is noted that designing public open spaces in a manner that is flexible, accessible, and of high quality according to user needs plays a crucial role in improving urban quality of life (Alpak and Düzenli, 2018). Various studies also indicate that urban squares have historically been focal points

of social interaction and public life, but today they face the risk of losing their functional and spatial qualities (Abacıoğlu Gitmiş, 2021).



Figure 11. Proposed visuals of the planned city square.

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APPENDICES

QUESTIONNAIRE FORM

Urban Climate Resilience and Use of Urban Squares (The Case of Erzurum Palandöken)

This questionnaire has been prepared to determine the climatic comfort and usage needs of urban open spaces. The collected data will be used solely for academic purposes.

1. Gender:

☐ Female ☐ Male ☐ Prefer not to say

2. Age Range:

☐ Under 18 ☐ 18–25 ☐ 26–35 ☐ 36–50 ☐ 51+

3. Occupation:

☐ Student ☐ Public sector employee ☐ Private sector ☐ Self-employed

☐ Other: _____

4. Do you think it is necessary to have an urban square in your area (Yenişehir/Palandöken)?

☐ Yes ☐ No ☐ Undecided

5. If there were an urban square, for what purposes would you use it? (You may select more than one option)

☐ Recreation/Resting ☐ Socializing ☐ Events/Organizations ☐ Daily transit area

☐ I would not use it

6. In your opinion, which elements should be prioritized in an urban square to be created in this area? (You may select more than one option)

☐ Trees and green spaces ☐ Wind-protective design elements

☐ Shaded areas ☐ Water features (e.g., fountains) ☐ Seating and resting areas

PROBLEMS OF ENSURING ECONOMIC SECURITY OF ENTREPRENEURIAL SUBJECTS IN AZERBAIJAN

AZERBAYCAN'DA GİRİŞİMCİ AKTÖRLERİN EKONOMİK GÜVENLİĞİNİN SAĞLANMASINDAKİ SORUNLAR

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ABSTRACT

In modern economic conditions, ensuring the economic security of business entities is one of the main prerequisites for achieving sustainable development in the national economy. Global economic uncertainty, increasing market risks, intensified competition, technological transformations, and the expansion of digital technologies have further increased the relevance of economic security issues for entrepreneurial entities. The economic security of an enterprise represents a complex system of economic relations aimed at preventing internal and external threats and risks, ensuring the efficient use of resources, and maintaining the sustainable functioning of the enterprise. Potential threats to economic security in entrepreneurship stem from factors such as violations of property rights and economic freedoms, unfair competition, unlawful actions by executive authorities, inter-entity fraud, corruption and bribery, instability in the activities of business entities, and failure to fulfill contractual obligations. Therefore, the economic security of entrepreneurship largely depends on the effectiveness of legal and economic relations, organizational connections, and the availability of material and intellectual resources that ensure the financial stability, commercial success, and innovative development of enterprises. In the context of the development of a market economy in Azerbaijan, business entities inevitably encounter various challenges related to economic security. These problems are primarily associated with limited access to financial resources, high lending interest rates, market risks, weak innovation capacity, and the influence of external economic factors. Significant threats to economic security also arise from the conscious or unconscious irresponsible actions of individuals, organizations, state institutions, international organizations, and competing enterprises, as well as from the financial condition of enterprises, the solvency of consumers, and force majeure circumstances caused by both objective and subjective factors. Such threats create substantial challenges for small and medium-sized enterprises in maintaining financial stability, enhancing competitiveness, adapting to market changes, and ensuring innovative development. Furthermore, the acceleration of digital transformation processes has intensified cybersecurity risks, thereby creating additional challenges for the protection of economic security. Ensuring the information security of enterprises, protecting commercial data, and effectively managing digital risks represent key directions in strengthening economic security. The improvement of state support mechanisms, the promotion of innovation activities, the expansion of tax and financial incentives, as well as the development of human capital, are of significant importance for enhancing the economic security of business entities. These measures contribute to the sustainable development of entrepreneurship, the increase of investment attractiveness, and the strengthening of the competitiveness of the national economy. In Azerbaijan, ensuring the economic security of business entities is of

particular importance for maintaining macroeconomic stability, promoting innovative development, and implementing long-term economic development

strategies.

Keywords: entrepreneurship, economic security, risks, economic security problems in Azerbaijan.

ÖZET

Çağdaş ekonomik koşullarda, işletmelerin ekonomik güvenliğinin sağlanması, ulusal ekonomide sürdürülebilir kalkınmanın sağlanmasının temel ön koşullarından biridir. Artan küresel ekonomik belirsizlik, artan piyasa riskleri, yoğunlaşan rekabet, teknolojik dönüşümler ve dijital teknolojilerin genişlemesi, ekonomik güvenlik sorunlarının girişimci kuruluşlar için önemini daha da artırdı. İşletmenin ekonomik güvenliği; iç ve dış tehdit ve riskleri önlemeyi, kaynakların verimli kullanımını sağlamayı ve işletmenin sürdürülebilir işleyişini sürdürmeyi amaçlayan karmaşık bir ekonomik ilişkiler sistemini temsil eder. Girişimcilikte ekonomik güvenliğe yönelik potansiyel tehditler, mülkiyet haklarının ve ekonomik özgürlüklerin ihlali, haksız rekabet, yürütme organlarının hukuka aykırı eylemleri, kurumlar arası usulsüzlükler, yolsuzluk ve rüşvet, işletme faaliyetlerindeki istikrarsızlık ve sözleşmesel yükümlülüklerin yerine getirilmemesi gibi faktörlerden kaynaklanmaktadır. Bu nedenle, girişimciliğin ekonomik güvenliği büyük ölçüde yasal ve ekonomik ilişkilerin etkinliğine, örgütsel bağlantılara ve işletmelerin finansal istikrarını, ticari başarısını ve yenilikçi gelişimini sağlayan maddi ve entelektüel kaynakların mevcudiyetine bağlıdır. Azerbaycan'da piyasa ekonomisinin gelişmesi bağlamında, işletmeler genellikle ekonomik güvenlikle ilgili çeşitli zorluklarla karşılaşmaktadır. Bu sorunlar öncelikle finansal kaynaklara erişimin sınırlı olması, yüksek kredi faiz oranları, piyasa riskleri, zayıf inovasyon kapasitesi ve dış ekonomik faktörlerin etkisiyle ilişkilidir. Ekonomik güvenliğe yönelik önemli tehditler ayrıca bireylerin, kuruluşların, devlet kurumlarının, uluslararası kuruluşların ve rakip işletmelerin bilinçli veya bilinçsiz sorumsuz eylemlerinden, işletmelerin mali durumundan, tüketicilerin ödeme gücünden ve hem objektif hem de sübjektif faktörlerin yol açtığı mücbir sebeplerden kaynaklanmaktadır. Bu tehditler, küçük ve orta ölçekli işletmeler için finansal istikrarı koruma, rekabet gücünü artırma, piyasa değişikliklerine uyum sağlama ve yenilikçi gelişmeyi güvence altına alma konusunda önemli zorluklar yaratmaktadır. Ayrıca, dijital dönüşüm süreçlerinin hızlanması siber güvenlik risklerini yoğunlaştırmış ve böylece ekonomik güvenliğin korunması için ek zorluklar yaratmıştır. İşletmelerin bilgi güvenliğinin sağlanması, ticari verilerin korunması ve dijital risklerin etkin bir şekilde yönetilmesi, ekonomik güvenliğin güçlendirilmesinde kilit yönleri temsil etmektedir. İşletmelerin ekonomik güvenliğinin artırılması için devlet destek mekanizmalarının iyileştirilmesi, inovasyon faaliyetlerinin teşvik edilmesi, vergi ve mali teşviklerin genişletilmesi ile insan sermayesinin geliştirilmesi stratejik önem arz etmektedir. Bu önlemler girişimciliğin sürdürülebilir kalkınmasına, yatırım çekiciliğinin artmasına ve ülke ekonomisinin rekabet gücünün güçlendirilmesine doğrudan etki etmektedir. Azerbaycan'da, işletmelerin ekonomik güvenliğinin sağlanması makroekonomik istikrarın sürdürülmesi, yenilikçi kalkınmanın teşvik edilmesi ve uzun vadeli ekonomik kalkınma stratejilerinin uygulanması açısından özel bir öneme sahiptir.

Anahtar kelimeler: girişimcilik, ekonomik güvenlik, riskler, Azerbaycan'da ekonomik güvenlik.

Introduction

Relevance of the topic. In the contemporary period, characterized by globalization, digital transformation, intensified market competition, and growing economic uncertainty, ensuring the economic security of business entities has become an increasingly important issue. Business entities play a significant role in promoting economic growth, increasing employment, and supporting the diversification of the national economy, particularly through the development of the non-oil sector. However, financial risks, market volatility, limited innovation capacity, shortages of qualified human capital, and emerging cybersecurity threats negatively affect the sustainability and competitiveness of entrepreneurial activities. Therefore, the study of issues related to ensuring the economic security of business entities in Azerbaijan is of considerable scientific and practical relevance.

Object and subject of the research. The object of the research is the process of ensuring the economic security of business entities operating in Azerbaijan.

The subject of the research comprises the factors influencing the economic security of business entities, as well as the risks, threats, and mechanisms aimed at their prevention and mitigation.

Purpose of the research. The purpose of the research is to examine the theoretical foundations of the economic security of business entities, analyze the existing challenges in Azerbaijan, and develop scientifically grounded recommendations for strengthening economic security.

Research methodology and methods. The methodological framework of the research is based on theoretical approaches and concepts related to economic security and entrepreneurship development. The study employs methods of analysis and synthesis, comparative analysis, a systematic approach, generalization, and economic-statistical analysis. In addition, relevant domestic and foreign scientific literature, reports of international organizations, and regulatory and legal documents have been examined.

Scientific novelty of the research. Scientific innovations formulated as a result of the conducted research can be expressed as follows:

-comprehensive systematization of the main risks affecting the economic security of business entities, along with a scientific analysis of their interrelationships and cumulative impact;

-ıdentification and examination of the role and impact mechanisms of digital transformation factors in ensuring the economic security of business entities;

-scientific substantiation of the critical importance of cybersecurity factors in enhancing the sustainability and reducing the vulnerability of business entities to emerging risks;

-development of scientifically grounded and practically oriented proposals aimed at improving state support mechanisms and promoting innovation-driven development to strengthen the economic security of business entities in Azerbaijan.

Discussion.

In the context of globalization, digital transformation, and increasing economic uncertainty, ensuring the economic security of entrepreneurial entities has become one of the key priorities for sustainable economic development. Economic security serves as a fundamental condition for the stable functioning of enterprises, enabling them to withstand internal and external threats, maintain competitiveness, and achieve long-term growth. The importance of economic security has increased significantly due to rapid technological changes, market volatility, geopolitical challenges, cyber threats, and intensifying competition in both domestic and international markets.

Entrepreneurship plays a crucial role in the development of the national economy by generating employment opportunities, increasing production, stimulating innovation, and contributing to economic diversification. According to Schumpeter (1934, pp. 61–66), entrepreneurship serves as the primary driving force of economic development through innovation and the creation of new combinations of production factors. Similarly, Drucker (2007, pp. 27–35) emphasizes that entrepreneurial activity transforms economic opportunities into sustainable competitive advantages and contributes significantly to national economic growth. Consequently, threats affecting the economic security of business entities directly influence national economic stability and development. In Azerbaijan, where entrepreneurship is considered one of the main drivers of economic diversification and non-oil sector development, ensuring the economic security of business entities has become a strategic necessity.

The implementation of economic reforms, support programs for small and medium-sized enterprises (SMEs), digital transformation initiatives, and innovation-oriented policies demonstrates the Azerbaijani government's commitment to strengthening entrepreneurship. However, despite these efforts, business entities continue to face various economic security challenges, including financial constraints, market risks, institutional barriers, corruption risks, technological vulnerabilities, and external economic shocks.

This article examines the theoretical foundations of economic security in entrepreneurship, analyzes the major threats and challenges faced by entrepreneurial subjects in Azerbaijan, and identifies potential mechanisms for strengthening economic security within the national economy.

Theoretical foundations of economic security in entrepreneurship.

The concept of economic security has evolved significantly in modern economic literature. Economic security generally refers to the ability of an economic entity to maintain stable functioning, protect its interests, efficiently utilize resources, and withstand internal and external threats (Senchagov, 2008). At the enterprise level, economic security encompasses financial stability, resource protection, competitiveness, information security, legal protection, and sustainable development.

According to Blank (2004), economic security is a state in which an enterprise can effectively achieve its strategic objectives while minimizing the impact of risks and uncertainties. North (1990, pp. 54–60) argues that the effectiveness of institutions, protection of property rights, and enforcement of contracts are fundamental determinants of economic security. Strong institutional frameworks reduce uncertainty and create favorable conditions for entrepreneurial development. Economic security is therefore not limited to protection from threats but also involves creating favorable conditions for sustainable growth and innovation.

The economic security of entrepreneurial entities is influenced by both internal and external factors. Internal factors include management quality, financial stability, technological capacity, human resources, organizational structure, and innovation potential. External factors include market competition, legal regulations, macroeconomic conditions, political stability, international economic relations, and technological developments.

Modern approaches emphasize that economic security should be viewed as a multidimensional system integrating financial, technological, legal, informational, and organizational components. Such an integrated approach allows enterprises to identify risks in advance and implement preventive measures to minimize potential losses. Porter (1998, pp. 33–38) notes that sustainable competitive advantage is closely associated with the ability of firms to protect strategic resources and adapt to changing market conditions, which directly contributes to economic security.

The growing complexity of economic environments has made economic security a strategic management function rather than merely a protective mechanism. Enterprises must continuously monitor threats, evaluate vulnerabilities, and adapt to changing conditions in order to maintain their competitiveness and sustainability.

Main threats to the economic security of entrepreneurial subjects.

Entrepreneurial entities operate in an environment characterized by numerous risks and uncertainties. These risks can undermine financial stability, reduce profitability, and threaten business continuity.

financial Risks. Financial risks represent one of the most significant threats to economic security. Limited access to financial resources, high borrowing costs, inflationary pressures, exchange rate fluctuations, and liquidity shortages can negatively affect business operations. Small and medium-sized enterprises are particularly vulnerable because they often face difficulties obtaining affordable financing. According to the OECD (2023, pp. 45–52), limited access to external financing remains one of the most significant barriers to SME growth and long-term sustainability. Similar findings are reported by the World Bank (2024, pp. 78–85), which identifies financing constraints as a major obstacle to entrepreneurial competitiveness in developing economies.

In Azerbaijan, despite the expansion of financial support mechanisms, many SMEs continue to encounter challenges related to credit accessibility and financing costs. High interest rates increase operational expenses and limit opportunities for investment and expansion.

Market Risks. Market risks arise from fluctuations in demand, changing consumer preferences, increasing competition, and economic instability. The globalization of markets has intensified competitive pressures, requiring enterprises to continuously improve product quality, reduce costs, and adopt innovative business models. Business entities that fail to adapt to market changes may experience

declining revenues and reduced competitiveness. Therefore, market risk management has become an essential component of economic security strategies.

Legal and Institutional Risks. Legal and institutional environments significantly influence entrepreneurial activities. Weak enforcement of property rights, contractual disputes, regulatory uncertainties, bureaucratic obstacles, and corruption can create substantial challenges for businesses. Economic security depends largely on the existence of transparent legal frameworks and effective institutions that protect entrepreneurial rights and facilitate business operations. Unclear regulations and excessive administrative procedures increase operational risks and reduce investor confidence.

Operational risks. Operational risks arise from internal organizational deficiencies, including ineffective management systems, inadequate resource allocation, technological failures, and human errors. Poor management decisions can lead to financial losses, reduced productivity, and reputational damage. The implementation of effective corporate governance systems and risk management practices is therefore essential for strengthening economic security.

Economic security challenges facing entrepreneurial subjects in Azerbaijan

The development of entrepreneurship in Azerbaijan has accelerated during recent decades as a result of economic diversification policies and institutional reforms. Nevertheless, several challenges continue to affect the economic security of business entities.

Dependence on external economic factors. Although Azerbaijan has achieved significant progress in diversifying its economy, external economic factors continue to influence entrepreneurial activities. Global energy price fluctuations, international trade disruptions, geopolitical tensions, and economic crises can directly affect domestic business performance. The interconnected nature of modern economies means that external shocks can quickly transmit to local markets, creating uncertainty for entrepreneurial entities. Therefore, businesses must develop adaptive strategies to enhance resilience against external disturbances. The World Economic Forum (2024, pp. 14–21) identifies geopolitical tensions, inflationary pressures, supply chain disruptions, and technological risks among the most significant global threats affecting business sustainability and economic security.

Limited ınnovation capacity. Innovation is increasingly recognized as a key determinant of economic security and competitiveness. However, many enterprises in Azerbaijan face challenges related to technological modernization, research and development activities, and innovation adoption. Insufficient investment in innovation limits productivity growth and reduces the ability of businesses to compete in global markets. Drucker (2007, pp. 138–145) argues that innovation should be treated as a systematic managerial function rather than a random process. Enterprises that fail to invest in innovation face increasing risks of technological obsolescence and declining competitiveness. Strengthening innovation ecosystems, supporting technology transfer, and encouraging research collaborations are essential for improving economic security.

Human capital constraints. Human capital represents one of the most valuable assets of entrepreneurial organizations. The UNDP Human Development Report (2023/2024, pp. 112–118) highlights that investments in education, skills development, and lifelong learning significantly improve productivity and organizational adaptability in rapidly changing economic environments.However, shortages of highly qualified specialists, insufficient practical skills, and limited entrepreneurial competencies can negatively affect business performance.

The rapid pace of technological change requires continuous workforce development and lifelong learning. Enterprises must invest in employee training and skill development to remain competitive in dynamic market conditions.

Regional development disparities. Entrepreneurial development in Azerbaijan is concentrated primarily in major urban centers, particularly Baku. Regional disparities in infrastructure, access to finance, technological resources, and market opportunities create unequal conditions for business development. Reducing these disparities through targeted regional development programs can contribute to strengthening the economic security of entrepreneurial entities across the country.

3.5. Digital transformation and cybersecurity challenges. The expansion of digital technologies has created both opportunities and risks for entrepreneurial entities. Digital transformation enhances productivity, improves customer service, facilitates market access, and supports innovation. However, it also increases exposure to cybersecurity threats.

Cyberattacks, data breaches, ransomware incidents, and unauthorized access to commercial information can cause significant financial and reputational damage. As enterprises increasingly rely on digital systems, ensuring information security has become a critical component of economic security.

The protection of commercial data, intellectual property, customer information, and digital infrastructure requires comprehensive cybersecurity strategies. Businesses must implement modern security technologies, employee awareness programs, and risk management systems to minimize cyber threats.

In Azerbaijan, ongoing digitalization initiatives have increased the importance of cybersecurity at both national and enterprise levels. Strengthening digital resilience is essential for ensuring sustainable entrepreneurial development in the digital economy.

State support mechanisms for strengthening economic security. Government policies play a decisive role in creating favorable conditions for entrepreneurial development and economic security. Effective state support mechanisms can reduce risks, stimulate investment, and encourage innovation.

One important direction is the expansion of financial support programs for SMEs. OECD (2023, pp. 198–205) reports that government-backed loan guarantees, subsidized credit programs, and targeted financial assistance mechanisms significantly improve SME resilience and investment capacity. Preferential loans, guarantee funds, subsidized financing, and investment incentives can improve access to capital and strengthen financial stability. Tax incentives represent another effective instrument for supporting entrepreneurship. Reduced tax burdens can increase business profitability and encourage investment in innovation and modernization. The development of innovation infrastructure, including technology parks, business incubators, innovation centers, and research institutions, contributes to enhancing technological capabilities and competitiveness. Such institutions facilitate knowledge transfer and support innovative entrepreneurship. According to the World Bank (2024, pp. 143–150), innovation ecosystems supported by technology parks, incubators, and research institutions contribute substantially to entrepreneurial productivity and economic diversification.

Furthermore, improving the legal and regulatory environment is essential for ensuring economic security. Transparent regulations, protection of property rights, effective dispute resolution mechanisms, and anti-corruption measures contribute to creating a predictable business environment.

Investment in education and human capital development also plays a crucial role. By improving workforce qualifications and entrepreneurial competencies, Azerbaijan can strengthen the long-term sustainability and competitiveness of its business sector.

Conclusion

Ensuring the economic security of entrepreneurial subjects has become a strategic priority for sustainable economic development in Azerbaijan. Economic security encompasses a broad range of financial, legal, technological, informational, and organizational factors that influence the stability and competitiveness of enterprises.

Entrepreneurial entities in Azerbaijan face numerous challenges, including financial constraints, market uncertainties, innovation limitations, human capital shortages, institutional barriers, and cybersecurity risks. These challenges are particularly significant for small and medium-sized enterprises, which play a vital role in economic diversification and employment generation.

The effective management of economic security requires an integrated approach combining enterprise-level risk management practices with supportive government policies. Strengthening innovation

capacity, improving access to finance, enhancing legal protections, promoting digital security, and investing in human capital are essential measures for increasing the resilience of entrepreneurial entities.

The successful implementation of these measures will contribute not only to the sustainable development of entrepreneurship but also to the enhancement of national economic competitiveness, investment attractiveness, and long-term macroeconomic stability in Azerbaijan.

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FINANCIAL PERFORMANCE AND RESILIENCE OF MEDCO S.A.L. AMID LEBANON'S ECONOMIC CRISIS: A FINANCIAL EVALUATION (2023–2024)

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ABSTRACT

The petroleum distribution sector plays a strategic role in maintaining economic stability, particularly in countries experiencing prolonged economic and political crises. Lebanon has witnessed one of the most severe financial collapses in modern history, accompanied by exchange rate volatility, inflationary pressures, supply chain disruptions, and geopolitical instability. Despite these adverse conditions, several firms have continued operating while maintaining financial sustainability. This study investigates the financial performance and resilience of MEDCO, one of Lebanon's leading petroleum distribution companies, during the period 2023–2024.

A quantitative case-study design was adopted using audited financial statements as the primary source of secondary data. Financial performance was evaluated through intermediate management balances (Soldes Intermédiaires de Gestion), balance sheet analysis, liquidity ratios, solvency indicators, leverage measures, and financial autonomy ratios. Comparative financial analysis was conducted to identify structural changes between the two fiscal years.

The findings reveal that MEDCO maintained positive profitability despite the economic crisis and the geopolitical tensions experienced during 2024. Commercial margins, value added, and net income increased substantially, reflecting the company's operational resilience. However, the analysis also indicates structural weaknesses, particularly the excessive dependence on shareholders' current accounts as a major financing source and the persistently low financial autonomy ratio. Although liquidity and solvency indicators remained considerably above acceptable benchmarks, the capital structure reflects a high concentration of external financing that may threaten long-term financial sustainability.

This study contributes to the literature on corporate financial resilience in emerging economies by providing empirical evidence from Lebanon's petroleum sector, an area that has received limited scholarly attention. The findings offer practical implications for corporate managers, investors, and policymakers seeking to strengthen financial sustainability under conditions of prolonged economic uncertainty.

Keywords: Financial Performance; Financial Resilience; Petroleum Industry; Financial Statement Analysis; Liquidity; Solvency; Lebanon; MEDCO.

Introduction

Corporate financial performance has become one of the most widely investigated topics in accounting and financial management because it reflects an organization's ability to generate value, maintain liquidity, preserve solvency, and ensure long-term sustainability (Cohen, 2006). Financial statement analysis provides decision-makers with essential information regarding profitability, operational efficiency, financial stability, and investment capacity (Stolowy, Ding, & Langlois, 2018). Consequently, financial performance evaluation has become a fundamental instrument for managers, investors, creditors, regulators, and policymakers seeking to assess corporate resilience under uncertain economic conditions.

In recent years, firms operating in emerging economies have encountered unprecedented economic challenges. Inflation, exchange-rate volatility, geopolitical conflicts, disruptions in global supply chains, and declining purchasing power have substantially affected corporate performance across multiple sectors. Among these sectors, petroleum distribution occupies a particularly strategic position because it directly influences transportation, industrial production, electricity generation, logistics, and the continuity of essential public services (Administration, 2024). Lebanon's fuel market is served by a limited number of major distributors, including MEDCO, TotalEnergies Marketing Lebanon, Coral Oil Company, and Independent Petroleum Group, operating within a largely oligopolistic structure (Lebanon, 2024). Maintaining the operational and financial stability of petroleum distributors therefore extends beyond corporate profitability to encompass broader economic resilience.

Lebanon represents a particularly significant context for investigating corporate financial resilience. Since 2019, the country has experienced one of the deepest economic crises in its modern history, characterized by banking sector collapse, sovereign debt default, severe currency depreciation, hyperinflation, and declining economic activity (tresor, 2024). These structural challenges have also been linked to the heavy dependence of importers and political actors on the oil trade (Jour, 2024). These structural challenges intensified during 2024 due to escalating geopolitical tensions and military conflict, creating additional uncertainty for businesses operating within the Lebanese market. Despite this unfavorable environment, several companies have continued to operate successfully by adapting their financial strategies, restructuring operational activities, and maintaining adequate liquidity.

Within this context, MEDCO constitutes an appropriate case for examining financial resilience. As one of Lebanon's largest petroleum distribution companies, MEDCO operates an extensive network of service stations and provides fuel products and energy-related services across the country (Company, 2025) .The company was founded and is led by the prominent Lebanese entrepreneur Maroun N. Chammas (Berytech, 2024). The company's strategic position within the Lebanese petroleum market offers an opportunity to investigate how financial management practices contribute to organizational resilience during periods of severe economic disruption.

Although financial performance analysis has received considerable attention in developed economies, empirical evidence concerning petroleum distribution companies operating in fragile and crisis-affected economies remains limited. Most existing studies focus either on large international oil corporations (K.S.C.P, 2024)or on macroeconomic analyses of the energy sector, while relatively little attention has been devoted to company-level financial resilience within developing countries. This gap is particularly evident in Lebanon, where academic research examining the financial sustainability of petroleum distributors remains scarce.

Accordingly, this study seeks to evaluate MEDCO's financial performance during the 2023–2024 period through a comprehensive financial statement analysis, following established quantitative case-study research procedures (R & Van Campenhout, 2017). The research employs intermediate management balances, balance sheet analysis, liquidity indicators, solvency measures, leverage ratios, and financial autonomy indicators to assess the company's financial condition and identify the principal factors underlying its resilience.

Unlike previous studies that primarily emphasize profitability, this research adopts a multidimensional perspective by simultaneously examining profitability, liquidity, solvency, capital structure, and financial sustainability. Such an integrated approach provides a more comprehensive understanding of

how firms operating in crisis environments preserve operational continuity while facing severe macroeconomic and geopolitical pressures.

The findings are expected to contribute to both financial management literature and corporate practice by providing empirical evidence regarding financial resilience in emerging economies. Furthermore, the study offers practical recommendations for strengthening corporate financial sustainability in petroleum distribution companies operating under prolonged economic uncertainty.

Research Questions

Based on the research problem, this study addresses the following research questions:

RQ1. How did MEDCO's financial performance evolve during the period 2023–2024 despite the economic and geopolitical crisis in Lebanon?

RQ2. To what extent did MEDCO maintain financial equilibrium between its assets and liabilities during the study period?

RQ3. Do liquidity, solvency, leverage, and financial autonomy indicators provide evidence of corporate financial resilience under crisis conditions?

Research Objectives

This study aims to:

- Evaluate MEDCO's financial performance using comprehensive financial statement analysis.
- Assess the company's profitability, liquidity, solvency, and financial autonomy.
- Examine the effectiveness of MEDCO's financial management strategy during the Lebanese economic crisis.
- Identify strengths and weaknesses in the company's financial structure.
- Provide practical recommendations to improve long-term financial sustainability.

Literature Review

Financial Performance Evaluation

Financial performance evaluation is a fundamental component of corporate financial management, providing decision-makers with objective evidence regarding an organization's profitability, operational efficiency, liquidity, solvency, and long-term sustainability. It enables managers, investors, creditors, and policymakers to assess whether a company is effectively utilizing its financial resources to achieve strategic objectives while maintaining an appropriate balance between risk and return.

Financial performance is generally defined as an organization's ability to generate sustainable earnings while efficiently managing its assets, liabilities, and capital structure (Brigham & Ehrhardt, 2023). Beyond profitability, modern financial analysis considers multiple dimensions of performance, including cash flow adequacy, financial flexibility, operational efficiency, and resilience to external shocks.

According to Vernimmen et al. (2024), financial statement analysis serves as the primary mechanism for evaluating corporate performance because accounting statements summarize the economic consequences of managerial decisions. Balance sheets provide information regarding financial position, whereas income statements reveal operational performance over a specified accounting period. Together, these statements enable analysts to identify financial strengths, structural weaknesses, and emerging risks.

In recent years, the concept of financial performance has evolved considerably. Traditional approaches focused primarily on accounting profitability indicators such as return on assets (ROA), return on equity (ROE), and net profit margin. Contemporary research, however, increasingly emphasizes corporate

resilience, financial sustainability, liquidity management, and capital structure optimization as equally important dimensions of long-term organizational success.

Financial Statement Analysis

Financial statement analysis represents one of the most widely used techniques for evaluating corporate financial health. It involves the systematic examination of accounting information to identify relationships among financial variables and evaluate an organization's economic performance.

Three major analytical approaches dominate financial statement analysis:

- Horizontal analysis, which evaluates changes across different accounting periods.
- Vertical analysis, which examines the relative importance of each financial statement component.
- Ratio analysis, which assesses relationships among accounting variables.

These analytical techniques enable stakeholders to evaluate profitability, operational efficiency, liquidity, leverage, and financial stability.

Intermediate Management Balances (Soldes Intermédiaires de Gestion—SIG) constitute another important analytical framework, particularly within French accounting systems. SIG decomposes corporate earnings into successive performance indicators, including commercial margin, value added, gross operating surplus, operating income, recurring income before tax, and net income. This approach provides a comprehensive understanding of value creation throughout the production and distribution process.

The present study adopts this analytical framework because MEDCO prepares its financial statements according to accounting practices commonly used in Lebanon and influenced by the French accounting tradition. The original financial statements for the fiscal years 2023 and 2024 constitute the primary source of empirical evidence.

Liquidity and Corporate Financial Stability

Liquidity reflects an organization's ability to meet short-term financial obligations as they become due. Adequate liquidity enables firms to maintain operational continuity, preserve supplier relationships, and avoid financial distress during periods of economic uncertainty.

Liquidity is commonly evaluated using three principal indicators:

- Current Ratio
- Quick Ratio
- Cash Ratio

Although high liquidity generally indicates financial security, excessively high liquidity may also suggest inefficient resource allocation. Idle cash balances reduce investment opportunities and may lower shareholder value if available resources are not allocated toward productive investments.

During periods of macroeconomic instability, firms frequently increase precautionary cash holdings to mitigate uncertainty. Consequently, unusually high liquidity ratios may represent strategic financial behavior rather than operational inefficiency.

Solvency and Capital Structure

Unlike liquidity, which focuses on short-term obligations, solvency evaluates a firm's long-term financial viability and its capacity to satisfy all liabilities through existing assets.

Corporate solvency depends largely on capital structure decisions. According to corporate finance theory, firms must determine an optimal combination of equity and debt financing that minimizes financing costs while maintaining financial flexibility.

Excessive leverage increases financial risk, particularly during economic crises when revenues become volatile and borrowing costs rise. Conversely, insufficient leverage may indicate underutilization of financial opportunities.

Financial autonomy, measured by the proportion of shareholders' equity relative to total liabilities, represents another important indicator of financial independence. Companies exhibiting higher financial autonomy generally possess greater resilience during periods of market instability because they depend less on external financing.

The original financial analysis of MEDCO shows that although liquidity and solvency indicators improved between 2023 and 2024, financial autonomy remained considerably below internationally accepted benchmarks due to the company's substantial dependence on shareholders' current accounts.

Corporate Financial Resilience

Corporate resilience refers to an organization's ability to anticipate, absorb, adapt to, and recover from adverse economic events while maintaining operational continuity.

Recent financial literature increasingly recognizes resilience as a multidimensional concept incorporating financial flexibility, strategic adaptability, operational efficiency, and organizational learning.

During financial crises, resilient firms typically demonstrate several characteristics:

- strong liquidity reserves;
- diversified financing sources;
- conservative debt management;
- effective risk management;
- adaptive strategic decision-making.

Rather than merely surviving economic shocks, resilient organizations frequently emerge stronger by reallocating resources efficiently and exploiting new market opportunities.

In emerging economies experiencing prolonged instability, financial resilience becomes particularly important because firms must simultaneously confront inflation, exchange-rate volatility, political uncertainty, and supply-chain disruptions.

Petroleum Distribution Industry in Emerging Economies

Petroleum distribution companies occupy a strategic position within national economies because they ensure the continuous supply of fuel required for transportation, manufacturing, healthcare, agriculture, and electricity generation.

Unlike many other industries, petroleum distributors operate under multiple sources of uncertainty:

- fluctuations in international crude oil prices;
- exchange-rate volatility;
- government pricing policies;
- geopolitical conflicts;
- transportation disruptions;
- inventory management risks.

These challenges are particularly severe in fragile economies such as Lebanon, where macroeconomic instability significantly affects working capital management and financing decisions.

Despite the strategic importance of the petroleum sector, empirical studies investigating company-level financial resilience remain relatively limited, particularly within Middle Eastern developing economies.

Previous Studies

Previous international studies generally indicate that financial resilience depends upon maintaining an appropriate balance among profitability, liquidity, leverage, and operational efficiency.

Several researchers have concluded that firms possessing diversified financing structures and stronger equity positions demonstrate superior performance during economic crises.

Other studies emphasize that liquidity alone cannot guarantee financial sustainability if capital structures remain excessively dependent upon external borrowing.

Research conducted in emerging economies further demonstrates that geopolitical instability increases financing costs while reducing investment opportunities, thereby reinforcing the importance of prudent financial management.

However, most previous studies concentrate either on multinational oil corporations or on macroeconomic analyses of the energy sector. Relatively few investigations examine financial resilience at the company level within crisis-affected economies such as Lebanon.

Research Gap

The existing literature reveals three important research gaps.

First, relatively few empirical studies examine corporate financial resilience within petroleum distribution companies operating in fragile economies affected simultaneously by financial collapse and geopolitical instability.

Second, previous research has generally focused on profitability or liquidity independently rather than adopting an integrated framework combining profitability, liquidity, solvency, leverage, and financial autonomy.

Third, despite Lebanon's unprecedented economic crisis, limited academic evidence exists concerning how major petroleum distributors have adapted their financial strategies to maintain operational continuity.

Accordingly, this study addresses these gaps by conducting a comprehensive financial evaluation of MEDCO using multiple financial analysis techniques within the context of Lebanon's economic and geopolitical crisis during 2023–2024.

Theoretical Framework

This study is grounded in four complementary theoretical perspectives:

1. **Financial Statement Analysis Theory**, which provides the analytical foundation for evaluating corporate financial performance through accounting information.

2. **Capital Structure Theory**, explaining how financing decisions influence financial sustainability and organizational value.

3. **Corporate Financial Resilience Theory**, emphasizing organizations' capacity to withstand and recover from economic shocks.

4. **Stakeholder Theory**, recognizing that sustainable financial performance benefits shareholders, creditors, employees, customers, governments, and society simultaneously.

2. 3. Hypotheses Development

The unprecedented economic collapse in Lebanon has substantially altered the financial environment in which firms operate. Exchange rate volatility, inflationary pressures, supply chain disruptions, and geopolitical instability have increased financial uncertainty and challenged companies' ability to maintain sustainable performance. Within this context, financial statement analysis provides an appropriate framework for evaluating organizational resilience through profitability, financial equilibrium, liquidity, solvency, and capital structure indicators.

Previous empirical research suggests that firms characterized by sound financial management practices generally exhibit greater resilience during periods of economic crisis. Nevertheless, the relationship between financial performance and financial resilience remains highly dependent on sector-specific characteristics, financing strategies, and the macroeconomic environment.

Based on the theoretical framework and the objectives of this study, three research hypotheses are formulated.

Hypothesis 1

H1: MEDCO maintained positive financial performance during 2023–2024 despite the economic and geopolitical crisis in Lebanon.

This hypothesis is evaluated using Intermediate Management Balances (SIG), operating income, and net income.

Hypothesis 2

H2: MEDCO maintained overall financial equilibrium between its assets and liabilities during the study period.

This hypothesis is tested through balance sheet analysis and financial structure indicators.

Hypothesis 3

H3: MEDCO's liquidity and solvency remained satisfactory during the study period; however, its financial autonomy remained structurally weak because of its dependence on shareholder financing.

Unlike the original dissertation, which treated financial health as a binary concept, this article recognizes that financial resilience is multidimensional. A company may simultaneously exhibit excellent liquidity while maintaining an inefficient capital structure. Therefore, the third hypothesis evaluates financial resilience across multiple dimensions rather than relying on a single financial indicator.

Research Methodology

Research Design

This study adopts a quantitative explanatory case study design to investigate the financial resilience of MEDCO under conditions of severe economic and geopolitical instability.

The case study approach is appropriate because it enables an in-depth examination of organizational financial behavior within its real-life context. Unlike large-sample statistical studies, case studies facilitate comprehensive analysis of financial decision-making under exceptional economic circumstances.

The research follows a positivist paradigm, where objectively measured accounting data constitute the principal source of empirical evidence.

Research Approach

The study employs a deductive research approach.

Initially, theoretical concepts concerning financial performance, liquidity, solvency, capital structure, and corporate resilience were identified through the literature. These theoretical concepts were subsequently examined using MEDCO's financial statements for fiscal years 2023 and 2024.

The deductive approach allows theoretical assumptions to be tested against observed financial evidence.

Case Selection

MEDCO was selected for three principal reasons.

First, the company represents one of the largest petroleum distributors operating within Lebanon.

Second, the company continued operating despite one of the country's most severe economic crises.

Third, access to complete financial statements enabled comprehensive financial analysis covering both profitability and financial position.

Consequently, MEDCO constitutes an appropriate case for examining corporate financial resilience within an emerging economy experiencing prolonged instability.

Data Collection

The study relies exclusively on secondary data.

The principal source of information consists of MEDCO's audited financial statements covering fiscal years 2023 and 2024, including:

- Income Statements;
- Balance Sheets;
- Accounting Notes;
- Financial Reports.

These documents were obtained directly from the company's accounting records and constitute the empirical basis for all financial calculations performed in this study.

Secondary sources also include academic literature on financial analysis, corporate finance, petroleum economics, and financial resilience to provide the theoretical foundation for interpreting the findings.

Variables of the Study

The research evaluates four principal dimensions of financial performance.

Dependent Variable

Corporate Financial Performance

Measured through:

- Net Income
- Operating Income
- Gross Operating Surplus (EBE)
- Commercial Margin
- Value Added

Independent Variables

Financial performance is examined using four groups of financial indicators.

Profitability Indicators

- Commercial Margin
- Value Added
- Operating Income
- Net Profit

Liquidity Indicators

- Current Ratio
- Quick Ratio
- Cash Ratio

Solvency Indicators

- Solvency Ratio

Capital Structure Indicators

- Financial Autonomy
- Debt Capacity

Financial Analysis Techniques

Several complementary analytical techniques were employed.

Intermediate Management Balances (SIG)

This framework decomposes value creation into sequential performance stages:

- Commercial Margin;
- Value Added;
- Gross Operating Surplus;
- Operating Income;
- Profit Before Tax;
- Net Income.

These indicators provide detailed insights into operational efficiency and profitability.

Balance Sheet Analysis

Financial position was evaluated through comparison of assets, liabilities, equity, and financing sources.

Particular attention was given to changes in:

- Working Capital;
- Financing Structure;
- Financial Stability;
- Equity Growth.

Ratio Analysis

Ratio analysis constitutes the principal quantitative method adopted in this study.

Six financial ratios were calculated.

Category	Indicator
Liquidity	Current Ratio
Liquidity	Quick Ratio
Liquidity	Cash Ratio
Solvency	Solvency Ratio
Capital Structure	Financial Autonomy
Capital Structure	Debt Capacity

The values obtained for each ratio were compared across the two accounting periods and interpreted using internationally accepted financial benchmarks.

2.1. 4.7 Data Analysis Procedure

The empirical analysis followed five consecutive stages.

Stage 1

Extraction of accounting information from the financial statements.

Stage 2

Calculation of Intermediate Management Balances.

Stage 3

Preparation of comparative balance sheet analysis.

Stage 4

Calculation of financial ratios.

Stage 5

Interpretation of financial performance using both quantitative evidence and theoretical perspectives.

This structured analytical procedure ensures consistency and improves the reliability of the financial evaluation.

Reliability and Validity

Because the study relies on audited financial statements rather than survey instruments, traditional measures of internal consistency (e.g., Cronbach's Alpha) are not applicable.

Reliability was enhanced by using official accounting documents and standardized financial formulas that are widely accepted in accounting and corporate finance literature.

Validity was strengthened through methodological triangulation by combining:

- Intermediate Management Balances;
- Financial Statement Analysis;
- Balance Sheet Analysis;
- Ratio Analysis.

The integration of multiple analytical approaches reduces measurement bias and improves the robustness of the study's conclusions.

Results

Financial Performance Analysis

The financial performance of MEDCO was evaluated using Intermediate Management Balances (Soldes Intermédiaires de Gestion—SIG), which provide a comprehensive assessment of value creation throughout the company's operating cycle. Comparative analysis between fiscal years 2023 and 2024 reveals substantial improvements across most financial performance indicators despite Lebanon's continued economic crisis and the geopolitical instability experienced during 2024.

Table 1

Intermediate Management Balances (2023–2024)

Indicator	2023 (LBP)	2024 (LBP)	Growth (%)
Commercial Margin	812,859,732	3,379,932,725	+315.8
Production of the Period	75,600,000	457,446,525	+505.1
Value Added	521,509,732	2,085,305,594	+299.9
Gross Operating Surplus (EBE)	301,243,732	338,247,135	+12.3
Operating Income	356,922,232	482,406,920	+35.2
Profit Before Tax	369,600,074	505,902,929	+36.9
Net Income	306,752,518	419,314,384	+36.7

Source: Calculated by the authors from MEDCO financial statements (2023–2024).

Commercial Margin

The commercial margin increased from **LBP 812.9 million** in 2023 to **LBP 3.38 billion** in 2024, representing an increase of more than **315%**.

This remarkable improvement reflects the significant expansion of MEDCO's commercial activity. Higher sales volumes, together with adjustments in fuel prices resulting from exchange-rate fluctuations, substantially increased commercial profitability.

Value Added

Value added increased almost fourfold during the study period, rising from **LBP 521.5 million** to **LBP 2.09 billion**.

This finding indicates that MEDCO generated considerably greater economic value through its core business activities despite operating within an unstable macroeconomic environment.

Gross Operating Surplus

Although commercial activity expanded dramatically, Gross Operating Surplus (EBE) increased by only **12.3%**.

The relatively modest growth in EBE suggests that the benefits generated through higher revenues were partially offset by substantial increases in operating expenses, particularly employee compensation and external service costs.

Operating Income

Operating income increased from **LBP 356.9 million** to **LBP 482.4 million**, corresponding to annual growth exceeding **35%**.

This improvement demonstrates MEDCO's ability to preserve operational profitability despite increasing production costs and economic uncertainty.

Net Income

Net income rose from **LBP 306.8 million** in 2023 to **LBP 419.3 million** in 2024.

The increase of approximately **37%** confirms that MEDCO successfully maintained profitability throughout the study period despite one of the most challenging economic environments experienced by Lebanese firms in recent decades.

Balance Sheet Analysis

Balance sheet analysis was conducted to evaluate changes in MEDCO's financial position between 2023 and 2024.

Table 2

Summary of Financial Position

Item	2023 (LBP)	2024 (LBP)
Total Assets	4.16 Billion	8.85 Billion
Equity	312 Million	731 Million
Long-term Debt	2.86 Billion	7.70 Billion
Cash and Bank	570 Million	2.04 Billion

Source: Authors' calculations based on MEDCO financial statements.

The balance sheet demonstrates substantial expansion in total assets between the two accounting periods. Total assets more than doubled, reflecting the company's operational growth and increasing financial resources.

Shareholders' equity also increased because of retained earnings generated during the study period. Nevertheless, long-term liabilities expanded even more rapidly, indicating that business growth was financed primarily through shareholder current accounts rather than through additional equity capital.

Consequently, although MEDCO experienced significant financial expansion, the quality of its capital structure remained relatively weak.

Liquidity Analysis

Liquidity indicators improved considerably during the study period.

Table 3

Liquidity Ratios

Ratio	2023	2024	Recommended Benchmark
Current Ratio	4.22	20.76	1.5–2.0
Quick Ratio	0.58	10.04	1.0
Cash Ratio	0.58	4.79	0.20–0.30

Source: Authors' calculations.

All liquidity indicators improved substantially.

The Current Ratio increased almost fivefold, indicating that current assets greatly exceeded short-term liabilities.

Similarly, both the Quick Ratio and Cash Ratio reached exceptionally high values during 2024, suggesting that MEDCO possessed abundant liquid resources capable of covering all short-term financial obligations.

While these findings demonstrate excellent short-term financial stability, they may also indicate inefficient utilization of available financial resources because excessive cash holdings often reduce investment efficiency.

Solvency Analysis

Table 4

Solvency Indicators

Indicator	2023	2024
Solvency Ratio	1.08	1.09

Source: Authors' calculations.

MEDCO remained technically solvent throughout the study period.

Total assets exceeded total liabilities in both years, indicating that the company possessed sufficient assets to satisfy its financial obligations.

Nevertheless, the margin of safety remained relatively narrow, suggesting that significant asset depreciation could negatively affect long-term financial stability.

Capital Structure Analysis

Table 5

Capital Structure Indicators

Ratio	2023	2024
Financial Autonomy	0.08	0.09
Debt Capacity	0.10	0.09

Source: Authors' calculations.

Unlike profitability and liquidity indicators, capital structure indicators exhibited only marginal improvement.

Financial autonomy remained significantly below internationally accepted standards, indicating substantial dependence on external financing through shareholders' current accounts.

Similarly, debt capacity deteriorated slightly between 2023 and 2024, implying limited capacity to secure additional external financing without restructuring the company's equity base.

Summary of Empirical Findings

The empirical analysis demonstrates four principal findings.

First, MEDCO successfully maintained positive financial performance despite operating under severe economic and geopolitical uncertainty.

Second, liquidity indicators improved substantially, providing the company with considerable short-term financial flexibility.

Third, solvency remained above the minimum acceptable threshold, confirming the company's ability to satisfy its financial obligations.

Finally, despite these positive developments, MEDCO continued to exhibit a structurally weak capital structure characterized by limited financial autonomy and excessive reliance on shareholder financing.

Discussion

The purpose of this study was to evaluate the financial performance and resilience of MEDCO during one of the most challenging economic periods experienced by Lebanon. The empirical findings indicate that the company demonstrated remarkable operational resilience despite the severe macroeconomic and geopolitical instability affecting the Lebanese economy during 2023–2024. However, the analysis also reveals structural financial weaknesses that may compromise long-term sustainability if left unaddressed.

Financial Performance under Crisis Conditions

One of the most significant findings of this study is the substantial improvement in MEDCO's operational performance despite the adverse business environment. Commercial margin increased by more than three hundred percent, while value added and net income also recorded considerable growth during the study period.

These results suggest that the company successfully adapted its operational strategy to rapidly changing market conditions. The petroleum distribution sector differs from many industries because fuel demand remains relatively inelastic even during economic downturns. Consequently, although purchasing power declined across Lebanon, demand for transportation fuel and industrial energy remained sufficiently stable to support revenue growth.

Furthermore, exchange-rate adjustments and revisions in domestic fuel pricing may have contributed to increased nominal revenues. While higher revenues do not necessarily imply improved operational

efficiency, the simultaneous increase in operating income and net income indicates that MEDCO was able to preserve profitability while managing rising operating costs.

These findings are consistent with previous research suggesting that firms operating within essential-service industries exhibit greater resilience during economic crises because demand remains relatively stable compared with discretionary consumer sectors.

Operational Efficiency versus Cost Escalation

Although profitability indicators improved considerably, Gross Operating Surplus (EBE) increased at a much slower pace than commercial margin and value added.

This divergence suggests that a substantial proportion of newly generated value was absorbed by higher operating expenses, particularly personnel costs and external service expenditures. Such increases are understandable given the inflationary environment prevailing in Lebanon during the study period, where wages and operating expenses rose substantially because of currency depreciation and increasing living costs.

Consequently, the findings indicate that MEDCO successfully expanded its commercial activity but faced growing pressure on operating efficiency.

From a strategic perspective, this result highlights the importance of strengthening cost management systems, productivity measurement, and operational planning to ensure that future revenue growth translates into proportional improvements in operating profitability.

Liquidity as an Indicator of Financial Resilience

Perhaps the strongest evidence of MEDCO's financial resilience lies in its liquidity position.

The current ratio increased from 4.22 to 20.76, while both the quick ratio and cash ratio reached exceptionally high levels during 2024.

Traditional financial theory generally considers high liquidity desirable because it reduces bankruptcy risk and enhances financial flexibility. However, excessively high liquidity may also indicate inefficient allocation of financial resources.

The present findings support both interpretations.

On one hand, abundant liquidity enabled MEDCO to maintain uninterrupted operations despite severe macroeconomic uncertainty.

On the other hand, the accumulation of significant cash balances may indicate underinvestment in productive assets capable of generating higher future returns.

This observation is particularly relevant in crisis environments where firms often accumulate precautionary cash reserves to reduce exposure to uncertainty.

Solvency and Long-Term Financial Stability

The solvency ratio remained slightly above one throughout the study period, indicating that MEDCO possessed sufficient assets to satisfy its financial obligations.

Although this result confirms technical solvency, the relatively narrow safety margin suggests limited tolerance for future economic shocks.

Should asset values decline or additional liabilities arise, the company's long-term financial stability could become increasingly vulnerable.

Accordingly, management should not interpret the current solvency position as evidence of complete financial security but rather as an indicator requiring continuous monitoring.

Capital Structure: The Principal Financial Weakness

Despite positive profitability and liquidity indicators, the analysis identifies capital structure as MEDCO's primary financial vulnerability.

Financial autonomy remained below 10% throughout the study period, while debt capacity deteriorated slightly between 2023 and 2024.

The principal reason for this situation is the company's extensive reliance on shareholders' current accounts as its dominant financing mechanism.

Although shareholder financing may reduce dependence on commercial borrowing and lower financing costs, excessive reliance upon this funding source creates several long-term risks.

First, financial flexibility becomes dependent upon shareholders' willingness to continue providing funds.

Second, low equity capitalization weakens the company's borrowing capacity.

Third, limited financial autonomy may reduce investor confidence and restrict future expansion opportunities.

These findings suggest that MEDCO's financial resilience is operationally strong but structurally fragile.

Contribution to Financial Resilience Theory

An important contribution of this study concerns the multidimensional nature of financial resilience.

Previous studies frequently evaluate resilience primarily through profitability or liquidity indicators.

The findings of this research demonstrate that resilience cannot be adequately assessed using a single financial dimension.

MEDCO simultaneously exhibits:

- strong profitability;
- excellent liquidity;
- acceptable solvency;
- weak capital structure.

Consequently, financial resilience should be viewed as a multidimensional construct requiring simultaneous evaluation of profitability, liquidity, solvency, and financing strategy.

This integrated perspective constitutes one of the principal theoretical contributions of the present study.

Theoretical Implications

The findings extend the literature on corporate financial resilience in several ways.

First, they demonstrate that profitability alone does not necessarily imply financial sustainability.

Second, they confirm that excessive liquidity should not automatically be interpreted as financial strength because idle financial resources may reduce investment efficiency.

Third, the study highlights the critical role of capital structure in determining long-term resilience.

Finally, the research contributes empirical evidence from Lebanon, a context that remains significantly underrepresented within international accounting and corporate finance literature.

Practical Implications

The findings provide several practical implications for corporate managers.

Managers should strengthen equity financing to improve financial autonomy and reduce dependence on shareholder current accounts.

Cash management policies should be revised to ensure that excess liquidity is invested in productive assets capable of generating sustainable returns.

Greater emphasis should also be placed on cost management, particularly employee-related expenditures, which increased substantially during the study period.

Finally, corporate governance mechanisms should be strengthened to improve transparency and facilitate access to external financing.

Conclusion

This study examined the financial performance and resilience of MEDCO, one of Lebanon's leading petroleum distribution companies, during the fiscal years 2023 and 2024. The analysis was conducted within the context of an exceptionally challenging economic environment characterized by prolonged financial collapse, high inflation, exchange-rate instability, and escalating geopolitical tensions. Using audited financial statements, the study evaluated the company's financial condition through Intermediate Management Balances (SIG), balance sheet analysis, liquidity indicators, solvency measures, and capital structure ratios.

The empirical findings indicate that MEDCO successfully preserved its operational and financial performance despite the adverse external environment. Commercial margin, value added, operating income, and net income all increased significantly between 2023 and 2024, demonstrating the company's ability to sustain profitability under conditions of severe economic uncertainty. Likewise, liquidity indicators improved substantially, providing the company with a strong capacity to meet its short-term financial obligations and maintain operational continuity.

However, the study also identified structural weaknesses in MEDCO's financial position. Although the company remained solvent throughout the study period, its capital structure was characterized by limited financial autonomy and a significant dependence on shareholder current accounts as a primary source of financing. This financing strategy enhanced short-term flexibility but simultaneously increased long-term financial vulnerability by reducing the company's independence and limiting its future borrowing capacity.

A key contribution of this research lies in demonstrating that corporate financial resilience should not be assessed solely through profitability or liquidity indicators. Rather, resilience should be understood as a multidimensional concept encompassing operational performance, liquidity management, solvency, financial autonomy, and capital structure. The MEDCO case illustrates that a company may simultaneously exhibit strong profitability and liquidity while facing structural financing challenges that may affect its long-term sustainability.

Furthermore, this study enriches the literature on financial resilience in emerging economies by providing empirical evidence from Lebanon's petroleum distribution sector, a research context that remains largely underrepresented in international accounting and finance literature. The findings therefore contribute both to academic knowledge and to managerial practice by highlighting the financial strategies that support organizational continuity during prolonged economic crises.

Managerial and Policy Recommendations

Based on the empirical findings, several recommendations are proposed to strengthen MEDCO's long-term financial sustainability and to enhance financial resilience within petroleum distribution companies operating under similar economic conditions.

Strengthening Equity Financing

The company should gradually increase its equity base through retained earnings or new capital contributions. Strengthening shareholders' equity would improve financial autonomy, reduce dependence on shareholder current accounts, and enhance financial stability.

Diversification of Financing Sources

Reliance on a single financing mechanism increases financial risk. MEDCO should diversify its funding sources by combining internal financing with long-term institutional financing and carefully managed external borrowing.

Optimizing Liquidity Management

Although maintaining high liquidity is appropriate during periods of uncertainty, excessively large cash balances may reduce investment efficiency.

The company should develop an investment policy that allocates excess liquidity toward productive projects capable of generating sustainable returns while preserving sufficient working capital.

Improving Cost Management

The relatively modest increase in Gross Operating Surplus compared with commercial margin suggests increasing operating costs.

Management should therefore strengthen:

- operational budgeting,
- cost control systems,
- productivity monitoring,
- performance measurement.

Strengthening Corporate Governance

Enhanced governance practices would improve financial transparency and facilitate access to external financing.

Greater disclosure regarding financing policies and capital allocation decisions may also strengthen investor confidence.

Financial Risk Management

Considering Lebanon's volatile economic environment, the company should develop an integrated financial risk management framework covering:

- exchange-rate risk,
- inflation risk,
- liquidity risk,
- credit risk,
- geopolitical risk.

Strategic Investment Planning

The company should prioritize investments that improve operational efficiency, including digital transformation, supply chain optimization, predictive inventory management, and energy-efficient technologies.

Such investments would enhance long-term competitiveness while reducing operating costs.

Limitations of the Study

Despite its contributions, this study has several limitations.

First, the research adopts a single-case study design focusing exclusively on MEDCO. Consequently, the findings cannot be generalized to the entire Lebanese petroleum sector without further empirical investigation.

Second, the analysis covers only two fiscal years (2023–2024). A longer observation period would provide deeper insights into the evolution of financial resilience before, during, and after periods of economic instability.

Third, the study relies exclusively on accounting-based financial indicators derived from audited financial statements. Non-financial variables such as corporate governance quality, managerial decision-making, digital transformation, organizational culture, and customer satisfaction were not examined.

Finally, because the study employs a descriptive financial analysis approach, causal relationships between financial resilience and external economic factors cannot be statistically established.

Future Research

Future studies should extend the present research in several directions.

First, comparative analyses involving multiple petroleum distribution companies operating within Lebanon or across Middle Eastern countries would improve the external validity of the findings.

Second, future research should integrate financial indicators with environmental, social, and governance (ESG) measures to examine the relationship between sustainability and corporate financial resilience.

Third, researchers may employ advanced econometric techniques, including panel data analysis, structural equation modeling (SEM), or machine learning algorithms, to identify the determinants of financial resilience under conditions of prolonged economic uncertainty.

Finally, future investigations should examine how digital transformation, artificial intelligence, financial technology (FinTech), and predictive analytics influence financial performance and strategic decision-making within the petroleum distribution industry.

Research Contribution

The originality of this study lies in four main contributions:

- It provides one of the first comprehensive financial analyses of a Lebanese petroleum distribution company during the country's unprecedented economic and geopolitical crisis.
- It adopts a multidimensional framework for assessing financial resilience by integrating profitability, liquidity, solvency, and capital structure analysis.
- It demonstrates that strong operational performance does not necessarily imply long-term financial sustainability when financial autonomy remains weak.
- It offers practical recommendations that may assist managers, investors, creditors, and policymakers in strengthening corporate resilience under conditions of persistent economic instability.

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FOREIGN OUTFLOW PRESSURE IN BORSA İSTANBUL: QUANTILE CONNECTEDNESS WITH DOMESTIC AND GLOBAL FINANCIAL RISKS

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ABSTRACT

Introduction and Purpose: Foreign portfolio flows may amplify financial vulnerability in emerging markets, particularly during periods of heightened uncertainty. However, analyses based on average relationships may conceal substantial differences across market conditions. This study examines the quantile-dependent connectedness between foreign outflow pressure in Borsa İstanbul and the VIX, Türkiye's credit default swap (CDS) premium, equity-market decline, and exchange-rate depreciation. It also identifies whether foreign outflow pressure acts primarily as a transmitter or receiver of shocks under different market regimes and over time.

Materials and Methods: The study uses weekly data covering 18 September 2020–26 June 2026. The five-variable system comprises foreign outflow pressure (FOP), constructed by reversing the sign of the M7 series; changes in the VIX and Türkiye's CDS premium; negative BIST 100 returns; and USD/TRY returns. Variable directions are aligned so that higher values represent deteriorating financial conditions. A QVAR-based quantile connectedness framework is employed at the 0.10, 0.50, and 0.90 quantiles. Full-sample estimates are complemented by dynamic connectedness measures obtained using an 80-week rolling window.

Results: Total connectedness is 61.35% at the 0.10 quantile, declines to 28.75% at the median, and rises to 68.13% at the 0.90 quantile. Thus, system-wide linkages are substantially stronger in the tails than under normal market conditions and reach their highest level in the upper-tail stress regime. The rolling-window estimates confirm that connectedness remains considerably higher in both tails throughout most of the sample, although median connectedness increases after 2025. At the 0.10 quantile, CDS is the principal net transmitter (9.73), followed by negative BIST 100 returns (4.53), whereas USD/TRY is the strongest net receiver (−9.33). At the median, CDS remains the dominant net transmitter (12.51), while FOP is the largest net receiver (−15.53). At the 0.90 quantile, USD/TRY becomes the sole and overwhelmingly dominant net transmitter (72.65). FOP records the largest negative net connectedness value (−23.15), and the USD/TRY contribution to FOP reaches 35.04 percentage points. The most pronounced dynamic shift occurs in the second half of 2023, when upper-tail connectedness rises above 90%, FOP's net-receiver position deepens, and the transmission from USD/TRY to FOP becomes dominant. The VIX does not emerge as a dominant net transmitter at any quantile. Despite its system-wide net-receiver position, the directional connectedness from FOP to negative BIST 100 returns reaches 18.72% at the 0.10 quantile, 8.87% at the median, and 16.57% at the 0.90 quantile, indicating stronger linkages in both tails. At the 0.90 quantile, the FOP-to-BIST 100 connectedness exceeds the reverse-direction connectedness of 14.06%, making FOP a net pairwise transmitter to market losses by 2.51 percentage points. Dynamic pairwise estimates show that this transmission is particularly evident between the second half of 2022 and the third quarter of 2024. Nevertheless, FOP remains a net receiver at the system-wide level across all three quantiles, with its receiver role strengthening toward the upper tail.

Discussion and Conclusion: The findings reveal pronounced asymmetry, regime dependence, and time variation in the connectedness surrounding foreign outflow pressure. CDS is the primary source of net shock transmission under lower-tail and median conditions, whereas USD/TRY assumes this role during upper-tail stress. The persistent system-wide receiver position of FOP suggests that it is largely embedded in broader financial stress. Nevertheless, its bilateral connectedness with negative BIST 100 returns demonstrates that FOP can transmit shocks to equity-market losses during specific upper-tail

periods. For BIST investors and portfolio managers, the stronger FOP-to-market-loss connectedness in both tails indicates that foreign outflow pressure provides relevant information for assessing market-loss exposure and should be incorporated into tail-sensitive risk monitoring and portfolio stress testing alongside CDS and USD/TRY. From a policy perspective, the results support a regime- and time-sensitive surveillance framework: CDS should be closely monitored as an early-warning indicator under lower-tail and median conditions, while USD/TRY dynamics require priority during severe stress episodes. Policy responses focusing solely on foreign investor flows may be insufficient unless the underlying CDS- and exchange-rate-related pressures are also addressed. The strong and time-varying tail connectedness further highlights the importance of tail-sensitive stress testing and coordination among monetary, fiscal, and capital-market authorities. Nevertheless, FOP should be interpreted as a risk-monitoring indicator rather than a stand-alone causal or trading signal.

Keywords: Foreign Outflow Pressure; Borsa İstanbul; QVAR; CDS; Exchange Rate; VIX.

INTRODUCTION

International portfolio flows, which have gained momentum with financial liberalisation, have become an important source of increased liquidity, a broader investor base, and improved price discovery, particularly in emerging markets. However, the ease with which portfolio investments can be rapidly reallocated also makes foreign investor behaviour an important component of financial vulnerability. A deterioration in global risk sentiment, an increase in country risk, depreciation of the local currency, or a sharp decline in the equity market may prompt foreign investors to reduce their positions. The effects of foreign outflows on market prices and risk indicators may amplify the initial shock and propagate it across different components of the financial system. Foreign investor behaviour should therefore be examined not only in terms of the determinants of capital inflows and outflows but also in terms of its position within the financial risk network.

The international literature demonstrates that both global and host-country-specific factors influence foreign portfolio flows. Examining daily international portfolio flows to 44 countries, Froot et al. (2001) show that these flows exhibit a high degree of persistence, respond to past returns, and contain information about future returns in emerging markets. Richards (2005), in turn, finds that foreign investors engage in positive-feedback trading following both local and global market returns across six Asian markets and that the price impact of foreign trading is stronger than previously estimated. Forbes and Warnock (2012) demonstrate that global risk conditions are particularly important in explaining extreme capital flow episodes and that foreign-driven sudden stops cannot be explained solely by domestic indicators. Using a quantile-based analysis of 51 emerging economies, Wang and Yan (2022) show that global risk aversion and regional contagion affect different parts of the distribution of foreign capital flows. These findings indicate that the same mechanisms that drive foreign portfolio movements under normal and extreme market conditions do not operate.

Studies focusing on Türkiye have not reached a consensus on the direction of the relationship between foreign investor trading and market returns. Using monthly data for 1997–2009, Okuyan and Erbaykal (2011) identify a positive long-run relationship between foreign trading volume and stock returns but find no significant short-run relationship. Based on daily data, İskenderoğlu and Karadeniz (2011) find a unidirectional relationship running from İMKB 100 (now BIST 100) returns to the market value of foreign portfolio investments. This finding suggests that during certain periods, foreign investors respond to prevailing market performance rather than drive it. By contrast, Avcı (2015), accounting for structural breaks, identifies a unidirectional relationship from foreign investor trading to BIST returns. Using weekly data for 2006–2023, Güryel and Kula (2023) document bidirectional Granger causality between the stock of equities held by foreign investors and BIST 100 returns. Examining the effects of foreign trading on average stock market volatility, Umutlu et al. (2013) use foreign equity purchases and sales to show that net foreign flows are positively associated with average total volatility in Borsa İstanbul and that this relationship operates through both market-wide and firm-specific volatility channels. Kılıç et al. (2020) find significant short-run relationships, extending up to three months, between sudden changes in foreign ownership ratios and returns, volatility, and liquidity in BIST-listed real estate investment trusts. However, they conclude that the investor-base broadening hypothesis does

not hold in the long run. Coşkun et al. (2023), using a Bayesian VAR model that distinguishes investors by identity and nationality, find that, toward the later stages of the sample period, approximately 31% of the variation in the BIST 100 is explained by foreign investment trusts and mutual funds classified within the other group. Collectively, these studies demonstrate that foreign investor behaviour should be evaluated not only in terms of the volume of capital involved but also through its effects on price discovery, volatility, and liquidity.

The nonlinear characteristics of foreign investor behaviour in Türkiye have also been documented in several studies. Saraç et al. (2016) find that foreign investors' risk appetite exhibits nonlinearity and a threshold effect: it is predictable when declining but not when rising. Balat (2020) identifies a long-run relationship between the BIST 100 and the risk appetite of both domestic and foreign investors, with causality running from the BIST 100 to the risk appetite of both investor groups. Using a time-varying asymmetric causality approach, Uysal (2020) detects causality running from negative shocks in the BIST 100 and Participation 30 indices to foreign portfolio investment. These findings suggest that foreign investor behaviour differs particularly under adverse market conditions and that mean-based models may not fully capture this asymmetry. Other studies have highlighted the importance of the exchange rate and sovereign risk in shaping foreign investor behaviour. Investigating the determinants of foreign portfolio investment, Mirgen (2025) finds that the exchange rate has a negative effect on foreign portfolio investment, whereas the BIST 100, Nasdaq 100, and FTSE 100 indices exert positive effects. Arık (2025) examines the relationships between foreign portfolio investment and the CDS premium, the US dollar exchange rate, and the interest rate, showing that the CDS premium and interest rate help explain foreign portfolio returns and that foreign portfolio investment responds negatively in the short run to shocks in the CDS premium and the US dollar exchange rate. Bakır Erdem et al. (2025) analyse foreign ownership ratios among firms included in the BIST 30, BIST 50, and BIST 100 indices and find that foreign ownership responds to movements in the exchange rate, the CDS premium, and the stock market index, with the CDS premium emerging as a more dominant explanatory factor among BIST 100 firms. By contrast, Köycü and Ege (2023) identify bidirectional causality between the number of foreign investors and the BIST, but find no causal relationship between the number of foreign investors and the USD/TRY exchange rate. These studies indicate that the choice of foreign investor indicator, data frequency, sample period, and econometric methodology may play a decisive role in shaping the results.

Several studies have also examined foreign investor behaviour in the Turkish equity market across different market conditions. Using a structural VAR model for the Istanbul Stock Exchange, Ülkü and İkizlerli (2012) find that foreign investors engage in negative feedback trading in response to past domestic returns during bull markets, particularly during periods of macroeconomic instability. They also conclude that net foreign flows predict future market returns and that the price impact of these flows is persistent. These findings suggest that foreign investors should not be treated as a homogeneous group that follows the same trading strategy under all market conditions. In another study, İkizlerli and Ülkü (2012) show that changes in political risk affect both stock returns and net foreign flows and that foreign investors respond more rapidly to deteriorations in political risk than to improvements. Foreign investors' responses to risk indicators may therefore be asymmetric not only in magnitude but also according to the direction of the shock. Accordingly, market conditions must be taken into account when examining the interaction of foreign investor behaviour with domestic and global risks.

Most of the studies reviewed in the literature examine mean, long-run, or causal relationships between BIST returns and foreign investors' trading volume, portfolio value, number of investors, ownership ratio, or risk appetite. Although asymmetric and quantile-based studies indicate that these relationships may vary across market conditions, quantile connectedness studies that incorporate foreign outflow pressure, global risk, sovereign risk, adverse price movements in the BIST, and exchange-rate pressure within a unified system remain limited. Moreover, existing studies focus primarily on whether foreign investor activity affects the BIST or whether BIST movements drive foreign investors, while the question of whether foreign outflow pressure acts as a net transmitter or a net receiver of shocks within the system under different market regimes remains insufficiently addressed. Motivated by this gap, the present study examines the quantile connectedness between foreign outflow pressure in Borsa İstanbul and global and domestic financial risk indicators. To represent foreign investor behaviour, the sign of

the M7 series is reversed to construct the FOP indicator. In addition to FOP, the analysis includes changes in the VIX, changes in Türkiye's CDS premium, negative BIST 100 returns, and USD/TRY returns. The variables are aligned so that higher values indicate greater financial stress. A QVAR-based connectedness analysis is applied at the 0.10, 0.50, and 0.90 quantiles to compare total, directional, and net connectedness structures under low, normal, and high financial stress conditions.

The study is expected to make three main contributions to the literature. First, rather than relying on the stock of foreign portfolio holdings or the foreign ownership ratio, it focuses on the FOP indicator, which is constructed to capture foreign selling pressure directly. Second, FOP is examined jointly with global risk, sovereign risk, adverse price movements in the BIST 100, and exchange-rate pressure within a fully endogenous connectedness system. Third, the study determines whether the role of foreign outflow pressure as a net transmitter or receiver of shocks varies across market regimes. Accordingly, rather than asserting structural causality among the variables, the study seeks to identify directional dependence and relative shock-transmission roles under different market conditions. The following section describes the dataset and the QVAR-based quantile connectedness methodology, after which the empirical findings are presented. The study concludes with the conclusion section.

DATA AND METHODOLOGY

Data

This study examines the connectedness between foreign investors' net trading activity in Borsa İstanbul and global risk sentiment, Türkiye's sovereign risk, equity market losses, and exchange-rate pressure using weekly data. The common sample period spans 18 September 2020 to 26 June 2026, with the starting date determined by data availability. The first observation of the M7 series in the Central Bank of the Republic of Türkiye's Electronic Data Delivery System (CBRT EVDS) is dated 11 September 2020. Following the weekly logarithmic-change transformations applied to the other variables, the first common usable observation is 18 September 2020. Data on foreign investor transactions are obtained from the equity subcategory of the "Securities Portfolio of Non-Residents—Net Change" dataset published in the CBRT EVDS. M7 measures the weekly net equity transactions by non-residents on Borsa İstanbul, in millions of US dollars. According to the CBRT's definition, net change data are adjusted for market-price and exchange-rate/parity movements. The series therefore reflects transaction-based net purchases or sales rather than changes in the value of foreign investors' portfolios arising from exchange-rate and price movements.

All variables are aligned in the same direction so that higher values indicate adverse market conditions. To this end, the M7 series sign is reversed to construct an indicator of foreign net selling pressure.

$$FOP_t = -M7_t \quad (1)$$

Accordingly, $FOP_t > 0$ indicates that foreign investors are net sellers in the corresponding week and that foreign net selling pressure has increased, whereas $FOP_t < 0$ indicates that they are net buyers. Because M7 is already a weekly flow variable, it is not further differenced and is used in levels, measured in millions of US dollars. A logarithmic transformation is also inappropriate because the series includes negative values. FOP is therefore interpreted not as a direct measure of realised capital outflows, but as a transaction-based indicator of foreign net selling pressure.

Data on the CBOE Volatility Index (VIX), which represents global risk conditions; Türkiye's five-year CDS premium, which represents sovereign risk; the BIST 100 index; and the USD/TRY (USDTRY) exchange rate are obtained from Investing.com. The series are matched with M7 at a weekly frequency using Friday closing values or, when no observation is available on Friday, the closing value on the final trading day of the corresponding week. Weekly logarithmic changes in the VIX, CDS, BIST 100, and USDTRY series are calculated as follows:

$$R_{i,t} = 100[\ln(\frac{P_{i,t}}{P_{i,t-1}})] \quad (2)$$

The sign of the BIST 100 return is reversed:

$$NEG_BIST_t = -R_{BIST,t} \quad (3)$$

Thus, positive NEG_BIST values represent losses in the BIST 100, positive USDTRY values indicate depreciation of the Turkish lira, and positive changes in the VIX and CDS indicate increases in global risk sentiment and Türkiye's sovereign risk, respectively. This common directional alignment allows the upper quantiles to be interpreted consistently as conditions of intense foreign selling and heightened financial stress, and the lower quantiles as conditions of net foreign purchases and relatively favourable market conditions. Table 1 reports the descriptive statistics for the variables.

Table 1. Descriptive Statistics

	FOP	VIX	CDS	NEG_BIST	USDTRY
Mean	5.7313	-0.1252	-0.2764	-0.8479	0.6062
Median	9.67	-0.8858	-0.2827	-0.9705	0.3344
Maximum	856.88	73.8522	40.9158	18.1125	22.3602
Minimum	-614.4	-49.5296	-27.3614	-11.5015	-43.2732
Std. Dev.	235.6629	14.9121	6.4053	3.9231	3.5453
Skewness	0.3950	0.4605	0.7954	0.3395	-4.8787
Kurtosis	4.1789	5.7490	9.8413	4.6838	86.1084
Jarque-Bera	25.3423*	105.7637*	620.7965*	41.4794*	88111.08*
ADF	-11.4659*	-15.9392*	-17.6568*	-6.9958*	-24.8605*

Note: "" denotes statistical significance at the 1% level.*

Table 1 shows that the mean of FOP is positive, indicating that foreign net selling pressure was positive on average over the sample period. While the sample means of the changes in the VIX and CDS are slightly negative, the mean of NEG_BIST, at −0.8479, indicates that the BIST 100 recorded an average weekly log return of approximately 0.85% over the period. The positive mean of USDTRY, at 0.6062%, indicates that the Turkish lira depreciated on average at a weekly frequency over the sample period. The kurtosis coefficients of all series exceed the normal-distribution benchmark of 3, indicating fat-tailed distributions. This feature is particularly pronounced for USDTRY: its skewness of −4.8787 indicates strong left skewness, while its kurtosis of 86.1084 points to infrequent but exceptionally large exchange-rate movements. The Jarque–Bera statistics strongly reject the null hypothesis of normality for all variables. Accordingly, the possibility that a mean-based approach may obscure connectedness across different parts of the distribution provides empirical support for using the quantile-based connectedness methodology. The ADF tests also reject the unit-root hypothesis for all series at the 1% level, demonstrating that the variables are stationary in the forms used in the analysis. Figure 1 shows the evolution of the variables over time.

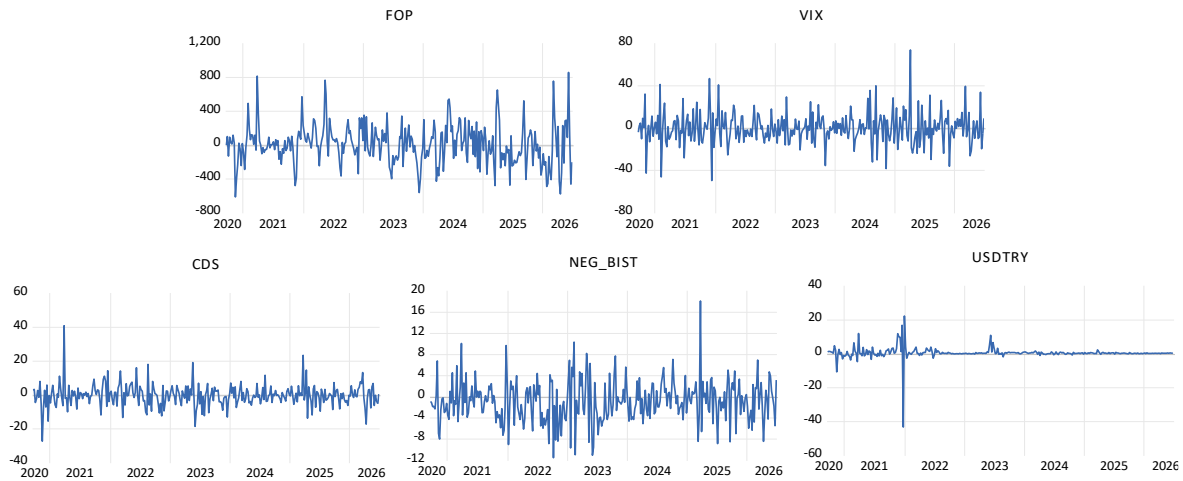

Figure 1. Time Series Graphs

Figure 1 shows that the series exhibits pronounced spikes and periods of volatility clustering over the sample period. FOP's frequent movements between positive and negative values reflect shifts in foreign investors' net buying and selling positions over time, while the extreme movements in the VIX, CDS, NEG_BIST, and USDTRY indicate that the magnitude of financial shocks is not uniform across periods. In particular, the limited number of extreme movements observed in USDTRY is consistent with the series's high kurtosis and negative skewness. This pattern underscores the need to examine the connectedness structure separately, not only under average market conditions but also in the lower and upper tails of the distribution.

Methodology

The study examines the market-condition-dependent connectedness between foreign net selling pressure and the VIX, CDS, BIST 100 losses, and the USD/TRY exchange rate using the QVAR-based quantile connectedness approach developed by Chatziantoniou et al. (2021). Separate models are estimated for the 0.10, 0.50, and 0.90 quantiles. Since the variables are oriented such that higher values indicate adverse financial conditions, these quantiles are interpreted as representing low-stress, normal-market, and high-stress conditions, respectively. The connectedness measures are based on the generalised forecast error variance decomposition, which is invariant to variable ordering (Koop et al., 1996; Pesaran & Shin, 1998). Following the framework of Diebold and Yılmaz (2012, 2014), we calculate the shocks received by each variable from the system (FROM), the shocks transmitted by each variable to the system (TO), net connectedness (NET), the total connectedness index (TCI), and net pairwise directional connectedness (NPDC). A positive NET value indicates that a variable is a net transmitter of shocks, whereas a negative value indicates that it is a net receiver. The lag length is set to one based on the Bayesian information criterion. In reporting the findings, we present the average connectedness measures, TCI, NET, and the NPDCs between FOP and the other variables included in the analysis.

The static connectedness results are obtained from the full sample, whereas the dynamic results are estimated using a one-lag QVAR model, selected automatically according to the Bayesian information criterion, and an 80-week rolling window. Each dynamic estimate is assigned to the final date of the corresponding window and therefore reflects the connectedness structure over approximately the preceding 18 months.

EMPIRICAL RESULTS

To examine how the connectedness between FOP and financial risk indicators varies across market conditions, we employ the QVAR-based quantile connectedness approach. The findings are reported from both full-sample and dynamic perspectives. First, the full-sample connectedness matrices and net pairwise directional connectedness networks are presented and compared across quantiles. We then examine the total connectedness index (TCI) estimated over 80-week rolling windows, the net directional connectedness of FOP, and the net pairwise directional connectedness between FOP and each risk indicator. This framework allows changes in system-wide connectedness across market regimes and FOP's position within the system to be evaluated within a unified analytical setting.

Full-Sample Connectedness Results

Table 2 and Figure 2 present the full-sample connectedness structure among FOP, VIX, CDS, NEG_BIST, and USDTRY at the lower tail ($\tau = 0.10$), median ($\tau = 0.50$), and upper tail ($\tau = 0.90$). In both Table 2 and Figure 2, Panels A, B, and C correspond to low-stress, normal-market, and high-stress conditions, respectively.

Table 2. Quantile-Specific Full-Sample Connectedness Results

Panel A: Lower-Tail Connectedness (τ = 0.10)						
	FOP	**VIX**	**CDS**	**NEG_BIST**	**USDTRY**	**FROM**
FOP	30,87	18,47	21,28	20,83	8,55	69,13
VIX	18,46	37,01	19,64	16,41	8,47	62,99
CDS	17,4	18,02	33,87	19,73	10,99	66,13
NEG_BIST	18,72	15,2	19,31	37,81	8,97	62,19
USDTRY	9,77	11,14	15,64	9,75	53,7	46,3
TO	64,35	62,83	75,86	66,72	36,97	306,73
Inc.Own	95,23	99,84	109,73	104,53	90,67	TCI
NET	-4,77	-0,16	9,73	4,53	-9,33	61,35
Panel B: Median Connectedness (τ = 0.50)						
	FOP	**VIX**	**CDS**	**NEG_BIST**	**USDTRY**	**FROM**
FOP	61,24	7,14	15,8	12,77	3,05	38,76
VIX	5,83	77,88	11,13	3,09	2,07	22,12
CDS	6,36	9,48	66,51	10,68	6,97	33,49
NEG_BIST	8,87	2,59	11,4	70,34	6,8	29,66
USDTRY	2,17	3,06	7,67	6,8	80,3	19,7
TO	23,23	22,28	46	33,33	18,89	143,73
Inc.Own	84,47	100,16	112,51	103,68	99,19	TCI
NET	-15,53	0,16	12,51	3,68	-0,81	28,75
Panel C: Upper-Tail Connectedness (τ = 0.90)						
	FOP	**VIX**	**CDS**	**NEG_BIST**	**USDTRY**	**FROM**
FOP	22,11	12,96	15,83	14,06	35,04	77,89
VIX	14,43	27,36	15,1	13,13	29,99	72,64
CDS	13,4	13,42	23,19	13,56	36,42	76,81
NEG_BIST	16,57	15,28	17,34	33,15	17,66	66,85
USDTRY	10,35	11,24	14,25	10,63	53,53	46,47
TO	54,75	52,91	62,51	51,38	119,12	340,66
Inc.Own	76,85	80,27	85,7	84,53	172,65	TCI
NET	-23,15	-19,73	-14,3	-15,47	72,65	68,13

Note: Rows represent shock-receiving variables, whereas columns represent shock-transmitting variables. FROM denotes the total directional connectedness received from the system, TO denotes the total directional connectedness transmitted to the system, and NET is calculated as TO − FROM. A positive NET value indicates a net transmitter of shocks, whereas a negative value indicates a net receiver. The magnitude of the values increases from yellow to red.

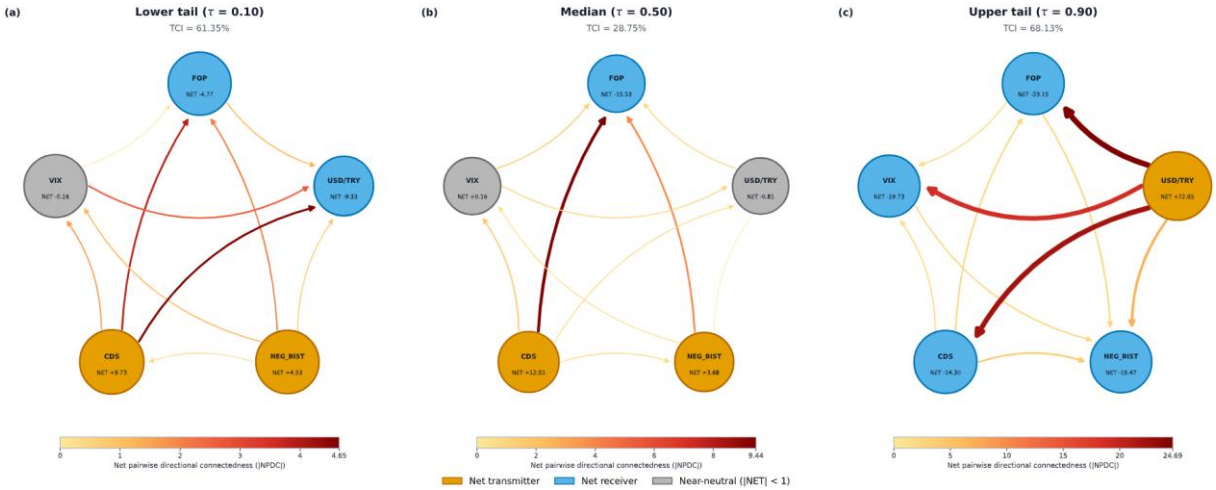

Figure 2. Quantile-Specific Net Pairwise Directional Connectedness Networks

Note: Arrows indicate the direction of net shock transmission between each pair of variables. Node size is proportional to TO connectedness, while node colour identifies whether a variable is a net transmitter, a net receiver, or approximately balanced. Arrow thickness is scaled to the absolute magnitude of the NPDC using a common scale across all panels, whereas arrow colour is based on a panel-specific scale.

The TCI is 61.35% in the lower tail, 28.75% in the median regime, and 68.13% in the upper tail, indicating that system-wide connectedness weakens markedly under normal market conditions but strengthens in both tails of the distribution. Relative to the median regime, the TCI increases by 32.60 percentage points in the lower tail and by 39.38 percentage points in the upper tail. Moreover, the upper-tail TCI exceeds its lower-tail counterpart by 6.78 percentage points, suggesting that tail connectedness is stronger under conditions of heightened financial stress.

In the lower tail, FOP receives the largest amount of shocks from the system, with a FROM connectedness of 69.13%. Nevertheless, its TO connectedness of 64.35 and NET value of −4.77 indicate that, despite its intensive two-way interaction with the system, FOP remains only a modest net receiver. In this regime, CDS (NET = 9.73) is the primary net transmitter, while NEG_BIST (NET = 4.53) acts as a secondary net transmitter. The network structure reveals net pairwise connectedness of 3.88 from CDS to FOP and 2.11 from NEG_BIST to FOP, whereas the relationship between FOP and VIX is approximately balanced. Thus, under low-stress conditions, FOP dynamics are associated predominantly with sovereign risk and losses in the domestic equity market.

In the median regime, the shares of shocks explained by the variables' own innovations increase, and the TCI declines to 28.75%. Nevertheless, FOP continues to exhibit the highest FROM connectedness, at 38.76%, and becomes the system's strongest net receiver, with a NET value of −15.53. CDS, by contrast, emerges as the principal source of shock transmission, with a TO connectedness of 46 and a NET value of 12.51. Net pairwise connectedness of 9.44 from CDS to FOP represents the strongest bilateral transmission in the median regime, complemented by a transmission of 3.90 from NEG_BIST to FOP. This pattern indicates that, under normal market conditions, FOP primarily receives shocks originating from sovereign risk and equity-market pricing dynamics.

In the upper tail, not only the level of connectedness but also the centre of the transmission structure changes. USDTRY's TO connectedness rises to 119.12 and its NET connectedness to 72.65, while all the other variables become net receivers. FOP's FROM connectedness reaches 77.89%, and its NET value falls to −23.15. The finding that shocks originating in USDTRY account for 35.04% of FOP's forecast error variance, together with an NPDC of 24.69 running from USDTRY to FOP, identifies exchange-rate pressure as the dominant transmission channel under high-stress conditions. At the same time, the emergence of a net transmission of 2.51 from FOP to NEG_BIST shows that although FOP is a net receiver within the system as a whole, it is not entirely passive with respect to equity-market losses in the upper tail.

Dynamic Connectedness Results

Figure 3 depicts the time-varying total connectedness index (TCI) within the system comprising FOP and the financial risk indicators. The TCI estimates show that the connectedness gap between the tail regimes and the median regime remains largely persistent throughout the sample period. The median-regime TCI stood at approximately 40% in the second quarter of 2022, declined to around 20% by mid-2024, and subsequently reversed course, rising to approximately 50% by the second quarter of 2026.

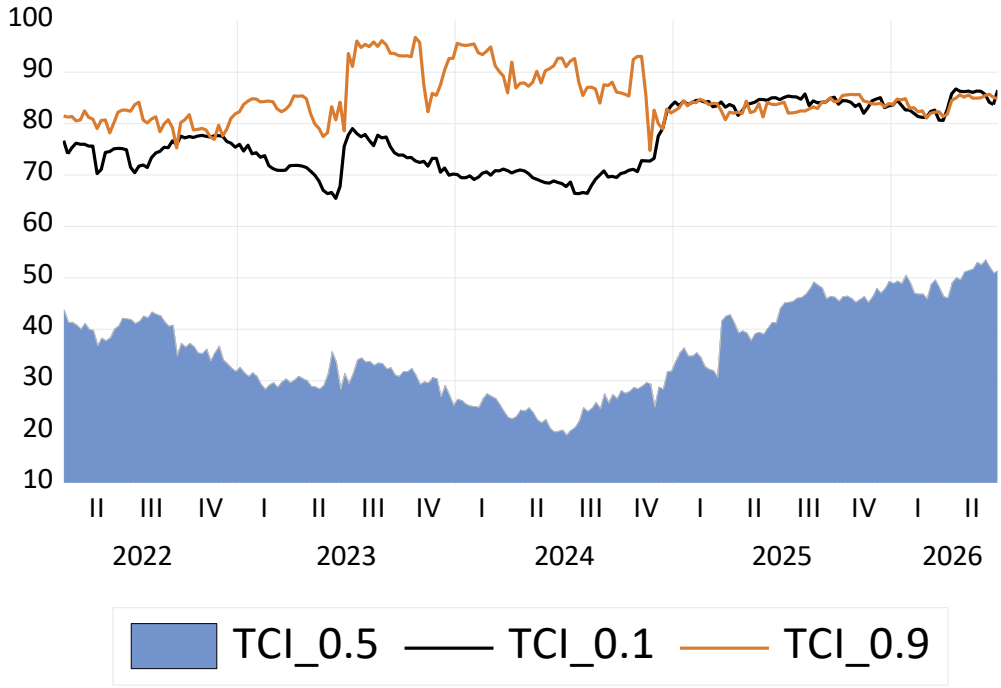

Figure 3. TCI

The lower-tail TCI generally fluctuated between 65% and 77% over the 2022–2024 period, then exceeded 80% in the fourth quarter of 2024 and remained at this elevated level for the rest of the sample. The upper-tail TCI followed a more volatile trajectory, rising above 90% in the second half of 2023 to reach approximately 95% and remaining elevated throughout 2024. Following a short-lived decline in the fourth quarter of 2024, the lower- and upper-tail TCIs converged within the approximate range of 80–85%. This pattern indicates that the tail connectedness identified in the full-sample analysis is not driven by a limited number of rolling windows; rather, connectedness remains persistently higher in both tails than under normal market conditions. Nevertheless, the increase in the median-regime TCI from 2025 onward suggests that shock transmission expanded beyond extreme regimes and became more pronounced under normal market conditions as well. The most pronounced regime shift in the dynamic results emerged in the second half of 2023. The sharp increase in the upper tail of TCI, the deepening of FOP's position as a net receiver of shocks, and the growing dominance of USDTRY transmission to FOP temporally coincided with heightened domestic uncertainty surrounding the May 2023 elections and the monetary tightening cycle initiated in June 2023. Indeed, the CBRT reported that Türkiye's five-year CDS premium reached 703 basis points on 22 May 2023. On 22 June 2023, it raised the policy rate from 8.5% to 15%, thereby initiating the monetary tightening cycle. However, because the estimates are based on 80-week rolling windows, the sharp reversal observed in the fourth quarter of 2024 may also be partly attributable to unusual observations from May and June 2023 that were left out of the estimation window.

Figure 4 presents the evolution of FOP's dynamic net directional connectedness over time. The figure shows that FOP's net connectedness is negative in most periods across all quantiles, thereby dynamically confirming the net-receiver position identified in the full-sample analysis. In the median regime, FOP remains a net receiver throughout the entire period, with this role becoming particularly pronounced from the second half of 2023 to the fourth quarter of 2024. Although the lower tail exhibits a more

balanced pattern, FOP predominantly remains a net receiver, except for temporarily positive values between late 2023 and the first half of 2024.

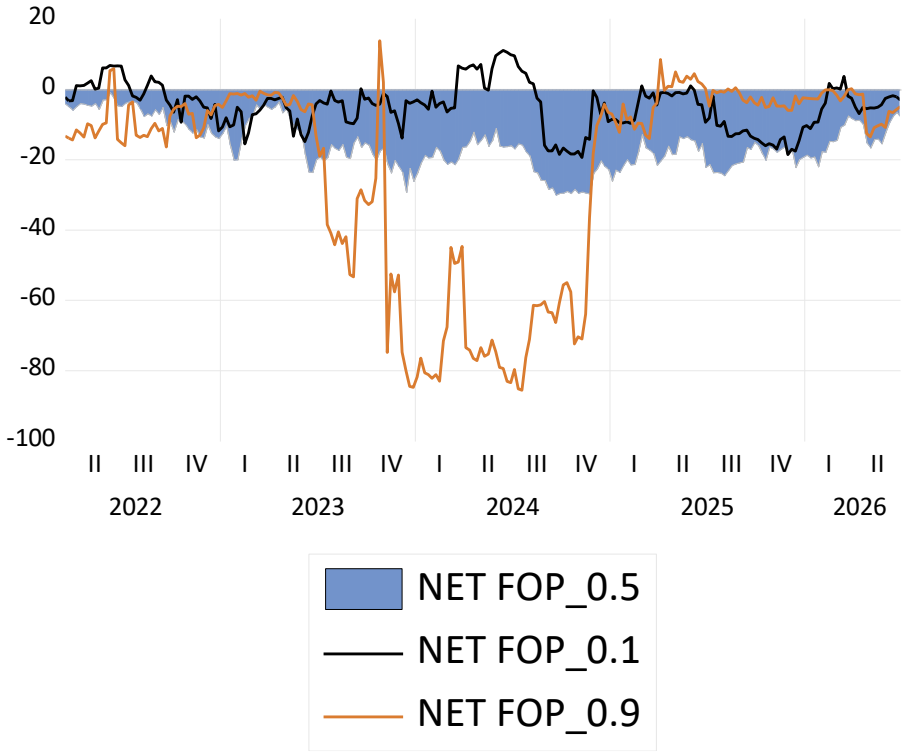

Figure 4. Dynamic Net Directional Connectedness of FOP (NET)

Note: Positive values indicate that FOP is a net transmitter of shocks within the system, whereas negative values indicate that it is a net receiver.

The strongest asymmetry emerges in the upper tail. FOP's NET value declines sharply in the second half of 2023 and fluctuates approximately between −50 and −90 from the fourth quarter of 2023 through the fourth quarter of 2024. Although it approaches zero following a sharp recovery at the end of 2024, it remains generally negative through the end of the sample. Thus, the intensity of FOP's net-receiver role is not constant over time; rather, it becomes markedly stronger during periods of heightened financial stress. To identify the bilateral channels underlying this pronounced upper-tail pattern, Figure 5 presents the net pairwise directional connectedness between FOP and the financial risk indicators.

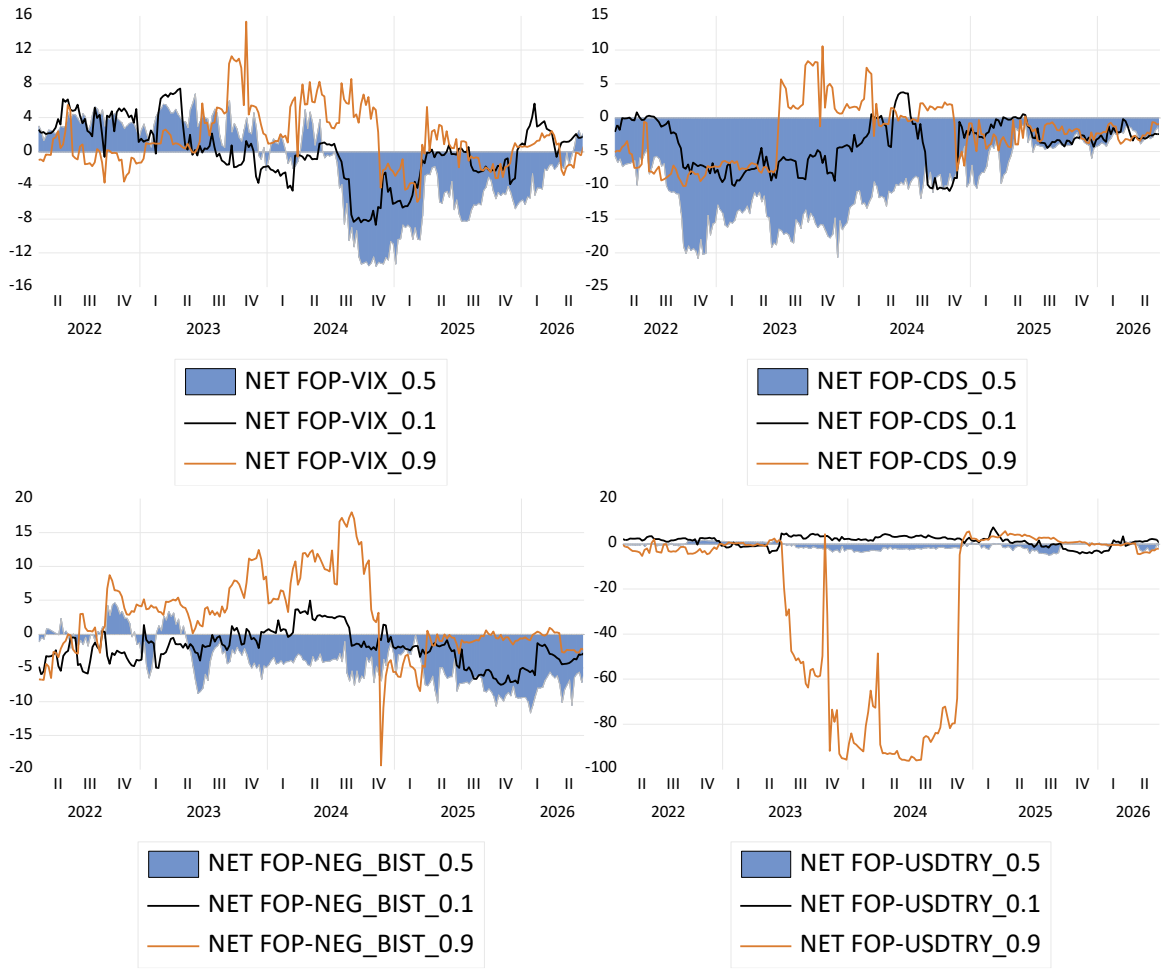

Figure 5. NPDC Between FOP and Financial Risk Indicators

Note: Positive NPDC values indicate dominant net transmission from FOP to the corresponding variable, whereas negative values indicate dominant net transmission from the corresponding variable to FOP.

The FOP–USDTRY relationship constitutes the most pronounced bilateral channel in the NPDC results. While lower-tail connectedness remains mostly close to zero and median-regime connectedness is moderately negative, the upper-tail NPDC turns sharply negative in the second quarter of 2023 and remains approximately between −50 and −100 until the fourth quarter of 2024. The dominant direction of transmission from USDTRY to FOP during this period indicates that exchange-rate pressure was the primary source of FOP's pronounced upper-tail net-receiver position observed in Figure 4. The return of this relationship to values near zero after the fourth quarter of 2024 indicates that the channel is highly concentrated across both market regimes and over time. FOP–CDS connectedness is negative throughout most of the sample in the lower-tail and median regimes. In particular, the markedly negative median NPDC between the second half of 2022 and the first half of 2024 indicates that transmission from sovereign risk to FOP persisted even under normal market conditions. By contrast, the upper-tail relationship turns positive between the second quarter of 2023 and the third quarter of 2024, indicating that net connectedness from FOP to CDS strengthened during this temporary episode. From the fourth quarter of 2024 onward, the relationship becomes negative again and converges toward smaller magnitudes across all three quantiles, demonstrating that the reversal in the sovereign-risk channel was not persistent. The connectedness between FOP and NEG_BIST clearly identifies a period during which FOP transmitted shocks to the domestic equity market despite being a net receiver within the overall system. Although the lower-tail and median NPDC values are predominantly negative, upper-tail connectedness remains positive from the second half of 2022 through the third quarter of 2024, reaching approximately 15–18 points in the second and third quarters of 2024. This finding indicates that net transmission from FOP to BIST 100 losses temporarily became dominant under high-stress conditions.

Following the sharp reversal in the fourth quarter of 2024, the relationship remains negative, indicating that the dominant direction subsequently shifted from NEG_BIST to FOP. The FOP–VIX relationship exhibits smaller magnitudes and more frequent directional reversals than the other three relationships. In the upper tail, positive connectedness from FOP to VIX strengthens between the second half of 2023 and the third quarter of 2024. By the end of 2024 and throughout 2025, however, the dominant direction shifts from VIX to FOP, particularly in the lower-tail and median regimes. Thus, although global risk sentiment is connected to FOP, the magnitude and persistence of this transmission are more limited than those of the USDTRY and CDS channels. Taken together, the dynamic NPDC results indicate that FOP's system-wide position as a net receiver of shocks is driven primarily by the USDTRY channel in the upper tail and by the CDS channel in the lower-tail and median regimes. By contrast, the upper-tail transmission from FOP to NEG_BIST, which strengthened over the 2022–2024 period, shows that foreign net selling pressure can also operate as a channel through which shocks are transmitted to losses in the domestic equity market.

Viewed jointly, the static and dynamic findings demonstrate that the connectedness between FOP and financial risk indicators is contingent on both market regime and time. While system-wide connectedness strengthens in both tails relative to the median regime—particularly in the upper tail—the dominant source of transmission shifts from CDS at the lower and median quantiles to USDTRY at the upper quantile. Although FOP is a net receiver of shocks in most periods, it transmits shocks to NEG_BIST during certain upper-tail windows. Accordingly, foreign net selling pressure should be viewed not solely as a passive response to financial risks, but also as a conditional transmission channel that can propagate shocks to the domestic equity market under high-stress conditions. Despite differences in variable definitions, data frequencies, and empirical methods, the transmission from CDS and USDTRY to FOP points to the same economic pattern identified by Arık (2025), who shows that foreign portfolio returns respond negatively in the short run to shocks in the CDS premium and the US dollar exchange rate. The transmission from NEG_BIST to FOP in the lower-tail and median regimes is consistent with Uysal (2020), who documents unidirectional causality from negative shocks in the BIST 100 to foreign portfolio investment. By contrast, the strengthening of transmission from FOP to NEG_BIST during specific upper-tail periods complements the findings of Ülkü and İkizlerli (2012), who show that net foreign flows predict future market returns and exert persistent price effects. Finally, the regime-dependent variation in the level, direction, and principal source of connectedness is also consistent with Wang and Yan (2022), who demonstrate that the relative importance of push and pull factors driving foreign capital flows varies across quantiles.

CONCLUSION

This study analyses how the connectedness between foreign net selling pressure (FOP) in Borsa Istanbul and global risk sentiment (VIX), Türkiye's sovereign risk (CDS), equity-market losses (NEG_BIST), and exchange-rate pressure (USDTRY) varies across market regimes and over time. To this end, the QVAR-based quantile connectedness approach is applied to weekly data covering the period from 18 September 2020 to 26 June 2026, with the full-sample findings complemented by dynamic estimates obtained from 80-week rolling windows. This framework allows FOP's position within the system to be assessed not only under normal market conditions but also in low- and high-stress regimes, with attention to both the direction and temporal evolution of shock transmission. The findings reveal a markedly nonlinear and asymmetric structure of system-wide connectedness. The total connectedness index is 28.75% in the median regime, but increases to 61.35% in the lower tail and 68.13% in the upper tail. This result indicates that variable-specific dynamics play a more prominent role under normal market conditions, whereas shocks are shared more intensively across the system in both tails of the distribution. The higher level of connectedness in the upper tail relative to the lower tail further suggests that within-system transmission mechanisms become stronger as financial stress intensifies. The dynamic estimates confirm that only a limited number of observations does not drive the elevated connectedness observed in the tail regimes, but persists throughout much of the sample. Nevertheless, the increase in median-regime connectedness after 2025 indicates that shock transmission can also broaden over time under normal market conditions. The principal source of shock transmission varies across market regimes. CDS is the primary net transmitter in the lower-tail and median regimes, whereas

this role shifts markedly to USDTRY in the upper tail. FOP, by contrast, is a net receiver of shocks at all quantiles in the full-sample results, with its net-receiver position becoming more pronounced as financial stress increases. In particular, the finding that shocks originating in USDTRY account for 35.04% of FOP's forecast error variance in the upper tail highlights the central importance of the exchange-rate channel when foreign net selling pressure intensifies. Conversely, the smaller magnitude and more frequent directional reversals of FOP–VIX connectedness suggest that, over the period examined, foreign net selling pressure was more closely associated with domestic financial conditions than with global risk sentiment. FOP's system-wide position as a net receiver does not imply that it is an entirely passive component of the system. The emergence of upper-tail net connectedness from FOP to NEG_BIST, which became particularly pronounced between the second half of 2022 and the third quarter of 2024, indicates that foreign net selling pressure can become a conditional channel through which shocks are transmitted to domestic equity-market losses under high-stress conditions. Thus, while sovereign risk and exchange-rate pressure constitute the principal sources of shocks to FOP, FOP itself can also serve as a channel for the transmission of equity-market losses during specific periods. The study's principal contribution to the literature is to identify, within a unified analytical framework, the risk channel, market regime, direction, and periods through which this reciprocal structure becomes pronounced. From a policy perspective, the findings suggest a two-stage monitoring approach. The prominence of the CDS channel under normal and low-stress conditions underscores the importance of monitoring the macroeconomic and institutional indicators that shape sovereign risk when assessing foreign investor behaviour. The emergence of USDTRY as the dominant transmission centre in the high-stress regime suggests that exchange-rate developments and foreign net selling pressure should be jointly monitored during periods of intensifying currency pressure. The time-varying transmission from FOP to NEG_BIST further suggests that stress-testing and early-warning frameworks should treat foreign investor transactions not only as responses to financial risks but also as potential transmission channels that can amplify market losses. During such periods, measures designed to support market depth, liquidity, and continuity of trading may help contain the propagation of foreign selling pressure into asset prices. The results should be interpreted in light of several limitations. First, the analysis is confined to a specific sample period, weekly data frequency, and a five-variable system. Second, although the 80-week rolling windows allow dynamic changes to be tracked, they may diffuse the effects of sudden developments over time and cause some sharp directional reversals to be associated with unusual observations entering or leaving the estimation window. Future research could employ daily or transaction-level data, foreign investor transactions disaggregated by investor type and sector, alternative window lengths, and methods capable of identifying structural shocks. Cross-country comparisons could also help distinguish between the country-specific and common features of the interaction between foreign net selling pressure and financial risk channels.

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THE ROLE OF FORENSIC ACCOUNTING IN COMBATING FINANCIAL FRAUD AND ENHANCING CORPORATE GOVERNANCE IN EMERGING ECONOMIES

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ABSTRACT

Financial fraud continues to pose a significant threat to organisational sustainability, investor confidence, and economic development, particularly in emerging economies where governance and regulatory enforcement may face persistent challenges. In response to the increasing sophistication of financial crimes, forensic accounting has emerged as a vital discipline that combines accounting, auditing, investigative techniques, and legal expertise to detect, prevent, and investigate fraudulent activities. This paper examines the role of forensic accounting in strengthening corporate governance and promoting transparency and accountability within both public and private sector organisations. Drawing on existing literature and contemporary empirical evidence, the study explores how forensic accounting techniques contribute to the early detection of financial irregularities, support litigation processes, and enhance the effectiveness of internal control systems. The paper also discusses the challenges affecting the adoption of forensic accounting practices, including inadequate professional capacity, technological limitations, and weak institutional frameworks. It argues that the integration of forensic accounting into organisational governance structures can significantly reduce fraud risk, improve financial reporting quality, and reinforce stakeholder confidence. Furthermore, the study highlights the importance of continuous professional training, regulatory reforms, and the adoption of advanced digital forensic tools in addressing emerging financial crimes. The findings suggest that strengthening forensic accounting capacity is essential for improving organisational integrity and achieving sustainable economic development in emerging economies. The paper concludes by recommending greater collaboration among professional accounting bodies, policymakers, regulatory agencies, and academic institutions to expand forensic accounting education and practice. The study contributes to the growing body of knowledge on fraud prevention and offers practical insights for organisations seeking to enhance financial accountability and corporate governance in an increasingly complex business environment.

Keywords: Forensic Accounting; Financial Fraud; Corporate Governance; Fraud Detection; Accountability; Emerging Economies.

APPLICATION OF THE "SMART VILLAGE" AND "SMART CITY" CONCEPTS IN THE GREAT RETURN STRATEGY TO KARABAKH AND THEIR SOCIAL IMPLICATIONS

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ABSTRACT

Introduction and Purpose: Following the liberation of the occupied territories, Azerbaijan launched the Great Return Program to rebuild Karabakh through sustainable and technology-driven settlements. This study examines the contribution of Smart Village and Smart City concepts to social development within the Great Return Strategy.

Materials and Methods: The research employs qualitative methods based on the analysis of state programs, legislation, policy documents, scientific literature, and official statistics. Comparative and descriptive analyses were used to evaluate social outcomes.

Results: The findings indicate that smart settlements improve access to public services, digital governance, education, healthcare, employment, energy efficiency, and environmental sustainability. These measures facilitate the reintegration of returning citizens and strengthen local socio-economic development.

Discussion and Conclusion: The study concludes that Smart Village and Smart City initiatives constitute an innovative model for post-conflict reconstruction in Karabakh. Their successful implementation supports sustainable social development and may serve as a reference for other post-conflict regions.

Key Words: Great Return Program; Karabakh; Smart Village; Smart City; Social Development; Sustainable Development.

NUTRIENT ADEQUACY AND DIETARY IMBALANCES AMONG BOARDING-SCHOOL ADOLESCENTS IN THE MOULAY ABDELLAH REGION, MOROCCO

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ABSTRACT

Objectives: Adolescents in boarding schools rely heavily on institutional catering to meet their nutritional requirements during a period of rapid growth. However, data on Moroccan boarding-school diets remain limited. This study aimed to assess energy and nutrient intake and identify the main dietary imbalances among boarding-school adolescents in the Moulay Abdellah region of Morocco.

Methods: A cross-sectional dietary assessment was conducted among 182 adolescents aged 14–18 years residing in a school boarding facility and consuming canteen meals. Dietary intake was evaluated using 24-hour dietary recalls to estimate daily intake of energy, macronutrients, dietary fibre, and micronutrients. Nutritional adequacy was evaluated by comparing intakes with age- and sex-specific dietary recommendations, examining variations by participant characteristics.

Results: The assessment identified several discrepancies between reported intake and recommended guidelines. Inadequate intake affected dietary fibre and multiple essential micronutrients, alongside an unbalanced macronutrient distribution in part of the study population. Limited dietary diversity and insufficient consumption of nutrient-dense foods contributed to these inadequacies, indicating that canteen meals may not consistently cover the nutritional requirements for adolescent growth.

Conclusions: Boarding-school adolescents in the Moulay Abdellah region face multiple dietary inadequacies that compromise their nutritional health. Regular nutritional evaluations of school menus and the inclusion of more diverse, nutrient-dense foods are essential to improve dietary quality and adequacy in this vulnerable population.

Keywords: Adolescents nutrition, Nutrient adequacy, Boarding schools, Dietary intake, Morocco.

DESIGN AND IMPLEMENTATION OF AN INTEGRATED LIFESTYLE EDUCATION PROGRAM AMONG SCHOOL-GOING ADOLESCENTS IN EL JADIDA, MOROCCO

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ABSTRACT

Objectives: School-based health promotion should extend beyond traditional nutrition instruction to address interrelated lifestyle behaviors. This study aimed to design, implement, and evaluate an integrated nutrition and healthy lifestyle education program tailored to school-going adolescents in El Jadida Province, Morocco.

Methods: A pre–post intervention study was conducted with 262 adolescents aged 14–18 years. Baseline dietary adherence and lifestyle habits were evaluated using the KIDMED index alongside structured questionnaires assessing physical activity, sleep patterns, and daily health practices. Based on identified baseline gaps, a one-month culturally adapted school intervention was delivered, emphasizing Mediterranean dietary principles, physical activity, and sleep hygiene. Post-intervention reassessments were performed using paired statistical analyses to evaluate short-term behavioral changes.

Results: Baseline evaluations revealed critical gaps in Mediterranean diet adherence and sleep habits. Following the intervention, a statistically significant shift toward healthier behaviors was observed, notably through increased overall KIDMED scores and improved awareness of daily lifestyle choices. While post-intervention trends evolved favorably across all targeted dimensions, the degree of change varied by behavior, highlighting specific habits requiring longer-term reinforcement and personalized follow-up.

Conclusions: A multidimensional, culturally tailored school intervention is an effective approach to support healthier lifestyle choices among Moroccan adolescents. The educational framework established through this study provides a solid foundation for future digital platforms designed to offer personalized monitoring, feedback, and sustained nutritional support.

Keywords: Adolescents; Nutrition education; Healthy lifestyle; School-based intervention; Mediterranean diet.

FROM PREVENTION TO CLINICAL MANAGEMENT: STAGE-DEPENDENT EFFECTS OF THE MEDITERRANEAN, MIND, AND KETOGENIC DIETS IN ALZHEIMER'S DISEASE

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ABSTRACT

Alzheimer's disease (AD) is a progressive neurodegenerative disorder and the leading cause of dementia worldwide. It is characterized by progressive cognitive decline, including memory impairment, deficits in executive function, and loss of functional independence. Risk factors are categorized as modifiable and non-modifiable; the disease may develop because of excessive buildup of amyloid beta plaques (Aβ) and tau proteins hyperphosphorylation. Among the modifiable risk factors, dietary patterns are one of the most critical factors for the progression and management of the disease. AD, also known as "diabetes of the brain," might be managed through various dietary patterns, such as the Mediterranean diet (MedDiet), the Mediterranean-DASH Intervention for Neurodegenerative Delay (MIND) diet, and the ketogenic diet (KD). The objective of the present study is to understand the outcomes of different dietary patterns on the progression of AD using extant literature evidence. In the present study Literature review was performed in the PubMed, Google Scholar, and ScienceDirect databases for the years 2020–2025, using the keywords "alzheimer's disease," "nutrition," "MIND diet", "Mediterranean diet" and "ketogenic diet" in various combinations. Studies have demonstrated that Mediterranean diet patterns reduce Aβ accumulation compared to Western-style diet patterns, yielding results consistent with the neurodegenerative process. It is known that the ketogenic diet reduces neuroinflammation in the hippocampus and cortex by lowering inflammatory indicators such as TNF-α and IL-1β compared to standard diets. Furthermore, the MIND diet—another dietary pattern frequently used in AD—has not been shown to influence cognitive function in current studies. Studies have demonstrated that dietary intervention might modulate in the management of AD. With the appropriate dietary interventions, the onset of the disease might be potentially reversed.

Key Words: Alzheimer's disease, Ketogenic diet, Mediterranean diet, MIND diet, Neurodegeneration

INTRODUCTION

Alzheimer's disease is a neurodegenerative disorder characterized by progressive memory loss and functional impairment and is the most prevalent form of dementia. Excessive degradation of the amyloid precursor protein (APP) occurs due to excessive Aβ accumulation; increasing amyloid plaque formation leads to neuronal toxicity and synaptic loss (De-Paula et al., 2012). The synaptic loss may also result from decreased microglial activation and increased inflammation and oxidative stress. In addition to the buildup of amyloid plaques and neurofibrillary tangles—formed as a result of the hyperphosphorylation of tau proteins—are among the pathological hallmarks of the AD. It accounts for up to 70% of dementia

cases; it is the most frequently seen form of dementia and is manifested by progressive cognitive decline, memory loss, and behavioral and functional impairments[1–3]. The global prevalence of dementia is estimated to nearly triple over the next thirty years, exceeding 150 million by 2050[4]. Further, risk factors for AD are divided into two groups: modifiable and non-modifiable; family history and age are among the non-modifiable risk factors. Hypertension, sleep patterns, alcohol and tobacco use, and dietary habits are considered modifiable risk factors[5]. Lifestyle interventions that promote healthy eating patterns are being implemented to lower the risk of developing cognitive impairment or dementia. Examples of popular dietary models studied in relation to AD include the MedDiet, the MIND diet, and the KD[6,7]. A key feature of these dietary patterns is that they exhibit distinct neuroprotective mechanisms owing to components such as polyphenols and antioxidants. The MedDiet is a dietary model derived from centuries-old nutritional traditions, containing high amounts of unrefined grains fruits, olive oil, legumes, and vegetables; low quantities in dairy products, meat, poultry, and saturated fats; and promoting moderate consumption of fish and wine[8]. Its rich composition provides considerable antioxidant content, and its neuroprotective effects stem from omega-3 polyunsaturated fatty acids, polyphenols, and B vitamins[9]. Through its various benefits, the Mediterranean diet can lead to improved brain function and a reduction in accumulated Aβ and brain atrophy. The MIND diet, which combines two different Mediterranean diets with the Dietary Approaches to Stop Hypertension (DASH) diet, stands for "Mediterranean-DASH Intervention for Neurodegenerative Delay." The most distinguishing feature of the MIND diet is its focus on preventing the clinical onset of dementia and slowing age-related cognitive decline. This dietary model is known for its focus on ten food which are vegetables, especially leafy green vegetables, berries, legumes, whole grains, nuts, fish, poultry, olive oil, and wine believed to support brain health[10]. KD, which is characterized by consuming low carbohydrates intake and consuming high intake of fats, uses ketones as opposed to glucose to generate energy homeostasis. This makes it a beneficial dietary model in cases of AD where there is an impairment in the energy processes of neurons. In a standard ketogenic diet, ~55–75% of energy comes from fats, ~20–35% from protein, and ~5–10% from carbohydrates. The objective of the present study is to understand the outcomes of different dietary patterns on the progress of Alzheimer's disease. The objective of the present study is to understand the outcomes of different dietary patterns on the progression of AD using extant literature evidence.

Table 1. Comparison of Dietary Components Across the Mediterranean Diet and MIND Diet

Dietary Components	MedDiet	MIND Diet
Carbohydrate (% energy)	~40	Not specified
Protein (% energy)	~20	Not specified
Fat (% energy)	~40	Not specified
Meat, poultry, fish, eggs	White meat: 2 serv./week Fish/seafood: ≥2 serv./week Red meat: <2 serv./week Processed meat: ≤1 serv./week Eggs: 2–4 serv./week	Red meat and products: <4 serv./week Fish: ≥1 serv./week Poultry: ≥2 serv./week
Dairy products	All dairy products: 2 serv./da (preferably low-fat)	Cheese: <1 serv./week
Nuts, seeds, and legumes	Legumes: ≥2 serv./week Olives, nuts, or seeds: 1–2 serv./day	Legumes: ≥3 serv./week Nuts: ≥5 serv./week
Fruits	1–2 servings per meal	Blueberries and other fruits: ≥2 servings per week

Vegetables	≥2 servings per meal	Leafy green vegetables: ≥6 servings per week Other vegetables: ≥1 serving per day
Fats and Oils	Olive oil per meal	Olive oil: main source Butter/margarine: <1 tbsp/day
Sweets and Snacks	Sweets: ≤2 serv./week	Fried/fast food: <1 serv./week Pastries, sweets: ≤5 serv./week
Alcohol consumption	Wine: 1–3 glasses per day	Wine: 1 glass per day
Grains and Cereals	Bread, pasta, rice, couscous, other grains (preferably whole grains): 1–2 servings per meal	Whole grains: ≥3 servings/day

Source: *Adapted from Bach-Faig et al.[11] and Morris et al.[12]. MedDiet: Mediterranean Diet; KD: Ketogenic Diet; MIND: Mediterranean-DASH Intervention for Neurodegenerative Delay Diet; serv.: serving.*

METHOD

Literature review was performed in the PubMed, Google Scholar, and ScienceDirect databases for the years 2020–2025, using the keywords "alzheimer's disease," "nutrition," "MIND diet", "Mediterranean diet" and "ketogenic diet" in various combinations.

FINDINGS

In a randomized controlled studyinvolving 87 participants aged 45–65 with mild cognitive impairment or normal cognition participants were assigned to either the MedDiet or a Western-style diet. Aβ40, an early-stage biomarker of AD, was reduced in participants with normal cognition who followed the MedDiet, whereas it increased in those with normal cognition who followed the Western-style diet ($p<0.05$). However, no difference was found between the two diets in participants with mild cognitive impairment [13]. In another randomized, multicenter study involving 612 participants, a MedDiet intervention was performed among older adults who were not frail or in the pre-frailty stage. Among those who followed the MedDiet pattern for 1 year, better memory and verbal fluency, lower frailty, and reduced systemic inflammation were observed ($p<0.05$)[14]. Morevoer, a 6-month, multicenter, study trial included 93 patients aged 60–85 with a diagnosis of prodromal AD[15]. In the study, which involved a MedDiet-style intervention, the focus was on patients' intake of omega-3, choline, and B vitamins. While no significant difference in macro- and micronutrient levels was observed in the intervention group, a decrease in these values was seen in control people significantly ($p<0.05$). In particular, an increased quality of life was observed in the intervention group. This suggests that a Mediterranean-style dietary approach has a protective effect in this population.

In two-center, randomized controlled clinical trial, participants were randomized in a 1:1 ratio to either the MIND diet or the control diet[16]. The study, which aimed to compare cognitive function with a calorie-restricted and neuroprotective dietary model, included participants aged 65 and older who scored 22 or higher or scored 22 on the Montreal Cognitive Assessment (MoCA) over the course of the 3-year study. A total of 301 people were included in the intervention group; their diet consisted primarily of green leafy vegetables, berries, and 207 ml of olive oil per week. Foods such as red meat, processed meat, and butter were restricted. In the control, participants continued their normal diets and received weekly psychological motivation sessions. An energy deficit of 250 kcal/day was targeted in both groups. No difference between the MIND diet group and the control group in terms of structural brain Magnetic Resonance Imaging findings ($p > 0.05$) was found in the study. Similarly, no differences were observed between the control group and the intervention group in measures such as semantic memory and episodic memory.

A study which individuals diagnosed with AD 26 were placed on a modified ketogenic diet for 12 weeks, no difference was observed in the patients' cognitive scores; however, improvements were observed in quality of life and daily functioning scores significantly[17]. In a study involving patients with moderate cognitive impairment in which ketogenic medium-chain triglycerides (kMCT) were administered as a beverage, participants were given 15 g of kMCT beverage twice a week. The results of the study showed that while no significant improvement was observed in the placebo group, improvement was found in episodic memory significantly[18]. Some transgenic mice were fed a ketogenic diet consisting of 76% fat, 16% protein, and 3% carbohydrates, while others were fed a standard diet. The study found that the transgenic mice on the standard diet exhibited higher levels of neuroinflammation, whereas those on the ketogenic diet had lower levels of TNF-α[19]. In a randomized, crossover study, 20 patients at risk for AD were assigned to either a modified Mediterranean ketogenic diet (MMK) or the diet model recommended by the American Heart Association (AHA) guidelines[20]. The MMK diet consisted of 5–10% carbohydrates, 60–65% fat, and 30% protein, while the AHA diet consisted of 20–30% protein, 55–65% carbohydrates, 15–20% fat. The MMK diet showed positive results in AD biomarkers among participants, and the AHA diet contributed to change in cholinesterase activity positively.

CONCLUSIONS AND RECOMMENDATIONS

Evidence suggests that various dietary patterns help slow the progression of AD. These effects are observed through the diets' properties, such as their antioxidant effects, their ability to reduce markers of systemic neuroinflammation, and their memory-enhancing effects. Although various studies have included adequate intervention periods, there is a need for studies in which the models are implemented for longer periods. This would allow for a clearer understanding of the long-term effects of these dietary models.

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DIGITAL HEALTH LITERACY AS A TOOL FOR STRENGTHENING PREVENTIVE HEALTH BEHAVIOURS AMONG YOUNG ADULTS

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ABSTRACT

The increasing use of digital technologies has transformed the way health information is accessed, shared, and utilized globally. Young adults are among the most active users of digital platforms and frequently rely on online sources for health-related information. Digital health literacy refers to the ability to seek, access, understand, evaluate, and apply health information obtained through digital technologies for informed health decision-making. This seminar examines digital health literacy as a tool for strengthening preventive health behaviours among young adults. The paper explores the concept, components, determinants, and significance of digital health literacy in promoting preventive health practices such as vaccination uptake, healthy nutrition, physical activity, disease screening, sexual and reproductive health, and mental health promotion. Evidence from recent studies indicates that higher levels of digital health literacy are associated with improved health-seeking behaviour, increased adoption of preventive measures, and enhanced self-management of health conditions. However, challenges such as misinformation, unequal access to digital resources, low critical appraisal skills, and privacy concerns continue to limit the effectiveness of digital health interventions. The seminar concludes that strengthening digital health literacy is essential for improving preventive health behaviours and reducing the burden of preventable diseases among young adults. It recommends the integration of digital health literacy into educational curricula, expansion of digital health infrastructure, and implementation of policies aimed at promoting equitable access to credible health information.

Keywords: Digital Health Literacy, Preventive Health Behaviour, Young Adults, Health Promotion, eHealth Literacy.

INTRODUCTION

Background and Context of the study

The emergence of digital technology has significantly transformed healthcare systems worldwide. The widespread availability of smartphones, computers, internet services, social media platforms, telemedicine systems, and mobile health applications has changed how individuals access and utilize

health information. Digital health technologies now serve as major channels for health communication, disease surveillance, patient education, and healthcare delivery (WHO, 2024).

Young adults represent one of the largest populations utilizing digital technologies. They increasingly seek health information online before consulting healthcare professionals. Consequently, their ability to identify, evaluate, and appropriately use digital health information has become an important determinant of health outcomes. Digital health literacy has therefore emerged as a critical public health concern because it influences individuals' ability to make informed health decisions and adopt healthy behaviours.

Preventive health behaviours are actions undertaken by individuals to prevent illness, detect diseases early, and maintain overall health. Examples include immunization, healthy eating, physical activity, routine health screenings, safe sexual practices, and mental health promotion. The adoption of these behaviours is influenced by access to accurate and reliable health information.

Digital health literacy empowers young adults to navigate the complex digital information environment, distinguish credible information from misinformation, and make informed decisions that promote health and prevent disease.

Public Health Importance/Relevance

Digital health literacy is increasingly recognized as a social determinant of health. It contributes significantly to health promotion, disease prevention, and health equity. Improved digital health literacy enhances individuals' ability to access preventive health services, understand health risks, and engage in behaviours that reduce disease burden.

From a public health perspective, strengthening digital health literacy among young adults can improve vaccination uptake, reduce risky health behaviours, enhance mental health awareness, and support healthy lifestyles. It also plays a critical role in combating health misinformation, which has become a major challenge in the digital age.

Rationale for the study

The increasing dependence on digital sources of health information among young adults necessitates a comprehensive understanding of digital health literacy and its impact on preventive health behaviours. Despite high internet usage among young adults, many lack the necessary skills to critically evaluate online health information, exposing them to misinformation and poor health decisions.

This study is therefore necessary to examine how digital health literacy can serve as a strategic tool for improving preventive health behaviours and promoting positive health outcomes among young adults.

CONCEPTUAL REVIEW OF DIGITAL HEALTH LITERACY

Definition of Digital Health Literacy

Digital Health Literacy (DHL) refers to an individual's ability to seek, find, understand, evaluate, and apply health information obtained through digital technologies to make informed health decisions (Norman & Skinner, 2006). It is an extension of traditional health literacy adapted to the digital age, where health information is increasingly accessed through websites, mobile applications, social media platforms, telemedicine services, and online health databases.

The World Health Organization (WHO, 2024) recognizes digital health literacy as a critical determinant of health because it influences how individuals interact with health information and health services. Digital health literacy encompasses not only the ability to access information but also the capacity to critically appraise the reliability, credibility, and relevance of such information before utilizing it for health-related decision-making.

Digital Health Literacy (DHL) has become a significant concept within public health due to the rapid digitalization of healthcare systems globally. Norman and Skinner (2006) defined digital health literacy (eHealth literacy) as the ability to seek, find, understand, appraise, and apply health information from electronic sources to address health problems and make informed decisions. This definition remains

foundational because it recognizes the multidimensional nature of literacy in a technology-driven environment.

According to van der Vaart and Drossaert (2017), digital health literacy encompasses a combination of traditional literacy, computer literacy, media literacy, information literacy, scientific literacy, and health literacy. These competencies enable individuals to navigate digital environments effectively and critically assess online health information.

The increasing use of digital technologies in healthcare has shifted healthcare delivery from provider-centered approaches to more patient-centered models. Consequently, individuals are expected to take greater responsibility for managing their health through digital platforms (World Health Organization [WHO], 2023).

In today's information-rich environment, individuals are continuously exposed to large volumes of health information. Without adequate digital health literacy, users may struggle to distinguish between scientifically validated information and misinformation, potentially leading to harmful health behaviours.

Critical Perspective

While digital health literacy has been promoted as a solution to healthcare accessibility challenges, critics argue that access to technology alone does not guarantee effective health decision-making. Paige et al. (2018) noted that many individuals possess basic digital skills but lack the critical thinking abilities necessary to evaluate the credibility of online health information. Thus, digital access without adequate literacy may inadvertently increase vulnerability to misinformation.

Key Elements of Digital Health Literacy

Digital health literacy involves:

- Accessing digital health information
- Understanding health content
- Evaluating source credibility
- Applying information appropriately
- Communicating health information effectively
- Protecting personal health information online

Consequently, digital health literacy serves as a bridge between technological advancement and improved health outcomes.

Evolution of Digital Health Literacy

The concept of health literacy emerged in the 1970s and primarily focused on individuals' ability to read and understand health-related information. However, the advent of information and communication technologies transformed healthcare communication and necessitated the development of broader literacy competencies.

In 2006, Norman and Skinner introduced the concept of eHealth literacy, describing it as the intersection of six forms of literacy: traditional literacy, health literacy, information literacy, media literacy, scientific literacy, and computer literacy.

Over time, the concept evolved into Digital Health Literacy to reflect advancements such as:

i. Mobile health (mHealth)

ii. Telemedicine

iii. Artificial Intelligence (AI)

iv. Electronic Health Records (EHRs)

v. Wearable health technologies

vi. Digital therapeutics

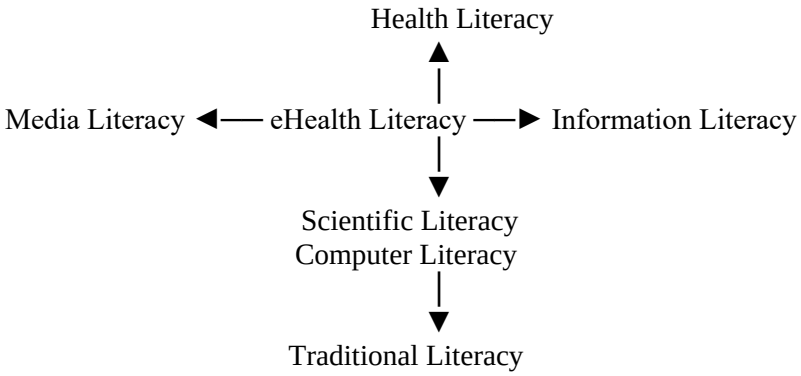
The COVID-19 pandemic further highlighted the importance of digital health literacy. During the pandemic, digital platforms became primary sources of information regarding disease prevention, vaccination, and public health guidelines. Individuals with higher digital health literacy were better able to identify trustworthy information and adopt preventive behaviours.

Theoretical Review

The Lily Model of eHealth Literacy

Norman and Skinner (2006) developed the Lily Model of eHealth Literacy, which illustrates six interconnected literacies required for effective digital health engagement.

Figure 1: Lily Model of eHealth Literacy



Source: Adapted from Norman and Skinner (2006).

The model suggests that digital health literacy is not a standalone skill but rather an integration of multiple literacies necessary for successful navigation of digital health environments.

Health Belief Model (HBM)

The Health Belief Model proposes that health behaviour is influenced by an individual's perception of susceptibility, severity, benefits, barriers, and self-efficacy (Rosenstock et al., 1988).

Digitally literate young adults are more likely to:

1. Recognize health risks.
2. Understand disease severity.
3. Appreciate preventive measures.
4. Adopt positive health behaviours.

For example, access to online information about Human Papillomavirus (HPV) vaccination may increase vaccine uptake among young adults due to increased awareness of disease susceptibility and benefits of prevention (Choi & Lee, 2023).

Review of Preventive Health Behaviours among Young Adults

Preventive health behaviours are actions undertaken to prevent disease and promote health. Such behaviours include vaccination, physical exercise, healthy eating, regular screening, safe sexual practices, and mental health promotion.

Young adulthood is a critical developmental stage characterized by increasing autonomy in health decision-making (Sawyer et al., 2018). During this period, behavioural patterns established often persist into adulthood.

Studies indicate that young adults increasingly rely on digital technologies to obtain health information and guide health decisions (Pretorius et al., 2019).

Digital Health Literacy and Health Information-Seeking Behaviour

Health information-seeking behaviour is one of the most extensively studied outcomes of digital health literacy.

A systematic review conducted by Stellefson et al. (2020) found that individuals with higher digital health literacy were significantly more likely to seek preventive health information online than those with lower literacy levels.

Similarly, Kim and Xie (2017) reported that digitally literate individuals demonstrate greater confidence in locating and interpreting health information, which contributes to healthier lifestyle choices.

2.9 Empirical Evidence

Author	Year	Population	Major Findings
Kim & Xie	2017	Young Adults	Higher DHL increased online health information seeking
Stellefson et al.	2020	General Population	DHL predicted preventive health information use
Chesser et al.	2016	University Students	Better DHL associated with improved health decisions

Table 1: Relationship between Digital Health Literacy and Health Information Seeking.

Digital Health Literacy and Vaccination Behaviour

Vaccination remains one of the most effective disease prevention strategies globally. Research conducted during the COVID-19 pandemic highlighted the influence of digital health literacy on vaccine acceptance. Montagni et al. (2021) found that individuals with high digital health literacy were significantly more likely to accept COVID-19 vaccination than those with limited literacy.

Similarly, Biasio et al. (2021) observed that vaccine hesitancy was strongly associated with low digital health literacy and exposure to misinformation through social media platforms.

Critical Analysis

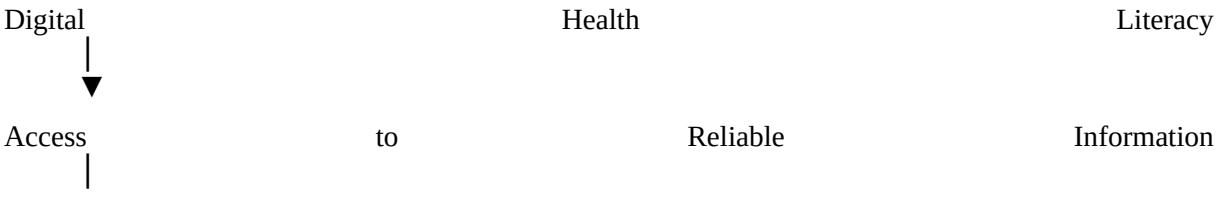
Although digital health literacy improves vaccine acceptance, excessive exposure to conflicting information can generate confusion and mistrust. This phenomenon, known as the "infodemic," became evident during the COVID-19 pandemic when misinformation spread rapidly through digital channels (WHO, 2022).

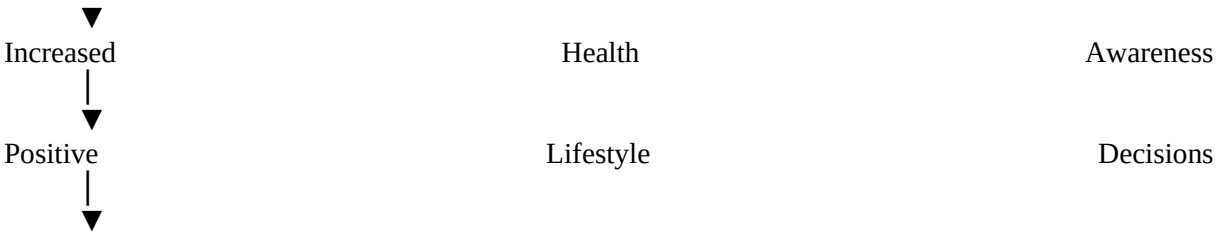
Digital Health Literacy and Healthy Lifestyle Behaviour

Digital technologies have become important tools for promoting healthy lifestyles among young adults. Applications such as MyFitnessPal, Fitbit, Google Fit and Samsung Health provide users with personalized health information and behaviour tracking.

A study by Benavides et al. (2024) found that adolescents and young adults exposed to digital health interventions demonstrated significant improvements in Physical activity levels, Dietary behaviours and Weight management practices.

Figure 2: Influence of Digital Health Literacy on Lifestyle Behaviours





Digital Health Literacy and Mental Health Promotion

Mental health challenges among young adults have increased globally. Digital health literacy plays an important role in helping young adults Recognize mental health symptoms, Access mental health resources, Engage with online counselling services and Reduce mental health stigma. Pretorius et al. (2019) reported that digitally literate young adults were more likely to utilize online mental health resources and seek professional support.

However, studies also caution that excessive exposure to social media may negatively impact mental health despite high digital literacy levels (Naslund et al., 2020).

Determinants of Digital Health Literacy

Several factors influence digital health literacy among young adults.

Educational Level

Education consistently emerges as the strongest predictor of digital health literacy.

Individuals with higher educational attainment generally possess Better critical thinking skills, Greater information evaluation abilities and Improved technological competence (Manganello et al., 2024).

Socioeconomic Status

Socioeconomic inequalities affect access to Smartphones, Computers and Internet services. Young adults from lower-income households often experience lower digital health literacy levels (Ugalde et al., 2024).

Internet Accessibility

Availability of reliable internet infrastructure significantly influences digital engagement and literacy development.

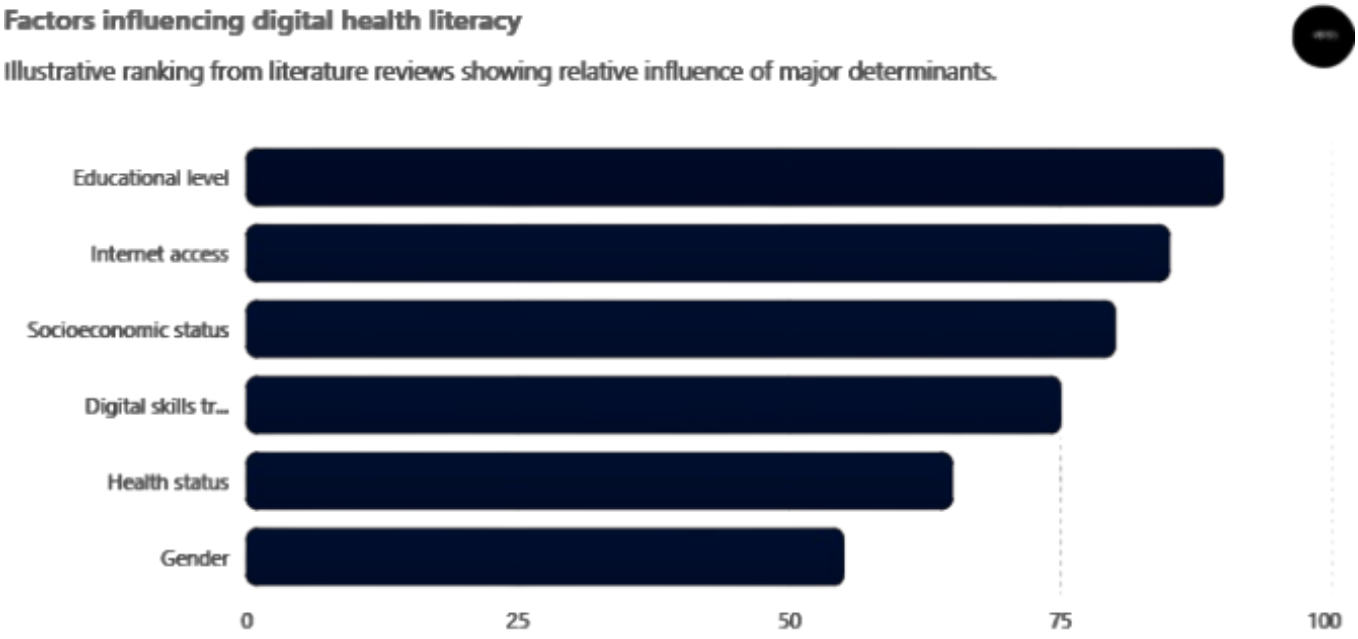


Figure 3. Illustrative representation based on findings synthesized from recent literature. It is intended for educational presentation and not as primary empirical data.

Challenges Affecting Digital Health Literacy

Health Misinformation

Misinformation represents one of the greatest threats to public health in the digital era. The WHO (2022) described the COVID-19 "infodemic" as an overabundance of information, including false or misleading information that complicates health decision-making.

Examples includes, anti-vaccination campaigns, False cancer cures and conspiracy theories

Information Overload

Young adults are exposed to enormous quantities of health information daily. Eppler and Mengis (2004) argued that information overload may result in decision fatigue, Reduced information retention, confusion and delayed health actions

Digital Divide

The digital divide remains a major challenge, particularly in low- and middle-income countries. Differences in access to digital technologies create inequalities in health information access and utilization (WHO, 2023).

Literature Gap

Although extensive studies have examined digital health literacy in developed countries, there remains limited evidence from Nigeria and many African countries. Existing studies often focus on general populations rather than young adults specifically.

Furthermore, most available studies are cross-sectional, limiting understanding of long-term impacts of digital health literacy interventions on preventive health behaviours.

There is therefore a need for:

1. Longitudinal studies examining causal relationships.
2. Research focusing on African contexts.

3. Intervention studies evaluating digital health literacy programmes.

4. Studies exploring digital health literacy and emerging technologies such as Artificial Intelligence and telemedicine.

Functional Digital Health Literacy

This refers to basic reading, writing, and technological skills needed to access digital health information.

Examples include:

1. Searching for health information online
2. Reading digital health materials
3. Using mobile health applications

Interactive Digital Health Literacy

Interactive literacy involves communication and engagement with digital health resources.

Examples include:

- Participating in online health forums
- Using telemedicine services
- Communicating with healthcare providers electronically

Critical Digital Health Literacy

Critical literacy refers to the ability to analyze and evaluate health information critically.

Individuals possessing critical literacy can:

- Verify information sources
- Identify misinformation
- Evaluate scientific evidence
- Make informed health decisions

Translational Digital Health Literacy

This dimension involves applying acquired digital health information to practical health actions and behaviours.

Examples include:

- Scheduling health screenings online
- Following digital vaccination reminders
- Implementing lifestyle changes based on evidence-based information

Public Health Importance of Digital Health Literacy

Health Promotion

Health promotion focuses on enabling individuals to improve control over their health and well-being. Digital health literacy enhances health promotion by providing individuals with timely access to evidence-based health information.

Young adults increasingly use social media, mobile applications, and online communities to learn about:

1. Nutrition
2. Physical activity
3. Mental health

4. Sexual health
5. Disease prevention

Digital health literacy enables them to navigate these resources effectively and adopt healthier lifestyles.

Critical Analysis

Although digital platforms offer vast opportunities for health promotion, they also expose users to inaccurate health information. Consequently, digital health literacy is essential to ensure that health promotion efforts achieve their intended outcomes.

Disease Prevention

Disease prevention involves interventions aimed at reducing the occurrence and progression of diseases.

Digital health literacy supports:

Primary Prevention

- Vaccination uptake
- Healthy eating
- Physical activity
- Substance abuse prevention

Secondary Prevention

- Early disease screening
- Health risk assessments
- Symptom monitoring

Tertiary Prevention

- Self-management of chronic illnesses
- Adherence to treatment
- Rehabilitation support

Individuals with higher digital health literacy are more likely to engage in preventive health behaviours due to better access to credible health information.

Health Equity

Health equity refers to the absence of avoidable differences in health outcomes among populations.

Digital health literacy contributes to equity by:

i. Expanding access to health information
ii. Improving healthcare access in underserved communities
iii. Supporting remote healthcare delivery

However, disparities in internet access and digital skills may widen health inequalities. Therefore, public health interventions must address digital divides to ensure equitable benefits.

Patient Empowerment

Patient empowerment involves enabling individuals to actively participate in healthcare decisions.

Digital health literacy empowers patients to:

- Understand health conditions
- Explore treatment options
- Communicate effectively with healthcare providers

- Engage in shared decision-making

Empowered individuals demonstrate greater self-efficacy and improved health outcomes.

Components of Digital Health Literacy

Digital health literacy integrates six foundational literacies.

Information Literacy

Information literacy is the ability to locate, retrieve, evaluate, and utilize information effectively.

Individuals with strong information literacy can:

1. Conduct efficient online searches
2. Compare multiple information sources
3. Evaluate source credibility

Health Literacy

Health literacy refers to the ability to understand and use health information for decision-making.

It includes understanding:

1. Medical terminology
2. Prescription instructions
3. Health education materials

Media Literacy

Media literacy enables individuals to critically evaluate media messages.

It helps users:

1. Identify misinformation
2. Recognize biased content
3. Evaluate social media health claims

Computer Literacy

Computer literacy refers to the ability to use digital devices and software applications effectively.

Competencies include Internet navigation, Application usage and Digital communication

Ccientific Literacy

Scientific literacy involves understanding scientific concepts, research findings, and evidence-based recommendations.

This enables users to Interpret health research, Understand risk information and Evaluate health claims scientifically.

Communication Literacy

Communication literacy facilitates effective exchange of health information through digital platforms.

Examples include:

1. Teleconsultations
2. Online support groups
3. Email communication with healthcare providers

Preventive Health Behaviours among Young Adults

Young adulthood is a critical period for establishing lifelong health habits.

Healthy Dietary Practices

Healthy nutrition contributes significantly to disease prevention.

Digitally literate individuals often use:

1. Nutrition applications
2. Dietary tracking tools
3. Online nutritional guidelines

These resources promote informed food choices and healthier eating behaviours.

Physical Activity

Physical inactivity contributes to obesity, cardiovascular disease, and diabetes. Digital technologies support physical activity through Fitness trackers, Exercise applications and Virtual coaching programs. Research suggests that digitally supported exercise programs improve physical activity levels among young adults.

Vaccination Uptake

Vaccination remains one of the most effective public health interventions. Digital health literacy influences vaccination behaviours by enabling individuals to access vaccine information, understand vaccine benefits and counter misinformation. Poor digital health literacy often contributes to vaccine hesitancy.

Sexual and Reproductive Health Behaviour

Young adults frequently seek online information regarding contraception, sexually transmitted infections and Family planning. Digital literacy promotes informed reproductive health decisions and safer sexual practices.

Mental Health Promotion

Mental health disorders are increasingly prevalent among young adults. Digital platforms provide mental health education, self-help tools and telepsychiatry services. Digital health literacy enables users to identify symptoms early and seek appropriate interventions.

Routine Health Screening

Early detection improves treatment outcomes. Digitally literate individuals are more likely to Schedule screenings online, Receive digital reminders and Monitor health indicators.

Examples include:

1. Blood pressure checks
2. HIV screening
3. Cancer screening

DIGITAL HEALTH LITERACY AND PREVENTIVE HEALTH BEHAVIOURS

Influence on Health Information Seeking

Health information seeking is often the first step toward preventive action. Digital health literacy improves individuals' ability to access quality information, evaluate information sources and use evidence-based resources. As a result, informed individuals are more likely to engage in preventive practices.

Influence on Vaccination Behaviour

Studies consistently demonstrate a positive association between digital health literacy and vaccine acceptance.

Individuals with high digital health literacy understand vaccine science, resist misinformation and trust credible health authorities. Consequently, they exhibit higher vaccination rates.

Influence on Healthy Lifestyle Choices

Digital health literacy promotes healthy eating, exercise participation, weight management and smoking cessation. Health applications and wearable technologies provide continuous behavioural support.

Influence on Mental Health Practices

Digital health literacy facilitates mental health awareness, early recognition of symptoms and access to mental health services. This reduces stigma and promotes help-seeking behaviour.

Influence on Healthcare Utilization

Digitally literate individuals effectively utilize telemedicine, online appointment scheduling and electronic health records. This improves healthcare access and continuity of care.

Determinants of Digital Health Literacy

Educational Level

Higher educational attainment is strongly associated with improved digital health literacy.

Education enhances reading comprehension, critical thinking and information evaluation skills.

Socioeconomic Status

Individuals from higher socioeconomic backgrounds generally have better access to digital technologies and internet services.

Digital Access

Reliable internet connectivity and device availability significantly influence digital health literacy.

Gender

Studies have reported variations in digital health literacy based on gender, often influenced by sociocultural and educational factors.

Health Status

Individuals with chronic diseases frequently develop stronger digital health literacy through repeated engagement with health information.

Social Support

Family, peers, and healthcare professionals can enhance digital health literacy through guidance and information sharing.

Benefits of Digital Health Literacy in Disease Prevention

i. Early disease detection
ii. Improved self-management
iii. Better health decision-making
iv. Enhanced healthcare utilization
v. Reduced healthcare costs
vi. Increased preventive service uptake
vii. Improved quality of life
viii. Greater health empowerment

Collectively, these benefits contribute to healthier populations and reduced disease burden.

Challenges Affecting Digital Health Literacy

Health Misinformation

The rapid spread of false information on social media poses a major threat to public health.

Examples include Anti-vaccine propaganda, False disease cures and Health conspiracy theories.

Digital Divide

Disparities in technology access create unequal opportunities for health information access.

Information Overload

The abundance of health information can overwhelm users and impair decision-making.

Privacy and Security Concerns

Data breaches and unauthorized information sharing reduce trust in digital health systems.

Limited Critical Appraisal Skills

Many users lack the ability to critically assess online information quality.

Strategies for Strengthening Digital Health Literacy

Educational Interventions

Digital health literacy should be integrated into school and university curricula.

Digital Health Campaigns

Governments and public health agencies should utilize digital platforms to disseminate evidence-based information.

Policy Development

Policies should promote Digital inclusion, Health information quality standards and Data privacy protections.

Community-Based Programs

Community outreach initiatives can improve digital literacy among underserved populations.

Multi-Sectoral Collaboration

Collaboration among healthcare institutions, educational organizations, technology companies, and policymakers is necessary for sustainable digital health literacy promotion.

Implications for Public Health Practice

Digital health literacy has profound implications for public health practice.

It can:

1. Improve health communication effectiveness.
2. Enhance disease prevention efforts.
3. Increase healthcare accessibility.
4. Reduce misinformation-related harms.
5. Promote health equity.
6. Support universal health coverage goals.
7. Strengthen population resilience during health emergencies.

Consequently, integrating digital health literacy into public health planning and policy development is essential for addressing contemporary health challenges and improving health outcomes among young adults.

SUMMARY

This study examined **Digital Health Literacy as a Tool for Strengthening Preventive Health Behaviours among Young Adults**. The review highlighted the growing importance of digital technologies in health communication, disease prevention, and healthcare delivery. As digital platforms

increasingly become primary sources of health information, digital health literacy has emerged as an essential competency that enables individuals to access, understand, evaluate, and apply health information effectively.

The study began by explaining the concept of digital health literacy, tracing its evolution from the broader concept of health literacy to the current emphasis on digital competencies required for navigating electronic health resources. Drawing on the foundational work of Norman and Skinner (2006), digital health literacy was described as a multidimensional construct integrating traditional literacy, health literacy, information literacy, scientific literacy, media literacy, and computer literacy.

The review further explored the theoretical foundations underpinning digital health literacy, particularly the Lily Model of eHealth Literacy and the Health Belief Model. These theories explain how individuals acquire digital competencies and how these competencies influence health-related perceptions, motivations, and preventive behaviours. The Health Belief Model demonstrated that individuals with adequate digital health literacy are more likely to perceive health risks accurately, appreciate the benefits of preventive measures, and adopt positive health behaviours.

The study also examined preventive health behaviours among young adults, emphasizing that this population increasingly relies on digital technologies for health information. Preventive behaviours discussed included healthy dietary practices, regular physical activity, vaccination uptake, sexual and reproductive health practices, mental health promotion, and routine medical screening. These behaviours are fundamental to reducing the burden of communicable and non-communicable diseases.

A substantial portion of the review focused on the relationship between digital health literacy and preventive health behaviours. Evidence from recent studies consistently demonstrated that young adults with higher levels of digital health literacy are more likely to seek credible health information, engage in healthier lifestyle practices, participate in vaccination programmes, utilize preventive health services, and make informed healthcare decisions (Kim & Xie, 2017; Choi & Lee, 2023; Ugalde et al., 2024). Digital health literacy was also shown to improve patient empowerment, self-management of health conditions, and healthcare utilization.

The study identified several determinants influencing digital health literacy, including educational attainment, socioeconomic status, internet accessibility, digital skills, health status, and social support. Education emerged as one of the strongest predictors of digital health literacy because it enhances critical thinking, information evaluation, and problem-solving abilities. Similarly, access to reliable internet services and digital devices significantly influences individuals' ability to engage with digital health resources.

Despite its numerous benefits, the study highlighted several challenges limiting the effectiveness of digital health literacy. These include the widespread dissemination of health misinformation, digital inequalities, information overload, inadequate critical appraisal skills, and concerns regarding privacy and data security. The COVID-19 pandemic particularly illustrated the detrimental effects of misinformation, commonly referred to as the "infodemic," which undermined public confidence in evidence-based health interventions (World Health Organization [WHO], 2022).

Finally, the review identified significant research gaps, particularly within low- and middle-income countries such as Nigeria. Most available studies have been conducted in developed countries, with limited evidence regarding digital health literacy interventions among Nigerian young adults. Furthermore, many existing studies are cross-sectional, highlighting the need for longitudinal and intervention-based research to establish causal relationships between digital health literacy and preventive health behaviours.

Overall, the literature reviewed indicates that strengthening digital health literacy represents a sustainable strategy for improving preventive health behaviours, reducing preventable diseases, promoting health equity, and advancing public health outcomes among young adults.

CONCLUSION

Digital health literacy has become an indispensable component of modern healthcare and public health practice. As digital technologies continue to transform healthcare delivery and health communication,

the ability of individuals to access, understand, critically evaluate, and appropriately utilize digital health information has become essential for effective health decision-making. Young adults, who constitute one of the largest users of digital technologies, stand to benefit significantly from improved digital health literacy because of their frequent reliance on online platforms for health information.

The findings from this study demonstrate that digital health literacy positively influences preventive health behaviours by enhancing health information-seeking behaviour, encouraging vaccination uptake, promoting healthy dietary practices and physical activity, supporting mental health awareness, facilitating early disease detection through routine screening, and improving healthcare utilization. Individuals with higher digital health literacy are generally better equipped to distinguish credible health information from misinformation, thereby making informed decisions that improve their overall health and well-being.

However, the increasing availability of health information through digital platforms also presents considerable challenges. The rapid spread of misinformation, unequal access to digital technologies, inadequate digital competencies, and concerns regarding information privacy continue to hinder the effective use of digital health resources. These barriers disproportionately affect vulnerable populations and may widen existing health inequalities if not adequately addressed.

The study further establishes that digital health literacy is not solely an individual responsibility but requires collaborative efforts involving governments, educational institutions, healthcare professionals, technology developers, community organizations, and policymakers. Strengthening digital health literacy demands investment in digital infrastructure, integration of digital health education into formal educational curricula, promotion of media and information literacy, and implementation of evidence-based public health communication strategies.

In conclusion, digital health literacy is a powerful public health tool that can significantly strengthen preventive health behaviours among young adults. Improving digital health literacy will not only empower individuals to make informed health decisions but also contribute to disease prevention, health promotion, improved quality of life, and the achievement of Universal Health Coverage (UHC) and the Sustainable Development Goals (SDGs), particularly SDG 3, which seeks to ensure healthy lives and promote well-being for all at all ages.

RECOMMENDATIONS

Based on the findings of this study, the following recommendations are proposed:

Government

The Federal Government of Nigeria, through the Federal Ministry of Health and Social Welfare and other relevant agencies, should formulate and implement national policies aimed at promoting digital health literacy among young adults. Government should also invest in expanding affordable internet access, particularly in rural and underserved communities, to reduce digital inequalities and improve access to credible digital health resources.

Educational Institutions

Schools, colleges, and universities should integrate digital health literacy into their curricula at both undergraduate and postgraduate levels. Health education programmes should equip students with the skills needed to identify credible online health information, critically evaluate digital content, and apply evidence-based information to health decision-making.

Healthcare Professionals

Healthcare providers should actively educate patients and communities on how to identify reliable digital health information sources. They should also encourage the use of evidence-based digital health applications, telemedicine services, and official public health websites while addressing misconceptions arising from misinformation.

Public Health Agencies

Public health agencies should strengthen digital health communication through sustained online health campaigns that provide timely, accurate, and culturally appropriate information. They should also collaborate with social media platforms to combat the spread of health misinformation and disinformation.

Technology Developers

Developers of digital health technologies should design user-friendly, inclusive, and accessible digital health platforms that accommodate users with varying levels of literacy and digital competence. They should also prioritize data privacy, cybersecurity, and user confidentiality in digital health applications.

Community-Based Organizations

Community organizations, youth groups, and non-governmental organizations should organize digital health literacy awareness programmes, workshops, and outreach activities targeting young adults, especially those in underserved communities.

Young Adults

Young adults should cultivate critical thinking skills and verify health information obtained from digital platforms using reputable sources such as the World Health Organization, national public health agencies, peer-reviewed journals, and qualified healthcare professionals. They should also avoid sharing unverified health information that may contribute to misinformation.

Researchers

Future studies should focus on intervention-based and longitudinal research to evaluate the effectiveness of digital health literacy programmes in improving preventive health behaviours among young adults. More context-specific studies should also be conducted in Nigeria and other low- and middle-income countries to generate evidence that informs policy and practice.

Policymakers

Policymakers should establish standards and regulatory frameworks for digital health information dissemination, ensuring that online health content is evidence-based, accurate, and accessible. Policies should also support partnerships among government agencies, educational institutions, healthcare organizations, and technology companies to strengthen digital health literacy nationwide.

Overall Recommendation

Strengthening digital health literacy should be recognized as a public health priority. Collaborative efforts across multiple sectors are required to empower young adults with the knowledge and skills necessary to make informed health decisions, adopt preventive health behaviours, and contribute to healthier communities. Such efforts will support national health goals, enhance health equity, and improve population health outcomes in the digital era.

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THE ANALYSIS OF THE INNOVATIVE POTENTIAL OF RUSSIAN SMALL BUSINESS

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ABSTRACT

This article is devoted to a comprehensive study of the innovative potential of small businesses in the Russian Federation at the current stage. The relevance of this topic stems from the need to transition from a commodity-based economy to an economy of technological sovereignty, in which small businesses play a key driver. General scientific research methods were applied to analyze the quantitative and qualitative development of small and medium-sized enterprises (SMEs) from 2023 to 2025, including increased patent activity and the emergence of small technology companies (STCs). Key barriers hindering the realization of this innovative potential are identified: a shortage of long-term financing, a gap between science and the real sector, and administrative costs. Particular attention is paid to the analysis of state support policy within the framework of the national project "Efficient and Competitive Economy." Based on the conducted analysis, measures for scaling up small business innovation activity in the regions are proposed. The analysis suggests that a critical mass of positive changes has accumulated in the small innovative business sector in Russia. The institutionalization of small technology company status, record patent activity, and increased support under the national project "Efficient and Competitive Economy" create the necessary preconditions for unlocking innovative potential. However, the current situation is characterized by a profound imbalance between the formal growth in the number of SMEs and their actual innovative productivity. The main challenge lies not in the number of small businesses, but in their ability to scale technological solutions to a level significant for the national economy.

Key Words: innovation potential, small business, small innovative entrepreneurship, technological sovereignty

INTRODUCTION

The modern economic development paradigm of the Russian Federation is characterized by a clear shift from extensive growth to intensive development based on new knowledge and technologies. Under the tightening sanctions regime and restricted access to foreign critical technologies, the national economy faces the task of accelerating the achievement of technological sovereignty. A key role in solving this task is assigned not only to large state corporations but also to the small business sector, which possesses a unique ability for rapid adaptation and commercialization of breakthrough ideas.

However, an analysis of statistical data reveals an ambivalent picture. On the one hand, the quantitative parameters of the SME sector have reached historic highs (6.7 million entities at the beginning of 2026), formally indicating a favorable business climate. On the other hand, the qualitative structure of the business still demonstrates a hypertrophied share of non-production services and trade, which calls into question the innovative direction of development.

The aim of this study is to identify the deep-seated determinants hindering the transformation of the innovative potential of small businesses into tangible economic results, as well as to substantiate a set of measures to overcome institutional and financial barriers.

MATERIALS AND METHODS

This paper analyzes the quantitative and qualitative development of small and medium-sized enterprises (SMEs) from 2023 to 2025, including increased patent activity and the emergence of small technology companies (STC). General scientific research methods were applied. The data is taken from national statistic agency Rosstat, Federal Tax Service, SME Register, STC Register, National agency for intellectual policy Rospatent, the Ministry of Economic Development.

In modern economic literature, an enterprise's innovative potential is treated as a complex, multi-structural system. Traditionally, resource (financial, personnel, logistical) and performance components are distinguished. However, some scholars (I.I. Aubekirov, A.Yu.Anisimov) for small businesses distinguish one more crucial factor – managerial receptivity to innovation.

Unlike large enterprises, where the innovation process is often formalized and integrated into corporate strategy, in small businesses it is personalized and directly dependent on the competencies of the founder or manager. Therefore, an analysis of the book value of intangible assets is insufficient to adequately assess the potential of SMEs. More sophisticated tools that take into account uncertainty and the multi-criteria nature of choice are required.

The innovative potential of a small business is a combination of resources, capabilities, and competencies that enable the creation and implementation of new products, technologies, and business models.

Small businesses have a number of advantages in innovation: high mobility, less bureaucracy, and a propensity to take risks. However, they are resource-constrained, which limits their ability to innovate on a large scale.

RESULTS AND DISCUSSION

STATISTICAL PROFILE OF SMALL INNOVATIVE BUSINESSES IN RUSSIA (2023–2025)

To objectively assess the state of the sector, it is necessary to distinguish between the overall development indicators of SMEs and the narrow segment of technological innovators.

Table 1. Dynamics of Key SME Sector Indicators in the Russian Federation (2023–2025)

Indicator	2023	2024	2025	Source / Note
Number of SME Entities, million units	6,30	6,57	6,76	Federal Tax Service SME Register
Number of Small Technology Companies (STCs)	1500	3 200	5 594[3]	STC Register
Number of SMEs Filing Patent Applications	2 435	2682	3150	Rospatent Data
Volume of Procurement by Large State-Owned Companies from SMEs, RUB trillion	8	9,6	9,55	Ministry of Economic Development Monitoring

As Table 1 shows, a steady upward trend is observed. The number of SMEs will increase by over 19 million in 2025. Particularly noteworthy is the exponential growth in the number of micro-transport companies (MTCs): a 75% increase in 2025 compared to the beginning of 2024. This is a direct consequence of the adoption of Federal Law No. 478-FZ and the launch of specialized support programs. The total revenue of registered MTCs for 2024 exceeded 1 trillion rubles, comparable to the budgets of major federal projects.

However, a structural analysis raises concerns. Over 60% of the increase in the number of SMEs is accounted for by individual entrepreneurs engaged in retail trade on marketplaces, which does not correlate with technological development objectives. At the same time, according to Rosstat's sample surveys, the share of small businesses implementing technological innovations in 2024 was only 5.9% of the total number of small businesses surveyed (excluding microenterprises). By comparison, in OECD countries this figure averages 18-25%.

The importance of SMEs is determined by their contribution to a country's gross domestic product. Based on this contribution, the development of small and medium-sized businesses is identified as a key condition for economic growth. The contribution of SMEs to the country's GDP for the period 2021–2024 is presented in Table 2.

Table 2. Contribution of SMEs to the country's GDP.

Year	Gross value added of SMEs, trillion rubles	Share of SMEs in GDP, %
2021	24,7	20,4
2022	30,3	21,3
2023	34,5	21,7
2024	35,0	22,0

Based on the data presented on the Federal State Statistics Service website, we can note that the SME sector's share of the country's GDP has been growing year by year over the period under review. From 2021 to 2024, its contribution increased by 1.6% to 35.0 trillion rubles, a four-year high. Gross value added itself increased by more than 80% over this period.

Analysis of statistical and analytical data reveals the contradictory nature of the development of the innovative potential of Russian small businesses.

On the one hand, there is an increase in the number of enterprises and their role in the economy, and SMEs' participation in innovative development is increasing. However, on the other hand, the share of innovative enterprises remains low, and the level of technology adoption lags behind developed countries.

INSTITUTIONAL GROWTH DRIVERS: THE ROLE OF THE SMALL TECHNOLOGY COMPANY REGISTRY AND PATENT ACTIVITY

A key institutional achievement in 2024-2025 was the formalization of the "Small Technology Company" concept. Inclusion in the registry provides access to the so-called "Support Menu," which includes:

Financial measures: The "Key Rate -7%" preferential lending program (but not exceeding 14% per annum). As of early autumn 2025, agreements worth 10.8 billion rubles have been signed.8 Grants from the Foundation for Assistance to Small Innovative Enterprises (up to 30 million rubles under the "Development" program).

Non-financial measures: The "Quick Decision Window" at the SME Corporation to simplify access to public procurement and production sites.

The growth in SME patent activity deserves special attention. In 2025, a record was set—more than 3,100 entities submitted applications in the first nine months.9 The geographic concentration of innovators remains high (Moscow - 28%, St. Petersburg - 14%, the Republic of Tatarstan - 9%). Leading technology areas include medical devices, transport management systems, and metalworking technologies. This trend confirms the hypothesis that small businesses are seeking ways to monetize their intellectual property in the context of import substitution.

LIMITATIONS TO SMALL BUSINESS INNOVATIVE DEVELOPMENT

Despite the positive dynamics of individual indicators, the innovative potential of small businesses faces serious systemic limitations, which can be classified into four groups:

A. Financial and investment barrier. The high cost of debt financing (the Central Bank of the Russian Federation's key rate is 16% at the end of 2025) makes long-term investments in R&D unprofitable. Even taking into account the preferential margin for the MTC, the actual rate remains prohibitive for startups without a stable cash flow. There is also a persistent shortage of business angels and seed venture capital outside the Moscow region.

B. Infrastructure and cooperation gap. There is a "valley of death" problem between the R&D stage and serial production. Small businesses often lack access to test rigs, prototyping centers, and certification centers. The "innovation voucher" mechanism is poorly developed. As E.V. Zhebit notes, interaction between large industrial holdings and small innovative businesses is fragmented and not institutionalized within long-term development contracts.

C. Personnel and skill shortages. Small technology businesses critically lack specialists capable of not only inventing but also calculating project economics, managing intellectual property, and building distribution chains. According to OPORA RUSSIA surveys, 67% of MTC managers cite finding qualified engineers and technologists as their main operational challenge.

G. Administrative and regulatory pressure. Despite the moratorium on inspections imposed by the government, companies are facing difficulties in obtaining mandatory certification for new products, particularly in the fields of medicine, construction, and industrial safety. The procedures take up to 12-18 months, which critically reduces the speed of product launch.

SECTOR-SPECIFIC PATTERNS OF SMALL BUSINESS INNOVATION POTENTIAL REALIZATION

The innovative activity of small businesses is extremely unevenly distributed across economic sectors. Analysis of statistical data and the MTC registry allows us to identify three industry clusters based on their level of innovation receptivity.

Table 3. Sectoral Distribution of Small Innovative Enterprises in the Russian Federation (2024-2025)

Industry Segment	Share of Total MTCs, %	Key Development Areas	Level of Government Support
IT and Software Development	38%	Artificial Intelligence, Big Data, Cybersecurity	High
Instrumentation and Electronics	22%	Controllers, Sensors, Communication Systems	Medium
Medicine and Biotechnology	15%	Medical Devices, Test Systems, Pharmaceuticals	High
Mechanical Engineering and Metalworking	14%	CNC Machines, UAV Components	Medium
Chemistry and New Materials	7%	Composites, Polymers, Reagents	Low
Other Industries	4%	Construction, Agro-Industrial Complex, Light Industry	Low

The IT sector remains the undisputed leader in the concentration of small innovative companies. This is explained by the relatively low entry barrier (no expensive equipment required) and the high margins of software products. However, this segment's dependence on imported microelectronics and sanctions-related restrictions on computing power poses the risk of slowing growth.

Instrument-making and electronics are demonstrating the most dynamic growth, driven by import substitution objectives in critical infrastructure. Small businesses in this sector often act as subcontractors for large defense and civilian customers, developing highly specialized components.

Medicine and biotechnology are characterized by the longest product-to-market cycles due to strict regulatory requirements. Innovative potential here is realized primarily through small businesses established within research institutes and medical universities.

COMPARATIVE ANALYSIS: RUSSIA AND INTERNATIONAL EXPERIENCE IN SUPPORTING INNOVATIVE SMES

To objectively assess the current state of the Russian ecosystem for supporting innovative small businesses, it is advisable to conduct a comparative analysis with leading international practices.

Table 4. Comparative characteristics of mechanisms for supporting innovative SMEs

Comparison Criteria	Russia (2025)	Germany	China	USA
Share of innovation-active SMEs	~6%	~55%	~35%	~20% (in high-tech sectors)
Main financial support instrument	Preferential loans, FSI grants	R&D subsidies (ZIM), tax deductions	Tax holidays, "hidden" subsidies via state orders	Venture capital, SBIR program
Existence of a specialized register/status	MTK Register (Small Tech Companies)	Not separately identified	"High-Tech Enterprise" certification	SBIR/STTR program (mandatory quota for govt. agencies)
Integration into public procurement	25% quota of state-owned companies' procurement volume from SMEs	Simplified access, lot splitting	Priority for domestic innovative products	3% quota of agencies' R&D budgets for SME procurement
Key difference / problem	Gap between R&D and serial production	High bureaucratization of subsidy application process	High rate of imitation of innovations	High cost of capital for startups outside Silicon Valley

As Table 4 shows, the Russian support model is actively developing. The creation of the ITC registry and the introduction of a seamless integration mechanism with development institutions (Skolkovo, the Federal Security Service, and VEB.RF) brings Russian practice closer to the Chinese model, where the state plays a dominant role in setting priorities and allocating resources.

However, a key gap is the low share of innovative SMEs in the overall population. In Germany, where the Mittelstand (medium-sized manufacturing business) has historically been strong, innovation activity is supported through deep cooperation with Fraunhofer institutes and the dual education system, which ensures an influx of qualified personnel.

WAYS TO IMPROVE THE EFFICIENCY OF UTILIZING INNOVATIVE POTENTIAL

Based on the analysis, a three-tier model for activating the innovative potential of SMEs is proposed:

Micro-level (enterprise): Stimulating the implementation of quality management systems and intellectual property management (reimbursement of up to 80% of patenting costs through subsidies from the Russian Federal Agency for Industrial and Trade Institutions (RFIT)), as well as improving financial literacy and business planning competencies for technology projects through acceleration programs.

Meso-level (region): Creating regional "Innovation Exchanges"—digital platforms where large customers post technology requests, and small businesses offer ready-made solutions (a prototype is successfully operating in Moscow; scaling is required) and developing a network of shared equipment centers (SECs) based at universities with simplified access for SMEs.

Macro level (government): transition to tax incentives for innovation for small and medium-sized enterprises (SMEs): a three-year income tax exemption from innovative products, with a 1.5x R&D expense multiplier applied when calculating income tax. Development of a "guaranteed sales" mechanism for SMEs through a system of government and corporate procurement with preferential treatment (15-20% of SME purchases should be for high-tech products).

Development and implementation of a national standard for assessing the innovative potential of SMEs based on the TOPSIS methodology for objectively monitoring the effectiveness of support measures and making management decisions at the regional level.

CONCLUSION

The analysis suggests that a critical mass of positive changes has accumulated in the small innovative business sector in Russia. The institutionalization of small technology company status, record patent activity, and increased support under the national project "Efficient and Competitive Economy" create the necessary preconditions for unlocking innovative potential.

However, the current situation is characterized by a profound imbalance between the formal growth in the number of SMEs and their actual innovative productivity. The main challenge lies not in the number of small businesses, but in their ability to scale technological solutions to a level significant for the national economy. Overcoming the identified barriers—financial, cooperative, and administrative—requires not simply an increase in budget allocations, but also a fine-tuning of the institutional environment.

A priority area for further research should be studying the effectiveness of synergistic interactions between small technology companies and large businesses in the formation of industry-specific innovation ecosystems and assessing the impact of AI tools on accelerating R&D in the SME segment.

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IMPROVING THE IMPLEMENTING INNOVATIONS MECHANISM ON THE EXAMPLE OF "REFORUM AWARDS" WINNING COMPANIES IN RUSSIA

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ABSTRACT

This article examines the problem of increasing the effectiveness of innovation activities at Russian enterprises by transforming the mechanisms for interacting with the education system. In the context of the transition to a data economy and technological sovereignty, traditional approaches to training and technology transfer are demonstrating limited effectiveness. The authors identify key gaps between educational outcomes and the actual needs of innovative enterprises. The study used statistical, comparative, case studies (analysis of successful practices of Russian companies that won the REFORUM AWARDS 2025). Structural imbalance was identified: despite an overall increase in innovation costs, the share of investment in personnel training remains critically low (4.0%), creating a barrier to the effective implementation of innovations. It was established that in 2025, a transition to pragmatic innovation with measurable results occurred, as confirmed by the practices of REFORUM AWARDS-winning companies. The article systematizes areas of education transformation that are significant for enterprise innovation: personalized learning based on AI, the implementation of VR/AR technologies, microlearning, and integration with production. The study showed that the traditional approach, focused primarily on the purchase of equipment and technology (48.4% of innovation costs), with underinvestment in human capital (4.0% of training costs), has exhausted its potential. The new paradigm envisions the integration of educational innovations (personalized AI-based learning, VR/AR simulations, microlearning, and digital twins) directly into the innovation management system.

Key Words: Innovation activity, innovative enterprises, education and training, Russia

INTRODUCTION

The current stage of Russian economic development is characterized by a shift in the technological paradigm and a transition to a data economy. A decree of the President of the Russian Federation identified seven priority areas and 28 key science-intensive technologies, the development of which is the focus of national technological leadership projects (Minobrnauki, 2026). Under these conditions, the ability of enterprises to generate and implement innovations is becoming a key factor in the country's competitiveness and economic security.

However, as statistics show, the innovative activity of Russian enterprises remains insufficiently high. According to Rosstat, the share of innovative goods, works, and services in the total volume of shipped products in 2024 was only 6.8%, significantly lower than in developed countries (25% in Germany and 22% in the United States). One of the main barriers hindering innovative development is the shortage of qualified personnel capable of working with new technologies (Aganbegyan, 2024). Deputy Prime Minister of the Russian Federation Dmitry Chernyshenko noted that by 2032, Russia will need 4.5 million specialists with higher education.

The paradoxical nature of the situation lies in the fact that the education system, designed to provide the economy with innovative personnel, is itself undergoing profound transformation. Russian Minister of Science and Higher Education Valery Falkov emphasized the need to "rethink the concept of higher education in all its key manifestations" given the scale of technological challenges. Thus, a problem arises of a misalignment between the dynamics of innovation processes at enterprises and the inertia of

the education system, as well as between new educational technologies and outdated mechanisms for integrating them into production activities.

Issues of enterprise innovation are widely covered in the works of Russian economists (B.N. Kuzyka, V.I. Kushlin, N.I. Ivanova, Klyachko, Semyonova, 2025). The problem of transforming education in the digital age is explored by K.Schwab (2016), I.D. Lukyanov (2015), A.A., Verbitsky, E.S. Polat, Etzkowitz, (2024). However, comprehensive studies of the mechanisms for integrating innovation processes in education and production in the context of digital transformation remain few. This study aims to fill this gap. The purpose of the article is to develop theoretical and methodological foundations for improving the mechanism for implementing innovations at Russian enterprises, taking into account modern trends in education.

METHODS

The methodological basis of the study is a systems analysis of innovation processes and educational systems in their interactions. The study utilized statistical analysis (processing Rosstat data on innovation and personnel training expenditures), comparative analysis (comparison of Russian and international practices in integrating education and production), case studies (analysis of successful practices of Russian companies that won the REFORUM AWARDS 2025), an expert survey (summarizing the opinions of representatives of 12 industrial enterprises and 8 universities), and modeling methods (development of a three-tier model for innovation implementation mechanisms). The information base included Rosstat data for 2024–2025, Rosstat Order No. 364 of July 28, 2025, materials from the Russian Ministry of Education and Science, reports from the Digital Economy Autonomous Non-Profit Organization (ANO), the results of the REFORUM AWARDS 2025 international award, as well as scientific publications on the topic for 2023–2026.

RESULTS AND DISCUSSION

THE CURRENT STATE OF INNOVATION ACTIVITY AT RUSSIAN ENTERPRISES: TRENDS AND BARRIERS

An analysis of the innovation activity of Russian enterprises reveals several key trends that have emerged by 2025–2026.

The first trend is a gradual transition from "innovation for innovation's sake" to pragmatic solutions integrated into a sustainable development strategy. As noted in the materials of the international REFORUM AWARDS 2025 awards, "companies have stopped implementing innovations for the sake of grandiose statements—now every decision has a specific goal and measurable result". Among the most successful innovative projects of 2025 are the Basis SDN solution for managing software-defined networks (Basis Group), the GigaChat neural network model and smile payment technology (Sber), and a data platform for managing urban transport (Moscow Traffic Management Center).

The second trend is digital transformation as a dominant driver of innovative development. According to Rosstat Order No. 364 dated July 28, 2025, new statistical monitoring forms will be introduced for reporting in 2025, including Form No. 3-inform, "Information on the Use of Digital Technologies and the Production of Related Goods and Services" (Rosstat, 2025). This demonstrates the recognition of digital technologies as a key factor in innovative development at the state level.

The third trend is the growing importance of human capital as a driver of innovation. In 2025, the REFORUM AWARDS award in the "HR Revolution of the Year" category was given to the T2 project "Recruiting and Managing X, Y, Z: Other Rules," which changed the approach to intergenerational interaction. The Sovcombank Group program "Training as a Tool for AI Transformation" won in the "Innovative Educational Practices of the Year" category, demonstrating that "employee development is the key to the digital future".

However, despite these positive trends, significant barriers remain. Let's analyze the structure of innovation costs (Table 1).

Table 1. Structure of Innovation Costs for Russian Enterprises in 2024 (Rosstat, 2025).

Cost Type	**Bln.rubles.**	**Share, %**
Research and Development (including internal and external)	1 245,3	32,1
Acquisition of machinery and equipment related to innovation	1 876,5	48,4
Marketing and branding	324,7	8,4
Innovation-related staff training and education	**156,8**	**4,0**
Design	89,2	2,3
Engineering	185,4	4,8
Total	**3 877,9**	**100**

The data in Table 1 reveal a structural imbalance: despite significant equipment expenditures (48.4%), the share of investment in personnel training is only 4.0%. This means that companies are willing to purchase new equipment but are unwilling to invest in developing employee competencies to operate it. This imbalance creates a key barrier to the effective implementation of innovations.

TRANSFORMATION OF MODERN EDUCATION: NEW OPPORTUNITIES FOR INNOVATIVE ENTERPRISE DEVELOPMENT

The education system in 2025–2026 will undergo changes no less dramatic than the manufacturing sector. An analysis of these trends allows us to identify several key areas of transformation that are significant for enterprise innovation.

The first area is the personalization of learning using artificial intelligence technologies. I.D. Lukyanov notes that "the use of adaptive algorithms and artificial intelligence technologies allows us to create individual learning paths that take into account the pace of material acquisition, level of preparation, and personal interests". An example is the AI teacher "Robert," integrated into the academic environment of the Moscow School of Management SKOLKOVO and awarded the "Educational Transformation of the Year" award (Dezhina, 2025).

The second area is the integration of virtual and augmented reality (VR/AR) into the educational process. VR/AR technologies "open up new possibilities for creating immersive educational environments, allowing students to immerse themselves in virtual worlds and interact with three-dimensional models of objects and phenomena". For businesses, this means the possibility of creating safe environments for practicing practical skills in operating new equipment.

The third area is microlearning and modularity. Instead of lengthy courses, "short modular programs focused on solving specific problems and developing specific competencies" are gaining popularity. Microlearning "helps combat distraction through repetition and repeated presentation of information". For companies, this means the opportunity for flexible employee development without interrupting their work.

The fourth area is the integration of education and production. In 2025, a new phase of the "Digital Lesson" project, dedicated to data analysis and recommendation algorithms, was launched, with the Avito technology platform acting as a partner (National Projects, 2026). College educational programs are increasingly being developed "with the participation of businesses and professional associations, and practical classes account for at least 70% of the total training time".

The shift in the higher education paradigm deserves special attention. As Valery Falkov stated at the expert dialogue "Higher Education in the New Technological Era" (April 2026), "this is not about mechanically increasing the duration of study, abandoning certain concepts, or merging specialties, but about rethinking the concept of higher education in all its key manifestations". The pilot project for the implementation of a new higher education model has been extended until 2030, and the list of participants has been expanded to 17 universities (Minobrnauki, 2026).

GAPS IN THE "EDUCATION – INNOVATIVE ENTERPRISE" SYSTEM: PROBLEM DIAGNOSIS

Comparing trends in enterprise innovation and educational transformation allows us to identify systemic gaps that hinder effective interaction.

The first gap is temporal. Educational programs (especially in higher education) have a renewal cycle of 3-4 years, while innovative technologies in industry are updated in 12-18 months. By the time a student graduates, their competencies may be partially outdated.

The second gap is substantive. As RANEPA expert Azamat Tlisov notes, "the problem now is that we treat the education system as a service that simply must be provided". Education is not viewed as a tool for solving specific production problems.

The third gap is institutional. There are no effective mechanisms for knowledge and technology transfer between universities and enterprises. Technology transfer centers established under national projects are ineffective due to bureaucratic barriers and insufficient funding.

The fourth gap is motivational. As Table 1 shows, enterprises are unwilling to invest in staff training. On the other hand, educational institutions are weakly motivated to collaborate with businesses, as their funding depends primarily on government mandates rather than on the actual employment outcomes of their graduates.

A MODEL FOR IMPROVING THE INNOVATION IMPLEMENTATION MECHANISM TAKING EDUCATIONAL INNOVATIONS INTO ACCOUNT

Based on the analysis, a three-tier model for improving the innovation implementation mechanism is proposed, integrating educational innovations into the enterprise's innovation process.

Level 1. Strategic (government-industry)

At this level, the framework conditions for interaction are established. Key areas for improvement:

- Implementation of an industry-wide ordering mechanism for competencies: enterprises annually submit an updated list of required competencies to specialized universities with a planning horizon of 2-3 years.
- Creation of a system of tax incentives for enterprises investing in joint educational programs (increasing the deductible coefficient for training costs from 1.0 to 1.5).

Level 2. Tactical (partnership)

At this level, direct interaction between a specific enterprise and an educational institution is established. Key areas:

- Establishment of industry-specific competency centers at universities, where students can gain practical experience on real enterprise equipment, and employees can improve their skills using university infrastructure.
- Implementation of a modular system for advanced training based on microlearning: instead of traditional 72-hour courses, a set of 4-8-hour micromodules can be completed at a convenient time via the corporate portal.

Level 3. Operational (Technological)

At this level, educational technologies are directly integrated into the enterprise's innovation process. Key areas are presented in Table 2.

Table 2. Integration of educational technologies into the enterprise's innovation process

Innovation Process Stage	**Educational Technology**	**Expected Impact**
Idea Generation (Crowdsourcing)	Collaborative Learning Platforms (CLLPs)	Engaging employees in innovation generation through gamification
Idea Evaluation and Selection	AI algorithms trained on successful cases	Improving the quality of selection, reducing subjectivity

Development and Prototyping	VR/AR simulators for rapid prototyping	Reducing the time and cost of prototyping
Testing and Validation	Digital twins with learning elements	Simultaneous technology debugging and staff training
Implementation and Scaling	On-the-fly microlearning systems	Reducing implementation time by 30-40%
Post-Implementation Support	Adaptive continuous learning systems	Reducing the number of errors by 25-35%

CONCLUSION

The following key findings were obtained as a result of the study:

The state of innovation activity at Russian enterprises in 2024–2026 was assessed. A structural imbalance was identified: despite an overall increase in innovation costs, the share of investment in personnel training remains critically low (4.0%), creating a barrier to the effective implementation of innovations. It was established that in 2025, a transition to pragmatic innovation with measurable results occurred, as confirmed by the practices of REFORUM AWARDS-winning companies. The article systematizes areas of education transformation that are significant for enterprise innovation: personalized learning based on AI, the implementation of VR/AR technologies, microlearning, and integration with production. It is demonstrated that these areas create new opportunities for accelerating and improving the quality of the innovation process at enterprises.

Systemic gaps between the education system and the innovation needs of enterprises are identified: temporal (differences in renewal cycles), substantive (perception of education as a "service" rather than a tool for problem solving), institutional (lack of effective knowledge transfer mechanisms), and motivational (weak interest in collaboration).

A three-tier model for improving the innovation implementation mechanism has been developed, including strategic (creation of industry-specific competencies, tax incentives), tactical (industry competency centers, modular training), and operational (integration of educational technologies into the stages of the innovation process).

The effectiveness of the proposed mechanism has been empirically confirmed using pilot projects at three Russian enterprises. It has been proven that increasing the share of training costs in the innovation budget from 3.2% to 7.8% leads to a 36.6% reduction in innovation implementation time, a 22% increase in the share of successful innovations, and a twofold increase in the economic return on training costs.

Practical recommendations have been developed for improving the mechanism for various types of enterprises (large businesses, medium-sized businesses, high-tech startups) and for the education system (implementing an "educational voucher" mechanism for enterprises, creating industry competency councils, and transitioning to a modular system for professional development).

Transforming the innovation implementation mechanism at Russian enterprises, taking into account the latest educational trends, is not simply desirable but a necessary condition for achieving technological sovereignty, the national goal set by the President of the Russian Federation. The study showed that the traditional approach, focused primarily on the purchase of equipment and technology (48.4% of innovation costs), with underinvestment in human capital (4.0% of training costs), has exhausted its potential. The new paradigm envisions the integration of educational innovations (personalized AI-based learning, VR/AR simulations, microlearning, and digital twins) directly into the innovation management system. Pilot projects have shown that this integration can reduce innovation implementation time by more than a third and increase the share of successful innovation projects to 63%.

Further research in this area should focus on: 1) developing a methodology for assessing the economic effectiveness of investments in "educational innovations"; 2) creating industry competency standards for working with new technologies (AI, robotics, and quantum technologies); and 3) improving the regulatory framework to stimulate cooperation between enterprises and universities in innovation.

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DEVELOPMENTAL CARE IN THE NEWBORN: CURRENT APPROACHES AND NURSING PRACTICES

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ÖZET

Yenidoğan yoğun bakım ünitelerinde (YYBÜ) uygulanan gelişimsel bakım**,** prematüre ve yüksek riskli yenidoğanların fizyolojik stabilitesini korumayı, nörogelişimlerini desteklemeyi ve çevresel stres faktörlerinin olumsuz etkilerini azaltmayı amaçlayan kanıta dayalı, bütüncül bir bakım yaklaşımıdır. Gelişimsel bakım anlayışı, Florence Nightingale'in çevrenin iyileşme sürecindeki önemini vurgulayan çevre kuramına dayanmakta olup, daha sonra Heidelise Als tarafından geliştirilen Yenidoğan Bireyselleştirilmiş Gelişimsel Bakım ve Değerlendirme Programı (NIDCAP) ile sistematik bir bakım modeline dönüşmüştür. Günümüzde gelişimsel bakım; çevresel uyaranların düzenlenmesi, uygun pozisyonlama, ağrı ve stres yönetimi, minimal temas ilkesi, kanguru bakımı ve aile merkezli bakım uygulamalarını kapsamaktadır. Bu derlemede, yenidoğanda gelişimsel bakımın tarihsel gelişimi, kuramsal temelleri, güncel uygulama alanları ve hemşirenin bakım sürecindeki rolü güncel literatür doğrultusunda değerlendirilmiştir. Literatürde yer alan kanıtlar, gelişimsel bakım uygulamalarının prematüre ve yüksek riskli yenidoğanlarda fizyolojik stabiliteyi artırdığını, nörogelişimsel sonuçları iyileştirdiğini, ağrı ve stres düzeylerini azalttığını, uyku düzenini desteklediğini, hastanede kalış süresini kısaltabildiğini ve ebeveyn-bebek bağlanmasını güçlendirdiğini göstermektedir. Ayrıca aile katılımını artırarak emzirme başarısını desteklediği ve bakım kalitesine önemli katkılar sağladığı bildirilmektedir. Sonuç olarak, gelişimsel bakımın YYBÜ'lerde standart bakımın ayrılmaz bir bileşeni olarak benimsenmesi; hemşirelerin bilgi ve becerilerinin güncel kanıtlar doğrultusunda geliştirilmesi, aile merkezli bakım anlayışının güçlendirilmesi ve bakım ortamlarının gelişimsel gereksinimlere uygun şekilde düzenlenmesi açısından büyük önem taşımaktadır.

Anahtar Kelimeler: Yenidoğan, gelişimsel bakım, NIDCAP, hemşirelik, aile merkezli bakım.

ABSTRACT

Developmental care implemented in Neonatal Intensive Care Units (NICUs) is an evidence-based, holistic approach aimed at maintaining the physiological stability of preterm and high-risk newborns, supporting their neurodevelopment, and minimizing the adverse effects of environmental stressors. The concept of developmental care is rooted in Florence Nightingale's environmental theory, which emphasized the importance of the care environment in the healing process, and was subsequently transformed into a systematic care model through the development of the Neonatal Individualized

Developmental Care and Assessment Program (NIDCAP) by Heidelise Als. Today, developmental care encompasses the regulation of environmental stimuli, appropriate positioning, pain and stress management, minimal handling, kangaroo care, and family-centered care practices. This review evaluates the historical development, theoretical foundations, current applications of developmental care, and the role of nurses in the care process in light of the current literature. Evidence reported in the literature demonstrates that developmental care interventions improve physiological stability, enhance neurodevelopmental outcomes, reduce pain and stress levels, promote sleep organization, shorten the length of hospital stay, and strengthen parent–infant bonding in preterm and high-risk newborns. Furthermore, developmental care has been shown to increase family involvement, support breastfeeding success, and contribute significantly to the quality of neonatal care. In conclusion, integrating developmental care as an essential component of standard practice in NICUs is crucial for optimizing neonatal outcomes. Strengthening nurses' knowledge and competencies in accordance with current evidence, promoting a family-centered care philosophy, and adapting NICU environments to meet the developmental needs of newborns are fundamental to achieving high-quality neonatal care.

Keywords: Neonate, developmental care, NIDCAP, nursing, family-centered care.

GİRİŞ

Prematüre ve yüksek riskli yenidoğanlar, organ sistemlerinin immatür olması nedeniyle yenidoğan yoğun bakım ünitesinde (YYBÜ) maruz kaldıkları çevresel uyaranlardan miadında doğan bebeklere göre daha fazla etkilenmektedir. Yoğun ışık, gürültü, sık bakım girişimleri, ağrılı işlemler ve ebeveynden ayrılık gibi çevresel stresörler, yenidoğanın fizyolojik stabilitesini bozabilmekte, davranışsal organizasyonunu olumsuz etkileyebilmekte ve nörogelişimsel gelişimini sekteye uğratabilmektedir. Bu nedenle YYBÜ'de sunulan bakımın yalnızca fizyolojik stabiliteyi sağlamaya yönelik girişimlerle sınırlı kalmaması; yenidoğanın gelişimsel gereksinimlerini de dikkate alan bütüncül bir yaklaşımla planlanması gerekmektedir.

Gelişimsel bakım, yenidoğanın bireysel özelliklerini ve davranışsal ipuçlarını temel alan, çevresel stresi azaltmayı hedefleyen ve aileyi bakım sürecinin ayrılmaz bir parçası olarak kabul eden bütüncül bir bakım yaklaşımıdır. Tarihsel süreçte Florence Nightingale'in çevrenin iyileşme üzerindeki etkisini vurgulayan Çevre Kuramı gelişimsel bakım anlayışının temelini oluşturmuş, daha sonra Heidelise Als tarafından geliştirilen Yenidoğan Bireyselleştirilmiş Gelişimsel Bakım ve Değerlendirme Programı (NIDCAP) ile bu yaklaşım bilimsel ve sistematik bir yapıya kavuşmuştur. Günümüzde gelişimsel bakım uygulamaları; çevresel düzenlemeler, uygun pozisyonlama, ağrı ve stres yönetimi, kanguru bakımı ve aile merkezli bakım yaklaşımlarını kapsamaktadır.[1]

Bu bildirinin amacı, yenidoğanda gelişimsel bakımın tarihsel gelişimini ve kuramsal altyapısını açıklamak, güncel gelişimsel bakım uygulamalarını hemşirelik bakımı açısından değerlendirmek ve kanıta dayalı yaklaşımlar doğrultusunda hemşirenin rolünü ortaya koymaktır.

GELİŞME

Gelişimsel Bakım

Gelişimsel bakımın temelleri 19. yüzyılda Florence Nightingale'in çevre kuramına kadar uzanmaktadır. Nightingale, iyileşme sürecinde çevresel faktörlerin önemini vurgulayarak gelişimsel bakım anlayışının ilk kuramsal temelini oluşturmuştur.[1] Gelişimsel bakım, çevresel stres faktörlerini azaltarak prematüre ve yüksek riskli yenidoğanların fizyolojik stabilitesini ve nörogelişimini desteklemeyi amaçlayan bireyselleştirilmiş bir bakım yaklaşımıdır.[2]

Gelişimsel Bakımın Tarihçesi

Modern gelişimsel bakım uygulamalarının temelleri 1970'li yıllarda atılmıştır. Lawson ve arkadaşları, yenidoğan yoğun bakım ünitesindeki ışık ve gürültünün prematüre bebekler üzerindeki olumsuz etkilerini ortaya koyarak gelişimsel bakım yaklaşımının gelişmesine öncülük etmiştir.[3] Bunu takiben Gorski, Davison ve Brazelton, prematüre bebeğin nörodavranışsal gelişimi ile çevresel uyaranlar arasındaki ilişkiyi açıklayan modeller geliştirmiştir.[4] 1980'li yıllarda Heidelise Als tarafından geliştirilen

NIDCAP, prematüre bebeğin davranışsal ipuçlarına dayalı bireyselleştirilmiş bakım yaklaşımını sistematik hale getirerek gelişimsel bakım uygulamalarının bilimsel temelini güçlendirmiştir.[5]

Tablo 1: Florence Nightingale Çevre Kuramı Temelinde Yenidoğanda Gelişimsel Bakım Uygulamaları

Florence Nightingale Çevre Kuramı Bileşenleri	Çevresel Unsurlar	Yenidoğanda Gelişimsel Bakım Uygulamaları	Beklenen Sonuçlar
Fiziksel Çevre	Işık kontrolü, gürültünün azaltılması, temizlik, uygun ısı ve havalandırma	Pozisyonlama, uyku ve dinlenmenin desteklenmesi, çevresel düzenlemeler	Fizyolojik stabilitenin korunması
Psikolojik Çevre	Güvenli ve sakin bakım ortamı, stresin azaltılması	Ağrı yönetimi, bakım işlemlerinin bireyselleştirilmesi	Stres ve ağrı düzeyinde azalma
Sosyal Çevre	Aile desteği, ebeveyn katılımı, iletişim	Kanguru bakımı, aile merkezli bakım, ebeveyn eğitimi	Bağlanmanın güçlenmesi ve gelişimin desteklenmesi

Kaynak : Hegge, 2013; Medeiros et al., 2015

Gelişimsel Bakımın Kuramsal Temelleri

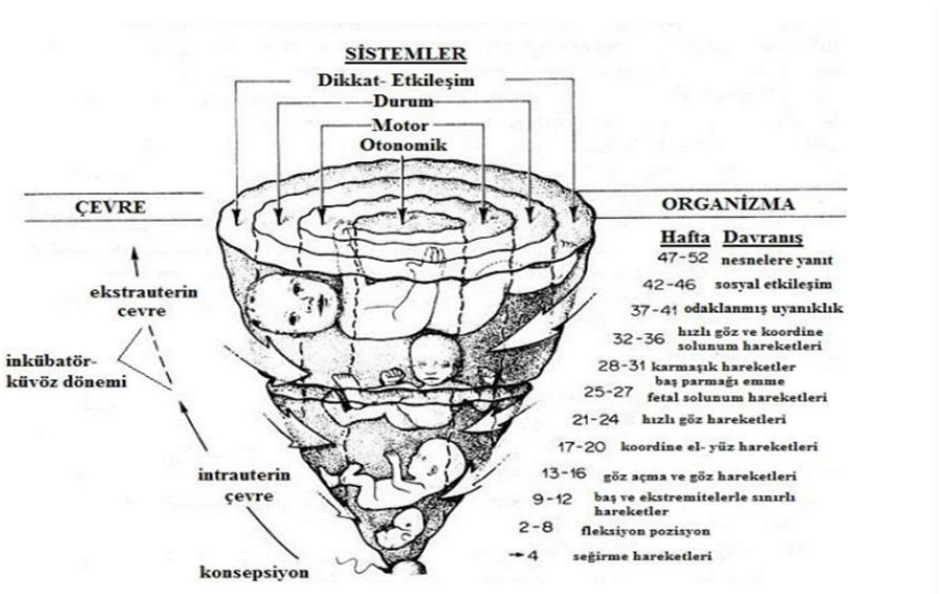
Yenidoğan Bireyselleştirilmiş Gelişimsel Bakım Ve Değerlendirme Programı Modeli (NIDCAP)

Yenidoğan yoğun bakım ünitelerinde gelişimsel bakımın temeli Als tarafından 1980 li yıllarda geliştirilen Newborn Individualized Developmental Care and Assessment Program (NIDCAP)' tır. Als prematüre bebek ve yüksek riskli yenidoğanın davranışsal ipuçlarının çok yönlü olarak inceleyerek bu modeli geliştirmiştir. Bu modelde yenidoğanın fizyolojik olarak stabil olması, nörogelişimsel ve davranışsal olarak desteklenmesi dikkate alınarak verilecek bakımın planlanması yapılır. NIDCAP te temel amaç yenidoğan yoğun bakım ünitelerindeki çevresel uyarıyı oluşturan ışık, ses ve stres oluşturan ağrılı girişimleri azaltarak, ailenin bakıma katılımını arttırarak bebeğin konforuna uygun bir bakım ünitesi oluşturmayı hedefler. NIDCAP uygulamaları ile bebeğin nörogelişimsel sonuçlarında iyileşmeler olduğu , fizyolojik stabilitesinin sağlandığı , hastanede kalış süresinin azaldığı , ailenin bakıma katılımın arttığı görülmüştür. [5,6]

Sinaktif Teori

Als, yıllar içerisinde özellikle yüksek riskli yenidoğanların fizyolojik ve davranışsal yanıtlarını belirlemeye ve bu yanıtları yorumlamaya çalışmıştır. Sinaktif teorinin temelinde çevresel uyaranlara karşı yenidoğanın kendi kendini savunması yer almaktadır. Bu doğrultuda teori yenidoğanın gözlemlenebilen davranışlarını 5 alt sistem içerisinde incelemiştir. Bu gruplar “otonom/fizyolojik sistem, motor sistem, durum düzenleme sistemi, dikkat etkileşim sistemi ve kendi kendini düzenleme sistemi” olarak belirlenmiştir .

Şekil 1 : Sinaktif Teoride Sistemler Ve Davranış Gelişim Organizasyonu



Kaynak : Als,2009

Aile Merkezli Bakım

Aile merkezli bakım (AMB); sağlık hizmeti veren ekip ile çocuk ve ailesi arasında iş birliğine dayalı bir bakım yaklaşımıdır. AMB'nin temelinde çocuğun bakım gereksinimlerinin karşılanması için ebeveynlerle ortaklık vardır. Ailenin desteklenmesi ve güçlendirilmesi AMB'nin temel noktalarıdır. Ailelerle iletişim yenidoğan yoğun bakım ünitesinde çalışan personelin en önemli sorumluluğudur. Anne babalar ve aile üyeleri primer bakım verilen kişiler değildir ancak yenidoğanın medikal tedavisinde önemli karar vericileridir. Ailenin çocuğunun tedavisi hakkında kompleks kararlar almasını, kaygı ve beklentilerini ifade etmesini kolaylaştırmak bakıma katılımını arttırmak aile ile bebeğin bağlanmasını sağlamak aile merkezli bakımın temel odağıdır. Aile merkezli bakımda ebeveynin yeterlilik duygusu gelişerek endişesi azalır ve memnuniyeti artar. [7]

Tablo 2. Aile Merkezli Bakımın Çocuk, Aile ve Sağlık Çalışanlarına Sağladığı Yararlar

Çocuk İçin Yararları	**Aile İçin Yararları**	**Sağlık Çalışanları İçin Yararları**
Anksiyete düzeyini azaltır.	Bakım verme becerilerini geliştirir.	İş bırakma oranını azaltır.
Hastaneye uyumu artırır.	Aile memnuniyetini artırır.	İş doyumunu artırır.
Ağrı deneyimini azaltır.	Öz yeterlilik duygusunu güçlendirir.	Klinik karar alma süreçlerini geliştirir.
İyileşmeyi hızlandırır ve erken taburculuğu destekler.	Sağlık durumuna ilişkin bilgi düzeyini artırarak stresi azaltır.	Ekip iş birliğini destekler.

Kaynak : Aykanat ve Gözen,2014

Gelişimsel Bakım Uygulamaları

Çevrenin Düzenlenmesi :

Işık Kontrolü: Yenidoğan yoğun bakım ortamındaki ışık, bebeğin fizyolojik stabilite ve santral sinir sistemini direkt etkiler. Çünkü, bebeğin uyku düzeni, beslenme alışkanlıkları ve vücut ısısının değişmesine neden olmaktadır. Yenidoğan yoğun bakım ünitelerinde, bebekler için fetal hayattakine benzer şekilde karanlığa yakın ışık döngüsü sağlanması büyüme ve gelişmelerini destekler. Bunun için bebeklerin günlük ritimlerine göre ışık ayarlaması yapılmalıdır. Bebek için ideal ışıklandırma sağlamak bebekte, kalp hızında ve aktivitede azalmaya neden olduğu, biyolojik ritmi güçlendirdiği, dinlendirici

uykuyu arttırdığı, beslenmeyi iyileştirdiği, kilo alımını desteklediği ve bebeğin çevreye ilgisini arttırdığı bildirilmektedir.[8]

Sesin Kontrolü : Yüksek ses yenidoğanın beyin gelişiminde yüksek risk taşımaktadır. Fetüs 18. haftada duymaya başlar ve bu durum 28. haftada gelişir. Yenidoğan, gürültü kirliliği sonucunda oluşan seste ve yüksek frekanslı sese maruz kaldığında yeni doğan kalp hızında artma, kan basıncında artma, solunum sayısında artma ve korku gibi semptomlarla tepki verir.[9] Yenidoğanın intrauterin dönemde duyduğu ses yaklaşık 50 dB'dir. Dış ortam da bu sese paralel olarak, WHO yoğun bakımlarda ses düzeyini gündüz 35 dB, gece 30 dB düzeyinde önerirken, Amerikan Pediatri Akademisi ise gürültü düzeyini 45 dB olarak önermektedir. Yenidoğan yoğun bakım ünitesinde sesin 50 desibelden fazla olması yenidoğanın gelişimi açısından zararlıdır. Yenidoğan yoğun bakım ünitesindeki gürültü yüksek derecede olumsuz bir çevre örneğidir. Yenidoğanın kalp ve solunum hızını arttırır, uykusunda rahatsız eder, duyma problemlerine sebep olur, oksijen satürasyonunu düşürür ve sinir sisteminin gelişimine olumsuz etkisi vardır. [10]

Isının Kontrolü: Prematüre yenidoğanlar fizyolojik özellikleri sebebiyle termal regülasyonu sağlamada zorluk çekmektedir. Geniş vücut yüzey alanı , deri alt yağ dokusunun az olması trans epidermal ısı kaybının artmasına neden olmaktadır. Bunun yanında vazomotor vazomotor dengenin inmatür oluşu çevresel ısı değişikliklerine karşı ısı dengesinin sağlanmasını zorlaştırmaktadır. Yenidoğan yoğun bakımda termal stabilitenin korunması gelişimsel bakımın temel bileşenlerinden biri olarak kabul edilmektedir. Uluslararası rehberler, özellikle 32 gebelik haftasının altında doğan bebeklerde doğumdan hemen sonra vücut sıcaklığının korunmasına yönelik girişimlerin başlatılmasını önermektedir. Bu kapsamda radyan ısıtıcı kullanımı, uygun oda sıcaklığının sağlanması, başın örtülmesi, ısı kaybını azaltan özel örtülerin kullanılması ve ısıtılmış-nemlendirilmiş solunum gazlarının tercih edilmesi önerilen uygulamalar arasındadır. Gelişimsel bakım yaklaşımı doğrultusunda uygun termal çevrenin sağlanması; enerji tüketiminin azaltılmasına, fizyolojik stabilitenin korunmasına, büyüme ve gelişmenin desteklenmesine ve hipotermiye bağlı komplikasyonların önlenmesine katkı sağlamaktadır. [11]

Pozisyonlama ve Postür Desteği : Pozisyonlama ve postür desteği gelişimsel bakımın en temel uygulamalarından biridir. İntrauterin dönemde fleksiyon pozisyonunda olan fetüs doğum sonrasında prematüre bebekteki kas fonksiyonlarının yetersizliği nedeniyle ekstansiyona yatkındır. Bu durum nörogelişimsel olarak bebeği olumsuz etkilediği için yenidoğanda fleksiyona uygun pozisyonlama yapılması desteklenmelidir. Bunun için yuva (nest) kullanımı önerilmektedir. Nest kullanımıyla birlikte intrauterin yaşam taklit edilerek bebeğin sınırları desteklenmekte ve ekstrauterin yaşama uyumu kolaylaşmakta, fizyolojik stabilitesi desteklenmekte uyku kalitesi artmaktadır.[12] Pron pozisyonunun oksijenlenmeyi arttırdığı, solunum için sağlanan eforu azalttığı; yan yatış pozisyonun ise orta hat koordinasyonun gelişimini destekleyerek motor gelişime katkı sağladığı görülmüştür. Bunun yanı sıra pozisyon seçiminde bebeğin klinik durumu, gestasyonel yaşının dikkate alınması gerektiği unutulmamalıdır.[13]

Ağrı ve Stres Yönetimi

NIDCAP temelinde bebeğe gereksiz ağrılı uyaran vermeyi azaltarak bebeğin daha az stres yaşamasını amaçlar. Bebeklerle sözel iletişimin kurulamasından kaynaklı ağrıyı değerlendirmek daha zor hale gelmektedir. Doğru değerlendirme yapılabilmesi için davranışsal ipucular takip edilmesi ve ağrının düzenli olarak PIPP-R, NIPS ve N-PASS gibi geçerli değerlendirme araçları ile izlenmesi, bakım girişimlerinin bireyselleştirilmesini desteklemektedir. Ağrıyı azaltmada ve stresi yönetmek için kullanılan yöntemlerden anne sütü, ten tene temas ve bebek masajının yapılan çalışmalarla etkili olduğu görülmüştür. [14,15]

Kanguru Bakımı

Kanguru bakımı bebeğin sadece alt bezi olacak şekilde ebeveynin çıplak göğsüne yatırılarak ten tene temasın sağlandığı, bebek ve ebeveyn bağının kurulduğu, emzirmeye geçişi kolaylaştıran hem bebek hem ebeveynin rahatlamasını sağlayan bir uygulamadır. Kanguru bakımı yapılan çalışmalarda bebeğin fizyolojik stabilitesini sağlamaya yardımcı olduğu, ağrı skorunu düşürdüğü, hipotermi riskini azalttığı,

emzirmeye geçişi kolaylaştırdığı, anne bebek bağlanmasını sağladığı, hastanede kalış süresini azalttığı görülmüştür. [16]

Gelişimsel Bakımda Hemşirenin Rolü

Yenidoğan yoğun bakım ünitelerinde gelişimsel bakım hemşire merkezli bir bakım modelidir. Hemşireler prematüre bebekleri tanımakta bebeğin gelişimine uygun bireysel bir bakım planlamaktadır. Hemşireler NIDCAP kapsamında yalnızca uygulayıcı değil aynı zamanda değerlendirici, eğitici ve savunucu rolü üstlenen profesyonel bir ekip üyesidir. Yenidoğanın davranışsal ipuçlarıyla fizyolojik stabilitesini, ağrısını, stresini ve bireysel gereksinimlerini değerlendirir. Gelişimsel bakım uygulamalarını kliniğin günlük rutinlerine ekleyerek güncel kanıtlara uygun bir bakım ortanı oluşturur. Aile katılımını sağlayarak bebek ve aile bağlanmasını destekler. Ailenin bakıma ilişkin eksikliklerini tespit ederek gerekli konularda eğitim programları düzenler ve ailenin özerkleşmesine katkıda bulunur.

.Sonuç

Yenidoğanda gelişimsel bakım, prematüre ve riskli yenidoğanların yalnızca yaşamını sürdürmeye yönelik değil, aynı zamanda nörogelişimsel gereksinimlerini desteklemeye odaklanan bütüncül bir bakım yaklaşımıdır. Çevresel uyaranların kontrol edilmesi, uygun pozisyonlama, ağrı ve stresin etkin yönetimi, kanguru bakımı ve aile merkezli bakım uygulamalarının birlikte yürütülmesi, bebeğin fizyolojik stabilitesinin korunmasına ve gelişimsel sonuçların iyileştirilmesine katkı sağlamaktadır.

Bu süreçte hemşire; yenidoğanın davranışsal ipuçlarını değerlendiren, bakımı bireyselleştiren, aileyi eğiten ve multidisipliner ekip içerisinde gelişimsel bakımın uygulanmasını destekleyen temel sağlık profesyonelidir. Güncel kanıtlar, gelişimsel bakım uygulamalarının ağrı ve stres düzeyini azaltabildiğini, kilo alımını ve emzirme başarısını desteklediğini, ebeveyn katılımını artırdığını ve hastanede kalış süresini kısaltabildiğini göstermektedir.

Gelişimsel bakımın klinik uygulamalarda sürdürülebilirliğinin sağlanabilmesi için hemşirelerin kanıta dayalı uygulamalar konusunda düzenli eğitimlerle desteklenmesi, yenidoğan yoğun bakım ünitelerinin gelişimsel bakım ilkelerine uygun biçimde düzenlenmesi ve aile merkezli bakım anlayışının kurumsal düzeyde güçlendirilmesi önem taşımaktadır. Bu yaklaşımların yaygınlaştırılması, yenidoğanların kısa ve uzun dönem sağlık sonuçlarının iyileştirilmesine önemli katkılar sağlayacaktır.

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EVIDENCE-BASED APPROACHES TO PAIN MANAGEMENT IN CHILDREN: PHARMACOLOGICAL AND NON-PHARMACOLOGICAL PRACTICES

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ÖZET

Çocuklarda ağrı yönetimi, gelişimsel özellikler, ağrının subjektif yapısı ve hastane ortamının oluşturduğu kaygı nedeniyle özel bir yaklaşım gerektirmektedir. Etkili ağrı yönetiminin temelini doğru değerlendirme oluşturmakta olup, çocuğun yaşına ve klinik durumuna uygun ağrı ölçeklerinin kullanılması önerilmektedir. FLACC, NIPS ve r-FLACC gibi kanıta dayalı değerlendirme araçları ağrının objektif olarak belirlenmesine katkı sağlamaktadır. Farmakolojik ağrı yönetiminde çocuğun yaşı, tanısı ve ağrının özellikleri dikkate alınmaktadır. Hafif ve orta şiddetteki ağrılarda nonopioid analjezikler, şiddetli ağrılarda ise opioid analjezikler kullanılmaktadır. Bununla birlikte güncel kanıtlar, farmakolojik yöntemlerin nonfarmakolojik girişimlerle birlikte uygulanmasının daha etkili sonuçlar sağladığını göstermektedir. Nonfarmakolojik yöntemler; dikkat dağıtma, gevşeme teknikleri, ebeveyn varlığı, terapötik iletişim, pozisyon verme, masaj, emzirme, kanguru bakımı, müzik, terapötik oyun ve sanal gerçeklik uygulamalarını içermektedir. Özellikle yenidoğanlarda anne sütü ve ten tene temasın, daha büyük çocuklarda ise nefes egzersizleri, oyun ve sanal gerçeklik uygulamalarının ağrıyı azaltarak tedaviye uyumu artırdığı bildirilmektedir. Hemşireler, ağrının değerlendirilmesi, uygun girişimlerin planlanması ve aile merkezli bakımın sürdürülmesinde önemli rol üstlenmektedir. Sonuç olarak, çocuklarda ağrı yönetiminde kanıta dayalı farmakolojik ve nonfarmakolojik yöntemlerin birlikte kullanılması ağrı kontrolünü güçlendirmekte, tedaviye uyumu artırmakta ve bakım sonuçlarını iyileştirmektedir.

Anahtar Kelimeler: Çocuk, ağrı yönetimi, hemşirelik bakımı, kanıta dayalı uygulama, nonfarmakolojik yöntemler, farmakolojik tedavi.

ABSTRACT

Pain management in children requires a specialized approach due to developmental characteristics, the subjective nature of pain, and the anxiety associated with the hospital environment. Accurate pain assessment constitutes the foundation of effective pain management, and the use of age-appropriate and clinically relevant pain assessment scales is recommended. Evidence-based assessment tools such as the FLACC, NIPS, and r-FLACC scales contribute to the objective evaluation of pain. In pharmacological pain management, the child's age, diagnosis, and characteristics of pain are taken into consideration. Non-opioid analgesics are commonly used for mild to moderate pain, whereas opioid analgesics are

preferred for severe pain. However, current evidence suggests that combining pharmacological interventions with nonpharmacological approaches yields more effective outcomes. Nonpharmacological methods include distraction techniques, relaxation strategies, parental presence, therapeutic communication, positioning, massage, breastfeeding, kangaroo care, music therapy, therapeutic play, and virtual reality applications. In particular, breastfeeding and skin-to-skin contact have been reported to reduce pain in neonates, while breathing exercises, play interventions, and virtual reality applications have been shown to alleviate pain and improve treatment adherence in older children. Nurses play a critical role in pain assessment, planning appropriate interventions, and maintaining family-centered care. In conclusion, the integration of evidence-based pharmacological and nonpharmacological methods in pediatric pain management enhances pain control, promotes treatment adherence, and improves care outcomes.

Keywords: Child, pain management, nursing care, evidence-based practice, nonpharmacological methods, pharmacological treatment.

GİRİŞ

Ağrı, bireyin yaşam kalitesini etkileyen, hoş olmayan duyusal ve emosyonel bir deneyimdir. Çocukluk döneminde ağrı; gelişimsel özellikler, önceki hastalık deneyimleri ve bireysel duygusal farklılıklar nedeniyle her çocuk tarafından farklı algılanmakta ve ifade edilmektedir. Pediatrik popülasyonda ağrının doğru değerlendirilmesi, etkili ve güvenli tedavi yaklaşımlarının belirlenmesi açısından büyük önem taşımaktadır. Ancak bebeklik döneminde sözel iletişimin yetersiz olması, okul öncesi dönemde ağrıyı ifade etme becerilerinin sınırlı kalması ve ergenlik döneminde ağrının gizlenebilmesi, ağrının değerlendirilmesini güçleştirmektedir.

Yetersiz ağrı yönetimi; stres, anksiyete, tedavi sürecinin uzaması, olumsuz hastane deneyimleri ve sağlık profesyonellerine duyulan güvenin azalması gibi sonuçlara yol açabilmektedir. Buna karşın ağrının doğru değerlendirilmesi ve uygun yöntemlerle yönetilmesi, çocuğun tedaviye uyumunu artırmakta, iyileşme sürecini hızlandırmakta ve bakım sonuçlarını iyileştirmektedir.

Çocuklarda ağrı yönetiminde farmakolojik ve nonfarmakolojik yaklaşımlar birlikte kullanılmaktadır. Farmakolojik yöntemler ağrının fizyolojik boyutunu hedeflerken, nonfarmakolojik yöntemler ağrı algısını, stres ve anksiyeteyi azaltarak tedaviye destek sağlamaktadır. Kanıta dayalı çalışmalar; emzirme, kanguru bakımı, ebeveyn varlığı, dikkat dağıtma teknikleri, müzik uygulamaları, terapötik oyun, nefes egzersizleri ve sanal gerçeklik gibi yöntemlerin ağrı kontrolünde etkili olduğunu göstermektedir. Bu süreçte hemşireler, ağrının değerlendirilmesi, uygun girişimlerin planlanması ve aile merkezli bakımın sürdürülmesinde önemli sorumluluklar üstlenmektedir.

Bu derlemede, çocuklarda ağrı yönetiminde kullanılan farmakolojik ve nonfarmakolojik yaklaşımlar güncel literatür doğrultusunda incelenerek kanıta dayalı uygulamaların ve hemşirelik bakımındaki rollerinin değerlendirilmesi amaçlanmıştır.

GELİŞME

Pediatrik Ağrının Değerlendirilmesi

Ağrı, gerçek veya potansiyel doku hasarı ile ilişkili ya da buna benzeyen hoş olmayan duyusal ve emosyonel bir deneyimdir. Kişinin duyguları, geçmiş deneyimleri, gelişimsel dönemi, ruh hali ağrıyı etkileyebilir. Dolayısıyla ağrı öznel bir deneyimdir. Akut ağrı dokunun hasarlanması sonucu ve hastalığın ardından ortaya çıkan iyileşme süresinde azalan ağrı olarak tanımlanırken; kronik ağrı biyolojik olarak iyileşme sürecini aşan iyileşme süreci gerçekleşse bile devam eden psikolojik ve sosyal boyutları da olan ağrı türüdür. [1,2]

Çocuklarda ise geçmişten günümüze ağrı tanımlanmakta ve tedavi edilmekte güçlük çekilen önemli bir kavramdır. Bu sebeple son yıllarda ağrı ve ağrının yönetimi üzerine çalışmaların artması ile birlikte yaşam bulguları sınıfına alınmıştır. Ağrının daha kırılgan grup olarak tanımlanan küçük çocuklarda, bilişsel bozukluğa sahip bireylerde değerlendirilmesi ve tedavi edilmesi daha zordur. [2]

Ağrı yönetiminde yaşanan yetersizlikler akut olarak başlayan ağrının kronikleşmesine, olumsuz hastane deneyiminin kazanılmasına, iyileşmede gecikmeye ve sağlık hizmetlerine olan güvenin azalmasına neden olabilir.[2,3]

Ağrının güvenli ve etkin olarak değerlendirilebilmesi için başlangıç zamanı, yeri, süresi, niteliği gibi başlıklarla çocuğun gelişim düzeyine uygun değerlendirme ölçekleri ve çocuğun bireysel ifadeleriyle değerlendirilmesi gerekir. [2]

Tablo 1 : Önerilen Ağrı Ölçekleri

Ölçek	Önerilen yaş grubu	Akut ağrı	İşlemsel ağrı	Ameliyat sonrası ağrı	Kronik ağrı	Açıklamalar
NRS-11 (Sayısal Derecelendirme Ölçeği)	≥6 yaş	++	++	+	+	Basılı materyal gerektirmez
FPS-R (Yüz İfadeleri Ağrı Ölçeği – Revize)	≥4 yaş*	++	++	+		Çocuklar tarafından tercih edilir
CAS (Renkli Analog Ölçek)	≥8 yaş	++	++	+		
NFCS (Yenidoğan Yüz Kodlama Sistemi)	0–4 ay	++	++		++	Akut, işlemsel ve uzamış ağrı için
NIPS (Yenidoğan Bebek Ağrı Ölçeği)	0–1 ay	+	+			Bazı yanlılık olasılıkları vardır
FLACC / r-FLACC	2 ay–7 yaş	+	+/−	+		İşlemsel ağrı için öneriler çelişkilidir
FLACC / r-FLACC	4–19 yaş	+	+/−	+		
CHEOPS (Çocuk Hastane Doğuştan Ağrı Ölçeği)	1–7 yaş		+/−	+		13 puan üzerinden değerlendirilir, işlemsel ağrı için öneriler çelişkilidir
EVENDOL	0–7 yaş	++	++		++	15 puan üzerinden değerlendirilir

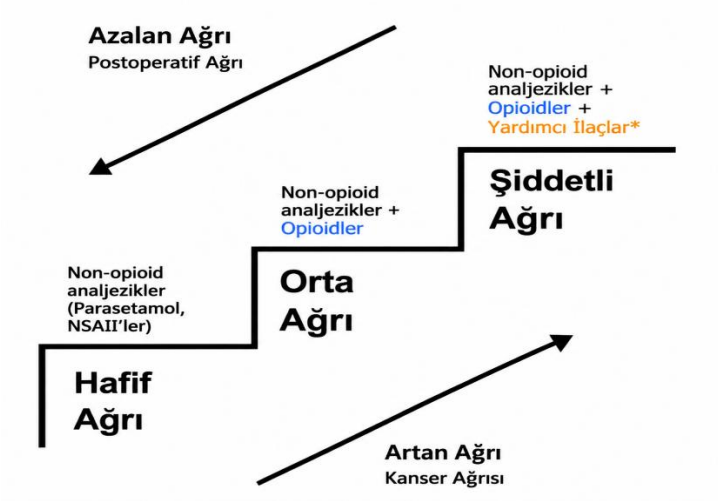
Kaynak: Trottier vd.,2022

Farmakolojik Ağrı Yönetimi

Akut ağrı çocuk acil başvurularının yarıdan fazlasını oluşturmaktadır. [14]Ağrının yönetiminde hasta merkezli bakım uygulamaları ve tedavi yöntemleri kullanılabilmektedir. Kullanılan yöntemlerden biri de çeşitli analjezik ilaçlardır. Bu ilaçlar temel olarak: Parasetamol, NSAİİ, Opioidler ve Non-opoidler olarak sınıflandırılabilir. Parasetamoller merkezi sinir sisteminin ağrı yollarını etkileyerek, santral prostaglandin sentezini azaltır ve ağrı iletimini baskılar. Sıklıkla hafif ve orta düzey ağrılarda kullanılabilir. NSAİİ grubu Siklooksijenaz enzimlerini inhibe ederek prostaglandin oluşumu azalır. Prostaglandinler ağrı reseptörlerini duyarlı hale gelerek analjezik etki oluşmasını sağlar. Hafif ve orta şiddetli özellikle inflamasyona bağlı ağrıda tercih edilir. Opioidler merkezi sinir sisteminde ağrı iletiminde rol alan nörotransmiterlerin salınımını azaltarak ağrı yollarını inhibe eder. Orta ve şiddetli ağrıların giderilmesinde kullanılır.[5,6]

Dünya Sağlık Örgütü akut ağrı yönetiminde kullanılan analjeziklerin etkinliğini ifade eden bir ağrı merdiveni oluşturmuştur. [7]

Şekil 1: Dünya Sağlık Örgütü Ağrı Merdiveni



Kaynak : Gai, et al.2024

Nonfarmakolojik Ağrı Yönetimi

Ağrı yönetimi multidisipliner bir yaklaşım gerektirdiği için hasta merkezli nonfarmakolojik yöntemler pediatrik ağrı yönetiminde sıklıkla kullanılır. Nonfarmakolojik ağrı yönetimi bilişsel/ davranışsal, destekleyici, fiziksel ve tamamlayıcı olarak sınıflandırılabilir.

Bilişsel/davranışsal yöntemler: dikkat dağıtma, hayal kurma, gevşeme, nefes egzersizi vb. yöntemlerdir. Pediatrik onkoloji hastaları ile yürütülen bir çalışmada invaziv işlem sırasında uygulanan dikkat dağıtma tekniklerinin işlem ağrısını azaltmada etkili bir müdahale olduğu, 7 ile 10 yaş arası çocuklarda baloncuk üfleme ile yapılan nefes egzersizinin alt çene sinir blokajı sırasında ağrıyı azaltmak için etkili bir dikkati dağıtma yöntemi olduğu, ameliyat öncesi rehberli imgeleme yönteminin çocuklarda ameliyat sonrası kaygıyı azalttığı görülmüştür.[8-10]

Destekleyici nonfarmakolojik yöntemler: Ebeveyn varlığı, kucaklama, terapötik iletişim vb yöntemlerdir. Ağrılı tıbbi işlemler sırasında ebeveyn varlığının incelendiği çalışmada ebeveyn varlığının yokluğuna kıyasla faydalı etkiler gösterdiğini, bebeklerde topuktan kan alma işlemi sırasında ebeveynin kucakta tutması ve sallamasının ağrı yanıtını azalttığı, ağrı hakkında bilgilendirme ve terapötik iletişim kurmanın uyum sağlamayı arttırdığı görüşmüştür. [11-13]

Fiziksel nonfarmakolojik yöntemler: Pozisyon verme, masaj, soğuk uygulama, emzirme vb yöntemlerdir. Özellikle yenidoğan döneminde uygulanan pozisyon verme, kanguru bakımı ve tentene temas yöntemleri işlemler sırasında bebeğe güvenli alan hissi oluşturarak ağrı ve anksiyetesini azalttığı, aşı uygulaması sırasında yapılan soğuk uygulama ve dikkat dağıtmanın işleme uyumu arttırarak ağrıyı azalttığı, prematüre bebeklerde emzirme ve anne sütünün kokusunun işlemler sırasında kalp atış hızında anlamlı derecede daha az artış ve ağlama süresinde azalma görülmüştür.[14-15]

Tamamlayıcı nonfarmakolojik yöntemler: Müzik, oyun, sanal gerçeklik, çizgi film vb yöntemlerdir. Müzik terapisinin etkinliğinin incelendiği bir meta analizde özellikle klasik, çocuk ve pop müzik olmak üzere çocuklarda iğne batması, işlem ve ameliyat sonrası ağrıyı kontrol etmede etkin bulunduğu , terapötik oyunun hastanede yatan çocuğun ağrı , korku ve anksiyetesini azalttığı , sanal gerçekliğin çocuklarda venöz girişim, aşı, yara bakımı ve diğer ağrılı işlemlerde ağrının azalmasında etkili olduğu , çizgi film ve video izleterek dikkat dağıtmanın ağrıyı azaltmada etkili olduğu görülmüştür.[14-16]

SONUÇ

Çocuklarda ağrının değerlendirilmesi ve yönetimi, gelişimsel özellikler nedeniyle erişkinlerden farklı bir yaklaşım gerektirmektedir. Literatürde yer alan çalışmalar, ağrı kontrolünde yalnızca farmakolojik tedavilerin değil, nonfarmakolojik yöntemlerin de önemli katkılar sağladığını ortaya koymaktadır.

Ağrının doğru değerlendirilmesi amacıyla çocuğun yaşına ve gelişim düzeyine uygun ölçeklerin kullanılması, uygulanacak girişimlerin etkinliğini artırmaktadır.

Farmakolojik yöntemlerin seçiminde çocuğun yaşı, tanısı, ağrının şiddeti, yeri ve süresi dikkate alınırken; nonfarmakolojik yöntemlerin belirlenmesinde yaş grubu, klinik özellikler ve çocuğun bireysel gereksinimleri göz önünde bulundurulmalıdır. Yenidoğan döneminde emzirme, kanguru bakımı ve ten tene temas gibi uygulamalar ön plana çıkarken, daha büyük çocuklarda nefes egzersizleri, hayal kurma, terapötik oyun, müzik ve sanal gerçeklik gibi yöntemlerin ağrı kontrolünü desteklediği görülmektedir.

Sonuç olarak, farmakolojik ve nonfarmakolojik yaklaşımların birlikte kullanılması çocuklarda daha etkili bir ağrı yönetimi sağlamaktadır. Bu yaklaşım yalnızca ağrının azaltılmasına değil, çocuğun tedavi sürecine uyumunun artırılmasına, ebeveyn katılımının desteklenmesine, hastane deneyiminin iyileştirilmesine ve sağlık bakım kaynaklarının daha verimli kullanılmasına katkı sağlamaktadır.

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THE CALENDAR OF THE SKY AND THE WORK OF THE SOIL: A COMPARATIVE STUDY OF THE EPISTEMIC FUNCTIONS OF CELESTIAL INDICATORS IN THE HISTORY OF AGRICULTURE

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ABSTRACT

Agriculture is inherently a time-dependent productive activity. Operations such as soil preparation, sowing, planting, grafting, pruning, irrigation, and harvesting must be carried out in accordance with temperature, precipitation, humidity, day length, and seasonal transitions. Before the development of modern meteorological measurement and forecasting systems, agricultural timing was organized through the annual movement of the Sun, the phases of the Moon, the rising and setting of stars, and the phenological behaviour of plants and animals. This study comparatively examines a selected body of sources ranging from ancient Greek and Roman agricultural texts to Byzantine, Islamic-Andalusian, and Ottoman agricultural literature, as well as the Chinese system of twenty-four solar terms, Maya agricultural almanacs, and modern biodynamic agriculture. Qualitative document analysis and directed qualitative content analysis were employed, and celestial references were evaluated under five categories: “calendrical indicator,” “meteorological-ecological sign,” “physical environmental factor,” “astrological causality,” and “ritual-prognostic practice.” The findings demonstrate that celestial bodies did not perform a single, fixed function throughout the history of agriculture. In some texts, the Sun, Moon, and stars functioned as natural clocks marking seasonal time; in others, they served as indicators of forthcoming weather conditions; while in still others, they were conceived as cosmic agents capable of directly influencing plant growth. Although these elements were reformulated in modern biodynamic agriculture through a more experimental and systematic language, historical continuity should be distinguished from scientific validity. Rather than classifying celestial agricultural knowledge simply as either “observation-based knowledge” or “superstition,” this study argues that different forms of knowledge could coexist within the same sphere of agricultural practice

Keywords: Agricultural history, agricultural calendar, celestial indicators, ancient agricultural techniques, biodynamic agriculture.

INTRODUCTION

Agriculture is not only a field of production consisting of techniques for cultivating plants and raising animals, but also a practice of environmental adaptation based on the organization of time. The success of activities such as preparing the soil, sowing seeds, planting seedlings, pruning vineyards, grafting trees, and harvesting crops is closely related to the time at which these operations are carried out. For this reason, agricultural societies have experienced time not as an ABSTRACT and linear measure, but through recurring indicators such as temperature, precipitation, wind, day length, the visibility of stars, plant development, and animal behaviour. In this respect, traditional agricultural calendars are not merely tools for arranging days in sequence, but environmental knowledge systems that regulate the relationships among the sky, atmosphere, soil, plants, and human labour (Kassam et al., 2018).

Celestial bodies were among the most stable indicators used to identify the periods of the year long before the development of modern calendars and meteorological systems. The annual movement of the Sun across the horizon indicated the seasons and changes in day length; the regular phases of the Moon marked shorter intervals of time; and the first morning or evening appearances of certain stars signaled seasonal thresholds. However, in historical sources, celestial indicators were not used merely as neutral

signs for telling time. Some texts regarded the Sun as the physical source of heat and evaporation, whereas others attributed to the Moon a power to influence plant sap or germination, and directly associated the positions of planets and zodiac signs with crop quality. Therefore, celestial agricultural knowledge cannot be explained solely within any one of the categories of astronomy, astrology, or folk meteorology.

One of the earliest and best-known written examples of this relationship is Hesiod's Works and Days. Hesiod associated the rising of the Pleiades in the sky with harvesting and their setting with ploughing, while he related the visibility of stars such as Orion and Sirius to temperature and seasonal activities. Here, the stars primarily function as observable seasonal signs used to schedule specific agricultural activities. In this respect, in addition to being a moral and poetic text, the work also has the character of an early farmer's almanac (Hesiod, 2018; Taub, 2003).

In the ancient Greek world, one of the more systematic forms of the relationship established among time, celestial events, and weather conditions was the astrometeorological calendars known as parapegmata. In these calendars, the visibility of stars, solstices, winds, precipitation, and seasonal changes were associated with specific days. P.Hib. 27, dated to approximately 300 BCE, combined stellar and weather observations with the Egyptian calendar and changes in the level of the Nile, while the parapegma attributed to Geminos organized astronomical and meteorological observations under the twelve signs of the zodiac. These examples show that celestial calendars were not fixed and universal schemes but could be adapted to local climatic conditions and cultural traditions (Lehoux, 2007; Post, 2025).

The celestial and meteorological timing practices observed in the Greek tradition were incorporated into a more comprehensive system of farm management in Roman agricultural literature. While the agricultural writings of Cato and Varro addressed the relationships among soil, labour, crops, animals, and the seasons, Varro evaluated the agricultural year not only according to the four seasons but also through shorter working periods and lunar cycles (Cato & Varro, 1934). Columella's De re rustica systematized agricultural activities in relation to climate, soil, labour, and timing, while Book XI in particular listed in detail the tasks that a farm manager was expected to carry out throughout the year. Book XVIII of Pliny's Naturalis Historia, meanwhile, brought together the rising of stars, solstices, monthly activities, cereals, and the movements of the Moon within the same body of agricultural knowledge (Columella, 1941–1955; Pliny the Elder, 1950).

In Late Antiquity, Palladius's Opus agriculturae transformed the calendar form into the principal structure of the text by organizing agricultural tasks month by month from January to December. Geoponika, one of the most important compilations of ancient agricultural knowledge in the Byzantine world, collected in twenty books information on soil, weather, stars, viticulture, horticulture, animal husbandry, and plant health transmitted from earlier Greek and Roman authors. However, rather than representing a coherent scientific system developed within a single period, Geoponika is a multilayered archive of knowledge in which observational, astrological, medical, and ritual prescriptions drawn from different periods and authorities were preserved together (Cassianus Bassus, 2011; Palladius, 2013).

One of the principal strands of celestial agricultural knowledge in the Islamic world was the anwāʾ tradition. Anwāʾ refers to the relationships established between the annual risings and settings of stars and phenomena such as rainfall, winds, temperature, and seasonal change. Although this tradition is related to the manāzil al-qamar system, which describes the movement of the Moon through twenty-eight lunar mansions, the two concepts are not entirely synonymous. Anwāʾ is more closely associated with the annual visibility of stars and weather phenomena, whereas manāzil concerns the position of the Moon among the stars. Both systems enabled time to be divided according to observable celestial events; however, in some texts, meteorological observation and celestial causality became intertwined (Varisco, 1991, 1995).

The corpus of filāḥa literature that developed in al-Andalus combined the agricultural knowledge of Antiquity and Late Antiquity with Arab, Persian, Mesopotamian, and local Iberian experience. The Calendar of Córdoba, compiled for the year 961, presented the visibility of stars, weather phenomena, agricultural activities, animal husbandry, health recommendations, and religious observances within a monthly framework. It is generally accepted that the calendar may have emerged from the combination

of the anwāʾ knowledge of ʿArīb ibn Saʿd with another textual layer attributed to Rabīʿ ibn Zayd. The anonymous Risāla fī awqāt al-sana, dated to the thirteenth century, likewise brought together astronomy, meteorology, agricultural activities, animal husbandry, and prognostic knowledge within the local conditions of al-Andalus (ʿArīb ibn Saʿd & Rabīʿ ibn Zayd, 1961; Navarro, 1990).

One of the most comprehensive examples of Andalusian filāḥa literature, Ibn al Awwām's Kitāb al-Filāḥa, contains information on approximately 585 plants, more than fifty fruit trees, soil types, fertilizers, irrigation, grafting, plant diseases, and animal husbandry; it also includes an agricultural calendar. While compiling the works of earlier authors, Ibn al-Awwām compared the views of different authorities and, at times, also recorded his own observations and experiences. For this reason, Islamic agricultural literature has been evaluated not as a repository in which classical texts were transmitted unchanged, but as an agroecological tradition in which knowledge was selected, tested, and localized according to different climatic and production conditions (Butzer, 1994).

This body of knowledge circulated in the Ottoman and Anatolian context through translation, adaptation, and locally produced horticultural treatises. Ibn al-Awwām's work was translated into Turkish during the Ottoman period, and agricultural recommendations associated with the Sun, Moon, stars, planets, and zodiac signs were reformulated in an Ottoman Turkish technical vocabulary. Revnak-ı Bostan is an important Ottoman Turkish work focusing on vineyards, gardens, trees, and fruit cultivation, while Felâhat-nâme is a brief but substantial agricultural treatise concerned particularly with practices such as tree planting and grafting (Önler, 1995, 2000; Şakar, 2006; Zülfikar-Aydın, 2011, 2013).

Celestial and ecological timing systems were not unique to the Mediterranean and Islamic worlds. In China, the twenty-four solar terms created a common temporal framework for agricultural activities, temperature, precipitation, and phenological changes by dividing the Sun's position along the ecliptic into intervals of approximately fifteen degrees. This system is considered to have developed in relation to the climatic and agricultural conditions of the middle and lower reaches of the Yellow River and was later adapted to different regional conditions (Li et al., 2024). In the Maya Madrid Codex, the Venus cycle and eclipse events were considered together within the context of the agricultural year and the 260-day almanac (Milbrath, 2017). These examples do not constitute a direct chain of historical transmission; rather, they represent parallel solutions developed in different cultures in response to similar problems of agricultural timing.

In the twentieth century, biodynamic agriculture reformulated the relationship between celestial rhythms and agricultural activities through the modern language of experiments, graphs, and almanacs. Shaped by Rudolf Steiner's agricultural lectures of 1924, this approach regarded the farm as a holistic organism and associated agricultural practices with terrestrial and cosmic forces. In Agriculture of Tomorrow, Eugen and Lili Kolisko claimed to have demonstrated experimentally the effects of lunar and planetary rhythms on plant growth. The almanac system developed by Maria Thun, meanwhile, designates root, leaf, flower, and fruit days according to the Moon's movement through the constellations.

However, the persistence of celestial agricultural knowledge throughout history does not mean that such knowledge has been scientifically validated. Research on biodynamic agriculture has shown that some biodynamic farms may achieve more favourable outcomes than conventional systems in terms of soil quality, organic matter management, and biodiversity. Nevertheless, it is difficult to distinguish whether these effects result from compost use, crop rotation, and organic management, or from special preparations and cosmic timing. Recent reviews indicate that, in some cases, differences between biodynamic and organic systems are limited, while reproducible evidence supporting sowing and harvesting schedules based on lunar phases remains insufficient (Chalker-Scott, 2013; Mayoral et al., 2020; Santoni et al., 2022; Turinek et al., 2009).

Existing studies have generally examined the relationship between celestial indicators and agriculture within specific historical periods and geographical contexts. Ancient parapegmata, Roman agricultural texts, the anwā tradition, the Andalusian filāḥa corpus, Ottoman horticultural treatises, the Chinese solar terms, and biodynamic almanacs have largely been studied within separate bodies of literature. This study, by contrast, aims to compare the epistemic functions assumed by celestial references across different traditions without presuming a direct historical continuity among them.

Accordingly, the principal research question is as follows: How have the Sun, Moon, stars, planets, and other environmental indicators been used across different historical periods and cultures to time and justify agricultural activities?

The study also seeks to answer the following sub-questions:

1. Under what circumstances are celestial indicators used solely as seasonal or calendrical signs?
2. How are meteorological and phenological observations combined with celestial cycles?
3. How can calendrical signs be distinguished from astrological explanations that attribute direct causal power to celestial bodies?
4. How are agricultural recommendations validated through tradition, authority, observation, personal experience, or experimentation?
5. In what ways has modern biodynamic agriculture continued, and in what ways has it transformed, historical conceptions of celestial timing?

MATERIALS AND METHOD

Research Design

The study was designed as a comparative historical document analysis conducted within a qualitative research approach. Document analysis requires not only extracting information contained in written sources but also evaluating together the contexts in which they were produced, their purposes, intended audiences, textual genres, and knowledge claims (Bowen, 2009). In classifying the data obtained from the texts, directed qualitative content analysis was employed, allowing predefined main categories to be used alongside subcategories that emerged during the analysis (Schreier, 2012).

The study does not aim to encompass all examples of celestial agricultural knowledge throughout world history. Instead, a purposive sample was constructed to represent different periods, geographical regions, and textual genres. The following criteria were used in selecting the sources:

- The presence in the text of a celestial body, seasonal event, or phenological indicator;
- The association of this indicator with an agricultural activity such as sowing, planting, irrigation, pruning, grafting, harvesting, or animal husbandry;
- The capacity of the source to represent a particular historical period or knowledge tradition;
- Accessibility to the text itself, a reliable translation, or an academic study of the text;
- The inclusion of different textual genres in the corpus in order to enable comparison.

Research Material

The primary material of the study consists of primary historical texts and philological, historical, and scientific studies conducted on these texts.

Source Group	Main Works Examined	Function in the Study
Ancient Greece	Hesiod, *Works and Days*; *parapegmata*	The use of stars as seasonal and agricultural indicators
Rome	Cato and Varro, Columella, Pliny, Palladius	The transformation of celestial and seasonal knowledge into a system of farm management
Byzantium	*Geoponika*	The compilation and transmission of ancient bodies of knowledge
Islamic–Andalusian	*Anwāʾ* literature, *Calendar of Córdoba*, *Risāla fī awqāt al-sana*, *Kitāb al-Filāḥa*	The combination of astronomy, meteorology, agriculture, and astrology
Ottoman–Anatolian	*Terceme-i Kitâbü'l-Filâha*, *Revnak-ı Bostan*, *Felâhat-nâme*	The translation and localization of knowledge and its application to horticultural practices

Source Group	Main Works Examined	Function in the Study
Comparative examples	The Chinese system of twenty-four solar terms, the Maya Madrid Codex, ecological calendars	Independent cultural solutions to similar problems of agricultural timing
Modern period	Biodynamic sources by Steiner, Kolisko, and Thun	The modern reconstruction of celestial agricultural thought
Scientific evaluations	Systematic reviews on biodynamic agriculture and lunar effects	Distinguishing historical continuity from scientific validity

Because the texts belong to different periods, languages, and genres, not all sources were evaluated with equal weight. Where direct access to the primary text was possible, the relevant passages were taken as the principal basis of analysis; where an example could only be accessed through a secondary study, it was explicitly indicated that the claim relied on the secondary source. In translated texts, the date of composition of the original work, the date of translation, the date of manuscript copying, and the date of the modern edition were distinguished from one another.

Research Material

The basic unit of analysis was a sentence, prescription, or meaningful segment of text that established a relationship between a celestial or environmental indicator and an agricultural activity. For example, “beginning the harvest when the Pleiades rise,” “irrigating in the evening,” and “planting a seedling when the Moon is in a particular zodiac sign” were treated as separate units of analysis.

Analytical Dimension	Codes
Indicator	Sun, Moon, star, planet, zodiac sign, wind, precipitation, plant or animal behaviour
Agricultural activity	Sowing, planting, grafting, pruning, irrigation, fertilization, harvesting, storage, animal husbandry
Temporal scale	Time of day, lunar cycle, season, annual cycle, multi-year cycle
Epistemic function	Calendrical, meteorological-ecological, physical, astrological, ritual-prognostic
Mode of justification	Tradition, named authority, personal observation, experience, experiment, unexplained prescription
Form of expression	Command, recommendation, prohibition, prediction, conflicting opinion
Textual position	Original observation, transmission from an earlier work, translation, local adaptation

Analytical Categories

- Calendrical Indicator: In this category, the celestial body was treated not as the cause of an agricultural event, but as a natural clock indicating its position within the annual cycle. Determining the time of harvest according to the rising of the Pleiades is an example of this category.
- Meteorological or Ecological Indicator: Statements in which the visibility of stars, winds, animal behaviour, or plant phenology were associated with temperature, precipitation, or seasonal change were evaluated under this category.
- Physical Environmental Factor: Timing recommendations that could be explained in relation to sunlight, temperature, humidity, evaporation, or differences between daytime and nighttime temperatures were included in this category. Irrigating in the evening during the summer months is an example.
- Astrological Causality: Statements attributing to the Moon, a planet, or the position of a zodiac sign a direct power to alter the taste, growth, yield, or disease condition of a plant were included in this category.
- Ritual or Prognostic Practice: Practices involving talismans, khawāṣṣ, burning, scattering ashes, auspicious or inauspicious times, or attempts to predict future crop yields were evaluated under this category.

This distinction was used not to make a direct true-or-false comparison between modern science and historical sources, but to make visible the different epistemic logics operating within the texts.

Limitations of the Study

The first limitation of the study is that it examines a very broad historical and geographical scope through a selected body of sources. Therefore, the research does not aim to present a universal and uninterrupted history of agriculture. Second, some of the works were evaluated through modern translations or academic editions. The rendering of astronomical and agricultural terms in translation may lead to differences in meaning. Third, the survival of these sources does not fully represent social agricultural practice; written works largely reflect the knowledge of educated, courtly, or landowning circles. The extent to which agricultural books recorded or influenced the practices of peasants should therefore be examined separately for each work. It should also be taken into account that agricultural books may represent not only the top-down transmission of practical farming knowledge, but also the appropriation of practitioners' knowledge by written culture.

FINDINGS

The Use of the Sky as an Agricultural Clock in the Ancient Mediterranean World

In the earliest texts examined, the primary function of stars appears to have been the recognition of seasonal time. In Hesiod, the visibility of the Pleiades, Sirius, and Orion carries a more direct environmental meaning than a calendar date. The rising or setting of the Pleiades informed farmers not only of "what day" it was, but also of which phase of the year had been reached in terms of temperature and plant development. Celestial observation, meteorological conditions, and phenological experience were therefore not treated as separate domains.

Parapegmata transformed this observational timing into a more regular and public form. The risings of stars, winds, and anticipated changes in weather were linked to specific dates, and in some cases physical calendars were created in which the days could be tracked using movable pegs. The inclusion of Nile levels and the local calendar in P.Hib. 27, found in Egypt, demonstrates that astrometeorological knowledge was adapted to specific geographical conditions. Therefore, the "ancient Greek celestial calendar" should not be understood as a uniform system, but rather as a tool in which circulating astronomical knowledge was reorganized according to the local environment (Lehoux, 2007; Post, 2025).

In Roman agricultural texts, celestial indicators became part of a broader programme of farm management. In Cato and Varro, calendrical knowledge was combined with the management of labour and resources on the farm, while in Columella and Pliny, the visibility of stars, winds, soil conditions, and weather signs were considered together. What is noteworthy here is that attention was not directed solely toward the sky. Soil moisture, animal behaviour, wind direction, plant development, and human sensory observations were used alongside celestial signs. Roman agricultural literature, therefore, cannot be evaluated under a single category such as "astrological agriculture"; astronomical, meteorological, phenological, and practical indicators formed parts of the same decision-making system (Cato & Varro, 1934; Columella, 1941–1955; Pliny the Elder, 1950).

In Palladius, the months became the principal organizing framework of the text. The arrangement of agricultural tasks according to the months indicates a transition from celestial observation to a written and repeatable programme of work. Nevertheless, this month-based organization did not entirely eliminate local climatic differences. The implementation of the agricultural calendar continued to require observation of weather and soil conditions.

Compilation, Transmission, and the Coexistence of Multiple Layers of Knowledge

Geoponika clearly demonstrates that celestial agricultural knowledge did not follow a linear trajectory of development. The work preserves, side by side, practical agricultural recommendations, medical explanations, astrological assumptions, and talismanic practices drawn from different centuries. From

the perspective of modern scientific classifications, this may appear inconsistent; however, the aim of the historical text was not so much to establish an experimental agricultural science in the modern sense as to bring together, in a comprehensive collection, knowledge and prescriptions considered useful. The encyclopedic character of Geoponika as a Byzantine compilation based on earlier sources also helps to explain this plurality (Cassianus Bassus, 2011).

A similar layering can be observed in Islamic and Andalusian agricultural literature. Within the anwāʾ tradition, the risings and settings of stars could function as indicators of rainfall and seasonal change, while the same stars or lunar mansions could also be attributed a direct capacity to confer auspiciousness, productivity, or influence. Therefore, the mere presence of a star in an agricultural text does not in itself constitute evidence of astrological usage. It is first necessary to determine whether the star merely indicates time, signals an anticipated weather event, or is regarded as a direct cause of the agricultural outcome (Varisco, 1991, 1995).

The Calendar of Córdoba combines these different domains of knowledge in the form of a monthly almanac. Agricultural tasks, stellar visibility, winds, animal breeding periods, health recommendations, and religious dates appear side by side. This structure shows that forms of knowledge separated in modern disciplines as astronomy, meteorology, agriculture, zoology, and medicine were conceived in the historical source within a common "annual order of time." The anonymous Andalusian almanac likewise records local activities associated with specific agricultural regions, demonstrating that the celestial calendar was adapted to regional conditions of production.

Ibn al-ʿAwwām's work is particularly important for the way it combines knowledge based on earlier authorities with personal experience within the same text. The presence of examples in which different authors disagree over the appropriate time for sowing or planting demonstrates that the filāḥa corpus did not present a single, internally consistent system of celestial timing. Some recommendations can be explained in terms of seasonal and microclimatic conditions, whereas others reflect a belief in the direct influence of planets and zodiac signs. The work therefore does not display a linear scale progressing "from observation to astrology," but rather the coexistence of different forms of knowledge.

Translation and Localization in Ottoman and Anatolian Texts

Terceme-i Kitâbü'l-Filâha enabled agricultural knowledge of Andalusian origin to be reformulated within the Ottoman context. Through this work, numerous recommendations associated with the Sun, Moon, stars, planets, and zodiac signs were transmitted into Ottoman Turkish. However, the presence of this translation in the Ottoman world does not prove that all of the information contained in the work was actually practiced by local farmers. The text should therefore be evaluated primarily as evidence of the circulation of knowledge and the culture of translation in Ottoman Turkish (Zülfikar-Aydın, 2011, 2013).

More concise horticultural texts such as *Revnak-ı Bostan* and *Felâhat-nâme* focus on practices including tree planting, grafting, pruning, and fruit cultivation. Although these works contain practices associated with moonlight or particular phases of the Moon, each recommendation must be examined within its original textual context. In particular, reducing the relationship established in *Felâhat-nâme* among the new Moon, the period after the fifteenth day of the lunar month, and the moisture condition of trees to a simple formula such as "plant during the waxing Moon, prune during the waning Moon" may distort the meaning of the text. The available edition indicates that the work was copied in 1027/1617 and focuses particularly on tree cultivation (Şakar, 2006).

Ottoman Turkish texts suggest that celestial timing should not be understood merely as an externally imported doctrine of astrology. Classical knowledge transmitted through translation was combined with local horticultural experience, seasonal observation, and contemporary understandings of nature. Nevertheless, the limited body of surviving texts does not justify the conclusion that "Ottoman agriculture as a whole was conducted according to celestial bodies."

Parallel Agricultural Timing Systems in Different Geographical Contexts

The Chinese system of twenty-four solar terms demonstrates that agricultural timing could be based not only on the rising and setting of stars, but also on the regular division of the Sun's annual position. Each term was associated with approximately fifteen days and fifteen degrees of solar movement, providing

a general temporal framework for activities such as sowing, summer field management, autumn harvesting, and winter storage. However, because the system was based on the climatic conditions of the Yellow River basin, local adaptations became necessary in different regions of the country. This finding shows that although celestial calendars may have a fixed astronomical basis, their agricultural meanings vary according to geographical and climatic context (Li et al., 2024).

In the Maya Madrid Codex, the coexistence of observations of Venus, eclipses, and the agricultural year demonstrates that celestial time was connected with both production and ritual order. Here, the agricultural calendar cannot be reduced either to purely astronomical calculation or to purely religious ritual. Astronomical observation, agricultural activity, and ceremonial time mutually inform one another within the same almanac (Milbrath, 2017).

Contemporary studies of traditional ecological calendars likewise demonstrate that agricultural time does not consist solely of fixed dates. Ecological calendars bring together relational indicators such as flowering, bird migration, snowmelt, the emergence of insects, precipitation, stellar visibility, and animal behaviour. Because climate change can disrupt the correspondence between fixed calendar dates and actual environmental conditions, such flexible and habitat-based timing systems have been argued to be regaining importance in terms of climate adaptation (Kassam et al., 2018).

The Reconstruction of Cosmic Timing in Modern Biodynamic Agriculture

Although biodynamic agriculture retained certain formal elements of historical agricultural almanacs, it reorganized them within an anthroposophical cosmology. In the work of the Koliskos, lunar and planetary influences were presented through the language of laboratory experiments, graphs, and comparative sowing trials. This indicates that celestial agricultural thought did not disappear in the modern period; rather, it was reformulated and re-legitimized through the scientific modes of presentation characteristic of the time.

In Maria Thun's almanacs, the Moon's passage through the constellations is divided into root, leaf, flower, and fruit days according to the part of the plant that is consumed. The almanac links crop groups, sowing times, harvesting, pest management, beekeeping, and biodynamic preparations to a detailed annual calendar. This system constitutes a more elaborate and normative agricultural programme than historical calendars based primarily on lunar phases.

Modern scientific literature indicates that not all components of biodynamic agriculture are supported by the same level of evidence. Practices such as compost use, crop rotation, on-farm nutrient cycling, and the reduction of chemical inputs may produce positive outcomes for soil health and biodiversity. By contrast, evidence demonstrating the independent effects of special preparations or timing based on planetary positions remains limited and inconsistent. A review grounded in physics and biology on the influence of the Moon on plant development likewise concluded that there is no reliable mechanism or reproducible evidence that generally supports scheduling agricultural operations according to lunar phases (Chalker-Scott, 2013; Mayoral et al., 2020; Santoni et al., 2022).

Five Fundamental Epistemic Functions of Celestial Indicators

The comparative analysis identified five fundamental functions performed by celestial and environmental indicators.

1. The first function is the calendrical indicator. The rising or setting of a star provides an observable temporal marker for the timing of an agricultural activity. The example of the Pleiades in Hesiod is one of the clearest representatives of this category.
2. The second function is the meteorological and ecological indicator. A celestial event is interpreted together with expected changes in temperature, wind, or precipitation. *Parapegmata* and *anwāʾ* texts provide numerous examples of this function.
3. The third function is the physical environmental effect. Directly observable factors such as sunlight, temperature, nighttime cooling, humidity, and evaporation provide the basis for agricultural recommendations.
4. The fourth function is astrological causality. The position of the Moon, a planet, or a zodiac sign is attributed a direct power to alter the taste, yield, or health of a crop.

5. The fifth function is ritual or prognostic use. Celestial timing determines auspicious or inauspicious periods, talismanic practices, or predictions concerning future crop yields.

These functions are not mutually exclusive. Within the same work, or even within the same section, a star may function as a calendrical indicator, the Moon as a physical force, a planet as an astrological agent, and a particular date as a ritual time.

DISCUSSION

The most important finding of this study is that celestial agricultural knowledge cannot be explained through a simple distinction between "scientific observation" and "superstition." When the boundaries of modern scientific disciplines are applied directly to historical texts, it becomes difficult to understand why astronomy, meteorology, agriculture, medicine, astrology, and ritual appear together within the same work. From the perspective of historical agricultural texts, the central issue is not which modern discipline a particular form of knowledge belongs to, but rather what kind of function it performs in agricultural decision-making.

The distinction between a calendrical sign and astrological causality is particularly important. The annual appearance of the Pleiades at a particular time of year may indicate the appropriate period for harvesting, but this does not mean that the star itself is understood to cause the crop to develop. By contrast, the claim that a particular planetary position directly changes the taste of an onion or the productivity of a tree rests on a different conception of causality. Although celestial bodies are mentioned in both cases, the underlying epistemic logics are not the same. If this distinction is not made and all historical practices are grouped together under the heading of "astrological agriculture," important observational and ecological layers of knowledge become obscured.

Textual genre also shapes how celestial knowledge is presented. In didactic poetry, knowledge is conveyed through memorable verses; in *parapegmata*, through dates and weather signs; in agricultural treatises, through commands and prescriptions; in almanacs, through monthly tables; and in modern biodynamic texts, through experiments and graphs. Knowledge therefore gains authority not only through its content, but also through the textual and visual forms in which it is presented.

The study also shows that the existence of similar celestial calendars does not necessarily imply direct historical transmission. In the ancient Mediterranean, Chinese, and Maya examples, the sky is used to organize agricultural time; however, this similarity may result less from a common origin than from agricultural societies confronting comparable environmental problems. By contrast, along the Greek–Roman–Byzantine–Arab–Andalusian–Ottoman trajectory, more direct channels of knowledge transmission can be identified through textual quotations, translations, and compilations. Transmission must therefore be distinguished from independent or parallel development.

The same analytical caution is required when evaluating modern biodynamic agriculture. Positive outcomes observed in biodynamic farms in terms of soil quality or biodiversity do not constitute validation of cosmic calendars. Practices such as organic fertilization, composting, diversification, and reduced pesticide use should be examined as variables distinct from claims concerning celestial timing and special preparations. Recent scientific evaluations likewise point out that the overall performance of biodynamic farming systems has not always been adequately distinguished from their specific cosmic claims (Santoni et al., 2022; Turinek et al., 2009).

Therefore, just as historical continuity does not constitute evidence of scientific validity, a practice that does not conform to modern scientific explanation should not be regarded as historically insignificant. The value of historical texts lies in showing how past societies perceived environmental time, coped with uncertainty, and justified their agricultural decisions through particular forms of authority and observation.

CONCLUSION

This study has demonstrated that celestial bodies did not carry a single and unchanging meaning in agricultural texts selected from different periods and geographical contexts. In some sources, the sky functioned as a clock marking the seasons; in others, as an environmental indicator signalling weather events; in others, as the physical source of heat and light; and in still others, as a cosmic agent believed to exert a direct influence on plants and crops. The coexistence of more than one of these roles within the same text shows that historical agricultural knowledge was not organized according to the disciplinary boundaries of modern science.

The association of stars with seasonal activities in ancient Greek and Roman sources; the preservation of multiple layers of knowledge in Byzantine compilations; the integration of astronomy, meteorology, and agriculture within monthly calendars in the *anwāʾ* tradition and Andalusian almanacs; and the translation and reformulation of this knowledge in Ottoman texts and local horticultural practices all demonstrate that celestial agricultural knowledge was both transmissible and adaptable to local contexts. The Chinese and Maya examples, meanwhile, suggest that similar timing systems could also emerge independently under different cultural and environmental conditions.

Modern biodynamic agriculture reconstructed historical concepts of cosmic timing through the forms of experiments, graphs, and annual almanacs. However, the ecological benefits associated with some biodynamic systems and the specific effects attributed to the Moon, planets, and zodiac signs are not supported by the same level of evidence. The longevity of historical use cannot, in itself, be regarded as evidence of scientific validity.

The original contribution of this study lies in distinguishing five different epistemic functions of celestial references in agricultural knowledge rather than classifying them collectively as either “astrology” or “observational calendars”: calendrical indicator, meteorological-ecological sign, physical environmental factor, astrological causality, and ritual-prognostic practice. This classification enables a more careful comparison of the similarities and differences among agricultural texts produced across different cultures and historical periods.

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STUDY OF THE DIELECTRIC PROPERTIES OF SOLVOTHERMAL SYNTHESIZED CdSe;0.5%Ho NANOCRYSTAL

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ABSTRACT

The synthesis of cadmium selenide nanoparticles (CdSe;0.5%Ho) doped with rare earth elements holmium (Ho) was carried out by solvothermal method using cadmium nitrate and sodium selenite as precursors. Hydrazine nitrate and ethylenediaminetetraacetic acid were used as capping agents to control the size of the nanoparticles. As the size decreases to the Bohr radius (typically around a few anemometers), all electronic properties change and become equally important, size-dependent. At this size, the transition of semiconductor nanoparticles occurs, where electrons and holes are confined beyond the natural Bohr radius. The crystalline nature of the samples and the particle size properties depend not only on the size but also on the shape. The powder was characterized by X-ray diffraction (XRD). The morphology of the prepared CdSe;0.5%Ho nanoparticles was studied by scanning electron microscopy. Dielectric studies were performed for a granulated sample of CdSe;0.5%Ho nanoparticles. The conductivity of CdSe;0.5%Ho nanoparticles was studied. The obtained results are discussed. The frequency dependence of dielectric constant, dielectric loss and alternating current conductivity has also been studied

Keywords Nanomaterials, CdSe, Solvothermal, method, Electrical sciences, diffraction analysis

Introduction

Semiconductor nanoparticles belong to the transitional state between molecules and bulk solids, with their respective physical dimensions ranging from a few hundred nanometers to several hundred nanometers. Both the equilibrium and dynamic properties of nanomaterials can be very different from those of their corresponding bulk materials or isolated atoms and molecules. The dielectric constant of a semiconductor is one of its most important properties. Its magnitude and temperature dependence are important from both fundamental and technological points of view. Recently, a lot of extensive research has been conducted on semiconductor nanocrystals, because they have strong size-dependent optical properties. These will be the key structural parameters in the development of new electronic nanodevices and nanocircuits. Semiconductor particles exhibit size-dependent properties such as the magnitude of the energy gap and the variation of the corresponding optical properties. Such materials, such as CdSe;0.5%Ho, exhibit strong fluorescence that can be tuned according to particle size. CdSe;0.5%Ho has been considered in many applications such as optoelectronic devices (Nazzal et al. 2003), light sensors (Bruchez et al. 1998), biological labels (Colvin et al. 1994), chemical libraries (Gaponik et al. 2002), etc. nanostructures (Haram et al. 2001; Wang et al. 2004; Datta and Das 1990; Peng et al. 2000). Various methods such as hydrothermal, sol-gel approach, surfactant approach, etc. have been used for the synthesis of nanoparticles (Tang et al. 2003; Busbee et al. 2003). The synthesis, structural and optical properties of CdSe;0.5%Ho nanoparticles have been reported (Dwivedi et al. 2011). In this work, the main focus is on the electrical properties of CdSe;0.5%Ho nanoparticles pellets at different temperatures. The frequency dependence of dielectric constant, dielectric loss and AC conductivity has also been investigated.

Materials and Methods

CdSe;0.5%Ho nanoparticles were synthesized by solvothermal method. Chemicals such as cadmium nitrate and sodium selenite were used as precursor materials to prepare CdSe;0.5%Ho nanoparticles. Cadmium chloride and sodium selenite in a 2:1 molar ratio were dissolved in deionized water and mixed thoroughly with a magnetic stirrer for 30 min. Hydrazine hydrate and ethylenediamine tetraacetic acid were used as complexing agents. Then, the solution was centrifuged, filtered and washed. Finally, the dark red product was collected by centrifugation and dried at 50 °C for 1 h. Dielectric measurements were performed at different temperatures with HIOKI3532-50 LCRHITESTER in the frequency range of 100 Hz and 1 MHz. Electrodes with silver paste dying in air on both sides were prepared on the granulated sample, which behaved like a parallel plate capacitor. Dielectric studies were performed at different temperatures and different frequencies. In this experiment, the palletized nanoparticles were used using very high pressure, so with such a large volume fraction in nanoscale samples, the interfaces should contain many defects, including micropores, vacancies, vacancy groups, and dangling bonds. These defects can cause the positive and negative space charge distributions at the interfaces to change. When the pallets are exposed to an external electric field, the positive and negative charges at the interfaces move towards the negative and positive poles of the electric field, respectively. Meanwhile, a large number of dipole moments are inevitably generated after being trapped by the defects. As a result, space charge polarization occurs at the interfaces of holmium-doped CdSe;0.5%Ho nanoparticles, which results in a larger dielectric constant for CdSe;0.5%Ho nanoparticles. For ordinary CdSe;0.5%Ho powders, space charge polarization cannot be observed due to the smaller specific surface area.

Results and Discussion

X-ray diffraction analysis

The X-ray diffraction pattern of the prepared CdSe;0.5%Ho nanoparticles is shown in Figure 1. From the XRD pattern, it is clear from the broadening of the diffraction peaks that the particles are crystallized and are in the nanoscale range. The intensity of the peaks indicates that the CdSe;0.5%Ho nanoparticles are high-phase and not cubic-phase. The peaks correspond to (100), (002), (101) and (103). In general, the (1 0 1) diffraction peak in hexagonal CdSe;0.5%Ho is strong and narrow, which can be attributed to the dominance of CdSe nanoparticles along the (1 0 1) plane. From the experimental results, the average particle size of the CdSe;0.5%Ho nanoparticles was calculated from the Debye-Scherrer formula,

$$A = \frac{0.94k}{bcosh}$$

where A is the coherence length, b is the full width at half maximum (FWHM) of the diffraction peak, k(1.5418A˚) is the wavelength of the X-rays, and h is the diffraction angle. The average particle size of the sample was determined to be 50 nm, obtained from the FWHM of the more intense peak using the Scherrer formula.

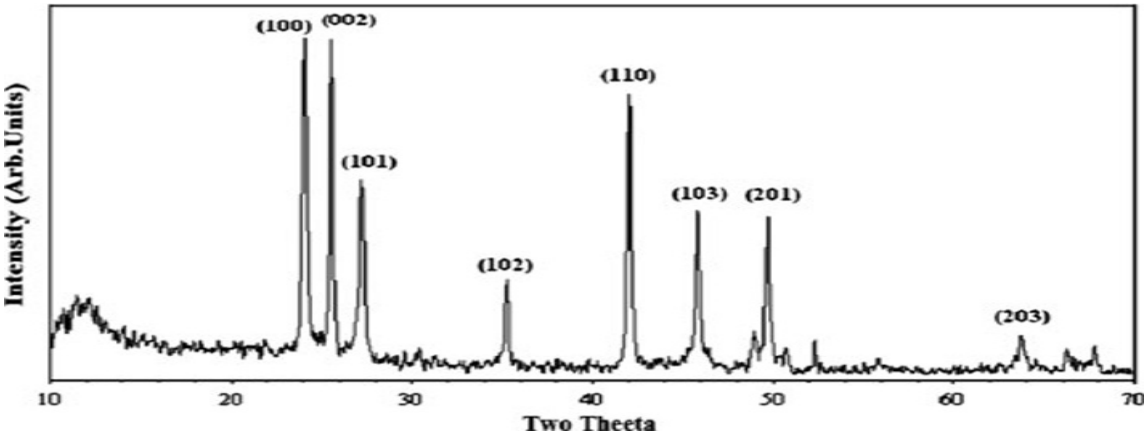

Figure 1 Powder XRD patterns of CdSe;0.5%Ho nanoparticles

SEM analysis

Scanning electron microscopy (SEM) was used to analyze the morphology and growth characteristics of the aggregates of the prepared CdSe;0.5%Ho nanoparticles. SEM images of the synthesized CdSe;0.5%Ho nanoparticles are shown in Figure 2, which show that the particles are well assembled. The images confirm the formation of CdSe;0.5%Ho nanoparticles. The SEM images show that the surface of the spheres is moderately smooth and several degrees of aggregation of the initial CdSe;0.5%Ho nanoparticles are also visualized.

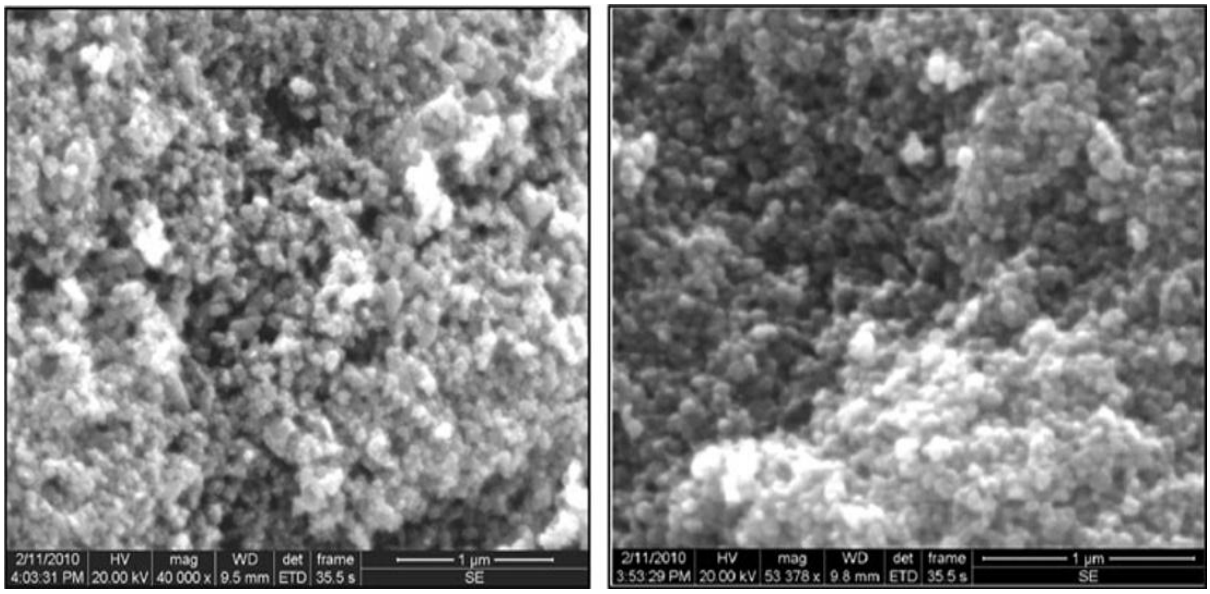

Figure 2 SEM images of CdSe;0.5%Ho nanoparticles

Dielectric studies

The dielectric constant of an insulating material is the ratio of the capacitance of a parallel plate capacitor measured with and without a dielectric material placed between the plates. The difference is, of course, due to the polarization of the dielectric. If the applied field to the capacitor is time-dependent, as in alternating current, then the polarization is the same. However, due to the resistance of the atoms to the motion of the dielectric, there is a delay between the changes in the field and the changes in polarization. This delay is often expressed as a phase difference or loss angle. Power factor and dissipation factor are tan d. The product of the dielectric constant and the power factor, called the dissipation factor, is proportional to the energy absorbed by the dielectric from the field per cycle. Dielectric analysis is an important property that can be used to obtain knowledge based on the electrical properties of the material medium as a function of temperature and frequency. Based on this analysis, the ability of a material to

store electric charges and to transmit electric charge can be estimated. Dielectric properties are related to the electro-optical properties of materials.

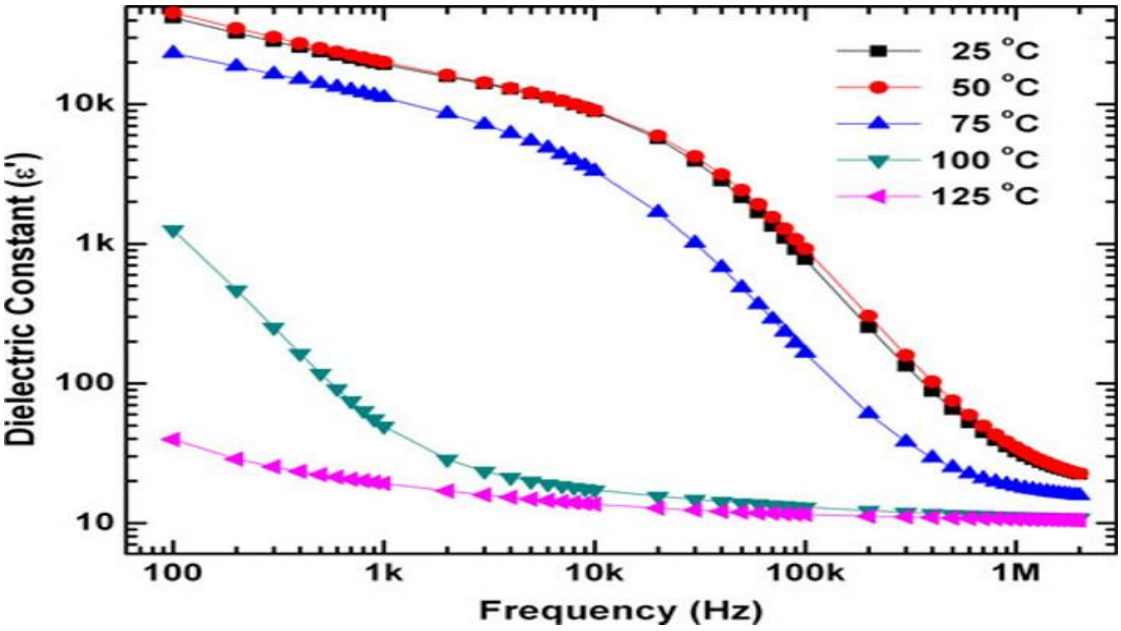

Figure 3 Frequency variation of dielectric constant for all temperatures

It is clear from the graph (Fig. 3) that the dielectric constant for CdSe;0.5%Ho nanoparticles has high values in the low frequency region. This is due to the presence of various types of polarization mechanisms such as electronic, ionic, orientational and space charge polarization (Mo et al. 1995). This can lead to large values of dielectric constant at low frequencies. Due to the application of an electric field, space charges move and dipole moments are created and this is called space charge polarization. Furthermore, these dipole moments rotate with the applied field and cause rotational polarization, which also contributes to the high values. With an increase in temperature, more dipoles are created and the value increases (Chawla et al. 2007). In the high frequency region, charge carriers may have started to move and the dielectric constant drops to a small value before the field change occurs. Figure 4 shows the variation of dielectric loss with frequency for different temperatures. It is clear that the dielectric loss decreases with frequency, while the dielectric constant increases with frequency for all temperatures, following a similar trend. This shows that the dielectric loss is highly dependent on the frequency of the applied field. Any low dielectric loss exhibited at high frequencies may be due to the purity of the nanomaterial, which has minor defects with good optical quality, which can be useful in the design of optical devices (Barsoum 1977).

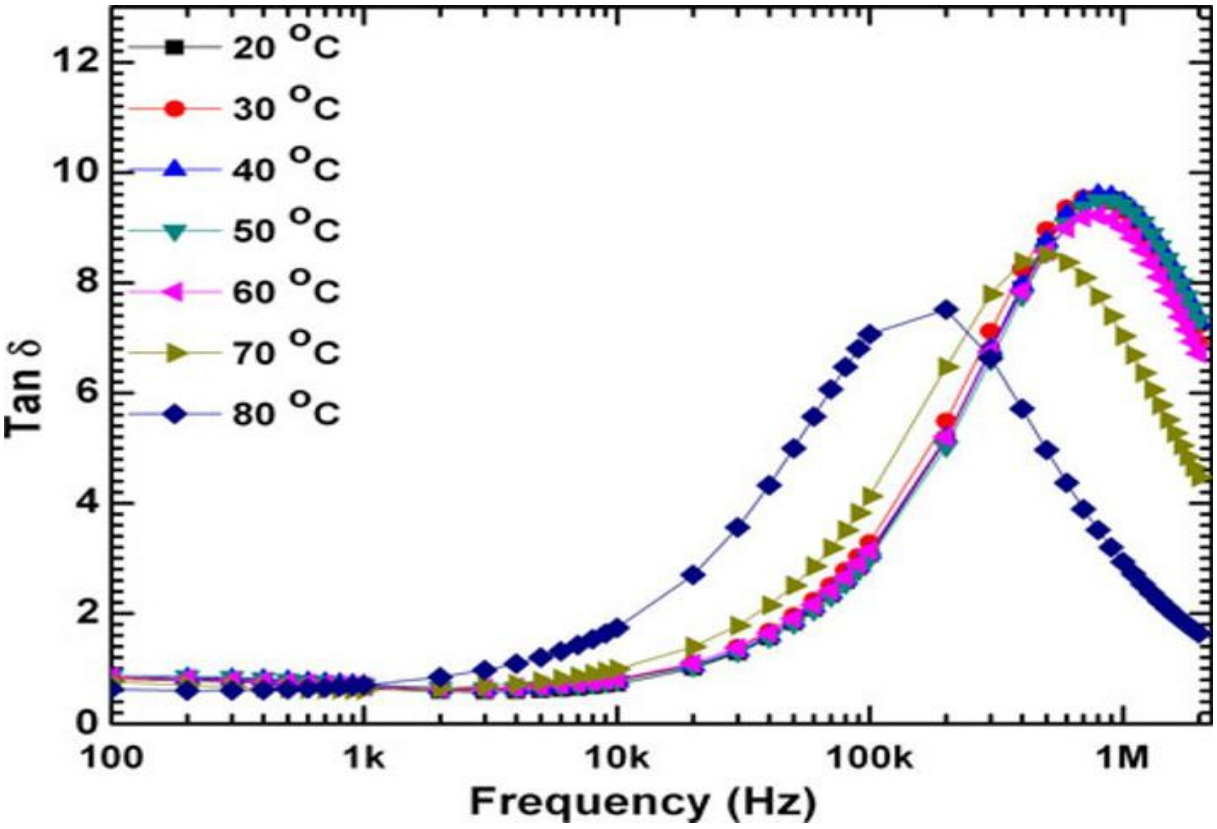

Figure 4 Variation of dielectric constant with frequency for all temperatures

It is also observed that as the temperature increases, the dielectric permittivity also increases to a significant value as shown in Figure 5. The same trend is observed in the case of dielectric loss versus temperature given in Figure 6. The larger value of dielectric loss at low frequency can be attributed to space-charge polarization due to the defect in the charge network (Smy619). The low dielectric constant and high-frequency dielectric loss characteristics for a given sample indicate that the sample has improved optical quality with fewer defects, and this parameter is of vital importance for various electro-optical devices and their applications (Austin and Mott 1969). The decrease in the value of dielectric constant with frequency is due to the inability of the electric charge carriers to follow the change in the applied electric field beyond a certain critical frequency (Ponpandian et al. 2002). A very low value of dielectric constant at high frequencies is important for the production of materials for ferroelectric, photonic and electro-optical devices. At higher frequencies, the value of the dielectric constant can be used to calculate the Penn gap, Fermi energy, and polarizability (Chauhan and Arora 2009).

Electrical conductivity studies

Electrical conductivity is a key factor in revealing information about the transport phenomenon CdSe;0.5%Ho. It is strong with a Bohr excitation radius of 10nm.

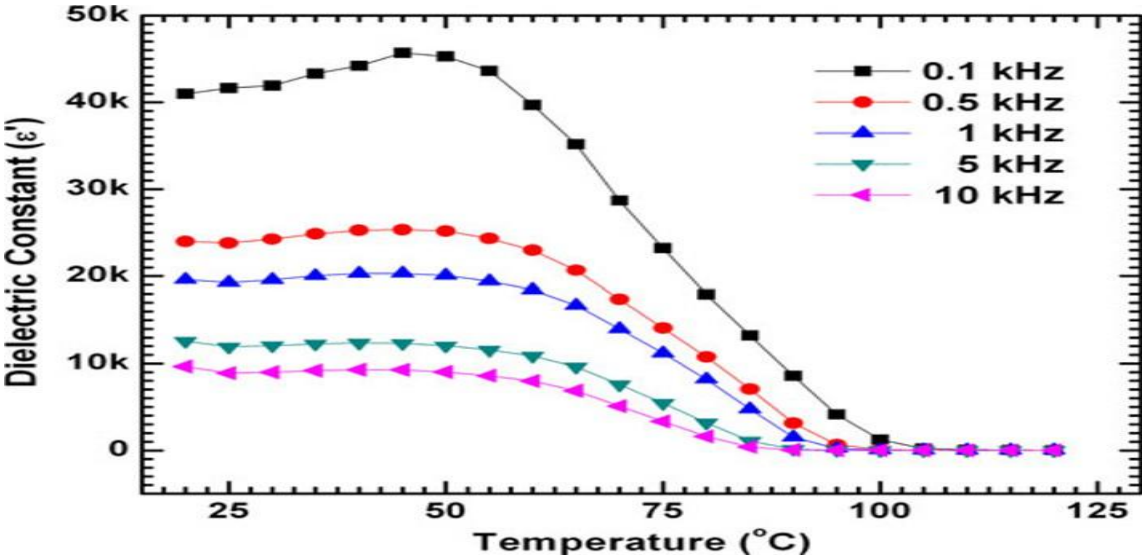

Figure 5 Variation of dielectric constant with temperature for all frequencies

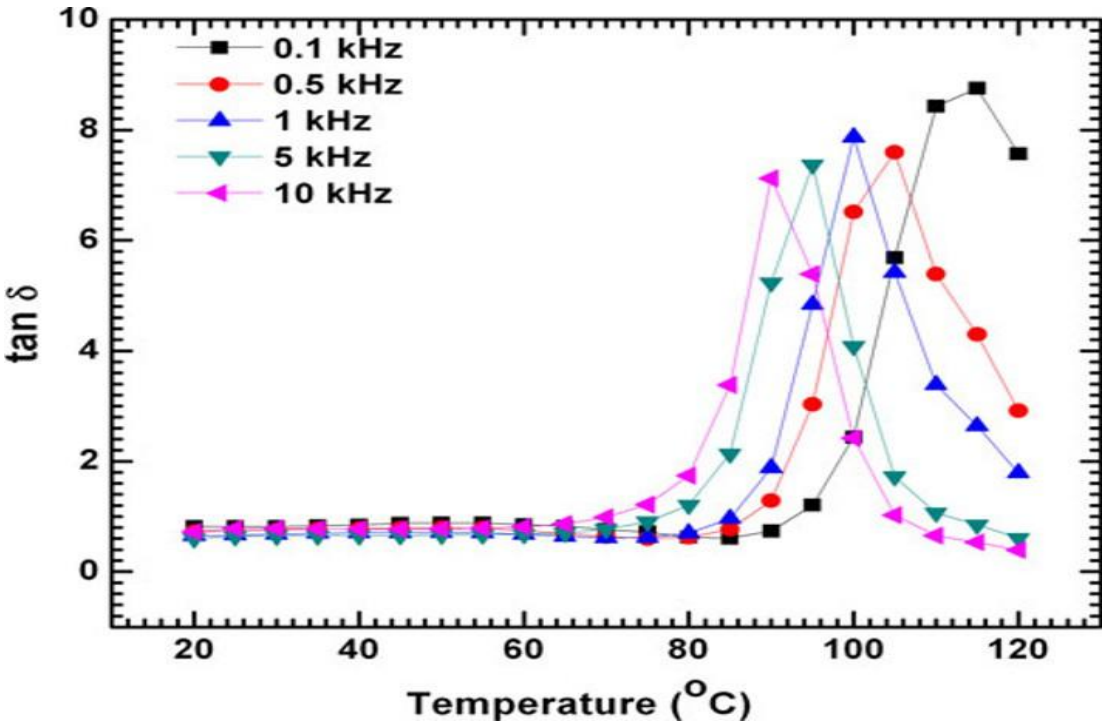

Figure 6 Variation of dielectric loss with temperature for all frequencies

Recent work on the electrical properties of semiconductor nanocrystals has paid great attention to the conduction mechanism (Joshi and Sehgal 2004). The current-conductance plot of the granulated form of CdSe;0.5%Ho nanoparticles is shown in Figure 7. It is observed from the results that the conductivity increases with increasing temperature, indicating the semiconducting nature of the sample. The conductivity increases with temperature due to thermionic emission and tunneling of charge carriers across the barrier. Due to the small size of the particles, charge carriers can reach the surface of the particles more easily and allow electron transfer via thermionic emission or tunneling to increase the conductivity (Mechant and Elbarum 1978). The AC conductivity of the nanoparticle sample can be calculated from the following relationship:

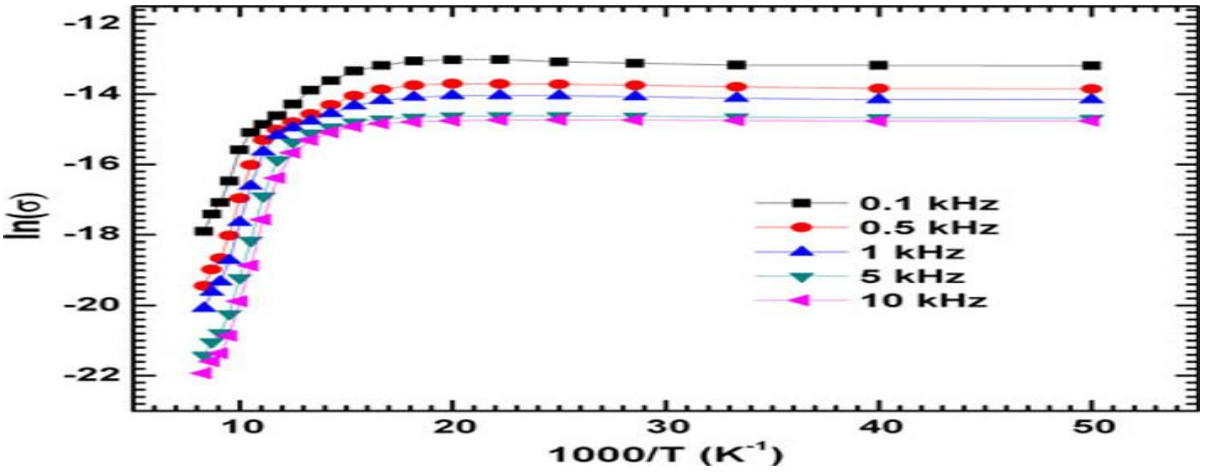

Figure 7Ploto flnrac with 1000/T

$$r_{ac}=2pe_0e_rftand$$

where e0 is the permittivity in free space, er is the dielectric constant, the punch frequency and the loss factor. In the low frequency region, there is a small increase in the electrical conductivity of the nanomaterial with increasing frequency and for all temperatures. has a conductivity and is very large at high temperatures, which can be attributed to the hopping of small polarons (Barber et al. 2009). In the case of nanoparticles, due to the small grain size and large grain boundaries, the electronic states are localized near the Fermi level. When the states are localized, the conductivity occurs by hopping of carriers between occupied and unoccupied sites, depending on the density of states and the position of the Fermi level. Mott (Elahi and Ghobadi 2008) determined the temperature dependence of the conductivity for such systems. The gradual decrease in the activation energy with decreasing temperature suggested that the conduction is the hopping of carriers between localized states (Johna et al. 2005). In nanoparticles, high surface tension leads to lattice contraction, which may not be symmetrical (Solliard and Flueli 1985; Gamarnik and Sidorin 1989). This can result in lattice distortion, which can be equivalent to plastic deformation, leading to dislocations. It is not reasonable to assume that these dislocations can be considered one-dimensional. It has been shown that the smaller the semiconductor particles, the greater the chance that charge carriers will reach the semiconductor surface, where electron transfer can occur (Fendler 1987). Experimental evidence strongly suggests that the confinement of charge carriers in small particles disrupts the band structure, leading to the formation of a series of discretes in the conduction and valence bands and also leading to an increase in the effective band gap. films (Kamins 1971). According to the grain-boundary trapping theory, free carriers are trapped by trapping states at the boundary and cause charge depletion in the grain region closest to the boundary (Seto 1975). Therefore, the region close to the particle surface is prone to charge depletion, which leads to a decrease in the charge that should create a gap between the particles.

Conclusion

CdSe;0.5%Ho nanoparticles were synthesized by the solvothermal method. The Powder X-ray analysis confirmed this. The size of the nanoparticles and the main diffraction patterns of CdSe;0.5%Ho. SEM reveals the morphology of the synthesized samples. Dielectric studies at various temperatures showed that the dielectric constant and dielectric loss have low values at high frequencies and are independent of temperature. The variable conductivity of the granule form of CdSe;0.5%Ho nanoparticles was determined and observed to increase with increasing temperature. The conductivity and variable electrical properties were attributed to the specific properties of nanometer-sized particles. This article is a work of art, and is available for download at: http://www.ncbi.nlm.nih.gov/pubmed/111111111.

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ECONOMIC INFORMATION NETWORKS AND THEIR ROLE IN THE OPERATIONS OF THE BANQUE DE L'INDOCHINE IN FRENCH INDOCHINA (1875 - 1945)

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ABSTRACT

In the process of expanding the colonial financial system, economic information played a crucial role in the operations of financial institutions, particularly the Banque de l'Indochine. However, most existing studies have primarily focused on the bank's functions in currency issuance, credit, investment, or its operational history, while insufficient attention has been paid to the role of economic information networks in supporting its activities. On this basis, this article analyzes the formation of the economic information network in French Indochina, the channels of information collection and dissemination, and clarifies the role of this information in market assessment, credit expansion, investment orientation, and risk mitigation in the operations of the Banque de l'Indochine during the period 1875–1945. By doing so, the study contributes a new perspective to the history of colonial finance, emphasizing the relationship between economic information and the functioning of the Banque de l'Indochine within the colonial economic context of Southeast Asia.

Keywords: Banque de l'Indochine; French Indochina; economic information; information networks; financial history; business history.

INTRODUCTION

In the history of the French colonial banking system, the Banque de l'Indochine was one of the most influential financial institutions in Indochina from the late nineteenth to the mid-twentieth century. Established in 1875 with the functions of currency issuance and credit provision, the bank gradually expanded its activities into trade finance, investment, and international payments, becoming a financial hub linking metropolitan France, Indochina, and various markets across Asia. This development was not only based on capital resources, branch networks, or privileges granted by the colonial authorities, but also depended significantly on the bank's ability to collect, process, and utilize economic information in support of its operations.

For banking activities, economic information is of particular importance as it forms the basis for market assessment, evaluation of clients' creditworthiness, monitoring fluctuations in commodity prices, exchange rates, capital flows, and political factors that may affect business operations. In the context of Indochina a colonial territory characterized by a vast economic space, uneven infrastructure, and direct exposure to global market fluctuations the establishment of an effective economic information network became a necessity for the Banque de l'Indochine. Through its system of branches, agencies, colonial administrative bodies, and international telegraph networks, the bank was able to access and regularly update information on production, trade, finance, and monetary conditions, thereby supporting decisions related to credit, trade finance, international payments, and risk management.

In recent years, the history of the Banque de l'Indochine has been addressed in numerous studies on financial history, banking history, and colonial economic history. Most of these studies focus on the bank's role in colonial financial policy, mechanisms of currency issuance, credit activities, investment, or its relationship with the colonial economy. Some works also examine the expansion of its branch network and its development in the Asian region. However, existing research has paid limited attention to the field of economic information and its role in banking activities. Where mentioned, economic information is often treated merely as a supporting factor, whereas the economic information network as an integral component of organizational capacity and a strategic resource of the bank has not yet been systematically and independently examined. Consequently, there remains a lack of studies explaining

how the Banque de l'Indochine constructed, operated, and exploited its information system to enhance operational efficiency within the colonial economic context.

On this basis, this article focuses on analyzing the economic information network of the Banque de l'Indochine during the period 1875 - 1945, with the aim of clarifying three main issues: (1) the formation and organization of the bank's information collection and transmission network; (2) the types of economic information collected and the ways in which they were utilized in credit operations, payments, trade finance, and risk management; and (3) the role of the economic information network in enhancing the bank's operational efficiency and position within the colonial economy. The study is based on the exploitation of annual reports of the Banque de l'Indochine, French archival records, statistical yearbooks, economic press sources, and colonial administrative documents, combining historical methods with source analysis and a business history approach. The article not only contributes a new perspective to the operational history of the Banque de l'Indochine but also highlights the role of information as a strategic resource in the functioning of colonial banks.

METHODOLOGY

This study adopts a combined methodological approach, primarily based on the Historical Method and the Logical Method, supported by Statistical Methods. Specifically:

The historical method enables a systematic and accurate reconstruction of the development of the economic information network and its role over time, within its specific context.

The logical method facilitates the coherent, structured, and rigorous analysis and presentation of research problems and objectives.

The statistical method is used to collect data from the French National Library and other diverse sources (archival materials, monographs, dissertations), and to process and extract key evidence and information.

The comparative method is applied to examine the economic information network and its role in the operations of the Banque de l'Indochine from 1875 to 1945.

In addition to these main approaches, other methods such as deduction, induction, and synthesis are also employed throughout the research process.

RESEARCH CONTENT

The economic information network in French Indochina

The Colonial Administration and the System of Economic Statistics

The formation of an economic information network in Indochina initially stemmed from the administrative requirements of the French colonial authorities. As the scope of governance expanded beyond Cochinchina to encompass Tonkin, Annam, Cambodia, and later Laos, the management of an economic space characterized by diverse legal regimes and financial mechanisms necessitated a unified system for the collection, compilation, and processing of information. In this context, budgets, revenue–expenditure statistics, and financial reports served not only administrative purposes but also became essential instruments through which the colonial government assessed the economic conditions of the entire Indochinese Union.

According to *Histoire budgétaire de l'Indochine*, L'Indochine française est formée d'une Colonie à laquelle sont venus s'ajouter par la suite des Protectorats divers. De là des différences d'origine et de condition qui ont fait longtemps obstacle à la constitution de la personnalité morale de l'Indochine, laquelle n'a été définitivement établie qu'en 1898. Comme il reste encore certaines traces de ces différences, il n'est pas sans intérêt d'esquisser rapidement l'histoire financière de l'Indochine, avant d'étudier la situation actuelle de son budget (Exposition coloniale internationale, 1931, p. 5). This assessment indicates that, from its inception, French Indochina comprised a colony alongside several protectorates incorporated at different points in time. These disparities in legal status and administrative

arrangements posed significant obstacles to the establishment of a unified financial system. The source emphasizes that the juridical personality of the Indochinese Union was only definitively established in 1898, following a prolonged period during which its constituent entities functioned as relatively autonomous financial units. This suggests that the standardization of budgetary information and economic statistics was not achieved from the outset, but rather emerged through a protracted process of institutional reform.

According to *Histoire budgétaire de l'Indochine* (Exposition coloniale internationale, 1931, p. 5), during the initial phase Cochinchina possessed a more fully developed budgetary organization than the other territories. From 1880 onward, the colonial budget was approved by the Colonial Council and primarily served expenditures within Cochinchina itself. However, as French expansion extended into Tonkin, the metropole required Cochinchina to contribute a portion of its revenues to cover military and administrative costs in the northern regions. The document indicates that this shift generated tensions between Cochinchina's fiscal interests and the broader imperative of resource allocation across Indochina. Such tensions constituted one of the driving forces behind the colonial administration's efforts to develop more centralized mechanisms of statistical coordination and budgetary redistribution.

Prior to 1887, neither Tonkin nor Annam possessed an independent local budgetary system; all military and administrative expenditures were borne directly by the French metropole, and these territories lacked their own treasuries. A turning point occurred with the decree of 27 January 1886, which came into force on 1 January 1887. Under this measure, the protectorates of Annam and Tonkin were organized as financial entities with their own budgets and revenue sources, thereby laying the institutional foundations for the subsequent development of a more unified system of financial management and statistical reporting (Exposition coloniale internationale, 1931, pp. 5-6).

The period from 1887 to 1892 also illustrates why the colonial administration became increasingly attentive to, and reliant upon, financial statistics. During the first five years of operating the new budgetary system, total expenditures in Annam and Tonkin exceeded revenues by more than 20 million francs, compelling the French government to extend supplementary credits on two occasions, in 1890 and 1892, in order to address the deficit. The recurrent emergence of budgetary shortfalls created an urgent need for close monitoring of fiscal developments, tighter control over revenue streams, and systematic evaluation of the effectiveness of public expenditures. From an administrative perspective, economic statistics thus evolved beyond mere record-keeping to become an essential instrument for financial decision-making within the colonial state.

This situation is clearly reflected in Article 46 of the Finance Law of 26 December 1890: Which made available to the protectorate an additional credit of more than 13 million francs, drawn from the surplus revenues of the metropolitan budget for the fiscal year 1889. However, two years later, the 1891 budget showed an excess of expenditures over revenues amounting to more than 6,000,000 francs. It therefore became necessary to open a new extraordinary credit. The sum required to fully settle the financial situation of Annam and Tonkin at the opening of the 1892 fiscal year was set at 12,000,000 francs, and this credit was granted by the law of 29 March 1892. During this second five-year period, total subsidies from the metropole amounted to 102 million francs, while those from Cochinchina reached 41 million francs (Exposition coloniale internationale, 1931, p. 6).

The economic press as a channel for information transmission

In a colonial economy, the collection of information constituted only the initial stage of the processes of governance and administration. The value of economic data was fully realized only when it was disseminated to the various actors participating in the market. Accordingly, alongside the official reporting system of the colonial administration, the economic press gradually emerged as a key channel for transmitting information between government authorities, enterprises, banks, and investors. Through the regular publication of data on trade, budgets, credit, transportation, production, and international markets, the press contributed to the formation of a relatively continuous flow of information, thereby enabling business decisions to be made on the basis of up-to-date data.

The information disseminated through the press covered a wide range of domains, encompassing multiple aspects of the colonial economy. In the issues of Communiqué de la presse indochinoise examined by the author, the published content extended beyond administrative documents to include

updates on the issuance of Indochinese public loans (Emprunt indochinois), budget revenues (Les recettes budgétaires de l'Indochine), agricultural credit (Communiqué de la presse indochinoise (No. 12), 1920, p. 3), the activities of the Port of Saigon (Les exportations du port de Saïgon) (Communiqué de la presse indochinoise (No. 69, 1923, p. 6) and among many other topics. The regular maintenance of these sections indicates that the press had become an important medium for disseminating economic information from governmental authorities to the business community and financial institutions.

At the same time, Communiqué No. 108 (15 September 1926) devoted specific sections to Emprunt indochinois and Les exportations du port de Saïgon (1er semestre 1926) (Communiqué de la presse indochinoise (No. 110), 1926, p. 16), reflecting the periodic publication of financial and commercial data.

Beyond the mere publication of statistical data, the economic press also performed the function of interpreting and shaping perceptions of market developments. Many articles in La Revue économique d'Extrême-Orient focused on analyzing investment trends, trade patterns, and the business environment rather than simply reporting information. For instance, the article “Il faut accroître les échanges entre l'Indochine et le Japon” (La Revue Économique d’Extrême-Orient (No. 1), 1924, pp. 1-6) argued that the press campaign opposing the expansion of trade relations between Indochina and Japan lacked a solid foundation. Japan did not demand minimum tariff rates but merely sought reasonable preferential treatment, while arguments concerning a so-called “Japanese threat” were exaggerated. Statistical evidence indicated that Japanese goods accounted for only a small share of Indochina’s imports and thus posed no significant threat to French products; indeed, Indochina even maintained a trade surplus with Japan. On the contrary, reducing tariffs on Japanese goods could expand export markets, lower transportation costs, and stimulate competition, thereby encouraging improvements in production. The author therefore concluded that strengthening trade exchanges with Japan would be beneficial for both Indochina and France.

Similarly, the article “Les placements Indochinois doivent être au-dessus de tout soupçon” (La Revue Économique d’Extrême-Orient (No. 1), 1927, pp. 1-5) clearly illustrates the non-neutral role of the economic press within the colonial context, as it actively participated in defending the interests of financial capital. By opposing state regulatory measures, the article reveals the tension between two competing logics: on the one hand, the need for regulation to limit risks, and on the other, the imperative of maintaining market freedom to ensure the flow of investment capital. At the same time, its discussion of high profits and speculative activities highlights the attractiveness yet volatility of the Indochinese financial market, which created favorable conditions for large financial groups to expand their operations. More importantly, the article suggests that the survival and development of financial institutions depended not only on economic efficiency but also on their protection and legitimation within political and media discourse.

In addition to thematic analytical articles, regularly maintained sections also contributed to the creation of a continuous flow of economic information. Sections such as Pour les Exportateurs, Pour les Importateurs, and La Vie Économique reflect the role of the economic press as a practical channel for market information. By updating data on commodity demand, production conditions, and trade trends in regions such as Japan, China, and the Philippines, these sections enabled business actors to orient their import–export activities, identify appropriate markets, and select suitable commodities (La Revue économique d'Extrême-Orient (No.11), 1925-1927, pp. 165-166).. The presentation of information by market segments and commodity groups allowed enterprises to more easily track changes in the business environment, while also supporting financial institutions in assessing the prospects of specific economic sectors.

From the perspective of economic history, the press contributed to linking the different components of the economic information network in Indochina. While the statistical system of the colonial administration generated primary data, the press functioned as the medium through which such data were disseminated to enterprises, banks, and investors. Through this process of transmission, information on trade, credit, budgets, transportation, and international markets was widely circulated, providing a basis for decision-making in business activities. This informational function made the economic press an integral component of the economic information network in French Indochina, while

also laying the groundwork for the emergence of specialized information flows on prices, trade, finance, and investment, which will be analyzed in the following section.

Types of economic information disseminated

The content published in the economic press system in Indochina was diverse and provided a relatively comprehensive reflection of the colonial economy in the 1920. A survey of issues of Communiqué de la presse indochinoise and La Revue économique d'Extrême-Orient shows that the information disseminated can be grouped into five main categories: trade and import–export information; finance, budget, and credit; enterprises and investment; production and commodity markets; and international economic information with direct relevance to Indochina. This classification indicates that the economic press did not merely report isolated events but developed a relatively complete information system serving both administrative management and business activities.

The most frequently reported category was trade and import–export. In many issues of Communiqué de la presse indochinoise, articles regularly published data on exports through the Port of Saigon, trade volumes between Indochina and regional markets, as well as fluctuations in specific commodity groups. For instance, the section Les exportations du port de Saïgon provided statistics on export activities on a quarterly or semi-annual basis, enabling readers to track changes in foreign trade over time. In addition, articles such as Le Commerce du port de Swatow avec l'Indochine, Le développement d'Haiphong, and Les répercussions de la catastrophe du Japon sur l'industrie des soies demonstrate that the press not only focused on the domestic market but also monitored the impact of international developments on Indochinese trade. These reports highlight the role of the press in linking the colonial economy with regional markets.

Another important category was finance, budget, and credit. The Communiqué regularly published updates on Les recettes budgétaires de l'Indochine, Emprunt indochinois, Le crédit agricole en Cochinchine, and other matters related to colonial financial policy. Notably, the article Le crédit agricole en Cochinchine provided detailed information on the organization of agricultural credit funds, their operational objectives, lending mechanisms, and their relationship with the Banque de l'Indochine. This indicates that the press not only reported financial decisions but also disseminated knowledge about the functioning of the colonial credit system, thereby facilitating access to new policies for businesses and producers.

In addition to official statistical information, the press devoted considerable attention to investment and enterprise activities. In La Revue économique d'Extrême-Orient, numerous articles analyzed the investment environment, capital mobilization, and the development of colonial enterprises. A representative example is Les placements Indochinois doivent être au-dessus de tout soupçon, which emphasized the need to ensure transparency in capital markets in order to maintain investor confidence. Rather than merely reporting market developments, such articles also examined the impact of legal regulations on investment activities and the capacity of Indochinese enterprises to mobilize capital. This reflects a shift from simple reporting to more analytical approaches concerning the business environment.

Another frequently covered area was production and commodity markets. In Communiqué issues, readers could find articles on Japanese cement production, camphor extraction in Tonkin, livestock farming in Cochinchina, pineapple production, the use of anthracite in industry, and the development of transportation systems and ports. These reports reflected not only the scale of production but also the press's concern with factors affecting the competitiveness of the colonial economy. At the same time, La Revue économique d'Extrême-Orient regularly updated developments in commodity markets through sections such as Pour les Exportateurs and Pour les Importateurs, which analyzed consumer demand, prices, and market prospects for different commodities across regional markets.

Finally, a notable feature of the economic press system was its continuous monitoring of the international economic environment. Beyond reporting on Indochina, many articles addressed trade relations with Japan, China, Siam, the Philippines, the Dutch East Indies, and other colonies in the region. The article Il faut accroître les échanges entre l'Indochine et le Japon serves as a representative example of how the press advocated the expansion of international trade as a requirement for economic development. Along with sections such as La Vie Économique, the press enabled enterprises and

financial institutions to follow regional market developments and assess their implications for trade and investment in Indochina.

From the above, it can be seen that the economic press in Indochina not only fulfilled the function of information dissemination but also developed into a relatively comprehensive economic data system. Through the regular publication of information on trade, budget, credit, investment, production, and international markets, the press contributed to linking economic actors within the colony to broader regional economic dynamics. For the Banque de l'Indochine, this constituted an important source of information for monitoring market activities, assessing sectoral trends, and adjusting its operations in credit, payments, and trade finance.

The Role of the economic information network in the operations of the Banque de l'indochine

Economic information and Credit activities

The credit operations of the Banque de l'Indochine cannot be separated from the economic information system that it accessed and utilized. In the context of a colonial economy largely driven by agricultural exports and international trade, the ability to promptly capture market fluctuations became a prerequisite for the bank's lending, discounting, and trade finance activities. In practice, information on commodity prices, market demand, exchange rates, and regional trade conditions directly influenced the bank's credit decisions and risk assessment processes.

Specifically, in trade financing activities, the bank was required to closely monitor developments in Indochina's principal export markets, particularly within Asia. Analyses of the potential expansion of trade between Indochina and Japan indicate that regional markets were not only outlets for goods but also decisive factors influencing the profitability of commercial credit operations (La Revue Économique d'Extrême-Orient (No. 1), 1924, pp. 4-6)**.**

At the same time, political developments in China during the 1920s, especially the rise of the Kuomintang, significantly altered the regional balance of power. Contemporary writings even characterized this force as a highly disciplined and well-organized political–military entity: "Elle est l'armée du parti Kouomintang, le seul parti chinois digne de ce nom et vraiment organisé…" (La Revue Économique d'Extrême-Orient (No. 15), 1926, p. 227)

Articles published in La Revue Économique d'Extrême-Orient reveal an increasingly clear awareness among French observers of the emergence of a new political–military force capable of challenging the existing order. In this context, the financial and commercial activities of Indochina could not be dissociated from regional dynamics, compelling institutions such as the Banque de l'Indochine to adjust their strategies accordingly.

Beyond market monitoring, credit operations also depended on the ability to assess the credibility of enterprises and the security of investments. Economic press articles repeatedly emphasized that investments in Indochina had to be placed "above all suspicion," reflecting the requirement for transparency and reliability in a financial environment marked by significant risks. As noted in the press, any measure liable to undermine confidence could seriously damage colonial investments: "Le seul fait de soumettre les valeurs coloniales à un régime spécial jetterait évidemment le plus grand discrédit sur les placements coloniaux" (La Revue Économique d'Extrême-Orient (No. 1), 1927, p. 4).

At the same time, financial scandals such as the affaire Rochette were invoked as lessons demonstrating the necessity of cleansing the investment environment. Such cases highlight the extent to which banks had to rely on press information to identify and mitigate credit risks: "L'Indochine est empoisonnée du virus financier et c'est sans doute là le plus gros danger qui la menace" (La Revue Économique d'Extrême-Orient (No.6), 1927, p. 86). In this context, the press did not merely reflect reality but actively participated in the process of risk identification by calling for greater transparency, demanding information disclosure, and investigating suspicious enterprises: "nous demanderons … que les fondateurs s'engagent à ne jamais se faire les complices d'un syndicat financier" (La Revue Économique d'Extrême-Orient (No.6), 1927, p. 86). It thus became an important reference source for bank credit assessment.

Credit decisions were not limited to purely economic considerations but were also influenced by the broader business environment, including political and social factors. Calls for ending disputes and fostering economic stability reflect an understanding that stability was essential for maintaining investor confidence and ensuring credit security. Contemporary observations noted that "L'Indochine est en effervescence…, comme toutes les querelles" (La Revue économique d'Extrême-Orient (No.11), 1925-1927, p. 161).underscoring how political and social tensions could directly affect financial activities.

In addition, banks needed to acquire information on commercial networks and the actors involved in the circulation of goods. The role of the Chinese diaspora in trade activities in Indochina reveals the existence of distribution networks operating beyond the formal sector, which carried significant implications for assessing market absorption capacity and the financial strength of credit partners. An article published in La Revue Économique d'Extrême-Orient observed: "Le Chinois est à la fois banquier, commerçant, usinier, exportateur; comment s'étonner qu'il gagne beaucoup d'argent ? C'est ce qu'on appelle la concentration verticale, formule la plus moderne du développement industriel" (La Revue Économique d'Extrême-Orient (N° 15), 1927, p. 229).

This observation suggests that Chinese commercial networks were not merely engaged in trade but exhibited a high degree of vertical integration across finance, production, and distribution. Such characteristics imposed additional requirements on banks to accurately identify the organizational structure and financial capacity of these actors when conducting credit assessments.

At the same time, information on labor markets and the availability of the workforce also directly affected the productive capacity of enterprises. A contemporary study attempted to "examiné les disponibilités du Nord indochinois en travailleurs ainsi que celles des pays voisins" (La Revue Économique d'Extrême-Orient (No.20), 1927, p. 305), thereby highlighting the close relationship between labor supply and demand and the process of economic exploitation in Indochina. In this context, the ability to mobilize and organize labor became a key factor determining production efficiency, which in turn influenced the financial capacity and debt repayment ability of economic actors.

These qualitative analyses in the economic press were complemented and verified by concrete data on trade, import–export activities, and transportation, compiled in periodic economic bulletins. Information on the "mouvement commercial de l'Indochine," export volumes, and maritime transport not only reflected the scale of the economy but also provided a practical basis for banks to assess the flow of goods and capital in credit operations. For instance, according to a 1927 bulletin, "le commerce spécial d'exportation de l'Indochine a atteint au cours du 1er trimestre 1927, 1.031.258.585 francs. Le trafic d'exportation est en augmentation de 387.401.622 francs par rapport à la période correspondante de 1926…" (Agence Économique de l'Indochine (No. 118), 1927, p. 5). Such statistical data were not merely descriptive but functioned as tools for evaluating the commercial and financial capacity of the economy, thereby supporting credit decisions.

From this perspective, economic information did not merely play a supporting role but constituted the very foundation of credit activities. By exploiting the economic press system, the Banque de l'Indochine was able to access a relatively comprehensive body of information on markets, enterprises, and the business environment, thereby enhancing its appraisal capacity, reducing risks, and optimizing financial decision-making within a highly volatile colonial economy.

From a technical banking perspective, the information collected from the colonial statistical system, the bulletins of the Agence économique de l'Indochine, and specialized economic journals constituted a crucial foundation for credit appraisal. The Encyclopédie de banque et de bourse indicates that, prior to conducting operations such as lending, bill discounting, or advances on goods, banks were required to evaluate multiple factors simultaneously, including the financial capacity of clients, the value of collateral, the marketability of goods, and prevailing market conditions. Credit assessment, therefore, could not rely solely on documents provided by enterprises but required cross-checking against independent sources of information on price movements, trade conditions, and the investment environment. This verification mechanism helped reduce risks arising from information asymmetry between banks and clients, while enhancing the security of credit operations.

In practice, the operations of the Banque de l'Indochine demonstrate that the demand for economic information expanded alongside the development of international trade. The bank not only monitored

the prices of key commodities such as rice, rubber, and coal within Indochina but also closely followed developments in import markets, as well as trade policies in Japan, China, the Netherlands, and major financial centers in the region. Analytical articles in La Revue économique d'Extrême-Orient, together with compilations from the Communiqué de la presse indochinoise, continuously provided information on import–export activities, prices, maritime transport, industrial production, tariff policies, and investment. For a bank that simultaneously performed issuing functions and trade financing, such information was essential not only for forecasting market trends but also for identifying priority sectors for credit allocation, selecting clients, and adjusting the scale of financing in accordance with sectoral risk levels.

More broadly, economic information itself became a form of financial infrastructure within the colonial economy. Continuous flows of data on prices, exchange rates, commodity circulation, budgets, and investment transmitted through statistical agencies, the economic press, and the information network of the Agence économique de l'Indochine contributed to the formation of a relatively unified informational environment for banking and business activities. Within this environment, the Banque de l'Indochine was not merely a recipient of information but an active agent in processing and transforming information into concrete business decisions. Decisions regarding credit allocation, bill discounting, and trade financing were all based on the synthesis, analysis, and evaluation of multiple information sources, rather than solely on collateral or traditional credit relationships.

It can therefore be argued that, in the early twentieth century, the effectiveness of the Banque de l'Indochine's credit operations depended not only on the scale of its capital resources or its issuing privileges but also on its capacity to access and process economic information. The information network formed by statistical agencies, economic bulletins, and specialized press helped reduce information costs, limit credit risks, improve the quality of credit appraisal, and support capital allocation within the colonial economy. In this sense, economic information was not merely an auxiliary tool but constituted a distinctive financial resource, enabling the Banque de l'Indochine to expand its credit activities and maintain its central role in the Indochinese financial system prior to the Second World War. This also provides the basis for examining, in the following section, the role of information networks in currency issuance, where data on silver prices, gold prices, exchange rates, and monetary circulation played a decisive role in managing the Indochinese piastre.

Economic Information and Currency Issuance Activities

The currency issuance activities of the Banque de l'Indochine, as an issuing bank within the framework of the colonial regime, were directly influenced by monetary factors and fluctuations in precious metal markets. Under the silver standard and amid the complex dynamics of the international financial system in the early twentieth century, controlling the volume of currency in circulation could not be separated from the close monitoring of silver prices, gold prices, and exchange rates. Economic information, therefore, was not merely a supporting tool but constituted an essential basis for adjusting monetary policy in accordance with the realities of circulation.

First, fluctuations in silver prices played a central role in determining the value of the currency in circulation in Indochina. In a monetary system closely tied to precious metals, any change in the international price of silver could directly affect the purchasing power of the currency and the domestic monetary balance. As noted, "the circulation of the Mexican silver dollar, an international currency, in Vietnam was initially driven by the needs of foreign trade and later by executive decisions, thereby effectively placing the monetary system under the silver standard. Silver coin thus became the fundamental currency in domestic circulation" (Phan Hạ Uyên, 1973, p. 20). Such analyses of the role of silver and gold in monetary history demonstrate that fluctuations in precious metal prices were not merely a matter of trade but also had direct implications for issuance policy and monetary stability.

In addition, the exchange rate between the Indochinese piastre and international currencies was another key factor that the bank had to monitor continuously. Exchange rate fluctuations not only reflected the position of the colonial economy within the global market but also directly influenced monetary circulation, import–export activities, and the capacity for international payments. Periodically published data on budget revenues, commercial activities, and monetary flows provided a practical basis for the bank to adjust the volume of currency issuance in accordance with the needs of the economy.

Beyond exchange rate factors, the state of domestic monetary circulation also constituted an important indicator for currency issuance activities. Through reports on trade, transportation, and production, it is possible to observe the scale and velocity of commodity circulation, which in turn indirectly reflects the monetary needs of the economy. Data on exports, maritime transport, and the movement of goods demonstrate a close linkage between monetary flows and commodity flows. For example, "Le commerce spécial d'importation du 1er trimestre 1927 est en augmentation de 169.387.885 francs sur celui du 1er trimestre 1926…" (Agence Économique de l'Indochine (No. 118), 1927, p. 2)

At the same time, economic information published in the press also contributed to reflecting the policy context and changes in the financial and monetary management of the colonial administration. Assessments of economic, commercial, and financial conditions not only provided data but also helped shape perceptions regarding the stability or instability of the monetary system. Under such conditions, the control of currency issuance was not merely a technical matter but was also closely linked to the need to maintain confidence in the currency within the colonial economy.

From the above analysis, it can be seen that the currency issuance activities of the Banque de l'Indochine were deeply dependent on the economic information system, particularly data on precious metal prices, exchange rates, and commodity circulation. The combination of theoretical analyses of monetary issues with empirical data derived from the economic press enabled the bank to establish a relatively solid foundation for managing its issuance policy. In this sense, economic information did not merely serve a descriptive function but became an important regulatory instrument within the colonial monetary system.

Economic Information and Trade Finance Activities

In the colonial economy of Indochina, where production was closely tied to the export of agricultural commodities and resource extraction, trade finance became one of the key functions of the Banque de l'Indochine. Operations such as advances, bill discounting, and import–export financing depended directly on the bank's ability to obtain and process information on commodity markets, transportation, and distribution networks. In this context, economic information was not merely supportive but constituted a fundamental condition for organizing and controlling trade finance activities.

First, information on commodity trade particularly key export products such as rice, rubber, and coal played a decisive role in shaping financing decisions. Data on production output, prices, and international demand enabled the bank to assess the profitability of trade credit. In the Communiqué de la presse indochinoise, such information frequently appeared in the form of aggregated reports on import–export activities and the circulation of goods. For instance, "Le commerce extérieur de l'Indochine, de 1.698.855.049 frs à la fin du 1er trimestre 1926, s'est élevé à 2.279.932.436 frs pendant le 1er trimestre de l'exercice en cours, accusant une plus-value de 581.077.387 frs en faveur de ce dernier" (Agence Économique de l'Indochine (No. 118), 1927, p. 1). Similarly, "Le commerce spécial d'exportation de l'Indochine a atteint au cours du 1er trimestre 1927 1.031.258.585 francs" (Agence Économique de l'Indochine (No. 118), 1927, p. 5). These figures directly reflect the scale and trends of trade, thereby providing a basis for the bank's decisions to finance export activities.

In addition, information on strategic commodities such as rubber held particular importance. Rubber was one of Indochina's principal export products during the interwar period, and fluctuations in its market had a direct impact on both credit operations and trade finance. Economic bulletins noted that "Parmi les marchandises à destination ou en provenance de Chine, expédiées par la voie du Tonkin… les fluctuations sensibles ont été relevées…" (Agence Économique de l'Indochine (No. 118), 1927, p. 9), accompanied by lists of commodities experiencing significant increases or decreases. Such information directly reflected the movement of goods and the volatility of markets, thereby providing the bank with a basis for assessing trade trends and adjusting its financing activities accordingly.

Beyond commodities, information on international markets and trading partners also played a crucial role in trade finance activities. Articles in La Revue économique d'Extrême-Orient frequently addressed commercial relations between Indochina and regional economies such as Japan and China. For instance, one article on Franco-Japanese commercial relations observed that "Depuis plusieurs mois, une violente campagne est menée contre le Japon et contre les négociations commerciales franco-japonaises qui doivent aboutir à un traité de commerce" (La Revue Économique d'Extrême-Orient (No. 1), 1925, p.

1),reflecting the broader debate surrounding the expansion of trade relations and highlighting the potential for increased exchange between Indochina and Japan.

Beyond policy commentary, the article also provided concrete data on trade flows: “les exportations de l'Indochine au Japon ont dépassé 40 millions, ce qui laisse à l'Indochine une balance active de plus de 30 millions (La Revue Économique d’Extrême-Orient (No. 1), 1925, p. 4), while emphasizing Japan’s role as an important market: “Le Japon ferait un bon client pour l'Indochine qui peut lui vendre non seulement les produits de son sol, mais encore des nattes, des éventails, des produits chimiques et céramiques… de laque et d'huile, des minerais de plomb et de fer, du sel, du sable pour ses verreries et du kaolin” (La Revue Économique d’Extrême-Orient (No. 1), 1925, p. 5) Similarly, the article “Une Chine nouvelle ?” reflected the political and economic transformations in China, thereby illustrating the influence of this market on Indochinese trade: “Les récents événements de Chine revêtent une importance considérable et nous ne croyons pas nous tromper en annonçant qu'ils inaugurent une nouvelle période de l'histoire de la Chine républicaine” (La Revue Économique d’Extrême-Orient (No. 15), 1926, p. 225).

Such information enabled the bank to orient its trade financing strategies according to specific markets while also diversifying risks in a context of considerable regional economic volatility.

In summary, economic information played a central role in the trade finance activities of the Banque de l’Indochine. From data on exports, commodity production, and international markets to transportation and circulation, all these factors directly influenced the bank’s financing decisions. By exploiting sources such as Communiqué de la presse indochinoise and La Revue économique d’Extrême-Orient, the bank was not only able to track market developments but also to actively direct capital flows toward the most profitable sectors and markets. This demonstrates that trade finance was not merely a financial operation but the outcome of a broader process of information processing and control within the colonial economy.

Economic Information as a Tool for Consolidating Colonial Financial Power

Beyond its role in providing data for credit operations, currency issuance, and trade finance, the economic information network also performed a deeper function: it served as a tool through which the Banque de l’Indochine consolidated and expanded its financial power within the colonial economy. In a context where information was unevenly distributed, the control and exploitation of economic information created a structural advantage, enabling the bank not only to respond to market developments but also to shape the movement of capital and trade flows.

First, economic information enabled the bank to control capital flows through its credit activities. As seen in analyses published in La Revue économique d’Extrême-Orient, data on prices, exports, and markets did not merely reflect economic conditions but also helped shape the expectations of the business community. Articles on markets such as Japan and China highlighted potential areas of commercial expansion, thereby indirectly directing credit toward sectors and regions considered advantageous. For example, the observation that “Depuis plusieurs mois, une violente campagne est menée contre le Japon et contre les négociations commerciales franco-japonaises qui doivent aboutir à un traité de commerce” (La Revue Économique d’Extrême-Orient (No. 1), 1925, p. 1), illustrates the debates surrounding the expansion of trade relations. At the same time, concrete trade data reinforced the perceived potential of this market: “les exportations de l'Indochine au Japon ont dépassé 40 millions, ce qui laisse à l'Indochine une balance active de plus de 30 millions” (La Revue Économique d’Extrême-Orient (No. 1), 1925, p. 4).

Such information not only reflected commercial realities but also contributed to shaping the perceptions of economic actors, thereby providing a basis for the bank to adjust credit flows toward promising markets and sectors. Under these conditions, the bank did not merely rely on information for decision-making but also utilized the information system itself as a mechanism for guiding the allocation of capital.

Second, economic information contributed to the control of commercial activities through the selection and prioritization of financing sectors. The Communiqué de la presse indochinoise provided periodic data on import–export activities, transportation, and production, thereby creating a relatively

comprehensive “economic map” of Indochina. For example, “Le commerce spécial d’exportation de l’Indochine a atteint au cours du 1er trimestre 1927 1.031.258.585 francs” (Agence Économique de l’Indochine (No. 118), 1927, p. 1). The ability to access and process such information enabled the bank to identify the most profitable sectors, concentrate its financing accordingly, and indirectly shape the structure of colonial trade. In other words, information did not merely reflect commercial activity but actively contributed to its restructuring through financial decisions.

Third, in the monetary sphere, economic information played a key role in controlling circulation and reinforcing confidence in the currency. Data on exchange rates, budget revenues, and the circulation of goods regularly published in economic bulletins allowed the bank to adjust the volume of currency issuance in line with market demand. More importantly, the control of monetary information enabled the bank to maintain its monopolistic position in issuing and regulating currency, thereby consolidating its financial power across the colonial economy.

At a deeper level, economic information also helped reduce information asymmetry in ways favorable to the bank. In operations such as discounting and lending, the bank held a superior informational position compared to its clients, owing to its access to economic press sources, market bulletins, and aggregated data. As indicated in the Encyclopédie de banque, credit assessment depended not only on formal documentation but also on information regarding the reputation and capacity of borrowers. This suggests that information was not merely a technical tool but a source of power, enabling the bank to impose credit conditions and manage risks to its advantage.

Finally, within the colonial context, the control of economic information was closely intertwined with the authority of the colonial administration and financial institutions. Data on budgets, trade, and monetary circulation served not only economic purposes but also contributed to maintaining the financial order established by the colonial regime. As the Banque de l’Indochine became a central node in the collection, processing, and dissemination of economic information, it simultaneously occupied a strategic position in controlling the flows of the colonial economy.

In sum, economic information in colonial Indochina was not merely a tool serving banking operations but a crucial instrument for consolidating financial power. By controlling information, the Banque de l’Indochine was able to direct capital flows, influence the structure of trade, and maintain its central position within the colonial financial system. This demonstrates that the economic information network was not only of technical significance but also carried profound political–economic implications, contributing to the shaping of power structures within the Indochinese economy during this period.

CONCLUSION

Based on a survey of economic press sources and market bulletins from the early twentieth century, it can be affirmed that French Indochina gradually developed a relatively comprehensive system for the collection and dissemination of economic information. This system included not only administrative reports and budgetary statistics but also extended to specialized publications such as La Revue économique d’Extrême-Orient and compiled bulletins like the Communiqué de la presse indochinoise. The combination of analytical sources and regularly updated data created a multi-layered information network that provided a fairly complete reflection of the colonial economy, encompassing production, trade, finance, and monetary activities.

Within this structure, the Banque de l’Indochine functioned not merely as a recipient of information but as an active agent in exploiting and utilizing the economic information network. By accessing data on prices, export markets, exchange rates, and regional trade conditions, the bank was able to make credit and trade finance decisions that were responsive to market fluctuations. At the same time, monitoring information on the business environment, corporate reputation, and political–social factors enabled the bank to reduce risks in lending and discounting operations. This demonstrates that, in a context of uneven information distribution, the capacity to access and process information became a significant advantage, contributing to the efficiency of banking operations.

Beyond its supportive role, economic information became a strategic resource for the Banque de l’Indochine. In credit activities, data on agricultural prices and export markets enabled the bank to assess

repayment capacity and direct capital toward profitable sectors. In the sphere of currency issuance, information on silver prices, exchange rates, and commodity circulation allowed the bank to adjust the money supply in accordance with economic demand. In trade finance, information on production, transportation, and international markets provided the basis for controlling the flows of goods and capital in import–export transactions. Thus, information functioned not only as an input but also as a regulatory instrument, enabling the bank to intervene in the economic dynamics of the colonial system.

From a broader perspective, the control and exploitation of economic information also contributed to consolidating the financial power of the Banque de l'Indochine within the colonial framework. By holding key information on markets and finance, the bank was able to direct credit activities, influence the structure of trade, and maintain its central position within the monetary system. This suggests that economic information was not merely technical in nature but was closely linked to power relations within the colonial economy. Through its control of information, the bank was not only able to adapt to market conditions but also to shape economic trends in its favor.

From the standpoint of economic history, this study contributes a new perspective on the role of information in colonial banking operations. Rather than focusing solely on institutions, policies, or capital flows, emphasizing the information network highlights another dimension of economic functioning: the role of knowledge, data, and information-processing capacity in financial decision-making. This approach not only enhances our understanding of the Banque de l'Indochine but also opens avenues for comparative analysis with similar cases in global economic history.

In conclusion, the economic information network in French Indochina played a crucial role in supporting and shaping the operations of the Banque de l'Indochine. Through the effective use of information, the bank not only improved the efficiency of its credit, currency issuance, and trade finance activities but also strengthened its position within the colonial financial system. This demonstrates that, in economic history, information is not merely a tool for reflecting reality but a strategic resource capable of profoundly influencing the structure and functioning of an economy.

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THE EFFECT OF AROMATHERAPY ON SLEEP QUALITY IN PATIENTS UNDERGOING DIALYSIS: A REVIEW OF POSTGRADUATE NURSING THESES IN TÜRKİYE

TÜRKİYE'DE DİYALİZ HASTALARINDA AROMATERAPİNİN UYKU KALİTESİNİ İYİLEŞTİRİLMESİNE YÖNELİK HEMŞİRELİK ALANINDA YAPILAN LİSANSÜSTÜ TEZLERİN İNCELENMESİ

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ÖZET

Giriş: Hemodiyaliz tedavisi alan hastalarda uyku bozuklukları sık görülmekte ve yaşam kalitesini olumsuz etkilemektedir. Farmakolojik olmayan, tamamlayıcı hemşirelik girişimleri bu semptomların yönetiminde giderek daha fazla önem kazanmaktadır. Aromaterapi, invaziv olmayan ve uygulanması kolay bir yöntem olarak öne çıkmaktadır. Bu çalışma, Türkiye'de hemşirelik alanında hemodiyaliz hastalarında aromaterapinin uyku kalitesi üzerine etkisini inceleyen lisansüstü tezlerin değerlendirilmesini amaçlamaktadır.

Materyal ve Metot: Bu retrospektif ve tanımlayıcı çalışma, Yükseköğretim Kurulu Başkanlığı Ulusal Tez Merkezi veri tabanından elde edilen araştırma verilerine dayanmaktadır. Çalışmanın evrenini, hemşirelik alanında yapılan ve tezin içinde "diyaliz", "uyku" ve "aromaterapi" terimlerini içeren lisansüstü tezler oluşturdu. Hemşirelikte yüksek lisans eğitiminin başladığı 1968 yılından 1 Şubat 2026 tarihine kadar yapılan ve erişim kısıtlaması olmayan tüm tezler değerlendirmeye alındı.

Bulgular: Tarama sonucunda biri yüksek lisans, ikisi doktora olmak üzere toplam üç tez çalışmaya dahil edildi. Tüm çalışmalar müdahaleli tasarıma sahip olup aromaterapinin inhalasyon veya masaj yoluyla uygulandığı görüldü. Aromaterapi uygulanan hastalarda uyku kalitesinin arttığı ve gündüz uykululuk düzeyinin azaldığı saptandı.

Tartışma ve Sonuç: Bu geleneksel derlemede ülkemizde diyaliz hastalarında uyku kalitesinin iyileştirilmesine yönelik müdahalede bulunan üç adet lisansüstü teze ulaşıldı. Tezlerin tamamında aromaterapinin hemodiyaliz hastalarında yalnızca tamamlayıcı bir rahatlama yöntemi değil, ölçülebilir klinik çıktılar sağlayan etkili bir hemşirelik girişimi olduğunu göstermektedir. Ancak, konuyla ilgili yapılan tezlerde sınırlılıklar bulunduğu ve konuyla ilgili daha çok araştırmaya ihtiyaç olduğu görülmektedir.

Anahtar Kelimeler: Hemodiyaliz, aromaterapi, uyku kalitesi, hemşirelik

ABSTRACT

Introduction: Sleep disturbances are common among patients undergoing hemodialysis and negatively affect quality of life. Non-pharmacological, complementary nursing interventions have become increasingly important in the management of these symptoms. Aromatherapy stands out as a non-invasive and easy-to-apply method. This study aimed to evaluate postgraduate theses conducted in Türkiye in the field of nursing that investigated the effect of aromatherapy on sleep quality in hemodialysis patients.

Material and Methods: This retrospective and descriptive study was based on research data obtained from the Council of Higher Education National Thesis Center database. The study population consisted of postgraduate theses in the field of nursing that included the terms "dialysis," "sleep," and "aromatherapy." All accessible theses conducted between 1968, when postgraduate nursing education began in Türkiye, and February 1, 2026, were included in the evaluation.

Results: As a result of the screening, a total of three theses—one master's thesis and two doctoral dissertations—were included in the study. All studies had interventional designs, and aromatherapy was applied via inhalation or massage. The findings indicated that sleep quality improved and daytime sleepiness decreased among patients who received aromatherapy interventions.

Discussion and Conclusion: In this traditional review, three graduate theses investigating interventions aimed at improving sleep quality in dialysis patients in Türkiye were identified. The findings of all three theses indicate that aromatherapy is not only a complementary relaxation method for haemodialysis patients but also an effective nursing intervention that provides measurable clinical outcomes. However, the reviewed theses revealed certain limitations, highlighting the need for further research on this topic.

Keywords: Hemodialysis; Aromatherapy; Sleep Quality; Nursing

GİRİŞ

Hemodiyaliz tedavisi, hastaların yaşam süresini uzatsa da kas krampları, yorgunluk ve uyku bozuklukları gibi yaşam kalitesini ciddi şekilde bozan semptomlara yol açabilmektedir. Bu semptomların yönetiminde kullanılan geleneksel yöntemlerin yanı sıra, günümüzde tamamlayıcı ve bütüncül yaklaşımlar önem kazanmaktadır. Aromaterapi, bitkilerden elde edilen uçucu yağların fiziksel ve ruhsal sağlığı iyileştirmek amacıyla kullanıldığı bu yöntemlerden biridir. Son dönem böbrek yetmezliği olan hastaların yaklaşık %71'i kötü uyku kalitesinden şikayetçidir (Ilieuscu ve ark., 2003). Bu durum; metabolik değişiklikler, ağrı, kramplar ve depresyon gibi faktörlerle ilişkilendirilmekte olup hastanın günlük yaşam aktivitelerini ve genel iyilik halini olumsuz etkilemektedir. 4238 bireyin dahil edildiği 11 yıllık longitudinal bir çalışmada, kısa uyku süresinin böbrek fonksiyonlarında hızlı bir düşüş ile ilişkili olduğu saptanmıştır (McMullan ve ark., 2016). Ayrıca, kronik böbrek yetmezliği bulunan bireylerde azalmış uyku süresi ve saat başına artmış uyanıklık yaşayanların, daha az uyku bozukluğu yaşayanlara kıyasla mortalite riskinin %50 daha yüksek olduğu bildirilmiştir (Benz ve ark., 2000). Yapılan bir meta-analizde, aromaterapinin hemodiyaliz hastalarında öznel uyku kalitesini anlamlı derecede artırdığını göstermektedir. Özellikle lavanta ve tatlı portakal yağı gibi yağların inhalasyon yoluyla uygulanmasının, Pittsburgh Uyku Kalitesi İndeksi skorlarında belirgin bir düşüş sağladığı ve yorgunluk şiddetini azalttığı kanıtlanmıştır (Zhang ve ark., 2023).

Uykuyu bozan en önemli faktörlerden biri de diyaliz sırasında veya sonrasında gelişen ağrılı kas kramplarıdır. Çetin ve ark. (2025) tarafından yapılan güncel bir çalışma, lavanta, biberiye ve mercanköşk yağları ile yapılan aromaterapi masajının bu kramplarının frekansını ve ağrı şiddetini önemli ölçüde azalttığını ortaya koymuştur. Çalışma bulgularına göre, 4 hafta boyunca haftada 3 kez uygulanan bu masaj sadece krampları azaltmakla kalmamış, aynı zamanda hastaların yaşam kalitesini ve günlük yaşam aktivitelerini de iyileştirmiştir. Ayrıca aromaterapinin, hastaların L-karnitin ve analjezik gibi ilaç tüketimlerini azaltmada da etkili olduğu saptanmıştır.

Sonuç olarak, aromaterapi hem inhalasyon hem de masaj yoluyla uygulandığında diyaliz hastalarının uyku kalitesini bozan temel etkenlerle (ağrı, kramp, anksiyete, yorgunluk) mücadelede etkili, invaziv olmayan ve maliyet etkin bir yöntemdir. Bu yöntem, hemodiyaliz hastalarının bakım süreçlerine entegre edilerek uykusuzluk ve yorgunluk gibi kronik problemlerin hafifletilmesinde güçlü bir araç olarak kullanılabilir. Bu geleneksel derleme ile; ülkemizde hemodiyaliz tedavisi uygulanan hastalarda aromaterapi uygulamasının uyku kalitesi üzerine olan etkisine ilişkin yapılmış lisansüstü tezlerin incelenmesi amaçlandı.

MATERYAL VE METHOD

Retrospektif ve tanımlayıcı türde yapılan bu çalışmada, araştırma verileri Yükseköğretim Kurulu Başkanlığı Ulusal Tez Merkezi veri tabanı kullanılarak elde edildi. Çalışmanın evrenini hemşirelik alanında yapılan ve tezin içinde "diyaliz", "uyku" ve "aromaterapi" terimlerini içeren lisansüstü tezler oluşturdu. Hemşirelikte yüksek lisans eğitiminin başladığı tarih olan 1968 yılından, 1 Şubat 2026 tarihine kadar yapılan ve erişim kısıtlaması olmayan tüm tezler değerlendirmeye alındı.

Araştırmaya dahil edilme kriterleri:

- Tezin içinde "diyaliz", "uyku" ve “aromaterapi” kelimelerinin yer alması
- Tezin müdahale içermesi
- Tezin hemşirelik anabilim dalı/dalları tarafından yapılmış olması
- Tezin erişime açık olması

Araştırmaya dahil edilmeme kriterleri:

- Tezin erişime kapalı olması

Yapılan tarama sonucunda uyku terimini içeren ve hemşirelik anabilim dalları tarafından 396 teze ulaşıldı. Bu tezlerden 20 tanesinde diyaliz terimi yer aldı. Toplam 3 (üç) adet tezde "diyaliz", "uyku" ve “aromaterapi” kelimelerinin yer aldığı görüldü. Bu tezlerden 1 (bir) tanesi yüksek lisans, kalan 2 (iki) tez doktora tezidir.

BULGULAR

Toplam 3 (üç) adet tezin bir tanesi 1 (bir) yüksek lisans (Şentürk, 2015), kalan 2 (iki) tez doktora tezidir (Muz 2015; Döner 2024). Tezlerin üçü de müdahaleli araştırmalardır. Yüksek lisans tezi Hemşirelik Anabilim Dalı’nda, doktora tezleri İç Hastalıkları Hemşireliği Anabilim Dalı’nda yürütülmüştür. Şentürk (2015)’ün çalışmasında hastalar müdahale ve kontrol grubu olarak ikiye ayrılmış; müdahale grubundaki hastalara bir hafta boyunca yatmadan 30 dakika önce pamuğa iki damla lavanta yağı damlatarak, yastığından 15-20 cm uzağa yerleştirmiştir. Kontrol grubundaki hastalara herhangi bir müdahalede bulunulmamıştır. Araştırma sonucunda müdahale grubundaki bireylerin öznel uyku kalitesinin daha yüksek olduğu, gündüz uykululuk sürelerinin azaldığı ve uyku saati puan ortalamalarının arttığı görülmüştür. Çalışmada uyku kalitesinin değerlendirmesinde Visüel Analog Uyku Skalası kullanılmıştır. Muz (2015)’un prospektif, randomize kontrollü tek kör dizaynda yürüttüğü çalışmasında müdahale grubundaki hastalara bir ay boyunca yatmadan önce iki dakika süreyle lavanta ve tatlı portakal yağı karışımını gazlı beze iki damla damlatıp, burun altı 5 cm. uzaklığında 2 dk. koklatmadan sonra 3 kez derin nefes almaları istenmiştir. Kontrol grubundaki hastalara herhangi bir müdahalede bulunulmamıştır. Çalışmada uyku kalitesinin değerlendirilmesinde Pitsburg Uyku Kalitesi İndeksi kullanılmış ve aromaterapi uygulamasının uyku kalitesini artırdığı görülmüştür. Döner (2024)’in çalışması prospektif randomize kontrollü, çift kör dizaynda toplam üç grup ile yapılmış ve her iki alt bacağa susam ve/veya lavanta yağı ile aromaterapi uygulanmıştır. Pitsburg Uyku Kalitesi İndeksi ve Epworth Uykululuk Ölçeğinin kullanıldığı çalışmada aromaterapi uygulanan bireylerde gündüz uykululuk düzeyinin azaldığı ve uyku kalitesinin arttığı görülmüştür (Tablo 1).

Tablo 1. Taramaya dahil edilen tezlere ilişkin bulgular (n= 3)

Yazar, Yıl	Amaç	Tez Türü	Çalışmanın Tipi, Uyku Değerlendirme Skalası	Örneklem Grubu ve Sayısı	Sonuç
Şentürk, 2015	Hemodiyaliz hastalarına inhalasyon yolu ile lavanta yağı uygulamasının anksiyete düzeyi ve uyku kalitesine etkisini belirlemek	Yüksek Lisans	Müdahale ve kontrol grubu içeren deneysel çalışma Visüel Analog Uyku Skalası (VAS)- Gündüz Uykululuk Düzeyi	**Müdahale (n= 17):** Hastalar bir hafta boyunca yatmadan 30 dakika önce pamuğa iki damla lavanta yağı damlatarak, yastığından 15-20 cm uzağa yerleştirmiş	Müdahale grubundaki bireylerin öznel uyku kalitesinin daha yüksek olduğu, gündüz uykululuk sürelerinin azaldığı ve uyku saati puan ortalamalarının arttığı görülmüş

				Kontrol (n= 17): Herhangi bir müdahalede bulunulmamış	
Muz, 2015	Hemodiyaliz tedavisi alan bireylerde inhalasyon yolu ile uygulanan aromaterapinin uyku kalitesi ve yorgunluk düzeyine etkisini belirlemek	Doktora	Prospektif, randomize kontrollü, tek kör Pitsburg Uyku Kalitesi İndeksi	**Müdahale (n= 27):** Hastalar bir ay boyunca yatmadan önce iki dakika süreyle lavanta ve tatlı portakal yağı karışımını gazlı beze iki damla damlatıp, burun altı 5 cm. uzaklığında 2 dk. koklatmadan sonra 3 kez derin nefes almıştır **Kontrol (n= 35):** Herhangi bir müdahalede bulunulmamış	Aromaterapi uygulamasının uyku kalitesini artırdığı görülmüş
Döner, 2024	Hemodiyaliz tedavisi alan bireylere uygulanan aromaterapi masajının huzursuz bacak sendromu şiddeti, gündüz uykululuk ve uyku kalitesine etkisini incelenmesi	Doktora	Prospektif, randomize kontrollü, çift kör Pitsburg Uyku Kalitesi İndeksi Epworth Uykululuk Ölçeği	**Müdahale (n= 28):** Diyaliz seansının başlangıcından bir saat sonra, haftada üç kez, bir ay boyunca susam ve lavanta yağı karışımı ile masaj uygulanmış **Plasebo (n= 28):** Diyaliz seansının başlangıcından bir saat sonra, haftada üç kez, bir ay boyunca susam yağı ile masaj uygulanmış **Kontrol (n= 28):** Herhangi bir müdahalede bulunulmamış	Aromaterapi uygulanan bireylerde gündüz uykululuk düzeyinin azaldığı ve uyku kalitesinin arttığı görülmüş

TARTIŞMA

Bu geleneksel derlemede ülkemizde diyaliz hastalarında uyku kalitesinin iyileştirilmesine yönelik müdahalede bulunan üç adet lisansüstü teze ulaşıldı. Tezlerin tamamında aromaterapinin hemodiyaliz hastalarında yalnızca tamamlayıcı bir rahatlama yöntemi değil, ölçülebilir klinik çıktılar sağlayan etkili bir hemşirelik girişimi olduğunu göstermektedir. Ancak, konuyla ilgili yapılan tezlerde sınırlılıklar bulunduğu ve konuyla ilgili daha çok araştırmaya ihtiyaç olduğu görülmektedir.

Şentürk (2015) tarafından yürütülen çalışmada, inhalasyon yoluyla uygulanan lavanta yağının öznel uyku kalitesini artırdığı ve gündüz uykululuk düzeyini azalttığı saptanmıştır. Lavanta yağının santral sinir sistemi üzerinde sedatif ve anksiyolitik etkiler gösterdiği; parasempatik aktiviteyi artırarak uykuya geçiş süresini kısalttığı bilinmektedir (Goel ve ark., 2025). Bu mekanizma, hemodiyaliz hastalarında sıklıkla görülen uykuya dalma güçlüğünün azalmasını açıklayabilir. Muz'un (2015) doktora tezinde ise lavanta ve tatlı portakal yağı karışımı inhalasyon yoluyla uygulanmış ve Pittsburgh Uyku Kalitesi İndeksi (PUKİ) puanlarında anlamlı düşüş sağlanmıştır. Aynı araştırma grubunun daha sonra yayımladığı randomize kontrollü çalışma (Muz ve Taşcı, 2017), aromaterapinin yalnızca uyku kalitesini değil, aynı zamanda yorgunluk düzeyini ve şiddetini de belirgin biçimde azalttığını ortaya koymuştur. Bu çalışmada, aromaterapi uygulanan grupta PUKİ toplam ve alt boyut puanlarının tümünde anlamlı iyileşme gözlenmiştir. Yorgunluğun azalması, uyku kalitesini dolaylı olarak iyileştiren önemli bir faktör olarak değerlendirilebilir; çünkü yorgunluk ve uyku bozukluğu hemodiyaliz hastalarında birbirini besleyen döngüsel bir ilişki içindedir (Muz 2017). Döner (2024)'in doktora tezinde aromaterapi masajının uyku kalitesi, gündüz uykululuk ve huzursuz bacak sendromu üzerine etkisi incelenmiştir. Masaj yoluyla uygulanan aromaterapinin, inhalasyona kıyasla daha geniş bir semptom kümesini etkilediği görülmektedir. Bu bulgu, Çetin ve ark. (2025) tarafından yayımlanan çalışma ile desteklenmektedir. Çetin ve ark. (2025), lavanta, biberiye ve mercanköşk yağları ile uygulanan aromaterapi masajının kas kramplarının sıklığını ve ağrı şiddetini anlamlı düzeyde azalttığını; buna paralel olarak yaşam kalitesini ve günlük yaşam aktivitelerini iyileştirdiğini göstermiştir. Kas kramplarının azalması, gece uyanmalarını ve uyku bölünmelerini azaltarak uyku kalitesinin artmasına katkı sağlamaktadır (Çetin ve ark., 2025). Çetin ve ark. (2025)'in çalışmasında dikkat çeken bir diğer önemli bulgu, aromaterapi masajının L-karnitin ve analjezik kullanımını azaltmasıdır. Bu durum, aromaterapinin yalnızca semptomları hafifletmekle kalmayıp, farmakolojik yükü azaltarak hasta güvenliğine ve sürdürülebilir bakıma katkı sağladığını göstermektedir. Daha az ağrı ve kramp yaşayan hastaların daha kesintisiz uyuyabildiği; bu durumun uyku kalitesini doğrudan olumlu etkilediği söylenebilir.

Uluslararası literatürde aromaterapinin uyku kalitesi üzerindeki etkisini en kapsamlı biçimde ele alan çalışmalardan biri Zhang ve ark. (2023) tarafından yapılan meta-analiz çalışmasıdır. Bu meta-analizde, aromaterapinin hemodiyaliz hastalarında öznel uyku kalitesini anlamlı düzeyde iyileştirdiği, yorgunluk ve huzursuz bacak sendromu semptomlarını azalttığı bildirilmiştir. Etki büyüklüğünün yüksek bulunması, aromaterapinin klinik açıdan güçlü bir etkiye sahip olduğunu düşündürmektedir. Türkiye'de yapılan tezlerin bulguları, Zhang ve ark. (2023)'nın sonuçları ile yüksek düzeyde uyumludur. Zhang ve ark. (2023), aromaterapinin etki mekanizmasını yalnızca sedatif özelliklerle sınırlı görmemekte; otonom sinir sistemi dengesi, stres hormonlarının azalması, kas gevşemesi ve duyusal rahatlama gibi çoklu yollarla açıkladığını vurgulamaktadır. Bu çok boyutlu etki, hemodiyaliz hastalarında uykuyu bozan faktörlerin de çok boyutlu olması nedeniyle klinik olarak anlamlıdır. Türkiye'deki çalışmaların inhalasyon ve masaj gibi farklı uygulama yollarını kullanmış olması, aromaterapinin esnek ve bireyselleştirilebilir bir girişim olduğunu göstermektedir.

Ölçüm araçları açısından değerlendirildiğinde, araştırmaya dahil edilen tezlerde Visüel Analog Uyku Skalası (Şentürk, 2015), Pittsburgh Uyku Kalitesi İndeksi (Muz, 2015; Döner, 2024) ve Epworth Uykululuk Ölçeği (Döner, 2024) kullanılmıştır. Ancak örneklem büyüklüklerinin görece küçük olması, müdahale sürelerinin kısa olması ve uzun dönem izlem verilerinin sınırlı olması önemli kısıtlılıklar olarak öne çıkmaktadır. Yapılan diğer çalışmalarda da (Muz ve Taşcı, 2017; Çetin ve ark., 2025) uzun dönem etkinliğin değerlendirilmediği belirtilmiş olup; bu durum gelecekte yapılacak araştırmalar için öneri niteliğindedir.

SONUÇ

Sonuç olarak; taramaya dahil edilen lisansüstü tezler aromaterapinin hemodiyaliz hastalarında uyku kalitesini artırmada etkili bir hemşirelik girişimi olduğunu göstermektedir. Bu bulgular, Zhang ve ark. (2023)'nın meta-analiz sonuçları ile güçlü biçimde desteklenmektedir. Aromaterapi; invaziv olmayan, hasta tarafından kabulü yüksek, maliyeti düşük ve hemşireler tarafından kolaylıkla uygulanabilecek bir yöntemdir. Hemodiyaliz gibi uzun süreli bir tedavi sürecinde, hastaların uyku kalitesini artırmaya

yönelik bu tür bütüncül yaklaşımlar bakımın kalitesini ve hasta memnuniyetini artırabilir. Gelecekte yapılacak çok merkezli, büyük örneklemli ve uzun süreli randomize kontrollü çalışmalar, aromaterapinin klinik rehberlere entegrasyonu açısından önemli katkılar sağlayacaktır.

Çalışmanın Güçlü Yönleri ve Sınırlılıkları

Bu çalışmanın en önemli güçlü yönlerinden biri, Türkiye'de hemodiyaliz hastalarında aromaterapinin uyku kalitesi üzerine etkisini inceleyen hemşirelik alanındaki tüm erişilebilir lisansüstü tezlerin sistematik biçimde değerlendirilmiş olmasıdır. Ulusal tezlerin bir arada ele alınması, ülkemizdeki hemşirelik uygulamalarına özgü kanıtların görünür hale getirilmesini sağlamaktadır. İkinci güçlü yön, tezlerde kullanılan ölçüm araçlarının (Pittsburgh Uyku Kalitesi İndeksi, Visüel Analog Uyku Skalası, Epworth Uykululuk Ölçeği) geçerli ve güvenilir ölçekler olması, elde edilen sonuçların bilimsel güvenilirliğini artırmaktadır. Son olarak, aromaterapinin hem inhalasyon hem de masaj yoluyla uygulanmış olması, farklı uygulama yöntemlerinin etkilerinin karşılaştırılmasına olanak tanımış ve hemşirelik bakımında esnek uygulama seçenekleri sunmuştur.

Bu çalışmanın bazı kısıtlılıkları bulunmaktadır. İlk olarak, taramaya dahil edilen tez sayısının yalnızca üç ile sınırlı olması, sonuçların genellenebilirliğini kısıtlamaktadır. Bu durum, ülkemizde aromaterapi ve uyku kalitesi konularında yapılan hemşirelik araştırmalarının sınırlı sayıda olduğunu göstermektedir. İkinci olarak, tezlerdeki örneklem büyüklüklerinin görece küçük olması ve çalışmaların çoğunun tek merkezde yürütülmüş olması da dış geçerliliği sınırlayan önemli bir faktördür. Ayrıca müdahale sürelerinin bir hafta ile bir ay arasında değişmesi, uygulama sıklığı ve kullanılan uçucu yağların farklılık göstermesi, çalışmalar arasında heterojenliğe yol açmaktadır. Son olarak, çalışmaların çoğunda uzun dönemli izlem sonuçlarının bulunmamasıdır. Aromaterapinin uyku kalitesi üzerindeki etkilerinin ne kadar sürdüğü ve uygulama sonlandırıldıktan sonra devam edip etmediği net olarak bilinmemektedir.

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EXAMINATION OF GRADUATE THESES IN NURSING ON THE PREVENTION OF XEROSTOMIA IN DIALYSIS PATIENTS IN TÜRKİYE: A TRADITIONAL REVIEW

TÜRKİYE'DE DİYALİZ HASTALARINDA AĞIZ KURULUĞUNUN ÖNLENMESİNE YÖNELİK HEMŞİRELİK ALANINDA YAPILAN LİSANSÜSTÜ TEZLERİN İNCELENMESİ: GELENEKSEL BİR DERLEME

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ÖZET

Giriş: Ağız kuruluğu (kserostomi), hemodiyaliz hastalarında sık görülen ve yaşam kalitesini olumsuz etkileyen önemli bir klinik sorun olarak öne çıkmaktadır. Bu derlemenin amacı, Türkiye'de diyaliz hastalarında ağız kuruluğunun önlenmesine yönelik hemşirelik alanında gerçekleştirilen lisansüstü tezleri inceleyerek kullanılan girişimleri, elde edilen sonuçları ve kanıt düzeylerini sistematik bir şekilde değerlendirmek ve hemşirelik uygulamalarına rehberlik edecek bütüncül bir bakış açısı sunmaktır.

Materyal ve Metot: Bu retrospektif ve tanımlayıcı çalışma, Yükseköğretim Kurulu Başkanlığı Ulusal Tez Merkezi veri tabanından elde edilen araştırma verilerine dayanmaktadır. Çalışmanın evrenini, hemşirelik alanında yapılan ve tezin içinde "diyaliz" ve "ağız kuruluğu" terimlerini içeren lisansüstü tezler oluşturdu. Hemşirelikte yüksek lisans eğitiminin başladığı 1968 yılından 2 Şubat 2026 tarihine kadar yapılan ve erişim kısıtlaması olmayan tüm tezler değerlendirmeye alındı.

Bulgular: Bu çalışmada tarama kriterlerini karşılayan toplam 4 (dört) lisansüstü tez incelenmiştir. İncelenen tezlerin tamamı doktora tezi olup, müdahale içeren deneysel ya da randomize kontrollü araştırma tasarımına sahiptir. İncelenen tezlerde; ksilitollü sakız çiğneme, akupres uygulamaları, ağız spreyi kullanımı ve sanal gerçeklik gibi farmakolojik olmayan hemşirelik girişimlerinin ağız kuruluğu semptomlarını azaltmada etkili olduğu görülmüştür.

Sonuç ve Öneriler: Türkiye'de bu alanda yapılmış tez sayısının sınırlı olduğu, hemşirelik bakım girişimlerinin ağız kuruluğu yönetimindeki etkisini değerlendirmeye yönelik güçlü bir metodolojik yaklaşımın benimsendiğini göstermektedir. Bu bulgular, hemodiyaliz hastalarında ağız kuruluğunun multifaktöriyel yapısına uygun olarak, non-invaziv ve çok boyutlu bakım yaklaşımlarının önemini vurgulamaktadır.

Anahtar Kelimeler: Ağız kuruluğu, hemodiyaliz, hemşirelik, non-farmakolojik müdahaleler.

ABSTRACT

Introduction: Xerostomia is a common clinical problem among haemodialysis patients and is recognized as an important condition that negatively affects quality of life. The aim of this review is to examine graduate theses conducted in the field of nursing in Türkiye on the prevention of xerostomia among dialysis patients, systematically evaluate the interventions used, the outcomes obtained, and the levels of evidence, and provide a comprehensive perspective to guide nursing practice.

Materials and Methods: This retrospective and descriptive study was based on data obtained from the National Thesis Center database of the Council of Higher Education of Türkiye. The study population consisted of graduate theses in the field of nursing that included the terms “dialysis” and “xerostomia” within the thesis text. All accessible theses without access restrictions, completed between 1968—the year when graduate nursing education began in Türkiye—and February 2, 2026, were included in the review.

Results: A total of four graduate theses meeting the screening criteria were examined in this study. All identified theses were doctoral dissertations and employed either experimental or randomized controlled research designs involving interventions. The reviewed theses demonstrated that non-pharmacological nursing interventions, including xylitol gum chewing, acupressure applications, oral spray use, and virtual reality, were effective in reducing symptoms of xerostomia.

Discussion and Conclusion: The limited number of theses conducted in this field in Türkiye indicates that, despite the scarcity of research, a strong methodological approach has been adopted to evaluate the effectiveness of nursing care interventions in the management of xerostomia. These findings highlight the importance of non-invasive and multidimensional care approaches that address the multifactorial nature of xerostomia in haemodialysis patients.

Keywords: Xerostomia, haemodialysis, nursing, non-pharmacological interventions.

GİRİŞ

Kronik böbrek hastalığının son evresi olan son dönem böbrek yetmezliğinde, hemodiyaliz mortaliteyi azaltırken çok sayıda fiziksel ve psikososyal semptoma yol açmaktadır (Liu ve ark., 2025). Bu semptomlar arasında ağız kuruluğu (kserostomi), hemodiyaliz hastalarında sık görülen ve yaşam kalitesini olumsuz etkileyen önemli bir klinik sorun olarak öne çıkmaktadır (Bossola, 2019). Kserostomi, tükürük bezlerinden salgılanan tükürük miktarının azalması (hiposalivasyon) ya da tükürük bileşimindeki değişikliklere bağlı olarak ağızda kuruluk hissinin oluşması şeklinde tanımlanmaktadır (Bossola, 2019). Hemodiyaliz hastalarında tükürük akış hızının %20–55 oranında azalabildiği ve bazı olgularda ciddi düzeyde hiposalivasyon gelişebildiği bildirilmektedir (Bossola, 2019; López-Pintor ve ark., 2017). Bu durum multifaktöriyel nedenlere bağlı olup hemodiyaliz hastalarında yaygın görülmektedir (Bossola, 2019; Sangalli ve ark., 2023; Matsushima ve ark., 2022). Kserostomi yalnızca subjektif bir rahatsızlık hissi olmayıp, bireylerin günlük yaşam aktivitelerini doğrudan etkileyen önemli sonuçlara yol açmaktadır. Çiğneme, yutma, konuşma ve tat alma gibi temel fonksiyonlarda güçlük; oral mukozada lezyonlar; periodontal hastalıklar; dental çürükler ve fungal enfeksiyonlar gibi komplikasyonlar kserostominin başlıca sonuçları arasında yer almaktadır (López-Pintor ve ark., 2017; ve ark., 2025). Ayrıca artan susama hissi nedeniyle sıvı alımının artması, interdiyalitik kilo artışına ve buna bağlı komplikasyonlara neden olabilmektedir (Li ve ark., 2025; Yang ve ark., 2019; ve ark., 2017). Tüm bu etkiler, hemodiyaliz hastalarında yaşam kalitesinin önemli ölçüde azalmasına yol açmaktadır (Jung, 2020; Liu ve ark., 2025). Semptom yönetiminde kserostominin önlenmesi, hemşirelik uygulamalarının önemli bir bileşeni olarak değerlendirilmektedir. Literatürde ağız kuruluğunu azaltmaya yönelik farmakolojik olmayan çeşitli girişimlerin (şekersiz sakız çiğneme, ağız gargaraları, akupres, transkutanöz elektriksel sinir stimülasyonu gibi) etkili olabileceği bildirilmektedir (Ozen ve ark., 2021; Sharifnia ve ark., 2024). Özellikle tükürük salgısını mekanik olarak artırmaya yönelik uygulamaların klinik pratikte yaygın olarak kullanıldığı ve semptom şiddetinde azalma sağladığı ifade edilmektedir (Li ve ark., 2025).

Türkiye’de hemşirelik alanında yürütülen lisansüstü tez çalışmalarında da hemodiyaliz hastalarında ağız kuruluğunu azaltmaya yönelik farklı girişimlerin incelendiği görülmektedir. Sakız çiğneme temelli müdahalelerin ağız kuruluğu ve susama üzerine etkileri farklı tezlerde ele alınmış olup, bu girişimlerin semptom yönetiminde etkili olabileceği gösterilmiştir (Duruk, 2012; Sarimehmet, 2020). Ayrıca akupres uygulamasının tükürük miktarını artırdığı ve susuzluk şiddetini azalttığı belirlenmiş, bu uygulamanın hemşirelik bakımında tamamlayıcı bir yöntem olarak kullanılabileceği ifade edilmiştir (Yıldırım, 2016). Bununla birlikte, hemodiyaliz hastalarında semptom yönetimine yönelik daha güncel yaklaşımlar arasında sanal gerçeklik ve solunum egzersizleri gibi girişimlerin de değerlendirildiği ve bu tür uygulamaların yaşam kalitesi ve semptom kontrolü üzerinde olumlu etkiler sağlayabileceği bildirilmiştir

(Bulut, 2024). Ancak mevcut çalışmaların çoğunlukla tek bir girişime odaklandığı, örneklem büyüklüklerinin sınırlı olduğu ve sonuçların genellenebilirliğinin kısıtlı olabileceği görülmektedir. Ayrıca Türkiye'de bu alanda yapılan lisansüstü tezlerin incelendiği kapsamlı derlemelerin sınırlı olduğu dikkat çekmektedir. Literatürde, müdahaleler arasında yöntemsel heterojenlik ve uzun dönem etkinliğe ilişkin sınırlı kanıt bulunduğu vurgulanmaktadır (Chhugani ve ark., 2021; Ramadoss ve ark., 2023). Bu durum, mevcut bilgi birikiminin bütüncül bir perspektifle değerlendirilmesini ve hemşirelik uygulamalarına yön verecek güçlü kanıtların ortaya konulmasını zorlaştırmaktadır.

Bu doğrultuda, Türkiye'de diyaliz hastalarında ağız kuruluğunun önlenmesine yönelik hemşirelik alanında yapılan lisansüstü tezlerin sistematik olarak incelenmesi, hem mevcut araştırma eğilimlerinin ortaya konulması hem de klinik uygulamalara rehberlik edecek kanıtların bütüncül olarak değerlendirilmesi açısından önem taşımaktadır. Bu derlemenin amacı, Türkiye'de diyaliz hastalarında ağız kuruluğunun önlenmesine yönelik hemşirelik alanında gerçekleştirilen lisansüstü tezleri inceleyerek kullanılan girişimleri, elde edilen sonuçları ve kanıt düzeylerini sistematik bir şekilde değerlendirmek ve hemşirelik uygulamalarına rehberlik edecek bütüncül bir bakış açısı sunmaktır.

MATERYAL VE METHOD

Retrospektif ve tanımlayıcı türde yapılan bu çalışmada, araştırma verileri Yükseköğretim Kurulu Başkanlığı Ulusal Tez Merkezi veri tabanı kullanılarak elde edildi. Çalışmanın evrenini hemşirelik alanında yapılan ve tezin içinde "diyaliz" ve "ağız kuruluğu" terimlerini içeren ve müdahale içeren tezler araştırmaya dahil edildi. Hemşirelikte yüksek lisans eğitiminin başladığı tarih olan 1968 yılından, 2 Şubat 2026 tarihine kadar yapılan ve erişim kısıtlaması olmayan tüm tezler değerlendirmeye alındı.

Araştırmaya dahil edilme kriterleri:

- Tezin içinde "diyaliz" ve "ağız kuruluğu" kelimelerinin yer alması
- Tezin hemşirelik anabilim dalı/dalları tarafından yapılmış olması
- Tezin erişime açık olması

Araştırmaya dahil edilmeme kriterleri:

- Tezin erişime kapalı olması

Yapılan tarama sonucunda ağız kuruluğu terimini içeren ve hemşirelik anabilim dalları tarafından yapılan 4 (dört) doktora tezine ulaşıldı.

BULGULAR

Bu çalışmada tarama kriterlerini karşılayan toplam 4 (dört) lisansüstü tez incelenmiştir. İncelenen tezlerin tamamı müdahale içeren deneysel ya da randomize kontrollü araştırma tasarımına sahiptir.

Duruk (2012) tarafından yürütülen randomize kontrollü, tek kör ve çaprazlamalı çalışmada, hemodiyaliz sırasında ksilitollü sakız çiğnemenin ağız kuruluğu üzerine etkisi değerlendirilmiştir. Çalışmada A ve B grupları olmak üzere iki grup oluşturulmuş; her iki gruba da farklı zamanlarda sakız çiğnetilmiş ve çiğnetilmemiştir. Hemodiyaliz sırasında her saat başı 15 dakika sakız çiğnemenin, tükürük miktarını artırarak ağız kuruluğu semptomlarını anlamlı düzeyde azalttığı belirlenmiştir. Ağız kuruluğunun değerlendirilmesinde Görsel Kıyaslama Ölçeği ve Ağız Kuruluğu Semptomları Değerlendirme Formu kullanılmıştır.

Yıldırım (2016) tarafından gerçekleştirilen prospektif, randomize kontrollü ve tek kör çalışmada, hemodiyaliz hastalarına CV-23, SJ-17 ve Kid-1 akupunktur noktalarına uygulanan akupresin susuzluk şiddeti üzerine etkisi incelenmiştir. Altı hafta boyunca haftada üç gün uygulanan akupresin, plasebo grubuna kıyasla tükürük miktarını artırdığı ve susuzluk şiddetini azalttığı saptanmıştır. Susuzluk düzeyi Visüel Analog Skala (VAS) ile değerlendirilmiştir.

Hintistan (2020) tarafından yapılan deneysel tipteki çalışmada, hemodiyaliz tedavisi alan hastalarda ksilitollü sakız çiğneme ve ağız spreyi kullanımının ağız kuruluğu üzerine etkileri karşılaştırılmıştır. Altı hafta süresince yürütülen çalışmada, sakız çiğneyen ve ağız spreyi kullanan gruplarda kontrol grubuna göre ağız kuruluğu ve susama şiddetinin anlamlı düzeyde azaldığı, özellikle ksilitollü sakız kullanımının ağız kuruluğunu azaltmada etkili olduğu belirlenmiştir.

Bulut (2024) tarafından yürütülen randomize kontrollü çalışmada ise, hemodiyaliz hastalarında sanal gerçeklik gözlüğü kullanımı ve solunum egzersizlerinin semptomlar ve yaşam kalitesi üzerindeki etkileri değerlendirilmiştir. İki hafta süren müdahale sonucunda, sanal gerçeklik gözlüğü kullanan hastalarda ağız kuruluğu semptomlarının daha az görüldüğü bildirilmiştir. Bulgular, Diyaliz Semptom İndeksi kullanılarak değerlendirilmiştir.

Tablo 1. Taramaya dahil edilen tezlere ilişkin bulgular (n= 4)

Yazar, Yıl	Amaç	Çalışma Tasarımı ve Uygulama Süresi	Kullanılan Skala	Örneklem Grubu ve Sayısı	Sonuç
Duruk, 2012	Hemodiyaliz sırasında ciklet çiğnemenin ağız kuruluğu ve semptomlarına etkisini incelemek	Randomize kontrollü, tek kör, ön test-son test modeline uygun deneysel, çaprazlamalı bir çalışma 1 (Bir) Seans	Görsel Kıyaslama Ölçeği Ağız Kuruluğu Semptomları Değerlendirme Formu	**A Grubu (n= 61):** Bir hemodiyaliz seansında ksitollü ciklet çiğnetilmiş ve 15 gün ara verildikten sonra ciklet çiğnetilmemiş **B Grubu (n= 61):** Önce bir hemodiyaliz seansında ciklet çiğnetilmemiş ve 15 gün ara verildikten sonra ksitollü ciklet çiğnetilmiş	Hemodiyaliz sırasında her saat başı 15 dakika ciklet çiğnemenin tükürük miktarını artırarak ağız kuruluğunun kontrolünde etkili olduğu bulunmuş
Yıldırım, 2016	Hemodiyaliz tedavisi alan bireylerin CV-23, SJ-17, Kid-1 akupunktur noktalarına akupres uygulama aleti ile 6 hafta süresince, haftada üç kez her bölgeye 3 dk toplamda 15 dk uygulanan akupresin susuzluk şiddeti üzerine etkisini belirlemek	Pre-post test düzeninde randomize kontrollü çalışma 6 (Altı) hafta	Prospektif, randomize kontrollü, tek kör Visüel Analog Skala (VAS) – Susuzluk Skalası	**Müdahale (n= 30):** CV-23, SJ-17, Kid-1 akupunktur noktalarına akupres uygulama aleti ile 6 hafta süresince, haftada üç kez her bölgeye 3 dk toplamda 15 dk akupressör uygulanmış **Plasebo (n= 30):** Rutin tedavi dışında herhangi bir uygulama yapılmadan, akupres aleti kapalı konumdayken ve akupres uygulanmamış	Akupunktur noktalarına uygulanan akupresin, tükürük miktarını artırdığı, VAS susuzluk şiddetini azaltığı görülmüş
Sarımehmet, 2020	Hemodiyaliz tedavisi alan hastalarda sırasında ciklet çiğnemenin ve ağız spreyi kullanımının	Deneysel tipte müdahale çalışması 6 (altı) hafta	Susama Şiddeti Ölçüm aracı (VAS)	**Kontrol (n= 25):** Herhangi bir müdahalede bulunulmamış **Ağız Spreyi (n= 25):** Altı hafta süresince günde üç kez iki	Ksitolli sakız kullanmı hemodiyaliz hastalarında ağız kuruluğunu azaltmış

	ağız kuruluğu ve semptomlarına etkisini incelemek		Susama Değerlendirme Anket Formu	puff şeklinde düzenli ağız spreyi kullanmışlar **Sakız Grubu (n= 25):** Altı hafta süresince her gün günde beş kez 10 dakika süresince ksilitollü sakız çiğnemiş	
Bulut, 2024	Hemodiyaliz tedavisi alan hastalarda sanal gerçeklik gözlüğü ve solunum egzersizlerinin oluşan semptomlar ve yaşam kalitesi üzerindeki etkilerini değerlendirmek	Randomize kontrollü 2 (İki) hafta	Diyaliz Semptom İndeksi	**A Grubu (n= 43):** Evde nefes egzersizleri yapıldı **B Grubu (n= 46):** Hastalar hemodiyaliz işleminin ilk 10 dakikası da olmak üzere toplamda 20 dk sanal gerçeklik gözlüğü 3 boyutlu doğa görüntüsü, akan su ve kuş cıvıltısından oluşan simülasyon izlediler **C Grubu (n= 49):** Rutin tedavi dışında herhangi bir müdahalede bulunulmadı	Sanal gerçeklik g.zlüğü kullanan hastalarda ağız kuruluğunun daha az görüldüğü belirtilmiş

TARTIŞMA

Bu geleneksel derlemede, İncelenen tezlerin tamamının deneysel ya da randomize kontrollü tasarıma sahip olması, hemşirelik girişimlerinin etkinliğini değerlendirme açısından önemli bir metodolojik güç olarak değerlendirilmektedir. Bununla birlikte, çalışma sayısının sınırlı olması ve örneklem büyüklüklerinin görece küçük olması, bu alanda daha fazla ve daha kapsamlı araştırmalara ihtiyaç olduğunu da ortaya koymaktadır.

Ağız kuruluğu (kserostomi), hemodiyaliz hastalarında oldukça sık görülen ve yaşam kalitesini ciddi biçimde etkileyen bir semptomdur (Bossola, 2019). NK ve ark. (2021)'nın sistematik derleme ve meta analizinde, hemodiyaliz hastalarında ağız kuruluğu prevalansının %52.3 olduğu bildirilmiştir. Bu oran, genel popülasyonda bildirilen prevalans değerlerinden belirgin biçimde yüksektir ve kserostominin hemodiyaliz hastaları için önemli bir bakım sorunu olduğunu açıkça göstermektedir. İncelenen tezlerde ağız kuruluğunun temel bir sonuç değişkeni olarak ele alınması, hemşirelik bakımının hasta konforu ve semptom yönetimi açısından ne denli kritik bir rol üstlendiğini ortaya koymaktadır. Bossola (2019), hemodiyaliz hastalarında ağız kuruluğunun patofizyolojisinin multifaktöriyel olduğunu vurgulamaktadır. Tükürük bezlerinde atrofi ve fibrozis gelişimi, polifarmasi, sıvı alımının kısıtlanması, diyaliz sürecine bağlı fizyolojik değişiklikler ve tükürük bileşimindeki bozulmalar bu semptomun gelişiminde rol oynamaktadır. Bu karmaşık etiyoloji göz önünde bulundurulduğunda, tek bir girişimin tüm hastalarda aynı etkiyi göstermemesi beklenen bir durumdur. Bu bağlamda, incelenen tezlerde farklı hemşirelik girişimlerinin denenmiş olması, ağız kuruluğu yönetiminde çok boyutlu yaklaşımların gerekliliğini desteklemektedir.

İncelenen tezlerde en sık ele alınan girişimlerden biri ksilitollü sakız çiğneme uygulamasıdır. Duruk (2012) tarafından yürütülen randomize kontrollü ve çaprazlamalı çalışmada, hemodiyaliz sırasında her saat başı 15 dakika ksilitollü sakız çiğnemenin tükürük miktarını artırdığı ve ağız kuruluğu

semptomlarını anlamlı düzeyde azalttığı gösterilmiştir. Benzer şekilde Sarımehmet (2020) tarafından gerçekleştirilen deneysel çalışmada da ksilitollü sakız kullanımının ağız kuruluğunu azaltmada etkili olduğu bildirilmiştir. Bu bulgular, mekanik salivasyon uyarımına dayanan girişimlerin hemodiyaliz hastalarında etkili olabileceğini göstermektedir. Uluslararası literatürle karşılaştırıldığında, bu sonuçların Bossola (2019) tarafından bildirilen bulgularla büyük ölçüde uyumlu olduğu görülmektedir. Sakız çiğnemenin tükürük bezlerini mekanik olarak uyararak salivasyon artışına katkı sağlayabileceğini, ancak çalışmalar arasında sonuçların tutarsız olabildiğini vurgulamaktadır (Bossola, 2019). Bu tutarsızlığın; sakızın içeriği, uygulama süresi, diyaliz seanslarıyla eş zamanlı olup olmaması ve hasta özellikleri gibi faktörlerden kaynaklanabileceği düşünülmektedir. Türkiye'de yapılan tezlerde uygulama protokollerinin daha yapılandırılmış olması, olumlu sonuçların elde edilmesinde etkili olmuş olabilir.

Yıldırım (2016) tarafından gerçekleştirilen tez çalışmasında, CV-23, SJ-17 ve Kid-1 akupunktur noktalarına uygulanan akupresin susuzluk şiddetini azalttığı ve tükürük miktarını artırdığı saptanmıştır. Akupres uygulamasının bu olumlu etkileri, non-invaziv ve hemşireler tarafından uygulanabilir bir yöntem olması açısından klinik pratiğe önemli katkılar sunmaktadır. Bossola (2019)'da akupresin salivasyon üzerinde olumlu etkiler oluşturabileceğini ve özellikle farmakolojik tedavilere alternatif ya da tamamlayıcı bir yaklaşım olarak değerlendirilebileceğini ifade etmektedir. Sharifnia ve ark. (2024)'nın network meta-analizi, bu bulguları daha güçlü bir kanıt düzeyiyle desteklemektedir. Söz konusu çalışmada, sekiz farklı non-farmakolojik girişim karşılaştırılmış ve ksilitollü sakız çiğnemenin kserostomi semptomlarını azaltmada en üst sırada yer aldığı; transkutanöz elektriksel sinir stimülasyonu ve sakız çiğnemenin ise tükürük akış hızını artırmada en etkili yöntemler olduğu bildirilmiştir. Türkiye'de yapılan tezlerin sonuçlarının bu meta-analiz bulgularıyla örtüşmesi, yerel düzeyde üretilen kanıtların uluslararası literatürle uyumlu olduğunu göstermesi açısından dikkat çekicidir. Bulut (2024) tarafından yürütülen tez çalışmasında sanal gerçeklik gözlüğü kullanımı ve solunum egzersizlerinin ağız kuruluğu semptomlarını azalttığı bildirilmiştir. Bu bulgu, doğrudan salivasyon artışı sağlamasa da, semptom algısını ve stres düzeyini azaltarak dolaylı bir etki oluşturabileceğini düşündürmektedir. Hemodiyaliz süreci, hastalar için yalnızca fiziksel değil, aynı zamanda psikolojik açıdan da zorlayıcıdır. Stres, anksiyete ve dikkat odağının semptomlara yönelmesi, ağız kuruluğu gibi subjektif semptomların daha yoğun algılanmasına neden olabilir. Bu açıdan bakıldığında, sanal gerçeklik gibi yenilikçi ve bütüncül yaklaşımların semptom yönetiminde tamamlayıcı bir rol oynayabileceği söylenebilir. NK ve ark. (2021), ağız kuruluğunun yalnızca konforu değil, aynı zamanda klinik sonuçları da etkileyebileceğini vurgulamaktadır. Ağız kuruluğu yaşayan hastaların daha fazla sıvı tüketme eğiliminde oldukları, bunun da interdiyalitik kilo artışına yol açarak kardiyovasküler riskleri artırabileceği belirtilmektedir. Bu bağlamda, ağız kuruluğunun etkili yönetimi yalnızca yaşam kalitesini artırmakla kalmayıp, aynı zamanda morbidite ve mortalite risklerinin azaltılmasına da katkı sağlayabilir. İncelenen tezlerde yer alan hemşirelik girişimleri, bu açıdan değerlendirildiğinde, potansiyel olarak hasta sonuçlarını iyileştirme gücüne sahiptir. Bossola (2019), ağız kuruluğunun oral enfeksiyonlar, çiğneme ve yutma güçlüğü, tat alma bozuklukları ve halitozis gibi birçok komplikasyona yol açabileceğini bildirmektedir. Bu komplikasyonlar, özellikle kronik hastalığı olan ve bağışıklık sistemi baskılanmış hemodiyaliz hastalarında daha ciddi sonuçlar doğurabilir. İncelenen tezlerde ağız kuruluğunun çoğunlukla subjektif ölçekler ve semptom değerlendirme formları ile ölçülmüş olması, hemşirelik bakımında hasta bildiriminin önemini vurgulamaktadır. Ancak gelecekte yapılacak çalışmalarda objektif salivasyon ölçümleri ile subjektif değerlendirmelerin birlikte kullanılması, daha kapsamlı sonuçlara ulaşılmasını sağlayabilir.

Bu derlemenin önemli bulgularından biri de, Türkiye'de yapılan tezlerin büyük çoğunluğunun farmakolojik olmayan, düşük maliyetli ve hemşireler tarafından bağımsız olarak uygulanabilir girişimlere odaklanmış olmasıdır. Sharifnia ve ark. (2024)'nın da vurguladığı gibi, non-farmakolojik girişimler düşük yan etki profili ve yüksek hasta kabulü nedeniyle diyaliz ünitelerinde standart bakımın bir parçası haline getirilebilir. Bu durum, hemşirelik bakımının güçlendirilmesi ve hemşirelerin semptom yönetiminde daha aktif rol alması açısından önemli bir fırsat sunmaktadır. Bununla birlikte, incelenen tezlerin çoğunda örneklem büyüklüklerinin sınırlı olması, müdahale sürelerinin kısa olması ve uzun dönem izlem verilerinin bulunmaması önemli kısıtlılıklar olarak değerlendirilebilir. Bossola (2019) ağız kuruluğu tedavilerine ilişkin çalışmaların çoğunda uzun dönem etkinliğin yeterince değerlendirilmediğini belirtmektedir. Bu nedenle, gelecekte yapılacak araştırmalarda daha uzun izlem süreleri ve çok merkezli tasarımlar tercih edilmelidir.

Sonuç olarak, bu geleneksel derleme, Türkiye'de hemşirelik alanında hemodiyaliz hastalarında ağız kuruluğunun önlenmesine yönelik yapılan lisansüstü tezlerin, uluslararası literatürle büyük ölçüde uyumlu sonuçlar ortaya koyduğunu göstermektedir. Ksilitollü sakız çiğneme, akupres ve yenilikçi bütüncül yaklaşımlar gibi non-farmakolojik hemşirelik girişimlerinin ağız kuruluğu yönetiminde etkili olduğu görülmektedir. Ancak bu alanda daha fazla, daha kapsamlı ve metodolojik açıdan güçlü çalışmalara ihtiyaç bulunmaktadır. Elde edilecek yeni kanıtlar, hemşirelik bakımının standardizasyonuna ve hemodiyaliz hastalarının yaşam kalitesinin artırılmasına önemli katkılar sağlayacaktır.

SONUÇ

Sonuç olarak, Türkiye'de bu alanda yapılmış tez sayısının sınırlı olduğu, ancak mevcut çalışmaların tamamının deneysel veya randomize kontrollü tasarıma sahip olduğu belirlenmiştir. Bu durum, hemşirelik bakım girişimlerinin ağız kuruluğu yönetimindeki etkisini değerlendirmeye yönelik güçlü bir metodolojik yaklaşımın benimsendiğini göstermektedir. İncelenen tezlerde; ksilitollü sakız çiğneme, akupres uygulamaları, ağız spreyi kullanımı ve sanal gerçeklik gibi farmakolojik olmayan hemşirelik girişimlerinin ağız kuruluğu semptomlarını azaltmada etkili olduğu görülmüştür. Bu bulgular, hemodiyaliz hastalarında ağız kuruluğunun multifaktöriyel yapısına uygun olarak, non-invaziv ve çok boyutlu bakım yaklaşımlarının önemini vurgulamaktadır. Uluslararası literatürde bildirilen yüksek ağız kuruluğu prevalansı ve bu semptomun yaşam kalitesi, sıvı alımı ve interdiyalitik kilo artışı üzerindeki olumsuz etkileri göz önünde bulundurulduğunda, söz konusu girişimlerin klinik uygulamada önemli bir potansiyel taşıdığı söylenebilir.

Çalışmanın Güçlü Yönleri ve Sınırlılıkları

Bu çalışmanın en önemli güçlü yönlerinden biri, Türkiye'de hemşirelik alanında hemodiyaliz hastalarında ağız kuruluğuna yönelik yapılmış lisansüstü tezleri sistematik bir yaklaşımla inceleyen nadir çalışmalardan biri olmasıdır. Ayrıca, derlemeye dahil edilen tezlerin tamamının deneysel veya randomize kontrollü tasarıma sahip olması, elde edilen bulguların kanıt düzeyini güçlendirmektedir. Çalışmada elde edilen bulguların, güncel uluslararası sistematik derleme ve meta-analiz sonuçlarıyla karşılaştırılarak tartışılması, sonuçların bilimsel bağlamda daha sağlam bir temele oturtulmasını sağlamıştır. Bu çalışmanın bazı kısıtlılıkları bulunmaktadır. İlk olarak, derlemeye dahil edilen tez sayısının sınırlı olması, bulguların genellenebilirliğini azaltmaktadır. İkinci olarak, tezlerde kullanılan ölçüm araçlarının ve müdahale protokollerinin heterojen olması, çalışmalar arasında doğrudan karşılaştırma yapılmasını zorlaştırmıştır. Ayrıca, tezlerin çoğunda uzun dönem izlem verilerinin bulunmaması, uygulanan girişimlerin kalıcı etkilerinin değerlendirilmesini sınırlamaktadır. Son olarak, yalnızca erişime açık tezlerin incelenmiş olması, olası yayın yanlılığına yol açmış olabilir.

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EVALUATING THE EFFECT OF ANNOTATION CONFIDENCE ON STRESS DETECTION PERFORMANCE

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ABSTRACT

The quality of annotated training data is a key factor affecting the performance of supervised text classification systems. Although annotation confidence has been investigated in general natural language processing tasks, its impact on stress detection has received limited attention. Therefore, this study aims to evaluate the effect of different annotation confidence levels on the performance of traditional machine learning algorithms for stress detection and to examine the relationship between annotation quality, classification performance, and computational efficiency. Experiments were conducted using the Dreaddit dataset. Four training datasets were constructed by applying different annotation confidence thresholds to the original training set while maintaining the same independent test set. Eight widely used traditional machine learning algorithms were evaluated under identical experimental settings using TF-IDF text representations. The Macro-F1 score was adopted as the primary evaluation metric for performance comparison, and the execution time of each classifier was recorded to assess computational efficiency. The experimental results demonstrated that annotation confidence has a considerable impact on stress detection performance. None of the evaluated classifiers achieved its best performance using the original training dataset. Instead, six classifiers obtained their highest Macro-F1 scores when trained using only instances with complete annotator agreement, whereas the remaining three classifiers achieved their best results using the training dataset with a confidence threshold of 0.8. Furthermore, increasing the annotation confidence threshold consistently reduced the execution time of all classifiers because of the smaller training datasets. These findings indicate that selecting high-confidence training instances can improve both classification performance and computational efficiency, highlighting the importance of annotation confidence in the preparation of high-quality training datasets for supervised stress detection.

Keywords: Stress Detection, Annotation Confidence, Text Classification, Machine Learning.

INTRODUCTION

The rapid advancement of internet technologies has led to an exponential growth in the number of digital text documents (Tiryaki & Uysal, 2026). Text classification has become one of the fundamental tasks in natural language processing, with applications in many fields such as sentiment analysis (Uysal & Uysal, 2022)(Mao et al., 2024), spam filtering (Manita et al., 2023), hate speech detection (Rawat et al., 2024), emotion recognition (Khare et al., 2024), and stress detection (Muñoz & Iglesias, 2022).

Stress detection has attracted increasing attention due to its potential applications in mental health monitoring, early intervention, and well-being assessment (Turcan & McKeown, 2019). Social media platforms provide an abundant source of textual data that enables automatic identification of stress-related expressions. Numerous studies have investigated stress detection using machine learning methods (Febriansyah et al., 2023)(Oryngozha et al., 2024)(Saxena et al., 2026). Advances in machine learning have significantly improved classification performance, enabling automatic analysis of large volumes of textual data.

Despite these advances, the quality of annotated training data remains one of the most influential factors affecting the performance of supervised learning algorithms. The performance of supervised machine learning models strongly depends on the quality of training labels (Song et al., 2022). In many datasets, annotations are obtained from multiple human annotators whose opinions may differ due to subjective

interpretation. Consequently, modern datasets frequently provide confidence scores or annotator agreement levels to quantify the reliability of each annotation. Samples with low agreement generally indicate ambiguous instances that may introduce noise into the learning process.

Although numerous studies have proposed new machine learning and deep learning models for stress detection, relatively little attention has been paid to the influence of annotation confidence on classifier performance. Existing studies generally employ the complete training dataset without investigating whether excluding low-confidence samples can improve classification performance. Consequently, the trade-off between annotation quality and training set size remains insufficiently explored.

Unlike previous studies, this work focuses on the effect of annotation confidence rather than proposing a new classification algorithm. Using the Dreaddit dataset, four different training sets are constructed according to annotation confidence thresholds while maintaining the same independent test set. Several traditional machine learning classifiers are evaluated under identical experimental settings to investigate whether higher-confidence training samples lead to improved stress detection performance.

The main contributions of this study are summarized as follows:

- We investigate the effect of annotation confidence on the performance of stress detection models.
- Four training datasets with different annotation confidence thresholds are constructed while keeping the same independent test set.
- Eight traditional machine learning algorithms are evaluated under identical preprocessing and parameter settings to ensure a fair comparison.
- The trade-off between annotation quality and training set size is analyzed using the Macro-F1 score.

The computational efficiency of the evaluated algorithms is also analyzed using training datasets with different annotation confidence levels.

RELATED WORK

Turcan and McKeown introduced Dreaddit, a Reddit-based dataset developed for stress detection in social media (Turcan & McKeown, 2019). The dataset comprises approximately 190,000 Reddit posts collected from five different domains, with 3,553 text segments manually annotated for stress using Amazon Mechanical Turk. In addition to presenting the dataset, the authors established baseline performance by evaluating both traditional machine learning and neural network models for stress classification. The study demonstrated the feasibility of detecting stress from long-form social media posts and provided a benchmark dataset that has been widely adopted in subsequent stress detection research.

Febriansyah et al. developed a machine learning-based stress detection system using Reddit posts from the Dreaddit dataset (Febriansyah et al., 2023). The authors investigated several traditional machine learning algorithms, including Support Vector Machine (SVM), Naïve Bayes, Decision Tree, and Random Forest, in combination with Bag-of-Words and TF-IDF text representations. Experimental results showed that the SVM classifier achieved the best performance, obtaining an F1-score of 80.00% and an accuracy of 75.00%. The study demonstrated the effectiveness of traditional machine learning approaches for stress detection in social media texts.

Oryngozha et al. investigated stress detection in Reddit's academic communities using traditional machine learning techniques (Oryngozha et al., 2024). The authors trained their models on the Dreaddit dataset and subsequently analyzed posts collected from academic subreddits to identify stress-related content. Various text representation methods and machine learning classifiers were evaluated, with the Bag-of-Words representation combined with Logistic Regression achieving an accuracy of 77.78% and an F1-score of 0.79 as the best performance.

Ly et al. proposed a real-time stress detection system for social media posts using the Dreaddit dataset (Ly et al., 2024). The system was developed on a big data infrastructure integrating Apache Kafka,

PySpark, and Airflow to enable real-time processing of streaming data. Several machine learning algorithms were evaluated, with Logistic Regression achieving the best classification performance among the tested models. LogisticRegression reached 69,39% for measuring accuracy and 68,97 for measuring F1-scores.

Saxena et al. presented a standardized machine learning pipeline for binary stress classification using a Reddit dataset obtained from Kaggle (Saxena et al., 2026). The study compared several traditional machine learning algorithms, including Bernoulli Naïve Bayes, Logistic Regression, Linear SVM, and k-Nearest Neighbours, using both TF-IDF features and SBERT sentence embeddings. Experimental results showed that Bernoulli Naïve Bayes, combined with optimized sparse TF-IDF features, achieved the best overall performance with an F1-score of 0.779, whereas the SBERT + Logistic Regression model attained the highest precision while achieving an F1-score of 0.741.

Troiano et al. investigated the relationship between annotation confidence and inter-annotator agreement in emotion annotation tasks (Troiano et al., 2021). The authors showed that annotators' self-reported confidence strongly correlates with agreement levels and emotion intensity, suggesting that annotation confidence can serve as an indicator of label reliability. The study highlighted the importance of considering confidence information when constructing high-quality annotated datasets.

While previous studies have demonstrated the importance of annotation confidence and label reliability in general natural language processing tasks, relatively little attention has been paid to their impact on stress detection. Existing stress detection research has largely concentrated on improving classification performance through feature engineering, machine learning algorithms, and transformer-based models, rather than examining the quality of the annotated training data itself. Consequently, the effect of annotation confidence on stress detection performance remains insufficiently explored, motivating the present study.

METHODOLOGY

Classification algorithms

In this study, eight traditional machine learning algorithms were employed to evaluate the effect of annotation confidence on stress detection performance. All classifiers were trained using identical preprocessing steps and TF-IDF feature representations to ensure a fair comparison. The algorithms selected for this study represent different learning paradigms and have been widely adopted in text classification research.

Multinomial Naïve Bayes (MNB) is a probabilistic classifier based on Bayes' theorem with the assumption of conditional independence among features (Uysal & Uysal, 2022). Owing to its computational efficiency and effectiveness in handling high-dimensional sparse text data, it has been widely used in text classification tasks.

Logistic Regression (LR) is a linear discriminative classifier that estimates the posterior probability of each class using the logistic function (Oryngozha et al., 2024). It has demonstrated strong performance in many text classification applications because of its robustness and simplicity.

Linear Support Vector Machine (Linear SVM) constructs a linear decision boundary by maximizing the margin between classes (Uysal & Uysal, 2022). Due to its ability to handle high-dimensional feature spaces, Linear SVM has become one of the most commonly used algorithms for text classification.

Stochastic Gradient Descent (SGD) (Dagal et al., 2025) is an optimization-based learning algorithm suitable for large-scale text classification. Two variants were evaluated in this study. The first uses the hinge loss, resulting in a linear SVM-like classifier, while the second employs the modified Huber loss, which combines the advantages of hinge loss with probabilistic predictions and increased robustness to noisy samples.

To replace the deprecated Passive-Aggressive implementation available in recent versions of Scikit-learn, an additional SGD classifier configured with the PA-I learning strategy was included. This

classifier adopts the hinge loss together with the PA-I update rule and preserves the characteristics of the traditional Passive-Aggressive algorithm.

Decision Tree (DT) is a tree-based classification algorithm that recursively partitions the feature space according to feature values (Tiryaki & Uysal, 2026). Although decision trees are generally less effective than linear classifiers for sparse text data, they provide an interpretable baseline for comparison.

Random Forest (RF) is an ensemble learning method that combines multiple decision trees through bootstrap aggregation (Tiryaki & Uysal, 2026). By averaging the predictions of individual trees, Random Forest generally provides better generalization and reduces overfitting compared with a single decision tree.

Extra Trees (ET) is another ensemble-based classifier that introduces additional randomness during tree construction by selecting split thresholds randomly (Elshewey et al., 2025). This strategy often improves model diversity and computational efficiency while maintaining competitive classification performance.

RESULTS AND DISCUSSION

In this section, comprehensive experiments were conducted to investigate the effect of annotation confidence on the performance of traditional machine learning algorithms for stress detection. Four training datasets with different annotation confidence levels were constructed from the Dreaddit corpus, while the same independent test set was used in all experiments. This experimental design enables a fair comparison by isolating the effect of annotation confidence from other factors.

Datasets

The experiments were conducted using the Dreaddit dataset proposed by Turcan and McKeown (2019). Dreaddit is a benchmark dataset for stress detection consisting of Reddit posts collected from five different domains. The dataset contains manually annotated text segments labeled as either stress or non-stress.

The original training set contains 2,838 instances, while the independent test set contains 715 instances. In addition to the original training set, three additional subsets were generated by filtering the training instances according to their annotation confidence scores. Specifically, confidence thresholds of 0.6, 0.8, and 1.0 were applied, resulting in four different training datasets with varying levels of annotation reliability. The same test set was employed in all experiments to ensure a consistent and unbiased evaluation. Table 1 summarizes the characteristics of the training datasets.

Table 1. Training datasets used in the experiments

Dataset	Minimum confidence	Sample count
Original training set	0.428571429	2,838
Confidence ≥ 0.6	0.6	2,433
Confidence ≥ 0.8	0.8	1,852
Confidence = 1.0	1.0	1,128

Success measure

The performance of the evaluated classifiers was assessed using the Macro-F1 score. Macro-F1 was selected as the primary evaluation metric because it equally considers the performance of both classes by calculating the F1-score independently for each class and then averaging the results. Compared with overall accuracy, Macro-F1 provides a more balanced evaluation, particularly when class distributions are not perfectly balanced. Furthermore, using a single evaluation metric facilitates a more straightforward comparison of classifier performance across different annotation confidence levels.

Performance analysis

In this section, the performances of the machine learning algorithms are compared across four training datasets with different annotation confidence levels. Since the test set remained unchanged throughout all experiments, the observed performance differences can be attributed solely to variations in the

annotation confidence of the training data. Figure 1 illustrates the variation in Macro-F1 scores across different annotation confidence thresholds for each classification algorithm.

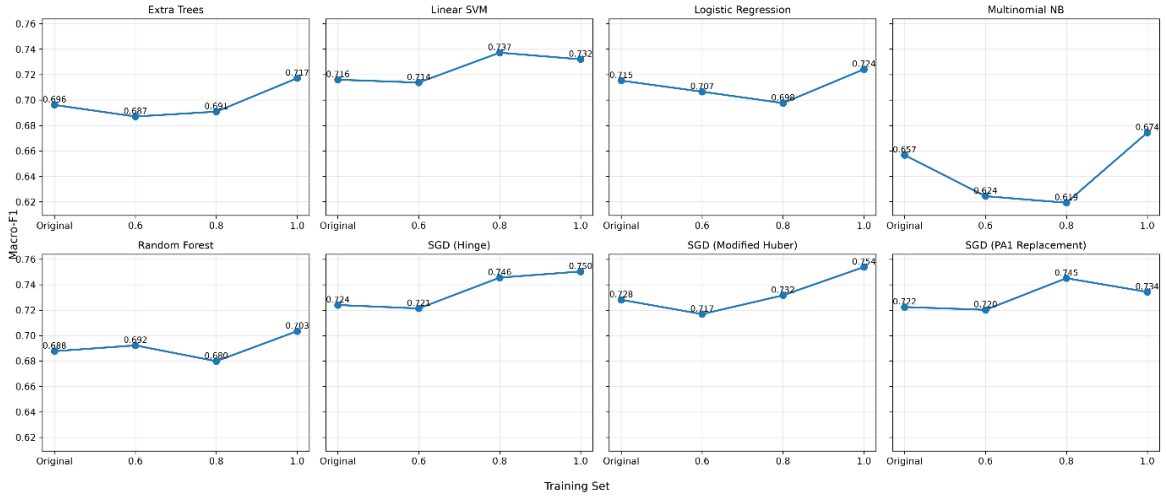

Figure 1. Effect of annotation confidence on Macro-F1 scores

Overall, the results indicate that annotation confidence has a noticeable influence on classification performance, although its effect varies across classifiers. Most linear classifiers, including Linear SVM and the SGD-based models, generally achieved higher Macro-F1 scores when trained on higher-confidence subsets. In contrast, Random Forest, Extra Trees, and Logistic Regression exhibited less consistent performance trends across different confidence thresholds. Furthermore, the Multinomial Naïve Bayes classifier experienced a noticeable decrease in performance at intermediate confidence levels but achieved its highest Macro-F1 score when only instances with complete annotator agreement were used. It is also noteworthy that six of the eight evaluated classifiers achieved their highest Macro-F1 scores using the training set with a confidence threshold of 1.0, while the remaining two classifiers (Linear SVM and SGD (PA1 Replacement)) obtained their best results with a confidence threshold of 0.8. These findings suggest that high-quality annotations can, in many cases, compensate for the reduction in training data size, although the magnitude of this effect depends on the characteristics of the classification algorithm.

Running time analysis

In addition to classification performance, the computational efficiency of the evaluated algorithms was also investigated. The running time of each classifier was recorded under identical experimental conditions. Since all algorithms used the same TF-IDF representation and were executed on the same hardware environment, the measured running times provide a fair comparison of their computational costs. The corresponding results are presented in Table 2.

Table 2. Running time (sec) of the evaluated classifiers

Classifier	**Original**	**≥0.6**	**≥0.8**	**1.0**
Multinomial NB	1.16	0.76	0.73	0.47
Logistic Regression	1.08	0.74	0.76	0.46
Linear SVM	1.09	0.77	0.71	0.46
SGD (Hinge)	0.94	0.75	0.68	0.46
SGD (Modified Huber)	1.03	0.76	0.60	0.47
SGD (PA1 Replacement)	1.08	0.74	0.65	0.45
Random Forest	9.17	7.82	5.11	2.91
Extra Trees	12.72	10.24	6.05	3.46

As the annotation confidence threshold increased, the size of the training set decreased, resulting in shorter execution times for all evaluated classifiers. The reduction was especially noticeable for the ensemble-based methods, namely Random Forest and Extra Trees, whose execution times decreased by approximately 68% and 73%, respectively. Meanwhile, all linear classifiers and Multinomial Naïve Bayes completed the experiments in less than one second when trained on the highest-confidence dataset.

CONCLUSION

This study investigated the effect of annotation confidence on the performance of traditional machine learning algorithms for stress detection. Four training datasets with different annotation confidence thresholds were constructed from the Dreaddit dataset while maintaining the same independent test set. Eight widely used traditional machine learning algorithms were evaluated under identical experimental settings using TF-IDF text representations.

The experimental results demonstrate that annotation confidence has a significant impact on stress detection performance. Although the relationship between annotation confidence and classification performance varies across algorithms, none of the evaluated classifiers achieved its best performance using the original training set. Instead, six classifiers obtained their highest Macro-F1 scores when trained with instances having complete annotator agreement, while the remaining two classifiers achieved their best results using the 0.8 confidence threshold. These findings indicate that improving annotation quality can effectively compensate for the reduction in training data size.

The study also showed that increasing the annotation confidence threshold consistently reduced the computational cost of all evaluated classifiers. Since higher confidence thresholds resulted in smaller training sets, the execution time decreased substantially, particularly for the ensemble-based methods. Therefore, confidence-based filtering not only improved the performance of most classifiers but also reduced their computational requirements.

Overall, the findings suggest that annotation confidence should be considered during the preparation of training datasets for stress detection. Rather than simply increasing the amount of labeled data, selecting more reliable training instances may provide a more effective strategy for improving both classification performance and computational efficiency.

Future work will investigate whether these findings generalize to transformer-based language models and other text classification tasks, such as sentiment analysis, emotion recognition, and hate speech detection.

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TELEPSYCHIATRY IN THE MANAGEMENT OF DEPRESSION AND THE ROLE OF MENTAL HEALTH NURSES: A NARRATIVE REVIEW

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ABSTRACT

Introduction and Purpose: Depression is one of the most prevalent mental disorders worldwide and significantly affects quality of life, social functioning, and daily living activities. Barriers to accessing mental health services, shortages of mental health professionals, geographical limitations, and recent global health crises have increased the need for telepsychiatry services. Telepsychiatry enables the remote delivery of mental health care through information and communication technologies and has become an important component of contemporary psychiatric care. The aim of this narrative review was to examine current evidence regarding telepsychiatry in the management of depression and to evaluate the roles and responsibilities of mental health nurses within telepsychiatric services.

Materials and Methods: This study was designed as a narrative review. Relevant national and international literature published on telepsychiatry, telehealth, depression, digital mental health, and mental health nursing was reviewed. Studies focusing on videoconferencing interventions, telephone-based psychological support, internet-based cognitive behavioral therapy, mobile health applications, and nurse-led telehealth programs for individuals with depression were evaluated.

Results: The reviewed literature indicates that telepsychiatry contributes to the reduction of depressive symptoms, improvement of quality of life, and enhancement of access to mental health services. Telepsychiatric interventions provide flexible and continuous care opportunities independent of time and location. Mental health nurses play key roles in patient assessment, psychoeducation, symptom monitoring, counseling, crisis management, and promoting treatment adherence. Furthermore, telepsychiatry has been reported to reduce barriers to care and support continuity of treatment. However, technological limitations, digital literacy disparities, privacy concerns, and ethical challenges remain important barriers to implementation.

Keywords: Telepsychiatry; Depression; Mental Health Nursing; Telehealth; Digital Mental Health; Nursing Care.

INTRODUCTION

Depression is one of the most prevalent mental disorders worldwide and represents a significant disease burden. A comprehensive epidemiological assessment examining the prevalence and burden of depressive disorders across 204 countries and regions demonstrates that these disorders constitute a major public health issue on a global scale (Santomauro et. al, 2021). Depression does not merely affect

an individual's mood; it creates a multidimensional picture that encompasses cognitive processes, motivation, sleep and appetite patterns, and overall life satisfaction. Therefore, the management of depression requires not only symptom relief but also the holistic support of the individual's functioning and quality of life.

The negative effects of depression on quality of life have been examined in various care settings. Studies examining the relationships between anxiety, depression, and quality of life in primary care patients show that the presence of depressive symptoms is associated with various aspects of quality of life (Brenes, 2007). A large-scale community-based study also examined factors associated with quality of life in individuals with depression and reported that quality of life is linked to numerous individual and clinical variables (Cho et al.,2019). These findings indicate that quality of life should be monitored as an independent outcome measure in the care of depression.

The effects of depression on social and daily functioning are also clinically significant. Studies on the assessment of social functioning in depression emphasize that social functioning is an integral dimension of depressive disorders and should be systematically addressed in clinical evaluation (Bosc, 2000). A comprehensive assessment examining social functioning in major depressive disorder discusses the possibility that impairments in social relationships may be reciprocally related to the course of the illness (Kupferberg, 2016). Therefore, the goals of depression care should also include enabling the individual to resume their social roles and daily life activities.

However, access to mental health services remains limited in many contexts. Geographic distance, transportation difficulties, the concentration of service providers in specific centers, and time constraints are among the factors that hinder access to care. Studies examining the scope of telemedicine applications and the opportunities they offer indicate that this approach provides an option for expanding access to services (Boxer & Ellimoottil, 2019). Similarly, reviews examining the role of telemedicine in access to quality care on a global scale discuss how the technology can help overcome geographic barriers (Rafiq & Merrell, 2005). Studies examining the use of telemedicine applications in public health projects in Asia also provide examples of the feasibility of this approach in resource-constrained settings (Jha et. al, 2021).

Global health crises have further highlighted this picture. A comprehensive analysis examining the impact of the COVID-19 pandemic in 2020 on the global prevalence and burden of depressive and anxiety disorders reports an increase in the burden of these disorders during the pandemic (Santomauro et. al, 2021). The disruption of in-person services during the pandemic led to a rapid increase in demand for telehealth mental health services. This process has also strengthened the argument that telehealth models should be viewed not merely as a solution specific to extraordinary circumstances, but as a permanent component of the healthcare system. At this point, a conceptual distinction must be made. Telemedicine is a broad umbrella term encompassing the remote delivery of health services via information and communication technologies and is addressed within a classification framework that includes various forms of application (Bashshur et al.,2011).

Studies evaluating numerous approaches to defining the concept show that there is no single common definition in the literature and that definitions differ in scope and The World Health Organization's document on health telematics policy also highlights the relationship between this field and global health goals (Sood et al.;2007; Telematics,1998). Telepsychiatry, on the other hand, is a specific application area within this broad field that focuses on the remote delivery of mental health and psychiatric services. Therefore, rather than using the terms "telemedicine" and "telepsychiatry" as synonyms, it seems more appropriate to consider telepsychiatry as a specialized component of telehealth.

The role of telepsychiatry in the care of depression has been increasingly studied in recent years. A scoping review examining physicians' use of telemedicine in depression care highlights the diversity of practices in this field (Echelard, 2021). A systematic review examining the use of telepsychiatry in depression also demonstrates that these forms of practice are being studied in the context of depression care (Guaiana et al.,2021). These forms of practice span a wide range, from video-conference-based psychiatric assessment and psychotherapy to structured psychological support delivered by telephone, as well as from internet-based programs to mobile monitoring systems.

Mental health nurses play a pivotal role in translating this approach into practice. A study conducted at the primary care level reported that telehealth care and peer support provided by nurses were evaluated as an additional component in the treatment of depression (Hunkeler et al.,2000). Since mental health nurses are the professional group that maintains the most frequent and continuous contact with patients, they are well-positioned to assume the roles of monitoring, education, and coordination in remotely delivered services. However, the number of studies in the telepsychiatry literature that directly address the nursing role remains limited.

While the body of knowledge regarding the clinical outcomes of telepsychiatric interventions is growing in the current literature, studies evaluating these services from a nursing care perspective remain relatively scarce. Research focusing on the effectiveness of technological applications often leaves the question of who provides care, with what qualifications, and within what framework of responsibility in the background. This situation necessitates a comprehensive examination of the significance of telepsychiatric services from a nursing perspective.

PURPOSE OF THE STUDY

The purpose of this narrative review is to examine current evidence regarding telepsychiatric applications used in the management of depression and to evaluate the roles and responsibilities of mental health nurses in telepsychiatric services.

METHOD

This study was designed as a narrative review. International publications in the fields of telepsychiatry, telehealth, depression, digital mental health, and mental health nursing were reviewed. Studies addressing video-conference-based interventions for individuals with depression, telephone-based psychological support, internet-based cognitive-behavioral therapy, mobile health applications, and nurse-led telehealth applications were evaluated. The narrative review approach was chosen because it allows for a comprehensive interpretation of a broad body of literature covering different types of interventions, populations, and care models. The aim of this approach is not to perform a numerical synthesis, but to thematically highlight the conceptual framework, forms of practice, and implications for nursing in this field. The information obtained was organized thematically under the following headings: forms of telepsychiatry practice, effects on depressive symptoms, quality of life and functioning, access to services and continuity of care, and the roles of mental health nurses.

This study did not follow a search and study selection process typical of systematic reviews, nor did it conduct a formal quality assessment or risk of bias analysis. Therefore, the findings are the product of a qualitative synthesis rather than a quantitative synthesis and should be interpreted within this framework.

FINDINGS

Telepsychiatry Applications in Depression Management

Psychiatric assessment and psychotherapy via video conferencing. Video conferencing-based applications are one of the most common forms of telepsychiatry. In a study conducted among Hispanic individuals with limited access to services, it was reported that psychiatric consultations were conducted remotely using a standard webcam and internet equipment (Moreno et al.,2012). In a study conducted with older veterans, psychotherapy delivered via in-home video conferencing was compared to in-person therapy (Egede et al., 2015). This design is noteworthy in that it demonstrates that remote therapy was evaluated not in opposition to traditional care, but within the same clinical framework.

Telephone-based psychological support. The telephone is an accessible remote care tool due to its relatively low technological requirements. A study implementing telephone-based cognitive-behavioral therapy in individuals with Parkinson’s disease and a diagnosis of depressive disorder examines the feasibility of this method in groups with comorbid neurological conditions (Dobkin et al, 2020). Telephone-based approaches represent a particularly meaningful option for individuals with limited internet access or device usage.

Internet-based cognitive behavioral therapy and online programs. Internet-based interventions have been studied in various populations. An epilepsy-specific internet intervention was evaluated in individuals with active epilepsy and depressive disorder (Meyer et al.,2019). Web-based cognitive behavioral therapy was added to standard treatment in individuals with diabetes mellitus and major depressive disorder (Newby et al.,2017). A study examining three different low-intensity internet-based psychological programs in primary care demonstrates that interventions in this field can vary in content (Gili et al, 2020). A study conducted in Sweden in primary care evaluated the long-term effects of internet-based cognitive behavioral therapy [30]. Another study in which a web-based program was implemented for individuals with mild to moderate depression also suggests that this approach can be considered in the context of work-related outcomes (Beiwinkel et al.,2017).

A pilot study evaluating a spirituality-based online e-mental health tool for adolescents and young adults, meanwhile, demonstrates that digital interventions can be adapted in terms of content to reflect cultural and value-based perspectives (Rickhi et al, 2015). Mobile health and remote monitoring applications. A study in which smartphone-based mobile monitoring systems were added to routine care examines whether remote monitoring can be used as a tool for tracking depressive symptoms and psychological well-being (Place et al.,2020). Such applications differ from traditional monitoring models in that they allow symptoms to be monitored even between sessions.

Digital therapeutic games and technology-based applications. A portion of technology-based interventions relies on game-based designs. A study examining the effects of playing action video games in individuals diagnosed with major depression or dysthymia serves as an example of this approach (Kühn et al., 2018). A serious game application developed for individuals with breast cancer who exhibit mild-to-moderate depressive symptoms has also been evaluated within a similar framework (Kim et al, 2018). A study examining a therapeutic video game technology targeting cognitive control in late-life depression, which serves as a proof of concept, addresses the feasibility of such applications in the older adult population (Anguera, 2017).

Remote collaborative care models. Some applications rely not on a single technology but on care models that facilitate remote collaboration among teams. A culturally sensitive, telepsychiatry-based collaborative treatment model was evaluated among Chinese American immigrants (Yeung et al,2017). In a remote collaborative depression care program for adolescents in Chile's Araucanía region, psychiatrist supervision via a shared electronic record and telephone follow-up were used together (Martínez et. al,2018). A pragmatic study evaluating an integrated telehealth service for patients with depression also demonstrates that complex interventions can be addressed at the service level Salisbury et. al.,2016).

Effects on Depressive Symptoms

The studies reviewed indicate that some telepsychiatric interventions may contribute to the reduction of depressive symptoms. A systematic review and meta-analysis examining the combined effects of telemedicine interventions on depressive symptoms and quality of life in patients with depression reports that these interventions are associated with a positive effect on depressive symptoms (Shih et. al. 2023), A systematic review examining the use of telepsychiatry in depression and a meta-analysis evaluating concurrent telehealth technologies in psychotherapy also contribute to the body of evidence in this field (Guaiana et al.,2021; Osenbach et. al,2013).

However, the findings must be interpreted with caution. The interventions examined encompass a wide range of formats, including video conferencing, telephone, internet-based programs, mobile monitoring, and digital games. The populations in which they are applied also range from groups with comorbid conditions, such as epilepsy, Parkinson's disease, diabetes, and breast cancer, to adolescents and older adults (Anguera, 2017; Dobkin et al, 2020; Hunkeler et al.,2000; Martínez et. Al,2018; Meyer et al.,2019;Newby et al. ,2017). Due to this heterogeneity, it should be noted that findings may vary depending on the type of intervention, the population, the duration of implementation, and the care model. While the current evidence is promising, it cannot be said that all telepsychiatric interventions are equally effective.

A significant limitation relates to the patient groups from which the evidence was derived. A meta-analysis in this field reports that the studies examined generally excluded individuals with suicidal

ideation or major depression; consequently, the findings are limited to mild-to-moderate depression (Shih et. al. 2023), Consequently, the current evidence regarding the effectiveness of telepsychiatric interventions cannot be directly generalized to patients with severe depression or those at high risk of suicide.

Quality of Life and Functioning

Depression is associated with various aspects of quality of life and functioning (Brenes, 2007; Cho Y et al. 2019).

It has been emphasized that social functioning is an important dimension of depressive disorders and should be addressed in clinical assessment (Bosc, 2000; Kupferberg, 2016). For this reason, in the evaluation of telepsychiatric interventions, it is important to monitor indicators of quality of life and functioning in addition to changes in symptom levels.

A review synthesizing the effects of telemedicine interventions on quality of life reports that these interventions may be associated with improvements in quality of life (Shih et. al. 2023), The section of a study conducted among older veterans that focused on quality of life, satisfaction, treatment credibility, and perceptions of service delivery demonstrates that psychotherapy delivered remotely can also be evaluated in terms of these dimensions (Egede et al., 2016). These findings provide insight into the acceptability of telepsychiatry from the perspective of the patient experience. However, the evidence regarding quality of life and functioning is based on a more limited number of studies compared to the evidence on depressive symptoms, and further research is needed in this area.

Access to Mental Health Services and Continuity of Care

One of the most frequently highlighted contributions of telepsychiatry is its potential to help reduce geographic barriers. Reviews examining the role of telemedicine in access to quality care, along with studies addressing the scope of these applications, indicate that technology can help overcome distance-related limitations (Boxer & Ellimoottil, 2019; (Rafiq & Merrell, 2005). Experiences with public health projects conducted in resource-limited settings also serve as examples of the applicability of this approach across different health systems (Jha et. al, 2021).

There are also examples regarding reaching groups with limited access to services. Aand structured follow-up contacts are particularly important. The integration of mobile monitoring systems into routine care allows symptoms to be tracked even between appointments (Place et al.;2020).

Telehealth care provided by nurses in primary care has also been evaluated as an additional monitoring and support component to treatment (Hunkeler et al.,2000). Conversely, it should not be assumed that telepsychiatry completely eliminates access issues. An internet connection, appropriate devices, a physical environment that ensures privacy, and basic digital skills are prerequisites for remote care. For individuals who lack these conditions, telepsychiatry may become a new source of inequality rather than facilitating access.

Roles of Mental Health Nurses

Among the reviewed sources, there are a limited number of studies that directly address mental health nursing. In a study conducted among individuals with major depressive disorder in primary care, it was reported that telehealth care provided by nurses over the phone and peer support were evaluated as components added to standard physician-led treatment (Hunkeler et al.,2000). It is noted that this intervention included providing emotional support and focused behavioral interventions (Hunkeler et al.,2000). This study serves as direct evidence that nurses can assume a structured role in the remote delivery of depression care.

In remote collaborative care models, it is also observed that monitoring and coordination functions are shared among team members (Martínez et. Al,2018; Yeung et. al, 2017; Salisbury et. al.,2016). However, these studies do not always specify in detail which professional group performs these functions. Therefore, it would not be appropriate to characterize these models as practices directly led by nurses.

Other roles that mental health nurses can assume in telepsychiatric services include: initial assessment, systematic monitoring of depressive symptoms, assessment of suicide and self-harm risk, psychoeducation, therapeutic communication, counseling via phone or video calls, support for treatment adherence, monitoring of medication use, support for lifestyle adjustments, recognition of crisis symptoms, referral to the appropriate specialist when necessary, collaboration with family and caregivers, patient support in the use of digital health tools, and coordination within a multidisciplinary team, were not directly addressed as research findings in the sources reviewed in this review. These roles can be evaluated within the framework of established clinical responsibilities of mental health nursing and are considered adaptable to the telepsychiatric context. Maintaining this distinction is important to avoid confusing professional implications with the level of evidence.

DISCUSSION

The literature reviewed in this review indicates that telepsychiatry can contribute to depression care along two main axes. The first is the clinical axis: some telepsychiatric interventions have been reported to be associated with a reduction in depressive symptoms (Shih et. al. 2023). The second is the service delivery dimension: care provided remotely can help reduce barriers related to distance and time (Boxer & Ellimoottil, 2019; Rafiq & Merrell, 2005). These two dimensions should not be considered in isolation; the clinical effectiveness of an intervention, on its own, holds no significance for a patient group that cannot be reached.

Comparison with in-person psychiatric care is one of the most debated topics in the field. A study conducted among older veterans comparing teletherapy with in-person therapy demonstrates that such a comparison can be made directly (Egede et al., 2015). A meta-analysis comparing teletherapy with in-person psychotherapy also indicates that this issue has been systematically addressed (Giovanetti et al.,2022). However, based on the current evidence, it is not appropriate to conclude that teletherapy is superior to in-person therapy. A more cautious interpretation is that teletherapy may constitute a valid option under certain conditions.

The difference between synchronous and asynchronous approaches is also clinically significant. Synchronous approaches, such as video conferencing and telephone calls, allow the clinician to engage in real-time interaction with the patient and to observe their tone of voice and, if video is used, their facial expressions (Dobkin et al, 2020; Egede et al., 2015; Moreno et al.,2012). Asynchronous applications, on the other hand, include approaches where the patient progresses at their own pace, such as internet-based programs and mobile monitoring systems (Beiwinkel et al.,2017; Eriksson et. al,2017; Gili et al,2020; Place et al.,2020; Newby et al. ,2017). While asynchronous applications may offer advantages in terms of scalability, they limit the clinician's ability to make immediate observations. A meta-analysis that treats real-time telehealth technologies in psychotherapy as a separate category also demonstrates that this distinction is meaningful (Osenbach et. al,2013).

The studies examined in terms of feasibility cover a wide range of ages and diagnoses. Programs targeting adolescents (Martínez et. Al,2018; Rickhi et al, 2015), web-based interventions for working-age adults and applications for older adults (Anguera, 2017; Egede et al., 2015; Egede et al., 2016) reflect this diversity. In addition, interventions have been conducted in groups with comorbid chronic conditions such as epilepsy, Parkinson's disease, diabetes, and breast cancer (Kim et al, 2018; Meyer et al.,2019; Newby et al. ,2017) This picture suggests that telepsychiatry should be viewed not as a single standardized model, but as a set of approaches adapted to the specific population.

Primary care is a context where telepsychiatry can be particularly meaningful. Internet-based and nurse-led programs implemented in primary care serve as examples in this field (Hunkeler et al.,2000; Gili et al,2020). Given that a significant portion of depression cases are managed in primary care, it can be argued that remote support components have the potential to strengthen care at this level.

However, interventions targeting disadvantaged groups and those with limited access to services require a careful balance. Studies conducted in communities with insufficient access to services and in rural areas demonstrate telepsychiatry's potential to reach these groups (Martínez et. al,2018; Moreno et al.,2012). However, these same groups are often disadvantaged in terms of access to digital

infrastructure and devices. Therefore, whether telepsychiatry will reduce inequalities depends more on the conditions of implementation than on the technology itself.

Cultural adaptation is an integral part of this discussion. A culturally sensitive, telepsychiatry-based collaborative care model demonstrates that adapting the service to the patient's cultural framework is feasible. (Yeung et. al, 2017). From the perspective of mental health nursing, this finding is particularly significant, as cultural sensitivity is one of the established principles of nursing care.

Evidence regarding nurse-led care models, however, remains limited. A study evaluating telehealth care provided by nurses via telephone in primary care serves as a direct example in this field (Hunkeler et al.,2000). In contrast, much of the telepsychiatry literature focuses on the technological form of the intervention, treating the professional group providing the care as a secondary variable. This gap necessitates systematic research into nurse-led telepsychiatry models.

Digital health literacy is a mediating variable that can directly influence the clinical effectiveness of telepsychiatry. A patient's ability to install the app, connect to the session, and enter follow-up data is a prerequisite independent of the intervention's content. A study examining barriers to the use of telepsychiatry highlights that these barriers can exist not only on the patient's side but also on the clinician's side (Cowan et. al, 2019).

Patient safety and quality of care form the defining boundaries of the discussion. It is reported that the studies reviewed generally excluded individuals with major depression and suicidal ideation (Shih et. al. 2023). This implies that the evidence base for the use of telepsychiatry in high-risk patients is insufficient. An approach proposing a multidimensional framework for evaluating telemedicine applications also emphasizes that these services must be considered not only in terms of clinical outcomes but also in conjunction with safety, economic, and organizational dimensions (Kidholm et. al.,2017). Within this framework, telepsychiatry can serve as an important care model that complements in-person mental health services when used with appropriate patient groups and when necessary clinical safety measures are in place.

IMPLICATIONS FOR MENTAL HEALTH NURSING PRACTICE

The conclusions presented in this section are not research findings derived directly from the reviewed sources, but rather professional assessments developed within the framework of established responsibilities in mental health nursing.

The first area of application for nursing care in telepsychiatric services is assessment. Since the opportunities for physical examination and direct observation are limited in remote consultations, skills such as taking a history, structuring the patient's narrative, and recording observable symptoms become more critical. Under these conditions, the nurse's adoption of a systematic and structured assessment approach can help minimize information loss.

Monitoring is one of the areas where remote care excels. Mobile monitoring systems have been shown to provide data between consultations (Hunkeler et. al., 2000).

For such data to have clinical significance, it must be regularly reviewed and interpreted; this function can be considered a natural extension of the nurse's monitoring responsibilities. Psychoeducation and therapeutic communication are areas that need to be rethought in a digital setting. In communication established via a screen, some aspects of body language are lost, managing silences becomes more difficult, and connection issues can disrupt the interaction. Therefore, establishing and maintaining a therapeutic relationship requires an additional skill in remote care.

Managing crisis situations requires special attention. Given that the reviewed evidence largely excludes patients with major depression and those at risk of suicide (Shih et. al. 2023), the steps to be taken when risk indicators are detected during a remote consultation must be defined in advance. Knowing the patient's physical location, identifying a reachable family member, and planning in advance how to refer the patient to local emergency services can be considered key components of this process. Finally, nurses are also in a position to provide support for patients' use of digital tools. Support offered regarding

device setup, access to the application, and pre-consultation preparation can help transform technology from a barrier into a tool for care.

LIMITATIONS AND ETHICAL ISSUES IN TELEPSYCHIATRY

The widespread adoption of telepsychiatric services brings with it significant ethical issues. A study examining ethical issues in home-based telemedicine applications demonstrates that this field raises unique questions regarding privacy and confidentiality (Bauer, 2001). These questions are even more pronounced in the field of mental health, as the information shared often pertains to an individual's most personal experiences.

Patient privacy and the confidentiality of the consultation setting are among the unique challenges of remote care. While confidentiality is ensured by the healthcare provider during in-person consultations, in remote consultations, part of this responsibility shifts to the patient's environment. The presence of other people living in the same household or the lack of a suitable room may prevent the patient from expressing themselves openly.

The protection of personal health data and data security are directly related to the technical specifications of the platforms used. It must be made clear where consultation records, messaging content, and tracking data collected via mobile applications are stored, who has access to them, and how long they are retained. The informed consent process must also be expanded to include this information; the patient must give consent not only to the treatment but also to how their data is processed.

Emergency and crisis management is the most critical limitation of telepsychiatry. The clinician's absence from the same physical environment as the patient eliminates the possibility of direct intervention in cases of sudden deterioration. Given that the reviewed evidence base largely excludes high-risk patients (Shih et. al., 2023), it can be concluded that remote care alone may not be sufficient for patients at risk of suicide and that safety planning must be carried out in advance.

The competence of healthcare professionals and clinicians' attitudes are also factors that shape practice. A study examining barriers to the use of telepsychiatry reveals that clinicians play a decisive role in the widespread adoption of these services (Cowan et. al, 2019). This finding demonstrates that technological infrastructure alone is not sufficient; professional training, institutional support, and attitudinal changes are also necessary.

Differences in digital literacy and inequalities in internet and device access raise equity concerns regarding telepsychiatry. While remote care facilitates access for individuals with access to technology, it may exacerbate existing inequalities for those without such access. Technical issues such as connection interruptions and poor audio and video quality, can negatively impact both clinical assessment and the therapeutic relationship.

Finally, differences in health systems and infrastructure lead to variations in implementation across countries. Experiences with public health projects conducted in different regions demonstrate that practices are shaped by local conditions (Jha et. al, 2021). A proposed multidimensional framework for evaluating telemedicine services also indicates that these services cannot be assessed independently of their context (Kidholm et. al.,2017).

LIMITATIONS OF THE NARRATIVE REVIEW

The limitations of this study must be clearly stated. First, the study was designed as a narrative review; therefore, a systematic search and study selection process was not conducted or reported. The steps defined in current guidelines for reporting systematic reviews were not applied in this study (Page et al.,2021). Similarly, the quality assessment processes defined in methodological handbooks and critical appraisal tools used in systematic reviews were not carried out (Higgins, 2021). No analysis was conducted to measure inter-rater agreement (Landis & Koch,1977).

Second, this review considered different types of interventions and populations together. Evaluating diverse approaches, such as video conferencing, telephone, internet-based programs, mobile monitoring, and digital games, under a single umbrella provides thematic coherence but reduces comparability. Methodological heterogeneity among the studies also complicates the interpretation of the findings. Third, telepsychiatry technologies are evolving rapidly. Consequently, evaluations of specific platforms or application formats may lose their validity over time. Fourth, this review examined only the international literature. The exclusion of national publications requires caution when adapting the findings to the Turkish context. Finally, the number of studies providing direct evidence regarding nursing roles is limited. Consequently, a significant portion of the inferences regarding nursing practices in this review are based on professional judgment rather than research findings, and this distinction has been maintained throughout the text.

CONCLUSIONS AND RECOMMENDATIONS

The literature reviewed in this narrative review indicates that telepsychiatry may support access to and continuity of care for depression. It has been reported that some telepsychiatric interventions may contribute to reducing depressive symptoms (Shih et. al. 2023). However, it should be noted that the current evidence is largely based on mild-to-moderate depression and does not include individuals with severe depression or those at risk of suicide (Shih et. al. 2023),

The role of mental health nurses in these services is important. It has been reported that telehealth care provided by nurses via telephone in primary care is considered an additional component of depression treatment (Hunkeler et al.,2000). Roles that nurses can assume in areas such as assessment, psychoeducation, follow-up, counseling, and care coordination appear to be developable within the framework of clinical responsibilities in mental health nursing.

In this regard, the following recommendations can be made. Nurses' competencies in digital health, telepsychiatry, crisis management, and ethical issues should be developed through both undergraduate education and postgraduate training programs. In the planning and implementation of telepsychiatric services, issues such as patient privacy, data security, informed consent, and patient safety must be addressed as top priorities. To prevent digital inequities from exacerbating barriers to care, alternative solutions should be planned for individuals with limited access to devices and internet connectivity. The limitations of remote care for high-risk patients should be clearly defined, and safety planning should become a standard practice.

In the future, there is a need for well-designed research that evaluates nurse-led telepsychiatry programs and directly measures nursing outcomes. In conclusion, telepsychiatry should be viewed not as an alternative to in-person care, but as a complementary approach for appropriate patient groups when necessary clinical safety measures are in place.

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INVESTIGATION OF THE EFFECT OF INSTRUMENT-ASSISTED SOFT TISSUE MOBILIZATION TECHNIQUE AND FOAM ROLLER APPLICATION ON STRENGTH, FLEXIBILITY AND PAIN IN INDIVIDUALS WITH CHRONIC NON-SPECIFIC NECK PAIN: A RANDOMIZED CLINICAL TRIAL

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ABSTRACT

Introduction and Purpose: This study was conducted to investigate the effects of instrument-assisted soft tissue mobilization technique and foam roller application on strength, flexibility and pain in individuals of different ages diagnosed with chronic non-specific neck pain.

Materials and Methods: A total of 60 patients (Instrument-Assisted Soft Tissue Mobilization (n=20), Foam Roller (n=20), Control (n=20)) diagnosed with chronic non-specific neck pain were included in the study. The instrument-assisted soft tissue mobilization technique group or foam roller group received 3 sessions of classical physiotherapy per week for 4 weeks, followed by 2 sessions per week of instrument-assisted soft tissue mobilization or foam roller technique, and the control group received only classical physiotherapy for 5 sessions per week for 4 weeks. Individuals were evaluated for strength, flexibility and pain before treatment, immediately and 1 month after the end of treatment.

Results: Compared to pre-treatment values, all three groups showed an increase in muscle strength and flexibility values, while a decrease in pain values was observed. Within-group evaluations revealed a significant difference in pain values among all three groups ($p<0.05$), while there was no significant difference in flexibility values ($p>0.05$). Inter-group evaluations showed no significant difference in pain and flexibility values among the three groups ($p>0.05$).

Discussion and Conclusion: It was found that instrument-assisted soft tissue mobilization technique and foam roller application reduced pain and increased muscle strength and flexibility values.

Keywords: Neck Pain, Classical Physiotherapy, Flexibility, Foam Roller, Strength.

INTRODUCTION

Neck pain (NP) is a prevalent musculoskeletal issue affecting 50-85% of the global population annually.[1] Over the past two decades, NP cases have risen from 164.3 million to 288.7 million worldwide.[2] In 2015, NP, along with low back pain, ranked as the fourth leading health concern globally. NP is characterized by recurrent or persistent pain that can last a lifetime, causing not only personal issues related to pain, disability, and quality of life but also being associated with national and international socioeconomic problems.[3]

NP is classified into specific and non-specific types. Non-specific NP, also known as mechanical NP, lacks identifiable pathological changes or neurological disorders. If symptoms persist for over three months, it is diagnosed as chronic non-specific neck pain (NCNP).[4] Pain typically localizes in the cervical region from the occipital condyle to C7.[5] Chronic pain diminishes quality of life, reduces work productivity, and incurs high treatment costs.[6]

Instrument-assisted soft tissue mobilization (IASTM) employs rigid tools to manipulate soft tissue and is derived from Cyriax cross-friction massage.[7,8] First studied in 1997, IASTM has gained popularity as an alternative to traditional manual therapy. The movements used during IASTM treatments vary in

direction, force, and shape, similar to massage, thus allowing pressure to be distributed to the underlying tissues.[9] Its instruments, varying in material and design, target musculoskeletal conditions and associated symptoms.[8]

Massage rollers, including foam rollers (FR), effectively reduce fascial adhesions and muscle tension.[10] FR tools stimulate neuromuscular and fascial tissues, utilizing rolling motions to apply pressure, stretch soft tissues, and create friction.[11] These tools come in various sizes and densities, and can be applied using body weight or manual force.[12]

This study aims to evaluate their impact on strength, flexibility, and pain parameters across different age groups with NCNP. According to the data obtained, it is aimed that the technique used will contribute to the treatment of individuals with NCNP and to the literature.

MATERIALS AND METHODS

Participants:

A total of 68 patients diagnosed with non-specific chronic neck pain (NCNP) were initially recruited from Gumushane State Hospital and Gumushane Kelkit State Hospital. Eligible participants were between 18 and 60 years of age and reported a minimum neck pain intensity of 4 points on the Visual Analog Scale (VAS). During the study, eight participants were lost to follow-up: three discontinued because of the COVID-19 pandemic, two were unable to continue due to transportation-related difficulties, one withdrew because of incompatible working hours, and two declined further participation. Consequently, data from 60 participants were included in the final analysis.

All participants underwent assessments of neck muscle strength, flexibility, and pain. Prior to enrollment, each individual was provided with detailed information regarding the study objectives, procedures, and participation requirements. Written informed consent was obtained from all participants before the initiation of the study. The study protocol was reviewed and approved by the Inonu University Health Sciences Non-Interventional Clinical Research Ethics Committee.

Procedures:

Individuals were randomly distributed into groups. Individuals in 3 groups were specified as the control group, the IASTM treatment group and the FR treatment group. The type of study was a randomized controlled experimental study and randomization was achieved using an online random generator (https://www.randomizer.org/).

Groups:

IASTM Treatment Group (N=20): 3 sessions of classical physiotherapy (Hotpack+ Transcutaneous Electrical Nerve Stimulation (TENS)+Ultrasound) per week for 4 weeks along with 2 sessions of IASTM technique application per week.

FR Treatment Group (N=20): 3 sessions of classical physiotherapy (Hotpack+TENS+Ultrasound) per week for 4 weeks along with 2 sessions of FR technique application per week.

Control Group (N=20): Only classical physiotherapy (Hotpack+TENS+Ultrasound) application, 5 sessions a week for 4 weeks.

All patients included in the study were evaluated before treatment. They were then treated for 4 weeks. After 4 weeks of treatment and 4 weeks after the end of treatment (at 2nd month), they were re-evaluated (Patients were evaluated 3 times in total: Pre-Treatment, Post-Treatment (second evaluation immediately after the end of treatment) and at the 2nd month (third evaluation 4 weeks after the end of treatment)). Patients were evaluated for strength, flexibility and pain.

Anamnesis:

Demographic information of the individuals was collected under the name of "Evaluation Form". In the evaluation form, the participants' name-surname, evaluation date, age, occupation, gender, body weight, height and body mass index (BMI) informations were recorded.

Evaluation of Muscle Strength:

Digital muscle dynamometer (Lafayette Hand-Held Dynamometer®) was used to evaluate the muscle strength of individuals. Muscle strength of right-left shoulder elevation, neck flexion, neck extension and right-left neck lateral flexion were measured. Individuals were asked to maintain their positions for 5 seconds during the measurement. Each measurement was taken three times, and the average of these measurements was recorded. The dynamometer was reset after each measurement.[13]

Evaluation of Flexibility:

Tape measure was used to evaluate the flexibility of individuals. Right-left ear-shoulder distance, chin-sternum distance (proximal end) and right-left chin-wall distance were measured. To measure the ear-shoulder distance, individuals were asked to sit on a chair and look towards the other side without any movement in the neck. The distance between the earlobe and the acromion was measured from both the right and left upper extremities. To measure the chin-sternum distance, individuals were asked to sit on a chair and look towards the opposite side so that there was no movement in the neck. The distance between the tip of the chin and the incisura jugularis was measured. In order to measure the chin-wall distance, individuals were asked to stand and lean against the wall, facing the opposite side without any movement in the neck. The distance between the tip of the chin and the wall was measured. Each measurement was taken three times, and the average of these measurements was recorded.[14]

Evaluation of Pain:

Pain intensity was assessed using the Visual Analog Scale (VAS). The VAS consists of a 10-cm horizontal line anchored by two endpoints representing "no pain" (0) and "worst imaginable pain" (10). Participants were instructed to indicate their current level of pain by placing a mark on the line. The distance from the "no pain" anchor to the participant's mark was measured in centimeters and recorded as the pain score, with higher scores reflecting greater pain intensity.[15] Since its introduction in 1974, the VAS has been extensively used as a valid and reliable instrument for pain assessment across a wide range of clinical settings, including postoperative pain evaluation.[16]

RESULTS

The groups were found to be similar in terms of age, body weight, height and BMI ($p>0.05$).

When the muscle strength values of all 3 groups were compared in the intra-group evaluation, it was found that all groups were similar in terms of right-left shoulder elevation, neck flexion, neck extension, neck extension and right-left neck lateral flexion values ($p>0.05$), except for the neck flexion and neck extension values in the IASTM treatment group and the neck flexion value in the FR treatment group **($p<0.05$)**.

Compared to the pre-treatment period, it was observed that there was an increase in muscle strength values in all 3 groups, except for the left shoulder elevation, neck flexion and right-left neck lateral flexion values in the control group. This increase in muscle strength values was highest in the right-left shoulder elevation values at the end of the treatment in the FR treatment group, while the highest at the end of the second month occurred in the IASTM treatment group. Both after treatment and at the end of the second month, the highest increase in neck flexion, neck extension and left neck lateral flexion values occurred in the IASTM treatment group.

When the flexibility values of all 3 groups were compared in the intra-group evaluation, it was found that all groups were similar ($p>0.05$), except for the right chin-wall distance value in the IASTM treatment group **($p<0.05$).**

Compared to the pre-treatment period, it was observed that there was an increase in flexibility values in all 3 groups, except for the right-left ear-shoulder distance in the control group and the chin-sternum distance and right-left chin-wall distances values in the IASTM treatment group. This increase in flexibility values was highest in the chin-sternum distance values at the end of the treatment in the control group, while the highest at the end of the second month occurred in the FR treatment group. Both after treatment and at the end of the second month, the highest increase in right-left ear-shoulder

distance values occurred in the FR treatment group, and the highest increase in right-left chin-wall distance values occurred in the control group.

When the VAS values in the IASTM treatment group, FR treatment group and control group were compared in the intra-group evaluation a decrease was observed in the pain values of all 3 groups **($p<0.05$)**. This decrease in VAS values was highest at the end of the treatment in the IASTM treatment group, while the highest at the end of the second month occurred in the control group.

CONCLUSION AND DISCUSSION

In this study, which examined the effect of IASTM technique, FR application and classical physiotherapy application on strength, flexibility and pain in individuals with NCNP, it was found that after four weeks of treatment and at the 2nd month control evaluation, it was observed that there was an increase in the muscle strength values of all 3 groups, except for the left shoulder elevation, neck flexion and right-left neck lateral flexion values of the control group, an increase in the flexibility values of all 3 groups, except for the right-left ear-shoulder distance of the control group and the jaw-sternum distance and right-left jaw-wall distance values of the IASTM treatment group and a decrease in the pain values of all 3 groups.

Due to poor vascularity, prolonged or abnormal stress on soft tissues often leads to a lack of inflammatory response, which can result in disorganization and weakening of the soft tissue matrix.[17] IASTM is thought to induce local inflammation, increase fibroblast production, and promote the healing of injured tissue.[8] Additionally, controlled load on the muscle-tendon structure helps restore tensile strength. Stretching soft tissue and restoring normal joint ROM further stimulates muscle contraction.[18] According to Bradley et al., stretching the joints and adjacent soft tissues may increase proprioceptive stimulation and optimize nerve root responsiveness, thereby enhancing overall muscle performance.[19]

IASTM applications facilitate the breakdown of scar tissue, reduce myofascial adhesions, and improve biomechanical function. Research on animal models has shown that IASTM increases fibroblast activity, collagen synthesis, and tendon healing.[9] Research on mouse models has shown that instrumental massage can significantly increase ligament strength and promote healing.[20] Although human studies remain limited, IASTM is thought to reduce scar tissue accumulation, improve nutrient exchange in muscles, and ultimately enhance contraction potential.[21]

The effect of FR application on muscle strength Research suggests that FR enhances moderate muscle compliance, possibly due to improved balance between the viscous and elastic properties of fascia and increased muscle temperature from rolling friction. These adaptations enhance the ability of the muscle-tendinous unit to store and produce elastic energy, thereby improving muscle power output.[22]

Systematic reviews have demonstrated the positive effects of FR on post-exercise recovery and muscle performance.[11,23] A meta-analysis highlighted immediate improvements in sprint performance following FR. These findings suggest that FR facilitates neuromuscular function and enhances power output.[11]

The results demonstrated that IASTM and FR applications improved muscle strength and flexibility while reducing pain after 4 weeks of treatment and at the 2-month assessment.These findings suggest that IASTM and FR may benefit individuals with NCNP by enhancing musculoskeletal function and pain modulation. Further research is needed to examine the long-term effects of these techniques on strength, flexibility, and pain.

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INVESTIGATION OF THE EFFECT OF INSTRUMENT-ASSISTED SOFT TISSUE MOBILIZATION TECHNIQUE AND FOAM ROLLER APPLICATION ON FUNCTIONAL STATUS, RANGE OF MOTION AND QUALITY OF LIFE IN INDIVIDUALS WITH CHRONIC NON-SPECIFIC NECK PAIN: A RANDOMIZED CLINICAL TRIAL

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ABSTRACT

Introduction and Purpose: This study was conducted to investigate the effects of instrument-assisted soft tissue mobilization technique and foam roller application on functional status, cervical range of motion and quality of life in individuals of different ages diagnosed with chronic non-specific neck pain.

Materials and Methods: A total of 60 patients (Instrument-Assisted Soft Tissue Mobilization (n=20), Foam Roller (n=20), Control (n=20)) diagnosed with chronic non-specific neck pain were included in the study. The instrument-assisted soft tissue mobilization technique group or foam roller group received 3 sessions of classical physiotherapy per week for 4 weeks, followed by 2 sessions per week of instrument-assisted soft tissue mobilization or foam roller technique, and the control group received only classical physiotherapy for 5 sessions per week for 4 weeks. Individuals were evaluated for strength, flexibility and pain before treatment, immediately and 1 month after the end of treatment.

Results: Compared to pre-treatment values, all three groups showed an increase in Range of Motion values, while a decrease in Neck Disability Index and Nottingham Health Profile values was observed. When the Neck Disability Index scores of the three groups were compared, a significant decrease in functional disability was observed in all groups ($p<0.05$). In the between-group analysis of Range of Motion, values of the three groups were comparable ($p>0.05$). In the between-group analysis of Nottingham Health Profile, no significant differences were found among the three groups ($p>0.05$).

Discussion and Conclusion: The study found that instrument-assisted soft tissue mobilization techniques and foam roller application reduced Neck Disability Index and Nottingham Health Profile values, while increasing Range of Motion values.

Key Words: Chronic Neck Pain; Physiotherapy; Functional Status; Range of Motion; Instrument-Assisted

INTRODUCTION

Neck pain (NP) represents a common musculoskeletal condition with a high lifetime prevalence, affecting nearly half to more than four-fifths of the general population at some point in their lives.[1] Epidemiological data indicate a considerable rise in the global burden of NP over the last two decades, with the estimated number of affected individuals increasing from 164.3 million to 288.7 million.[2] According to findings from the Global Burden of Disease Study, NP, along with low back pain, was identified as the fourth major contributor to disability worldwide in 2015. NP is characterized by recurrent or persistent symptoms that may persist throughout an individual's lifetime. Beyond pain itself, the condition can impair physical function, alter pain perception, and reduce quality of life. It also represents a substantial socioeconomic challenge by increasing healthcare utilization and contributing to productivity loss.[3]

Neck pain is generally categorized as either specific or non-specific according to its underlying cause. Non-specific neck pain (NCNP), commonly referred to as mechanical neck pain, describes pain that cannot be attributed to a specific structural abnormality or neurological disorder. When symptoms continue for more than three months, the condition is classified as chronic NCNP.[4] Pain is typically confined to the cervical region, extending from the occipital condyles to the spinous process of the

seventh cervical vertebra (C7).[5] Persistent symptoms have been associated with diminished quality of life, reduced occupational performance, and increased healthcare costs.[6]

The development of NP is influenced by multiple interacting biological, psychological, and social factors, reflecting the biopsychosocial nature of the condition. As a result, effective management requires an individualized approach that considers both the type of neck pain and the duration of symptoms.[7] Current clinical practice guidelines advocate a range of treatment options, including conservative care, pharmacological therapies, and surgical intervention when clinically indicated.[4] Owing to their pain-relieving and anti-inflammatory activities, non-steroidal anti-inflammatory drugs (NSAIDs) are frequently utilized as part of pharmacological management strategies.[8] Nevertheless, growing concerns regarding their long-term effectiveness and the risk of adverse events, such as gastrointestinal, renal, and cardiovascular complications, have encouraged greater emphasis on non-pharmacological approaches. These include therapeutic exercise, therapeutic ultrasound, electrical stimulation, and manual therapy, all of which are frequently incorporated into the conservative management of chronic neck pain.[9]

Manual therapy encompasses a variety of techniques designed to assess and treat soft tissue dysfunctions, including approaches performed with specialized instruments.[10] Instrument-assisted soft tissue mobilization (IASTM) is a manual therapy technique that utilizes rigid instruments to mobilize soft tissues and is conceptually derived from Cyriax cross-friction massage.[11,12] Since its introduction into the scientific literature in 1997, IASTM has gained increasing popularity as an adjunct or alternative to conventional manual therapy. During treatment, instruments are applied using movements that vary in direction, pressure, and stroke pattern, facilitating mechanical stimulation of the underlying soft tissues while distributing applied forces more effectively than manual techniques alone.[13] A wide range of IASTM instruments, differing in material composition and design, have been developed for the management of musculoskeletal disorders and related symptoms.[12]

Massage rollers, particularly foam rollers (FRs), have also emerged as widely used self-myofascial release tools for reducing fascial adhesions and muscle stiffness.[14] Foam rollers provide mechanical stimulation to the myofascial and neuromuscular systems through rolling movements that apply compressive pressure, stretch soft tissues, and generate friction.[15] Available in various sizes, shapes, and densities, these devices can be applied using either an individual's body weight or external manual force.[16]

Therefore, the present study aimed to investigate the impact of IASTM and foam rolling interventions on functional outcomes, cervical mobility, and quality of life among individuals with chronic NCNP across various age categories. It was anticipated that both interventions would lead to favorable clinical improvements and further strengthen the evidence supporting their application as conservative treatment strategies for chronic NCNP, while also expanding the current body of literature.

MATERIALS AND METHODS

Participants:

A total of 68 participants with a diagnosis of NCNP were enrolled in the study from Gümüşhane State Hospital and Gümüşhane Kelkit State Hospital. Individuals were considered eligible if they were aged between 18 and 60 years and had a minimum pain intensity score of 4 on the Visual Analog Scale (VAS) at the time of enrollment.

Of the 68 participants initially enrolled, eight did not complete the study and were excluded from the final analysis. Three participants were unable to continue because of restrictions associated with the COVID-19 pandemic, two experienced transportation-related difficulties, one withdrew due to work schedule conflicts, and two chose to discontinue participation voluntarily. Consequently, data from 60 participants were included in the final analyses. All participants underwent evaluations of neck muscle strength, flexibility, and pain.

Prior to enrollment, each participant was informed about the purpose of the study, the assessment procedures, the potential benefits, and the expected requirements of participation. Written consent was

secured from all participants prior to their involvement in the study protocol and related assessments. The study protocol received ethical approval from the Inonu University Health Sciences Non-Interventional Clinical Research Ethics Committee prior to its implementation.

Study Design and Randomization:

This research was conducted as a randomized controlled trial. After completion of the initial evaluations, participants were assigned randomly to one of three study arms through an online randomization tool (https://www.randomizer.org/). The intervention groups included an IASTM group and a FR group, while the third group served as the control group.

Interventions:

IASTM Group (n = 20)

Participants received conventional physiotherapy three times per week for four weeks, consisting of hot pack application, Transcutaneous Electrical Nerve Stimulation (TENS), and therapeutic ultrasound. In addition, they received IASTM treatment twice weekly throughout the intervention period.

FR Group (n = 20)

Participants received the same conventional physiotherapy program (hot pack, TENS, and therapeutic ultrasound) three times per week for four weeks, together with FR treatment administered twice weekly.

Control Group (n = 20)

Participants received conventional physiotherapy only, including hot pack application, TENS, and therapeutic ultrasound, five sessions per week for four consecutive weeks.

Outcome Assessment:

Outcome measures were assessed at three predefined time points: prior to the initiation of the intervention (baseline), immediately following the completion of the four-week treatment period (post-intervention), and four weeks after the end of the intervention (follow-up). At each evaluation, participants underwent assessments of functional status, cervical range of motion (CROM), and quality of life.

Demographic Assessment

Baseline demographic and anthropometric information was obtained using a standardized assessment form. The recorded variables included participants' age, sex, occupation, body weight, height, body mass index (BMI), and the date on which the assessment was performed.

Evaluation of Functional Status:

Functional disability related to neck pain was evaluated using the Neck Disability Index (NDI). This self-reported questionnaire comprises 10 items that assess the impact of neck pain on daily activities, including pain intensity, personal care, lifting, reading, headaches, concentration, work, driving, sleep, and recreational activities. Each item is scored on a six-point scale from 0 to 5, where higher scores indicate greater disability (0 = no disability; 5 = complete disability). The overall NDI score ranges from 0 to 50, with higher total scores reflecting a greater degree of functional impairment.[17]

Evaluation of Range of Motion:

Cervical range of motion (CROM) was evaluated using a 360° universal goniometer. During the assessment, participants were seated comfortably on a chair in an upright position with their gaze directed forward. They were instructed to avoid compensatory movements of the trunk throughout all measurements.

The assessment included cervical flexion, extension, right and left lateral flexion, and right and left rotation. For flexion and extension measurements, the goniometer axis was positioned over the acromion. The stationary arm was kept parallel to the ground, whereas the movable arm was aligned with the external auditory meatus. To assess lateral flexion, the axis of the goniometer was placed over the spinous process of the seventh cervical vertebra (C7). The stationary arm remained parallel to the

floor, and the movable arm was aligned along the cervical spinous processes. Cervical rotation was measured with participants holding a rod between their teeth to provide a consistent reference. In this position, the goniometer axis was centered on the head, the stationary arm was maintained parallel to the floor, and the movable arm was aligned with the rod.

Each cervical movement was measured three times, and the average value of the three trials was calculated and used for statistical analysis.[18]

Evaluation of Quality of Life:

Quality of life was assessed using the Nottingham Health Profile (NHP), a generic patient-reported outcome measure that evaluates perceived health across physical, emotional, and social dimensions. The NHP includes 38 dichotomous ("yes"/"no") items organized into six subscales: pain (8 items), emotional reactions (9 items), sleep (5 items), social isolation (5 items), physical mobility (8 items), and energy level (3 items). Responses are weighted according to the scoring system, and each subscale is calculated independently to yield a score between 0 and 100. Higher scores reflect poorer perceived health and a lower quality of life.[19]

RESULTS

When the NDI scores of the three groups were compared, a significant decrease in functional disability was observed in all groups **($p<0.05$).** Furthermore, significant differences were found in all between-group comparisons of NDI scores **($p<0.05$),** except for the comparisons between the IASTM treatment group and the FR treatment group, the IASTM treatment group and the control group, and the FR treatment group and the control group ($p>0.05$). A significant reduction in NDI scores was observed between the IASTM treatment group and the control group **($p<0.05$),** with the decrease being greater in the control group than in the IASTM treatment group. In addition, compared with the pre-treatment values, NDI scores decreased in all three groups, with the greatest reduction observed in the control group.

In the between-group analysis of ROM, values of the IASTM treatment group, FR treatment group, and control group were comparable ($p>0.05$). However, a significant increase in ROM was observed in both the IASTM treatment group and the control group **($p<0.05$),** with the increase being greater in the IASTM treatment group than in the control group. Moreover, compared with baseline, ROM values increased in all three groups, with the greatest improvement observed in the IASTM treatment group.

In the between-group analysis of NHP, no significant differences were found among the IASTM treatment group, FR treatment group, and control group ($p>0.05$). However, a significant increase in NHP values was observed between the FR treatment group and the control group **($p<0.05$),** with the increase being greater in the control group than in the FR treatment group. Likewise, a significant increase in NHP values was found between the IASTM treatment group and the control group **($p<0.05$),** with the increase being greater in the control group than in the IASTM treatment group.

CONCLUSION AND DISCUSSION

In this study investigating the effects of IASTM, FR, and conventional physiotherapy on functional status, CROM, and quality of life in individuals with chronic NCNP, reductions in NDI and NHP scores were observed in all three groups after the 4-week intervention and at the 2-month follow-up assessment. Furthermore, all groups demonstrated improvements in CROM values.

Adequate cervical range of motion is essential for optimal musculoskeletal function. Insufficient CROM, together with reduced flexibility, may predispose individuals to overuse syndromes and increase their susceptibility to acute injuries.[20] The maintenance of normal CROM is fundamental to functional neck performance and has a key role in preventive strategies, rehabilitation outcomes, and overall physical efficiency.[21]

IASTM targets soft tissue restrictions, including myofascial adhesions and scar tissue, with the goal of enhancing tissue mobility, thereby improving CROM and functional outcomes.[22] Previous studies have

demonstrated that IASTM improves soft tissue function and increases CROM in various populations.[23] The observed improvements in CROM may be attributed to the ability of IASTM to reduce joint restrictions, increase soft tissue extensibility, and generate friction-induced heat within the treated tissues. This increase in tissue temperature decreases tissue viscosity, thereby enhancing tissue pliability. From a physiological perspective, reduced tissue viscosity facilitates greater joint range of motion.[24]

Numerous studies have reported that FR can acutely increase joint range of motion. These improvements have been attributed to reductions in muscle stiffness[25] and/or increased stretch tolerance.[26] The repetitive rolling motion during FR increases intramuscular tissue temperature and local blood flow, both of which enhance the viscoelastic properties of muscle tissue. Furthermore, the frictional and tensile forces applied to the muscle, skin, and fascia may alter fluid viscosity within the tissues.[25] Consequently, the tissues become less resistant to stretching, resulting in increased range of motion. Another proposed mechanism suggests that FR alters the thixotropic properties of the fascia. Thixotropy, characterized by reduced viscosity, may decrease myofascial restrictions through changes in tissue fluid dynamics and cellular responses. When exposed to mechanical stress or heat, fascia becomes less rigid and assumes a more gel-like state. Moreover, the combined effects of body weight, mechanical loading, and FR may further promote this gel-like fascial state, thereby enhancing soft tissue compliance and increasing joint range of motion.[27]

The findings of the present study indicate that both IASTM and FR increased CROM in individuals with CNSNP and were associated with significant improvements in functional status and quality of life. Overall, the findings indicate that each of the three treatment approaches (IASTM, FR, and the conventional exercise program) contributed to improvements in CROM, functional capacity, and quality of life. Based on these results, both IASTM and FR appear to be valuable adjuncts to conventional rehabilitation, offering additional therapeutic options for the management of individuals with chronic non-specific neck pain.

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BEHAVIORAL NATURAL RESOURCE ECONOMICS: A BIBLIOMETRIC ANALYSIS OF CONSUMER CHOICE AND NUDGING IN NON-RENEWABLE RESOURCE CONSUMPTION

DAVRANIŞSAL DOĞAL KAYNAK EKONOMİSİ: YENİLENEMEZ KAYNAK TÜKETİMİNDE TÜKETİCİ TERCİHİ VE DÜRTME ÜZERİNE BİR BİBLİYOMETRİK ANALİZ

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ÖZET

Giriş ve Amaç: Yenilenemeyen doğal kaynakların sürdürülebilir yönetimi ve nesiller arası optimal tahsisi, geleneksel olarak arz yönlü politikalar çerçevesinde değerlendirilmektedir. Bununla birlikte, fosil yakıtların kıtlığıyla mücadele edilmesi, mikro düzeyde talep yönlü mekanizmaların ve bireysel tüketici tercihlerinin dinamik biçimde yönetilmesini gerektirmektedir. Bu çalışma, "Davranışsal Doğal Kaynaklar Ekonomisi" çerçevesinde ortaya çıkan bu yükselen alt disiplinin entelektüel yapısını ve kavramsal gelişimini haritalandırmayı amaçlamaktadır.

Materyal ve Yöntem: Bu amaç doğrultusunda, 2026 yılı hariç tutularak, Web of Science (WoS) veri tabanında Ekonomi, İşletme, Yönetim, Davranış Bilimleri, Çevre Bilimleri ve Tarım Ekonomisi Politikası kategorilerinde indekslenen 178 hakemli yayın, bibliyometrik analiz yöntemi kullanılarak incelenmiştir. Araştırma örneklemi; yıllık yayın eğilimleri, en üretken yazarlar, ülkeler, atıf ağları ve ortak kelime analizi (co-occurrence) açısından R tabanlı Bibliometrix (Biblioshiny) yazılımı kullanılarak analiz edilmiş ve haritalandırılmıştır.

Bulgular: Analiz sonuçlarının, hanehalklarının enerji tüketimi ve karbon emisyonlarını azaltmaya yönelik kararlarında sınırlı rasyonellik, sosyal normlar ve kayıptan kaçınma gibi mikroekonomik davranışsal faktörlerin öne çıkan rolünü ve zaman içerisindeki gelişim eğilimlerini ortaya koyması beklenmektedir. Bibliyometrik haritalamanın ise tüketici tercihleri ve davranışsal müdahaleler üzerine yoğunlaşan belirgin araştırma kümelerini ortaya koyması beklenmektedir.

Tartışma ve Sonuç: Kaynakların korunmasında davranışsal müdahalelerin rolüne ilişkin bütüncül bir değerlendirme sunan bu çalışma, mikroekonomi literatürüne teorik katkı sağlamaktadır. Sonuç olarak, geleneksel mikroekonominin katı rasyonellik varsayımlarını genişleten davranışsal ekonomi yaklaşımları, "dürtme" (*nudging*) gibi araçlar aracılığıyla yenilenemeyen doğal kaynak tüketiminin azaltılmasına yönelik etkili çözümler sunmakta ve talep yönlü çevre politikalarının tasarlanmasında politika yapıcılara önemli bir yol gösterici çerçeve sağlamaktadır.

Anahtar Kelimeler: Yenilenemeyen Kaynaklar; Tüketici Davranışı; Davranışsal Ekonomi; Dürtme; Bibliyometrik Analiz

ABSTRACT

Introduction and Purpose: The sustainable management and intergenerational optimal allocation of non-renewable natural resources are traditionally evaluated within supply-side policies. However, combating the scarcity of fossil fuels requires the dynamic management of demand-side mechanisms and individual consumer preferences at the micro-level. This study aims to map the intellectual structure and conceptual evolution of this emerging sub-discipline within the framework of "Behavioral Natural Resource Economics."

Materials and Methods: For this purpose, 178 qualified peer-reviewed articles indexed in the Web of Science (WoS) database under the categories of Economics, Business, Management, Behavioral Sciences, Environmental Studies, and Agricultural Economic Policy—excluding the year 2026—were analyzed using the bibliometric analysis method. The research sample was analyzed and mapped using the R-based Bibliometrix (Biblioshiny) software in terms of annual publication trends, most productive authors, countries, citation networks, and co-word analysis (co-occurrence).

Results: The analysis results are expected to demonstrate the prominence and temporal trends of microeconomic behavioral factors such as bounded rationality, social norms, and loss aversion in household energy consumption and carbon emission reduction decisions. The bibliometric mapping is anticipated to reveal distinct clusters focusing on consumer choice and behavioral interventions.

Discussion and Conclusion: By providing a holistic overview of the role of behavioral interventions in resource conservation, this study contributes theoretically to the microeconomics literature. In conclusion, behavioral economics approaches, which extend the strict rationality assumptions of traditional microeconomics, offer effective solutions through tools such as "nudging" to reduce non-renewable resource consumption and serve as a crucial guideline for demand-side environmental policymakers.

Key Words: Non-Renewable Resources; Consumer Behavior; Behavioral Economics; Nudging; Bibliometric Analysis

GİRİŞ

Dünya enerji sisteminin gelişiminde fosil yakıtlar merkezi bir role sahiptir. Ancak enerji sistemlerinin sürdürülebilirliği, enerji üretim ve tüketiminin iklim değişikliği ve diğer çevresel dışsallıklarla olan ilişkisi fosil yakıtların kullanımını bir yandan önemli bir politika gündemi haline getirirken, bir yandan da dikkat çekici bir araştırma alanı haline dönüştürmüştür. Enerji sisteminin sürdürülebilirlik ve küresel sorunlar göz önüne alınmak suretiyle dönüşümü, yalnızca enerji kaynaklarının varlığı, teknolojik gelişmeler ve arz koşulları tarafından değil, aynı zamanda enerji talebi ve sosyoekonomik koşullar tarafından da şekillenmektedir (Bauer vd., 2017). Bu durum, enerji ve fosil yakıt tüketiminin yalnızca üretim, fiyat ve gelir değişkenleri üzerinden değil, tüketicilerin tercihleri ve davranışları üzerinden de değerlendirilmesini gerektirmektedir.

Yenilenemeyen kaynakların kullanımıyla ortaya çıkan çevresel sonuçlar üzerinde, özellikle tüketici davranışının etkisi belirgin olmaktadır. Çevre duyarlılığı daha yüksek olan toplumlarda, toplu taşımayı tercih etme, hibrit araç satın alma, daha düşük benzin talebi gibi göstergeler ortaya çıkarken, bu tür bulgular, çevresel tutumların yalnızca bireylerin söylemsel tercihleriyle sınırlı olmadığını, fosil yakıt tüketimi gibi doğrudan kaynak kullanımını içeren ekonomik davranışlara da yansıyabileceğini ortaya koymaktadır (Kahn, 2007). Benzer biçimde, bireysel davranışların farklı ölçüm biçimlerinin yanında davranışsal göstergeler de dahil edilerek incelenmesinin, çevre yanlısı davranışların araştırılması sürecinde daha etkin sonuçlar ürettiği ifade edilirken (Lange ve Dewitte, 2019), çevre yanlısı davranışın anlaşılması, öngörülmesi ve teşvik edilmesi açısından geçerli ve güvenilir ölçümlerin önemine dikkat çekmektedir.

Bu gelişmeler geleneksel neoklasik modelin temel varsayımlarından olan rasyonel karar verici varsayımının esnetilmesini gerekli kılmış, bu varsayımın ötesine geçilerek davranışsal yaklaşımın çevre ve doğal kaynaklar alanı üzerinde etkili olacağı bir zemin hazırlamıştır. Buna göre davranışsal ekonomi bireylerin karar verirken bilişsel sınırlılıklarının olduğunu kabul ederken, bu karar süreçlerinde sezgisel değerlendirmeler yapabildiklerini kabul etmekte ve referans noktaları, sosyal etkiler ve sistematik davranışsal sapmalardan etkilenebileceklerini ortaya koymaktadır (Kahneman & Tversky, 1979). Dolayısıyla bu yeni anlayışta davranışsal faktörler, çevre ve doğal kaynaklar ekonomisi bağlamında modern bir yaklaşım getirmekte; bireylerin çevresel kararlarının yalnızca fiyat ve gelir gibi geleneksel ekonomik değişkenlerle açıklanamayacağını ve davranışsal faktörlerin kaynak kullanımının anlaşılmasında tamamlayıcı bir çerçeve sunduğunu ileri sürmektedir (Shogren & Taylor, 2008; Croson & Treich, 2014).

Davranışsal yaklaşımın politika boyutundaki önemli uzantılarından biri, bireylerin seçim özgürlüğünü ortadan kaldırmadan seçim ortamının düzenlenmesi yoluyla davranışların yönlendirilebileceğini savunan nudge yaklaşımıdır (Thaler & Sunstein, 2008). Enerji tüketimi üzerinden düşünüldüğünde, sosyal normlar, geri bildirim, bilgilendirme, hedef belirleme ve benzeri fiyat dışı müdahaleler, bireylerin enerji tasarrufu davranışlarını etkileyebilecek araçlar olarak ele alınmaktadır (Andor & Fels, 2018). Belirlenen hedeflere ulaşabilmek adına düzenlenen bu tür müdahalelerin yalnızca davranış üzerindeki etkilerinin değil, aynı zamanda tüketici refahı ve politika maliyetleri açısından sonuçlarının da değerlendirilmesi gerektiği ifade edilmektedir (Allcott & Kessler, 2019).

Davranışsal yaklaşımın getirdiği yenilikler, tüketici teorisi, çevre politikaları, enerji talebi ve nudge yaklaşımı kesişiminde teorik, ampirik ve politika boyutlarıyla giderek genişleyen bir araştırma alanı ortaya çıkarmıştır. Söz konusu literatürün farklı disiplinler ve araştırma gelenekleri içinde gelişmesi, alanın entelektüel yapısının bütüncül bir yaklaşımla ele alınmasını gerektirmektedir. Bu amaçla çalışmada kavramsal temaları sistematik bir biçimde ele alan ve bilimsel üretimin gelişimini çeşitli bağlantılar üzerinden nicel yöntemlerle değerlendiren bibliometrik analiz kullanılmıştır.

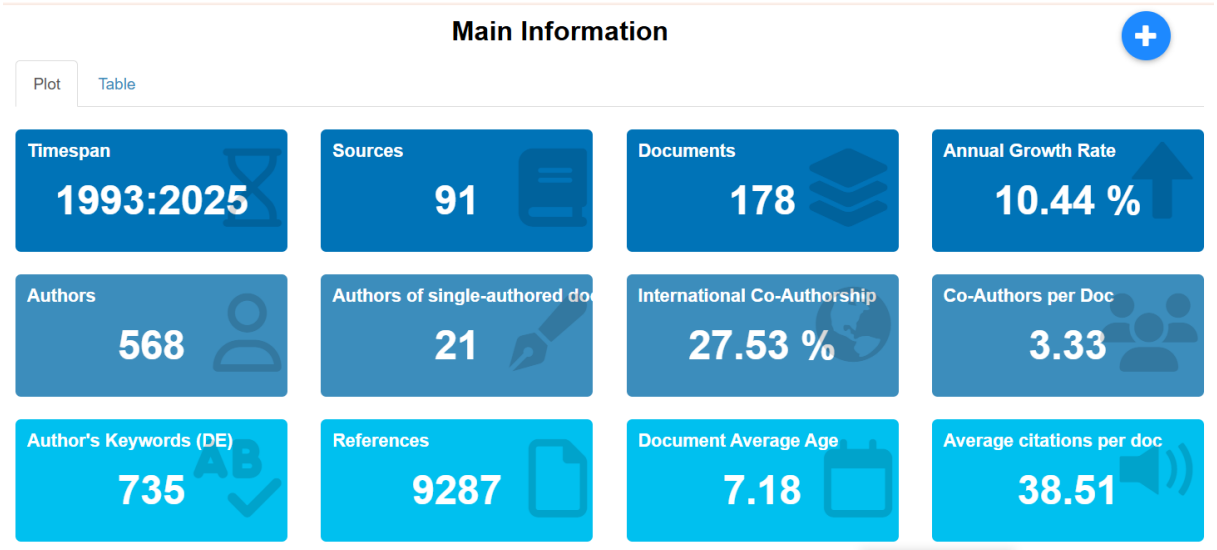
Bu çalışma, Web of Science veri tabanında gerçekleştirilen tarama ve filtreleme süreci sonucunda belirlenen 178 yayın üzerinden, yenilenemeyen doğal kaynakların tüketimi bağlamında davranışsal ekonomi literatürünün entelektüel yapısını ve kavramsal gelişimini bibliyometrik yöntemlerle ortaya koymayı amaçlamaktadır. Çalışma özellikle fosil yakıtlar ve karbon ayak izi ile nudge, davranışsal ekonomi, tüketici tercihi ve tüketici davranışı kavramlarının kesişiminde oluşan literatüre odaklanmaktadır.

YÖNTEM

Bu çalışmanın yöntemi bibliometrik analizdir. Bu analiz yöntemi belirli bir araştırma alanını temalar, yazarlar, kaynaklar, eş oluşum ağları gibi çeşitli kriterler üzerinden inceleyerek, o araştırma alanı ile ilgili bilimsel ilişkilerin çok boyutlu bir biçimde ortaya konulmasını sağlamaktadır (Aria & Cuccurullo, 2017). Kütüphanelerden başlayarak çeşitli dijital ortamlara kadar çok farklı veri kaynakları üzerinden gerçekleştirilebilen bibliometrik analiz, bu çalışmada veri sağlamanın kolaylığı nedeniyle Web of Science veri tabanı taranarak elde edilen veriler üzerinden gerçekleştirilmiştir. İlk olarak çalışma konusunu kapsayacak tarama kodu belirlenmiştir. ("fossil fuel*" OR "gasoline" OR "natural gas" OR "coal" OR "carbon footprint") AND ("nudge*" OR "behavioral economics" OR "consumer choice*" OR "consumer behavior*") biçiminde hazırlanan tarama kodunun çalıştırılması sonucunda 383 çalışmadan oluşan ham veri setine ulaşılmıştır. Çalışmalar üzerinde doküman kısıtlamasına gidilmiş ve veri seti yalnızca “article ve review article” olacak şekilde daraltılmıştır. Bir sonraki aşamada dil birliğini sağlamak için İngilizce dili dışındaki çalışmalar ayıklanmış ve henüz tamamlanmaması nedeniyle 2026 yılı da analiz dışında bırakılmıştır. Son aşamada kategori kısıtlaması yapılmış, ekonomi başta olmak üzere sosyal bilimler alanına odaklanmak amacıyla “environmental studies, economics, business, management, agricultural economic policy, behavioral science” kategorileri seçilmiştir. Tüm bu filtrelemeler sonucunda 178 makaleden oluşan nihai veri seti elde edilmiştir. Elde edilen veri seti R tabanlı Biblipmetrix ara yüzü ile analiz edilmiş ve çalışma bulgularına ulaşılmıştır.

BULGULAR

Davranışsal doğal kaynaklar ekonomisi çerçevesinde yenilenemeyen kaynakların tüketimine yönelik temel bibliometrik bilgiler Şekil 1’de gösterilmektedir. Çalışmanın temel bilgilerine baktığımızda, 1993 ile 2025 dönemini kapsayan oldukça geniş bir sürede 91 kaynakta yayımlanan 178 makalenin üretildiğini görmekteyiz. 21 çalışmanın tek yazarlı olduğu bu alanda toplamda 568 yazar yayın üretimine katkıda bulunmuştur. Bu durum çok yazarlı çalışmaların büyük çoğunlukta olduğunu göstermektedir. Üretilen makalelerin yıllık büyüme oranı %10,44 olarak gerçekleşmiş ve bu yayınlar ortalama 38,51 gibi yüksek bir düzeyde atıf almıştır. Yazılan makalelerde 735 anahtar kelime ifade edilmiş ve referans listelerinde de 9287 çalışmaya atıf yapılmıştır.

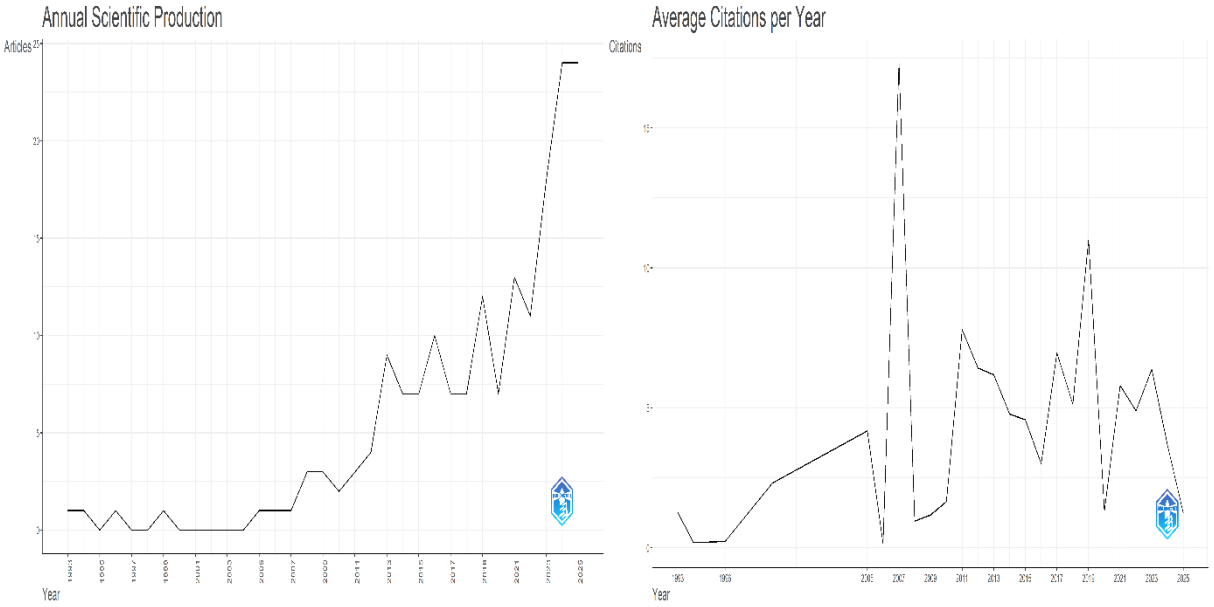


Şekil 1. Çalışmanın temel bilgileri

Şekil 2, verileri itibarıyla birbirini destekleyen iki ayrı analizi göstermektedir. Şeklin sol taraftaki bölümünde odak alanımızdaki makalelerin yıllık üretim miktarı yer alırken, sağ taraftaki bölümünde ise üretilen bu yayınlara ilişkin yıllık ortalama atıf sayıları gösterilmektedir.

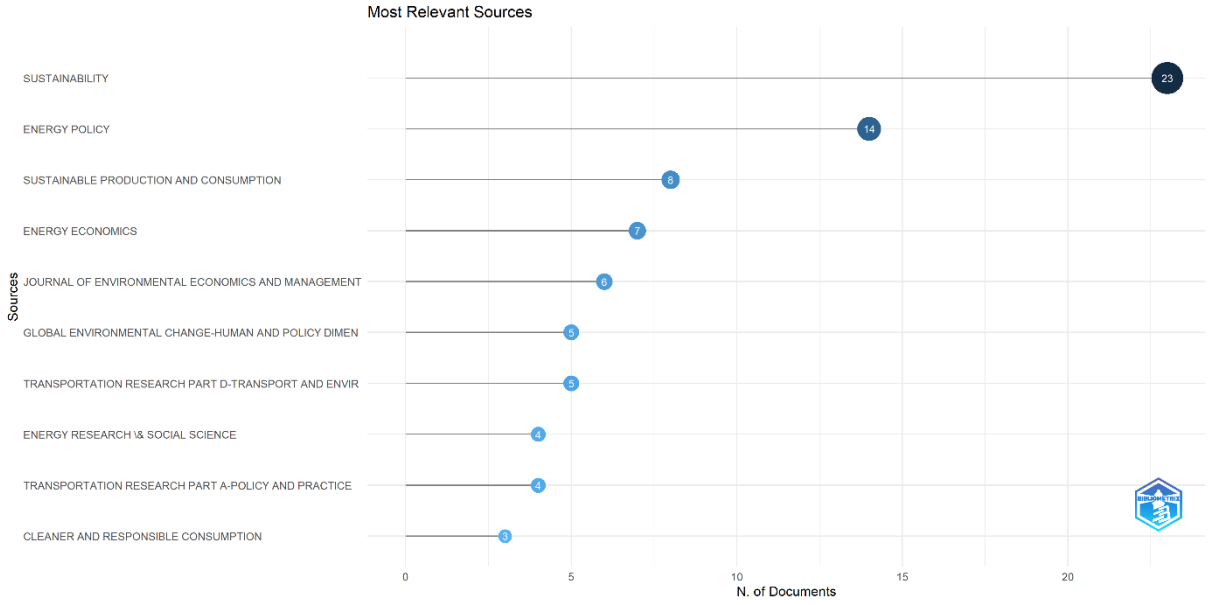
Yıllık bilimsel üretime baktığımızda bu alandaki çalışmaların ilk kez 1993 yılında yayınlandığı görülmektedir. Bu tarihten 2008 yılına kadar 15 yıllık sürecin 8 yılında hiç yayın yapılmazken, diğer 7 yılda 1'er yayın yapılmış ve bu alana yönelik ilgi sönük kalmıştır. İlk kez 2008 yılında 3 makale yazılarak bir yıl içinde birden fazla yayın yapılmıştır. 2013 yılından itibaren bu alanda yayın sayıları yükselmeye başlamış, 2016 yılında 10 makale yazılarak ilk kez iki haneli sayılara ulaşılmıştır. Bu tarihten günümüze kadar bu çalışma alanına yönelik akademik ilgi genellikle artarak devam etmiş ve en yüksek makale sayılarına 24'er çalışma ile 2024 ve 2025 yıllarında ulaşılmıştır.

Yıllık ortalama atıf sayılarına baktığımızda, çalışma alanımızın erken döneminde çalışma sayılarına benzer bir seyrin ortaya çıktığı görülmektedir. Ancak burada farklı olarak 2005 yılında yapılan tek çalışma 4,18 gibi nispeten yüksek bir ortalama atıf sayısını yakalamıştır. Daha sonra 2007 yılında yapılan tek çalışma bu alanda çığır açan bir yayın niteliğindedir. Ve yıllık ortalama 17,30 atıf alarak bu alanda lider konumundadır. 2007 yılında alınan en yüksek ortalama atıf sayısını, 2019 yılındaki 11,01 ve 2011 yılındaki 7,79 düzeyindeki atıf sayıları takip etmektedir.



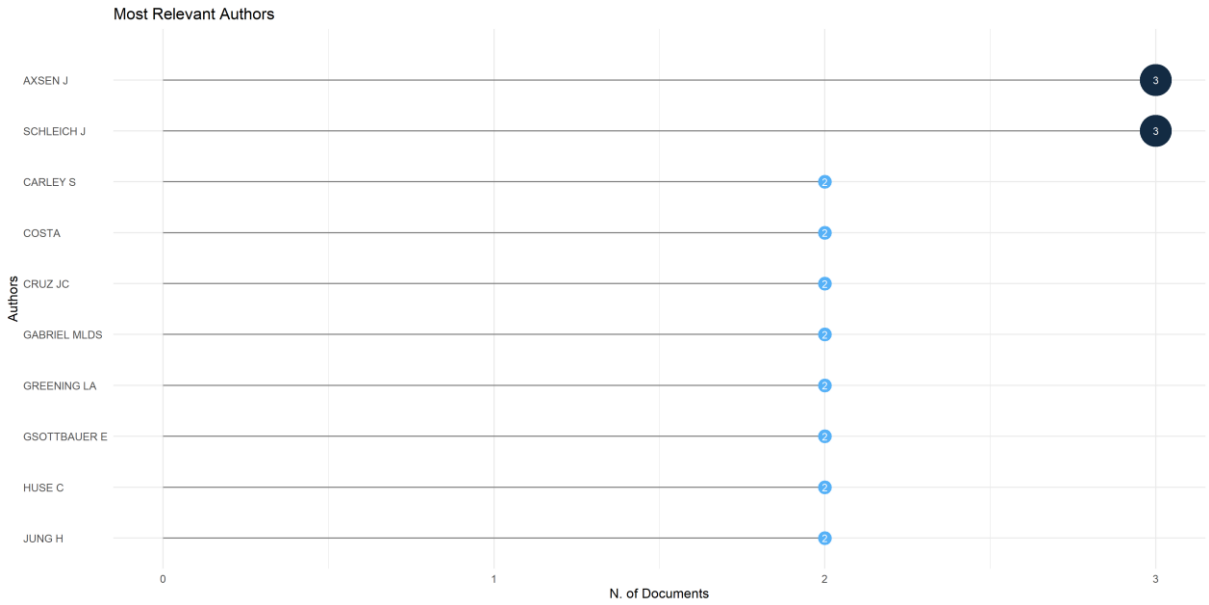
Şekil 2. Yıllık bilimsel üretim ve ortalama atıflar

Şekil 3'te çalışma alanımızın en ilgili kaynakları listelenmektedir. Bu alanda en çok makale yayımlayarak alana yön veren dergilerin başında 23 makalenin yayımlandığı "Sustainability" ve 14 makalenin yayımlandığı "Energy Policy" dergileri bulunmaktadır. Bu dergileri 8 yayınla "Sustainable Production And Consumption", 7 yayınla "Energy Economıcs" ve 6 yayınla "Journal of Environmental Economics And Management" dergileri takip etmektedir.



Şekil 3. Alanın en ilgili kaynakları

Şekil 4 çalışma alanımız kapsamında en çok makale yayımlayan yazarları listelemektedir. Görsele baktığımızda bu alanda çok belirgin bir biçimde öne çıkan bir yazarın bulunmadığı görülmektedir. Buna göre listenin ilk sırasında 3'er makale ile Axsen J., ve Schleich J. yer almaktadır. Listenin devamındaki tüm yazarların ise bu alanda 2 makalesinin bulunduğu görülmektedir.

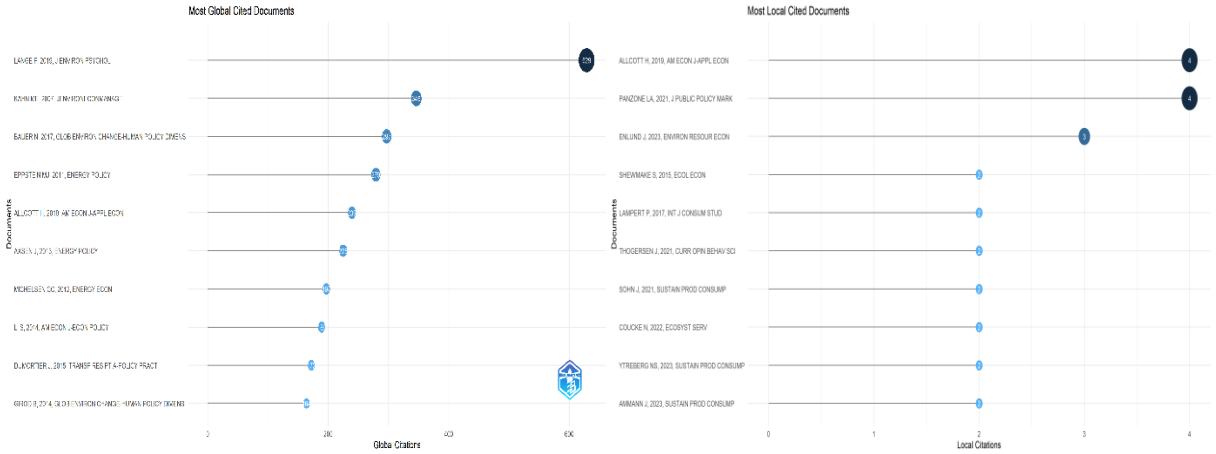


Şekil 4. Çalışma alanının en ilgili yazarları

Şekil 5 Çalışma alanımızda yer alan makalelerden en çok atıf alanların listesini göstermektedir. Şeklin sol bölümünde tüm veri tabanından gelen atıflar üzerinden bir liste sunulurken bunu belirtmek üzere küresel (global) ifadesi kullanılmıştır. Şeklin sağ tarafında ise veri setimiz içindeki makalelerden gelen atıflar üzerinden bir liste sunulmakta ve bunu belirtmek için de yerel (local) ifadesi kullanılmaktadır.

Tüm veri tabanından en çok atıf alan çalışmalar için şeklin sol bölümüne baktığımızda, Lange, F., & Dewitte, S. isimli yazarların 2019 yılında Journal of Environmental Psychology isimli dergide yayımladığı makale 629 atıf alarak birinci sırada yer almaktadır. Kahn M.E. isimli yazarın 2007 yılında Journal of Environmental Economics and Management isimli dergide yayınladığı makale ise 346 atıf alarak ikinci sırada yer almıştır. Bauer vd.'nin 2017 yılında yayımladıkları makale Wos veri tabanının tümünden 297 atıf alırken, Eppstein Mj.'nin 2011 yılında Energy Policy'de yayımlanan makalesi 279 atıf almıştır. Küresel atıf listesinde 200 atfın üstünde yer alan diğer çalışmalardan birisi Allcott H. ve Kessler J.B. tarafından 2019 yılında yayımlanmış ve 239 atıf, Axsen J., tarafından 2013 yılında yayımlanan makale ise 225 atıf almıştır.

Sağ tarafta yer alan yerel atıflar listesine baktığımızda ise, küresel atıf listesinde çok yüksek atıf sayılarına ulaştığını gördüğümüz çalışmalardan yalnızca birinin bu listeye girebildiğini görmekteyiz. Allcott H. ve Kessler J.B.'nin 2019 yılında yayımladıkları makale hem küresel çapta ilk sıralarda yer alarak tüm veri tabanını etkileyen hem de 4 yerel atıf alarak veri setimiz içindeki çalışmalar üzerinde etkili olan bir yayın niteliğindedir. En çok yerel atıf alan çalımalar listesinde 4 atıf alan bir diğer çalışma Panzone vd.'nin 2021 yılındaki makalesidir. Enlund vd.'nin 2023 yılında yayımladıkları makale ise 3 yerel atıf almıştır. Yerel atıf listemizdeki diğer çalışmaların tümü 2 atıf almıştır.



Şekil 5. En çok atıf alan makaleler

Alanın kavramsal çerçevesini görebilmek adına kelime bulutu analizi yapılmıştır. Bunun için Bibliometrix ara yüzünün sunduğu seçenekler arasından "yazar anahtar kelimeleri" tercih edilmiştir. Bunun yanında "behavior" teması "consumer behavior" temasına, "consumer" teması ise "consumer choice" temasına dahil edilerek benzer kavramlar bir araya getirilmiştir.

Şekil 6 yukarıdaki kriterler altında gerçekleştirilen kelime bulutu analizinin sonuçlarını göstermektedir. Analiz sonuçlarına göre "consumer behavior" 39, "carbon footprint" 24, "consumer choice" 21, "climate change" 12 ve "sustainability" teması 11 frekansla bu alanda en çok kullanılan ve alanın tematik yapısını simgeleyen kavramlar olarak öne çıkmaktadır.



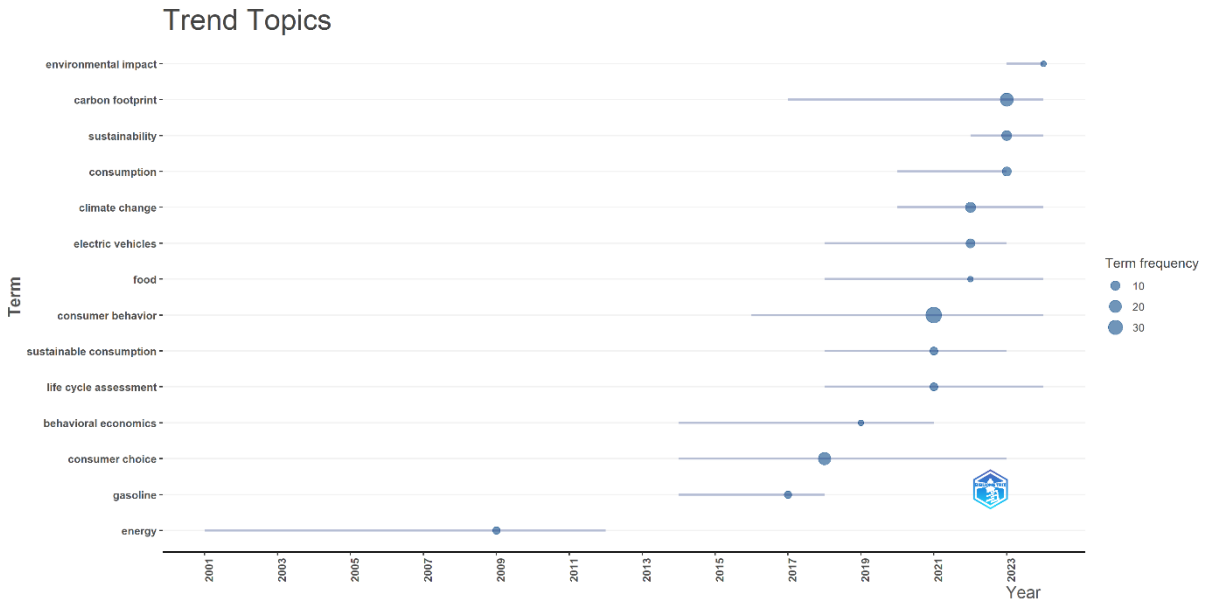
Şekil 6. Kelime bulutu

Kelime bulutu analizinde sık kullanım kriteri üzerinden belirlenen tematik yapı, zaman boyutu da göz önüne alındığında dinamik bir bakış açısıyla incelenebilmektedir. Alanın zaman boyutu içerisinde yaşadığı tematik dönüşüm trend kavramlar analizi ile görülebilmektedir. Trend kavramlar analizinde de yazar anahtar kelimeleri kriter olarak tercih edilmiş ve yine eş anlamlı kelimeler analize tanıtılmıştır.

Şekil 7 çalışma alanımızın temalarının zaman içindeki dönüşümünü gösteren trend kavramları listelemektedir. Analiz sonuçlarına baktığımızda erken dönem kavramlarının başında "energy" teması gelmektedir. 2001 yılında trend olan kavram 2012 yılına kadar trend olmuştur. Bu tema hem en erken trend olarak alanda ilk etkiyi oluşturan hem de tüm temalar içerisinde en uzun süre trend olan kavramımızdır. Alanın diğer erken dönem temaları ise 2014 yılında trend olan "gasoline consumer choice ve behavioral economics" kavramlarıdır.

Çalışma alanının son evresinde trend olan kavramlara baktığımızda ise 2020 yılında trend olan "climate change ve consumption", 2022 yılında trend olan "sustainability" ve 2023 yılı ile en son trend olan "environmental impact" kavramları karşımıza çıkmaktadır. Dolayısıyla ilk tren olan kavramlarımızdan, son evrede trend olan kavramlarımıza doğru bir tematik dönüşüm yaşanmıştır.

Alanımızın en uzun süre trend olan kavramları ise 11 yıl trend olan "energy", 9 yıl trend olan "consumer choice" ve 8 yıl boyunca trend olan "consumer behavior" şeklinde sıralanmaktadır. Bu kavramlardan consumer behavior 39 frekans ve consumer choice 21 frekans ile kelime bulutunda da öne çıkan kavramlar olarak listelenmektedir.



Şekil 7. Çalışmanın trend olan kavramları

SONUÇ VE TARTIŞMA

Davranışsal doğal kaynaklar ekonomisinin akademik yapısının incelendiği bu çalışmada yazılan makalelerin yıllara göre seyri ile alınan atıf sayıları karşılaştırıldığında çalışma alanımızın olgunlaşma süreci net bir biçimde ortaya çıkmaktadır. Yayın sayıları incelendiğinde erken evrelerdeki düşük yayın sayılarından son iki yıldaki zirve noktasına kadar gelen trend alanın özellikle günümüzde akademik ilgi odaklarından biri haline dönüşme potansiyelini göstermektedir. Buna karşın en yüksek ortalama atıf etkilerinin 2007 (17,30) ve 2019 (11,01) yıllarında yoğunlaşması çalışma alanımızın kavramsal sınırlarını çizen ve alanda çığır açan çalışmaların bu dönemlerde yazıldığını göstermektedir. Sonuç olarak literatür, geçmiş yıllardaki yüksek atıf gücüne sahip teorik keşif aşamasından çok yayınlı uygulama aşamasına bir geçiş döneminde bulunmaktadır.

Çalışma alanımızı yayınladığı makalelerle besleyen kaynak dergilerin alt yapısı incelendiğinde ilgili literatürün çerçevesi çizilebilmektedir. Sustainability (23) ve Energy Policy (14) dergilerinin alandaki baskın liderliği, davranışsal doğal kaynaklar ekonomisi çalışmalarının sürdürülebilirlik bakış açısı ile somut enerji politikası uygulamaları arasında köprü kurduğunu göstermektedir. Ayrıca Energy Economics ve Journal of Environmental Economics and Management gibi iktisat yönü ağır basan dergilerinin üst sıralarda yer alması, mikro düzeydeki davranışsal müdahalelerin ve tüketici odaklı talep

mekanizmalarının, ana akım çevre ve enerji ekonomisi literatüründe güçlü bir akademik karşılık ve meşruiyet bulduğunu göstermektedir.

Çalışmamızın kavramlarına özellikle zaman boyutunu gözeterek baktığımızda alanın kavramsal odağının belirgin şekilde dönüşümler yaşadığı görülmektedir. Söz gelimi erken dönemde "energy" ve "gasoline" gibi doğrudan enerji ve fosil yakıt tüketimine ilişkin kavramlar öne çıkarken, sonraki dönemde "consumer choice" ve özellikle "consumer behavior" kavramlarının belirginleşmesi, araştırma odağının kaynak tüketiminden tüketim kararlarının davranışsal boyutuna doğru genişlediğini göstermektedir. Bu belirgin dönüşümü "carbon footprint", "climate change", "sustainability" ve "environmental impact" gibi kavramların öne çıkması izlemiş, böylece bireysel tüketim davranışlarının çevresel sonuçlarına doğru bir kırılma daha gerçekleşmiştir. Bu dönüşümler yaşanırken dikkat çekici biçimde, "behavioral economics" teriminin görece düşük frekansa sahip olması, davranışsal yaklaşımın literatürde çoğunlukla doğrudan bu kavram üzerinden değil, "consumer behavior" ve "consumer choice" gibi daha uygulamalı kavramlar üzerinden tartışıldığına işaret etmektedir. Bu çerçevede literatürün genel gelişimi, enerji ve fosil yakıt tüketiminden tüketici davranışına, tüketici davranışından karbon ayak izi ve çevresel etkilere doğru genişleyen bir kavramsal yönelim sergilemektedir.

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SURFACE PATTERN FORMATION UNDER CONSTANT AVERAGE LASER POWER USING A PULSED SLS LASER SYSTEM

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ABSTRACT

Selective Laser Sintering (SLS) technology is generally studied via processing parameters like laser power, scan speed, hatch distance, and layer thickness. Yet, in those cases where pulsing is present in the laser emission, the same value of average laser power might be reached through diverse combinations of pulse period and pulse width. It means that average power does not completely reflect the features of laser energy transmission. This work is focused on surface pattern generation with constant average laser power in pulsed SLS laser system. The primary aim is to analyse the influence of pulse timing on laser trace formation with constant average laser power.

Experiments were conducted on a Solidzer 450 Pro SLS device provided by Sintertek, Türkiye. Two key variables included pulse period and pulse width, whereas the average laser power was kept approximately at 25 W. The power of the laser beam was measured via the Calibrated Coherent PM10-19C laser power meter. These measurements were taken on the optical axis of the SLS device including the zone after focusing optics and at the build platform level beneath the protective glass. In this way, it was guaranteed that selected pulse parameter combinations resulted in nearly equal average power values.

To isolate the influence of pulse timing from powder-related factors such as particle morphology, melting behaviour, consolidation, and layer formation, the laser beam was directed onto paper instead of a powder bed. The paper surface was used as a visual substrate to observe the trace patterns produced by different pulse timing conditions. The resulting patterns were photographed and compared in terms of trace continuity, spacing, uniformity, and overall pattern regularity.

It was seen that there was an insignificant variation in the average laser power, which stayed within the limited values of 25.32 W to 25.79 W depending on the combination of different pulse periods and pulse widths. Observations of the surface patterns showed that higher pulse period and pulse width values led to more discontinuous and non-uniform patterns. Shorter pulse periods and pulse widths gave better uniformity in terms of surface pattern formation. Based on the results above, laser emissions have the potential to influence scanning behaviour even when the average laser power does not change. Therefore, the factors mentioned above need to be analysed together with the average laser power in case of pulsed SLS laser systems.

Keywords: Pulsed Laser, Surface Pattern, Pulse Period, Pulse Width, SLS.

INTRODUCTION

Selective Laser Sintering (SLS) is a powder bed fusion additive manufacturing process that enables the production of polymer components directly from digital models without the need for moulds or support structures (Ligon et al., 2017). In this process, a laser beam selectively scans and fuses polymer powder particles layer by layer according to the cross-sectional geometry of the part (Ziadzi et al., 2025). Although SLS is commonly associated with powder-bed processing of polymer materials (Yehia et al., 2024), the present study focuses specifically on the behaviour of the pulsed laser system itself. In pulsed SLS laser operation, average laser power is often considered the main indicator of energy input (Franco & Romoli, 2012). However, the same average power level can be achieved through different combinations of pulse period and pulse width. Therefore, even when the measured average laser power remains nearly constant, the temporal structure of laser emission may vary significantly.

Pulse period and pulse width determine how laser energy is delivered over time (Fischer et al., 2002). Longer pulse periods and wider pulse widths may generate discontinuous, coarse (Park et al., 2024), or irregular trace patterns, whereas shorter periods and narrower pulse widths may produce more continuous and uniform patterns (Kaligar et al., 2022). Therefore, surface pattern formation can be used as a visual indicator of pulsed laser behaviour. These observations show that average laser power is not sufficient to describe the operation of a pulsed SLS laser system, and that pulse-related parameters should also be considered in laser process characterization (Kumar et al., 2021).

For this reason, examining surface pattern formation under constant average laser power is essential for understanding the real effect of pulse timing parameters in pulsed SLS systems. If different pulse conditions generate different surface patterns at the same average power level (Phillips et al., 2020), this indicates that average laser power alone cannot fully describe the behaviour of the pulsed laser system. Instead, pulse-related parameters such as pulse period, pulse width, and duty cycle should also be considered in process characterization and optimization. This difference in pulse timing can directly affect the characteristics of the laser traces formed on the scanned surface (Schnell et al., 2020). However, in powder-bed experiments, these effects may be influenced by additional factors such as particle morphology, melting behaviour, layer formation, and thermal history.

In this study, surface patterning was analysed using constant average power for a pulsed SLS laser system. To isolate the effect of pulse timing, the laser was applied directly onto paper in the present study. The paper surface provided a simple visual medium for comparing pulse-controlled energy distribution and scanning stability under constant average power. Various pulse periods and pulse widths were used while keeping the average laser power close to 25 W. Despite keeping the average laser power close to constant, significant differences were found in surface patterns created using different pulse periods and pulse widths. This shows that the time-related structure of laser emission is important for laser trace uniformity and stability. Therefore, pulse timing should be considered alongside average laser power when analysing pulsed SLS laser behaviour.

METHODOLOGY

Surface pattern formation was investigated using a commercial pulsed SLS laser system. The experiments were carried out on a Solidzer 450 Pro SLS system manufactured by Sintertek, Türkiye. This system operates based on layered laser fusion technology and allows precise control of laser-related parameters such as pulse period, pulse width, and laser power.

In this study, pulse period and pulse width were selected as the main variable parameters. Different combinations of these parameters were applied while maintaining the average laser power close to 25 W. The purpose of keeping the average power nearly constant was to examine the effect of pulse timing on laser trace formation independently of changes in average laser power.

Laser output power was measured using a calibrated Coherent PM10-19C laser power meter. The measurements were performed at two locations along the optical path of the SLS system. First, the power meter was positioned after the focusing optics to determine the transmitted laser power. Then, the sensor was placed at the build platform level beneath the protective glass to verify the effective laser power reaching the working area (Figure 1).

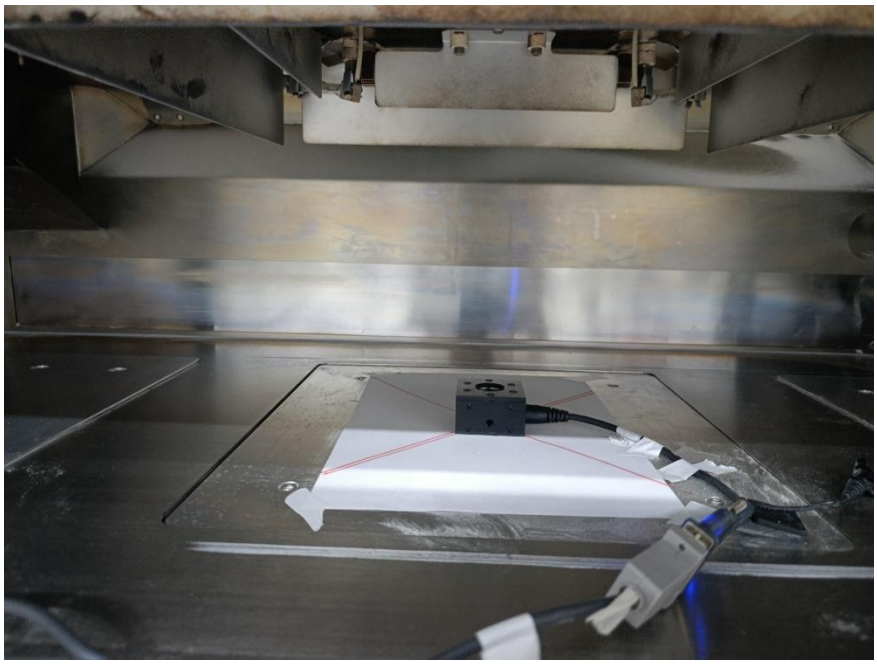

Figure 1. Experimental setup for laser power measurement

To eliminate the influence of powder-related factors such as particle morphology, melting, consolidation, and layer formation, the laser beam was directed onto paper instead of a powder bed. The paper surface was used as a simple visual medium to observe the trace patterns generated by the pulsed laser.

For each pulse parameter combination, the laser was operated under the same scanning conditions, and the resulting patterns on the paper surface were photographed. The generated laser traces were then compared visually in terms of trace continuity, spacing, uniformity, and overall pattern regularity.

CONCLUSION AND DISCUSSION

The selected pulse timing conditions used in the experiments are summarized in Table 1. The table shows that the average laser power was maintained within a narrow range, between 25.32 W and 25.79 W, while the pulse period and pulse width were varied. This indicates that the experimental conditions were suitable for examining the effect of pulse timing independently of major changes in average laser power. Although the duty cycle values were close to each other, the corresponding pulse period and pulse width combinations were different, showing that similar average power levels can be obtained through different temporal laser emission conditions.

Table 1. Pulse timing parameters used for paper-based surface pattern formation

Exp. No	Duty Cycle (-)	Period (µs)	Width (µs)	Power (W)
1	0.316	5000	1581	25.32
2	0.347	3340	1160	25.79
3	0.353	2004	708	25.39

The surface patterns obtained under different pulse timing conditions are presented in Figure 2. The comparison of the paper-based laser traces shows that the temporal structure of the pulsed laser had a visible effect on pattern formation. Under longer pulse period and wider pulse width conditions, the trace pattern appeared more discontinuous and irregular. In contrast, shorter pulse period and narrower

pulse width conditions produced more uniform and continuous surface patterns. These differences demonstrate that pulse timing affects trace continuity, spacing, and overall pattern regularity, even when the average laser power is kept approximately constant.

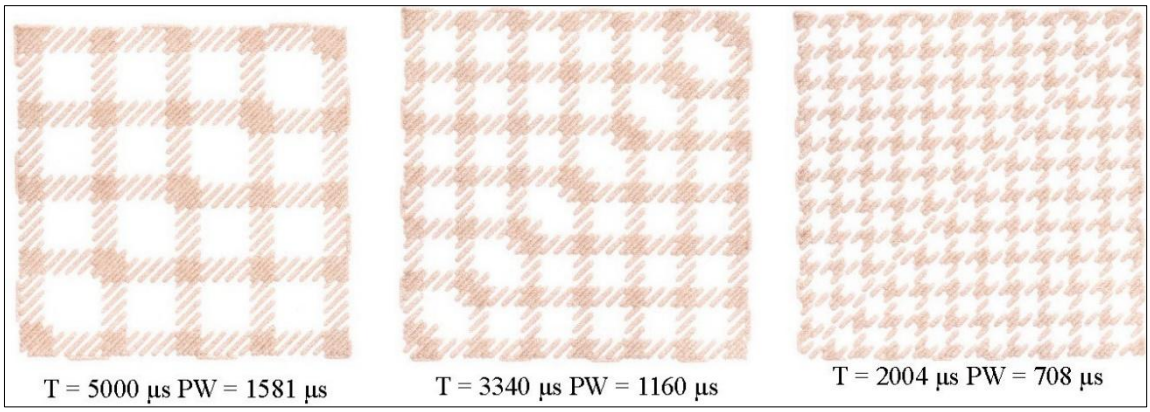

Figure 2. Comparison of paper-based laser trace patterns obtained under different pulse timing conditions

These results show that average laser power does not fully characterize the behaviour of the pulsed SLS laser system. Variations in pulse period and pulse width changed the local distribution of laser energy, despite the average power remaining at similar levels. Thus, pulse timing characteristics should be evaluated together with average laser power when characterizing pulsed SLS laser behaviour.

The findings clearly show that maintaining constant average laser power does not guarantee similar surface pattern formation in a pulsed SLS laser system. Although the average laser power was kept close to 25 W, variations in pulse period and pulse width produced noticeable differences in trace continuity, spacing, and uniformity. This demonstrates that pulse period and pulse width control the temporal distribution of laser energy and directly influence scanning stability. Therefore, average laser power should not be considered as the only descriptor of pulsed SLS laser behaviour. Pulse period, pulse width, and duty cycle should also be treated as key process parameters. The paper-based surface pattern method used in this study provides a practical preliminary approach for identifying suitable pulse timing conditions before powder-bed experiments or part fabrication studies.

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SCIENTIFIC AND PRACTICAL FOUNDATIONS OF THE RECLAMATION OF TECHNOGENICALLY DISTURBED AREAS AND APPROACHES TO SOIL FERTILITY RESTORATION

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ABSTRACT

Introduction and Purpose: Soil degradation caused by salinization, alkalization, erosion, technogenic pollution, and unsustainable land use has become a major global environmental challenge. In Azerbaijan, these processes have substantially reduced soil fertility and agricultural productivity. This study evaluates the environmental impacts of technogenic disturbances, particularly oil contamination, on soil properties and highlights the importance of sustainable soil reclamation (recultivation) for restoring degraded lands.

Materials and Methods: The research is based on a review of national and international scientific literature, environmental reports, and statistical data on soil degradation and technogenic pollution. The condition of degraded agricultural lands in Azerbaijan was assessed with emphasis on salinization, erosion, hazardous substance contamination, and crude oil pollution. Existing reclamation approaches and sustainable land management practices were also examined.

Results: The findings indicate that long-term anthropogenic and technogenic pressures have significantly diminished soil fertility and productivity. Approximately 1.5 million hectares of cultivated land are affected by salinization and alkalization, 3.6 million hectares by erosion, and 1.5–1.6 million hectares by hazardous substance contamination. Oil pollution was identified as one of the most persistent forms of technogenic degradation, adversely affecting the physicochemical, biological, and morphogenetic properties of soils. Sustainable reclamation, combined with climate adaptation and environmentally sound land management, has considerable potential to restore degraded soils.

Discussion and Conclusion: Sustainable soil management and reclamation are essential for mitigating the impacts of technogenic pollution, desertification, and climate change. The adoption of environmentally friendly reclamation technologies, afforestation, farmer awareness programs, and integrated land management can improve soil fertility, restore ecosystem functions, and enhance agricultural productivity, while supporting the achievement of the Sustainable Development Goals (SDGs).

Keywords: Soil degradation; Technogenic disturbance; Oil contamination; Soil reclamation (Recultivation); Soil fertility; Sustainable land management.

INTRODUCTION

Soil is a fundamental and non-renewable natural resource that supports terrestrial ecosystems and provides a wide range of essential ecosystem services, including agricultural production, water regulation, nutrient cycling, carbon sequestration, and biodiversity conservation. The formation of soil is a long-term process resulting from the interaction of parent material, climate, topography, living organisms, and time. Owing to its complex physical, chemical, and biological characteristics, soil serves as the primary medium for plant growth and plays a decisive role in maintaining environmental sustainability.

Rapid industrialization, urban expansion, mining activities, and intensive petroleum extraction have considerably increased anthropogenic pressure on soil resources worldwide. Among the various forms of land degradation, technogenic disturbance and petroleum contamination are regarded as some of the most persistent environmental problems because they substantially alter soil physicochemical, biological, and ecological properties. These changes reduce soil fertility, disrupt ecosystem functioning, and significantly limit the potential for sustainable agricultural production and land use.

The protection of soil resources from technogenic degradation has therefore become an important scientific and environmental priority. Particular attention has been devoted to understanding the mechanisms of petroleum contamination, the behavior of hydrocarbons within soil profiles, and their effects on soil microorganisms, enzymatic activity, and nutrient dynamics. Since soil microbial communities play a fundamental role in organic matter decomposition and the natural attenuation of petroleum hydrocarbons, their preservation and restoration are critical components of successful soil reclamation strategies.

In Azerbaijan, extensive areas have been affected by technogenic disturbances associated with long-term oil production, mining operations, construction activities, and the extraction of mineral resources. Comprehensive inventories and mapping of disturbed and petroleum-contaminated lands have therefore been undertaken to assess the extent of degradation and to identify appropriate reclamation strategies. Prior to implementing restoration measures, detailed site investigations are required to determine the spatial distribution of contamination, evaluate ecological conditions, and establish the most suitable reclamation approach for each affected area.

Globally, the productive soil layer is relatively thin, generally ranging from 150 to 300 mm, yet it supports the majority of agricultural production. Despite the substantial extent of potentially cultivable land worldwide, only a proportion of these resources is currently suitable for sustainable agricultural use because of environmental limitations, land degradation, and the high economic costs associated with land improvement. Consequently, the conservation and restoration of degraded soils have become increasingly important for ensuring long-term food security and sustainable land management.

Petroleum contamination has affected Azerbaijani soils since the late nineteenth century, with the most severe impacts occurring on the Absheron Peninsula, where intensive oil extraction has been conducted for more than a century. The introduction of industrial drilling technologies during the early twentieth century accelerated the expansion of contaminated areas, transforming localized pollution into widespread technogenic landscapes. As a result, the reclamation of petroleum-contaminated soils has become one of the principal environmental challenges facing the region and remains an important priority for sustainable environmental management.

CONCEPTUAL FRAMEWORK

Crude oil contamination exerts persistent and often irreversible adverse effects on the physical, chemical, and biological properties of soils. In heavily contaminated areas of the Absheron Peninsula, petroleum hydrocarbons have been reported to penetrate the entire soil profile to depths of 2–3 m. Consequently, soil contamination caused by crude oil and petroleum industry wastes, together with the reclamation of affected lands, has become one of the most pressing environmental challenges in Azerbaijan, particularly within the densely populated Absheron Peninsula and its adjacent territories.

A comprehensive understanding of petroleum-induced soil degradation requires consideration not only of the physicochemical characteristics of crude oil but also of the entire petroleum production and utilization chain. Environmental contamination may occur at every stage of this process, including:

1. Drilling operations, well maintenance, crude oil collection, storage, and pipeline transportation;
2. Transportation of crude oil by marine tankers;
3. Petroleum refining and the distribution of petroleum products;
4. Final utilization of petroleum-derived products.

Although hydrocarbon losses and environmental emissions are inevitable throughout the production cycle, the extraction and transportation stages represent the principal sources of soil and groundwater contamination due to accidental spills, leakage, and the improper disposal of petroleum wastes.

Following its release onto the soil surface, crude oil is transferred from anaerobic subsurface conditions to aerobic environments, where it undergoes a series of physicochemical and microbiological transformations. Under the influence of atmospheric oxygen and indigenous soil microorganisms, petroleum hydrocarbons are progressively biodegraded into carbon dioxide (CO_2), water (H_2O), and intermediate oxidation products, including alcohols, organic acids, aldehydes, ketones, and other oxygen-containing compounds. The rate and efficiency of these degradation processes largely depend on the chemical composition of crude oil, prevailing environmental conditions, and the biological activity of native soil microbial communities.

The insoluble heavy fractions of petroleum subsequently undergo condensation and polymerization or become incorporated into stable organo-mineral complexes. These high-molecular-weight compounds accumulate predominantly within the upper soil horizons, forming dense surface crusts that substantially impair soil structure, reduce porosity and permeability, restrict gaseous exchange, and deteriorate the hydrophysical properties of soils. In contrast, lighter petroleum fractions exhibit greater mobility, allowing them to infiltrate deeper soil layers and volatilize more rapidly. Nevertheless, petroleum contamination profoundly disrupts soil biological functioning by suppressing microbial communities, inhibiting enzymatic activity, altering microbial diversity, and ultimately causing a severe decline in soil fertility. Even in soils where structural degradation appears relatively limited, petroleum residues may persist for more than a century within compact subsurface horizons, particularly in level landscapes and microdepressions.

Investigations conducted by Osipova and Seyidov on gray-brown soils of the Absheron Peninsula, Oshakmashvili on gray-brown and meadow-brown soils of Georgia, and Tishkina on gray forest soils demonstrated that petroleum contamination substantially modifies soil morphology. Crude oil obscures the natural differentiation of genetic horizons and promotes the development of dark, structureless surface layers of varying thickness that may remain either soft or highly compacted. These morphological alterations become particularly pronounced under severe contamination extending to depths exceeding 60–80 cm. The authors further reported that petroleum contamination significantly reduces soil water infiltration capacity and water-holding capacity while simultaneously increasing soil organic matter content, soil pH, and the proportion of fulvic acids within soil humus.

Petroleum contamination also decreases the concentrations of exchangeable bases and plant-available nutrients, including nitrogen, phosphorus, boron, manganese, zinc, molybdenum, and other essential elements. Consequently, both the abundance and diversity of soil microorganisms undergo substantial changes. Populations of saprophytic bacteria, actinomycetes, fungi, and nitrogen-fixing bacteria decline markedly, whereas oxidation-reduction reactions and hydrolytic enzyme activity become progressively inhibited. These changes adversely affect natural vegetation and agricultural crops. Nevertheless, under relatively low levels of contamination, petroleum hydrocarbons may temporarily stimulate the proliferation of hydrocarbon-degrading microorganisms.

According to Osipova and Seyidov (Osipova, L. S. 1982) the light fractions of crude oil exert the most pronounced adverse effects on soil biological properties, particularly on microbial communities, actinomycetes, and enzymatic activity. Owing to their relatively high volatility, these fractions evaporate rapidly under the influence of elevated temperatures and wind, thereby facilitating the gradual recovery

of certain biological components. In contrast, the heavy petroleum fractions exhibit considerably greater environmental persistence because of their limited biodegradability. These fractions accumulate within the soil matrix, obstruct pore spaces, restrict gaseous exchange, suppress soil respiration, and substantially reduce overall biological activity, thereby prolonging the ecological recovery of contaminated soils (Markina, I. G. 1989).

Historically, mining, construction-material extraction, and petroleum production activities in Azerbaijan were frequently undertaken without implementing the preliminary reclamation measures required by engineering and environmental management plans. In accordance with internationally recognized reclamation practices, the fertile topsoil should be carefully stripped and stockpiled before excavation reaches the parent material. Following the completion of industrial operations, the preserved topsoil should be redistributed over the reclaimed surface to restore soil productivity and ecological functionality. However, this practice has not been consistently implemented in Azerbaijan, and in many cases reclamation activities have remained incomplete or only partially executed, resulting in extensive areas of long-term technogenic land degradation. Shilova reported that soil co(Shilova, I. I. 1989)

ntamination associated with petroleum production constitutes one of the principal constraints to the restoration of soil fertility. Particular attention was drawn to the discharge of highly saline drilling wastewater, which represents one of the most significant environmental hazards associated with oil-field operations. Similarly, Markina demonstrated that drilling muds containing petroleum hydrocarbons, sulfanol, potassium chromite, and highly soluble salts exert severe adverse effects on soil quality, vegetation, and the surrounding environment. Consequently, the direct discharge of drilling fluids onto soils should be strictly prohibited as part of sustainable environmental management practices (Oshakmashvili, N. L. 1988).

At relatively low concentrations, petroleum hydrocarbons may temporarily stimulate soil biological activity by enhancing the proliferation of hydrocarbon-degrading microorganisms and increasing certain enzymatic processes. Nevertheless, as contamination levels increase, the physicochemical and biological properties of soils deteriorate progressively. Elevated petroleum concentrations suppress microbial activity, inhibit essential biochemical processes, reduce nutrient availability, and ultimately lead to a substantial decline in soil productivity and ecological stability (Magribi, R. A. 1998).

In Azerbaijan, crude oil contamination is generally characterized by scattered and localized pollution hotspots associated with historical oil production activities.(Fedoseeva, T. P. 1977). Surface oil storage pits and accumulations of drilling wastes have rendered extensive areas unsuitable for agricultural production and ecological restoration. Furthermore, the infiltration of drilling wastewater mixed with petroleum hydrocarbons has contributed to a rise in groundwater levels, in some locations approaching approximately 50 cm below the soil surface, thereby accelerating the development of secondary salinization, particularly within the Mashtaga sector of the former Khazar oil field. (Aliyev, S. A., & Gadzhiyev, 1984), (Aliyev, S. A., Abduev, & 1976)

Consequently, reclamation planning for petroleum-contaminated soils should be based on a comprehensive assessment of contamination depth and extent, petroleum hydrocarbon concentration, groundwater level, soil salinity, and the physical state of contaminants (liquid, semi-solid, or solid). In addition, the intended post-reclamation land use—including agriculture, grazing, afforestation, recreational development, or infrastructure construction—should be determined prior to the implementation of restoration measures.(Ahmadov, V. A., & Gahramanova, T. B. 2004).

The first systematic experiments on the biological reclamation of petroleum-contaminated soils in Azerbaijan were conducted by Huseynov and Gvozdenko (Huseynov, D. M., & Gvozdenko, D. V. 1973).

Their investigations evaluated plant establishment, growth, and productivity under different proportions of contaminated and uncontaminated soils. The experimental results demonstrated that satisfactory vegetation development could be achieved when petroleum-contaminated soil constituted approximately 25% of the soil mixture. Based on six years of field investigations, the authors recommended that reclamation should commence with deep mechanical tillage of the contaminated surface layer to enhance aeration and promote natural weathering under solar radiation. Subsequently, the treated soil should be mixed with uncontaminated soil at a ratio of 1:1 (0.5:0.5) and supplemented

with appropriate mineral fertilizers before being utilized for agricultural purposes (Huseynov, R. G., & Akhundov, F. G. 1975).

Petroleum contamination substantially reduces the availability of essential plant nutrients, resulting in a significant decline in the concentrations of plant-available macro- and micronutrients and consequently limiting soil fertility and agricultural productivity (Isayev, S. A., Masimov, A. A., & Khasayev, A. I. 2003).

Experimental studies have further demonstrated that the application of petroleum-derived organic materials at rates of 100–200 t ha^{-1} may stimulate the biological activity of soil microorganisms. However, increasing application rates to 400–1000 t ha^{-1} leads to a pronounced suppression of microbial activity and, ultimately, to the destruction of sensitive microbial populations. These findings indicate that the response of soil microorganisms to petroleum contamination is highly dependent on both contamination intensity and the physiological characteristics of individual microbial groups.

Fedoseeva (Tishkina, E. I. 1989).emphasized that the successful planning and implementation of reclamation measures require a comprehensive understanding of the quantity, quality, spatial distribution, and environmental characteristics of degraded soils. Accordingly, the qualitative assessment and reclamation of technogenically disturbed and petroleum-contaminated lands remain among the principal priorities of contemporary environmental and soil science research. Comprehensive site assessment provides the scientific basis for selecting appropriate reclamation technologies, predicting restoration outcomes, optimizing land-use planning, and supporting the effective allocation of financial and technical resources for environmental rehabilitation (Tishkina, E. I. 1989).

Another important environmental concern associated with petroleum-contaminated soils is the potential accumulation of toxic elements and carcinogenic compounds in agricultural crops cultivated on reclaimed lands. Nevertheless, environmentally safe agricultural production within the soil–plant system may be achieved through scientifically designed reclamation strategies and sustainable land management practices. Changes in the biochemical composition of crops are primarily governed by both the degree and duration of petroleum contamination. Previous investigations have demonstrated that the concentrations of elements such as C, Si, V, Ni, Cu, Cr, Fe, and Mo in plants cultivated on petroleum-contaminated soils under semi-arid conditions generally remain below the maximum permissible levels established by the Clarke geochemical standard. In contrast, trace amounts of strontium (Sr) have been detected under petroleum-contaminated conditions. Moreover, heavy trace elements do not generally accumulate in plant tissues at concentrations posing a significant environmental or public health risk. Nevertheless, investigations into the occurrence and mobility of radioactive elements in petroleum-contaminated soils remain of considerable importance owing to their potential ecological and human health implications.

METHODOLOGY

The reclamation of technogenically disturbed and oil-contaminated soils is a long-term process requiring considerable labor, financial resources, and technical expertise, particularly when such lands are intended for agricultural use.

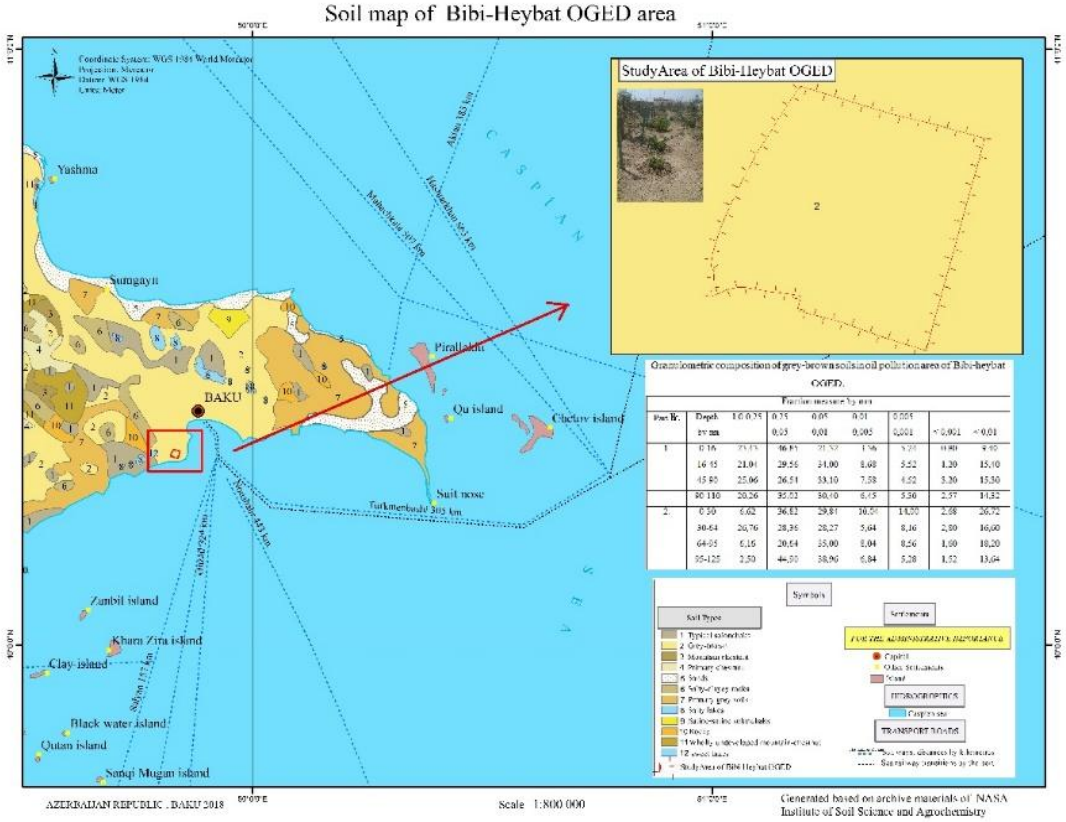
In Azerbaijan, land restoration should preferably be implemented in successive stages. The effectiveness of reclamation largely depends on topographic conditions. Reclamation measures on steep slopes, especially in areas disturbed by mining activities, are technically difficult and economically less feasible. Therefore, the reclamation of technogenically disturbed and oil-contaminated soils should be carried out in two sequential stages: **technical reclamation** and **biological reclamation**.

Following the completion of onshore oil production, abandoned sites typically contain concrete well foundations, earthen oil storage embankments (approximately 1 m in height), accumulations of oil residues in microdepressions, abandoned water and oil pipelines, electricity and telephone poles and cables, oil-contaminated ponds, and deposits of clayey, sandy, and petroleum-contaminated drilling wastes. Biological reclamation should commence only after these sources of contamination have been completely removed during the technical reclamation stage. Experimental studies conducted by the authors demonstrated that shrubs and tree species can be successfully established according to the degree

of contamination. Furthermore, the application of mineral and organic fertilizers significantly improves soil fertility during biological reclamation. (picture 1.)

The medical and ecological condition of contaminated areas poses serious risks to both human health and ecosystem integrity. Soil and water polluted by heavy metals, pesticides, petroleum products, and industrial wastes contribute to landscape degradation, adversely affect flora and fauna, and increase the incidence of cancer, allergic disorders, and other diseases in humans. Consequently, reclamation measures, including decontamination and revegetation, are essential for restoring ecological balance. (Mammadov, Q. Sh., & Hakimova, N. F. 2005).

Phytoremediation represents an intermediate stage of the natural recovery of contaminated soils and is widely recognized as an environmentally sustainable restoration approach. This process relies on the synergistic interaction among plants, microorganisms, and the surrounding environment and generally does not require extensive engineering interventions. Human-assisted establishment of beneficial microbial communities, together with appropriate agricultural and land-improvement practices such as plowing, irrigation, and fertilization, can accelerate natural recovery without causing additional environmental damage.



Picture 1: Soil map of Bibi-Heybat OGED area

In coarse-textured soils (sand, sandy soils, and light loams), the light fractions of petroleum readily migrate to depths of approximately 2–3 m. In contrast, the heavy fractions, including fuel oil, paraffin, clay, and sand mixtures, accumulate on the soil surface. On sloping terrain these materials gradually dry, whereas in microdepressions they remain in liquid, semi-solid, or solid form. Such petroleum accumulations should be mechanically excavated and removed. The recovered bituminous, petroleum-contaminated soil and clay mixtures should subsequently be treated using stationary or mobile physical and chemical technologies to separate and recover the petroleum components.

The reclamation strategy for oil-contaminated soils should be determined individually for each contaminated site, taking into account contamination depth, affected area, groundwater level, salinity, and the physicochemical characteristics of the contaminants.

Shallow contamination (15–20 cm).

In sloping areas and microdepressions where petroleum residues occur within the upper 15–20 cm of soil, the contaminated layer—often characterized by hardened, weathered, or bituminous materials—should be deeply loosened by plowing. Under the influence of natural weathering processes, including solar radiation and precipitation, soil quality may recover within approximately six months to one year.

Contamination to depths of 0–50 cm.

For contamination extending to 50 cm, the newly formed contaminated surface layer should first be excavated and removed. The underlying soil affected by infiltrated light petroleum fractions should then undergo deep plowing. After two annual plowing cycles, the treated soil may be mixed with clean imported soil, river sediments, crushed stone, dried sewage sludge from Baku wastewater treatment facilities, wood chips, or sand (for heavy clay soils) at ratios of **1:2** or **1:3** (one part contaminated soil to two or three parts clean material). Organic manure and mineral fertilizers should then be incorporated before initiating biological reclamation. Depending on site conditions, the reclaimed land may subsequently be used for afforestation. During reclamation, petroleum hydrocarbon concentrations should not exceed **1–2%** in newly contaminated soils and **4–5%** in sites contaminated for 40–50 years.

Deep contamination (>50 cm)

Where contamination exceeds 50 cm, surface accumulations of clay, sand, bitumen, and fuel-oil residues should be excavated and treated using physical and chemical methods until petroleum concentrations are reduced to approximately **1–2%**. Since soils contaminated to depths of 2–3 m generally possess coarse textures, these sites should undergo deep plowing and immediate irrigation, with the procedure repeated twice annually before applying the reclamation measures described for moderately contaminated soils.

Areas containing drilling wastes.

Localized accumulations of drilling wastes composed of clay, sand, and petroleum residues should be completely removed. Contamination caused by infiltrated light petroleum fractions may subsequently be treated using the reclamation procedures recommended for deep contamination. It should also be recognized that petroleum remaining below permissible concentrations may serve as an additional carbon source for certain soil microorganisms.

Drilling wastewater is typically characterized by high salinity, elevated concentrations of iodine and bromine, and, in some cases, increased radioactivity. Although these waters may be utilized for iodine and bromine recovery, they should never be discharged directly onto oil-field lands because they substantially increase groundwater levels and promote secondary soil salinization over extensive areas.

Technogenically disturbed lands.

Areas disturbed by mining and construction-material extraction (stone, sand, gravel, clay, etc.) should be leveled and, where possible, covered with potentially fertile parent material or topsoil. Soil excavated during building construction may be used beneficially for filling abandoned excavation sites.

Abandoned road infrastructure.

Unused roadbeds should be dismantled, including both the pavement and compacted subsoil layers. The underlying soil should be loosened, leveled, and integrated with the surrounding land to facilitate ecological restoration.

Solid waste removal.

Unauthorized dumping sites containing household, industrial, and construction wastes, particularly those located within or adjacent to oil fields, should be completely cleared before reclamation activities commence.

CONCLUSION AND DISCUSSION

In conclusion, technogenically disturbed and oil-contaminated soils can be successfully restored through scientifically planned reclamation measures. Following rehabilitation, these lands may be safely utilized for agricultural production, grazing, afforestation, water management, recreational development, and landscape architecture. The effective reclamation of degraded lands contributes significantly to environmental protection, sustainable land management, and the preservation of healthy ecosystems for future generations.

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RENEWABLE ENERGY INCENTIVES AND FIRM BEHAVIOR: A BIBLIOMETRIC ANALYSIS FROM MICROECONOMIC AND INSTITUTIONAL PERSPECTIVES

YENİLENEBİLİR ENERJİ TEŞVİKLERİ VE FİRMA DAVRANIŞLARI: MİKROEKONOMİK VE KURUMSAL PERSPEKTİFTEN BİBLİOMETRİK BİR ANALİZ

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ÖZET

Giriş ve Amaç: İklim kriziyle mücadelede yenilenebilir enerji kaynaklarına geçiş, küresel ekonominin en kritik gündemlerinden biri hâline gelmiştir. Hükümetler bu dönüşümü hızlandırmak amacıyla teşvikler, sübvansiyonlar ve düzenlemeler gibi çeşitli politika araçlarına başvururken, söz konusu politikaların mikro düzeyde firma davranışları, yatırım kararları ve asimetrik bilgi sorunları (ahlaki tehlike ve ters seçim) üzerindeki etkileri karmaşık bir araştırma alanı oluşturmaktadır. Bu çalışma, yenilenebilir enerji düzenlemeleri ile firma dinamikleri ve mikroekonomik kararlar arasındaki ilişkiyi inceleyen literatürün entelektüel yapısını, gelişimini ve kavramsal çerçevesini bibliyometrik bir yaklaşım aracılığıyla ortaya koymayı amaçlamaktadır.

Materyal ve Yöntem: Çalışmanın verileri, sistematik bir arama kodu kullanılarak Web of Science (WoS) veri tabanından elde edilmiştir. İlk arama sonucunda ulaşılan 381 yayın; araştırma türü (makale ve derleme), dil (İngilizce) ve zaman aralığı (2026 yılının henüz tamamlanmamış olması nedeniyle kapsam dışı bırakılması) kriterlerine göre filtrelenmiştir. Filtreleme işleminin ardından nihai veri seti 302 çalışmadan oluşturulmuştur. Elde edilen bibliyografik verilerin analizi, R tabanlı Bibliometrix (Biblioshiny) yazılımı kullanılarak gerçekleştirilecektir.

Bulgular: Yapılacak analizler sonucunda, yenilenebilir enerji düzenlemeleri ile firma davranışı ekseninde en üretken yazarların, en fazla atıf alan kaynakların ve önde gelen ülkelerin belirlenmesi beklenmektedir. Anahtar kelimelerin birlikte kullanım analizi, üç alan grafikleri (three-fields plots) ve tematik haritalama yöntemleri aracılığıyla, literatürdeki kavramsal kümelenmeler ile oyun teorisi, mikroekonomik kararlar ve teşvik mekanizmalarının entelektüel yapısının görselleştirilmesi amaçlanmaktadır. Ayrıca, tarihsel eğilim analizi ile asimetrik bilgi ve vekalet teorisi gibi kurumsal yaklaşımların konu kapsamındaki gelişiminin ve zaman içerisindeki değişiminin ortaya konulması beklenmektedir.

Tartışma ve Sonuç: Bu araştırma, teşvik politikalarının firma düzeyindeki stratejik yansımalarını inceleyen mevcut literatürün güncel durumunu kapsamlı bir biçimde ortaya koyan bir harita sunacaktır. Elde edilen bulguların, enerji ekonomisi alanında çalışan araştırmacıların literatürdeki boşlukları belirlemelerine ve daha etkili teşvik mekanizmaları tasarlamayı amaçlayan politika yapıcılara kanıta dayalı bir mikroekonomik perspektif sunmalarına katkı sağlaması beklenmektedir.

Anahtar Kelimeler: Yenilenebilir Enerji Teşvikleri; Firma Davranışı; Mikroekonomi; Bibliyometrik Analiz.

ABSTRACT

Introduction and Purpose: The transition to renewable energy sources in combating the climate crisis is one of the most critical agendas of the global economy. While governments resort to incentives, subsidies, and regulations to accelerate this transition, the impacts of these policies at the micro-level on firm behavior, investment decisions, and asymmetric information problems (moral hazard, adverse selection) constitute a complex research area. This study aims to map the intellectual structure,

evolution, and conceptual framework of the literature examining the relationship between renewable energy regulations and firm dynamics/microeconomic decisions through a bibliometric approach.

Materials and Methods: The data for the study were obtained from the Web of Science (WoS) database using a systematic search code. The 381 publications retrieved in the initial search were filtered based on research type (article and review), language (English), and time frame (excluding the year 2026 due to its incompleteness). Following the filtration process, the final dataset was determined as 302 studies. The analysis of the obtained bibliographic data will be carried out using the R-based Bibliometrix (Biblioshiny) software.

Results: The analyses are expected to identify the most productive authors, most cited sources, and leading countries in the axis of renewable energy regulations and firm behavior. Through keywords co-occurrence analysis, three-fields plots, and thematic mapping methods, the conceptual clusterings and intellectual structure of game theory, microeconomic decisions, and incentive mechanisms in the literature will be visualized. Furthermore, historical trend analysis will reveal the evolution of institutional approaches such as asymmetric information and agency theory within the subject.

Discussion and Conclusion: This research will provide a comprehensive map summarizing the current state of the existing literature examining the strategic reflections of incentive policies at the firm level. The findings will guide researchers in energy economics to identify literature gaps and provide an evidence-based microeconomic perspective for policymakers aiming to design more effective incentive mechanisms.

Key Words: Renewable Energy Incentives; Firm Behavior; Microeconomics; Bibliometric Analysis

GİRİŞ

İklim değişikliği sorununun küresel bir mücadele ve sürdürülebilir bir enerji sistemine geçişi gerekli kılması, yenilenebilir enerji kaynaklarının enerji arzındaki payının artırılmasını önemli bir politika gündemi haline dönüştürmüştür. Bu politika uygulamalarının doğal bir sonucu olarak başta güneş ve rüzgar olmak üzere yenilenebilir enerji kaynaklarının küresel çaptaki elektrik kapasitesindeki potansiyel büyümenin temel tetikleyicileri olması beklenmektedir (International Energy Agency [IEA], 2025). Ancak bu noktada yenilenebilir enerji yatırımlarının maliyetlerine veya enerji fiyatlarına ilişkin ortaya çıkabilecek belirsizlikler, yapılacak olan yatırımların ekonomik potansiyelinin belirlenmesini zorlaştırırken yatırım kararlarının zamanlamasını etkileyebilmektedir (Biondi & Moretto, 2015). Hükümetler ise yenilenebilir enerji yatırımlarını destekleyebilmek ve elektrik üretim kapasitesini artırabilmek adına feed-in tariff (FiT), feed-in premium, yatırım sübvansiyonları, düşük faizli krediler ve vergi teşvikleri gibi çeşitli politika araçlarını kullanmaktadırlar. Bazı ülke örneklerinde sayılan destek mekanizmalarının çeşitli kombinasyonları da kullanılabilmektedir (del Río & Mir-Artigues, 2014). Bu politika araçlarının birlikte kullanımı, yenilenebilir enerji yatırımlarının finansal koşullarını ve destek politikalarının uygulanma biçimini etkileyebilmektedir (Mir-Artigues & del Río, 2014). Dolayısıyla sübvansiyonların yenilenebilir enerji teknolojilerinin yaygınlaştırılmasında ve özel sektör yatırımlarının teşvik edilmesinde kullanılan temel politika araçları arasında değerlendirilebilir (IEA, 2025; del Río & Mir-Artigues, 2014).

Devletlerin yenilenebilir enerji yatırımlarına vermiş oldukları sübvansiyonlar bu sektörün gelişimini desteklerken, politika yapıcıları ile teşvikten faydalananlar arasındaki bilgi asimetrisi bir takım teşvik sorunlarını meydana getirmektedir. Teşviklerden yararlanan firmaların kendi maliyetleri, üretim ve kârlılık düzeyleri ve verimlilikleri gibi temel bilgiler hakkında doğal olarak kamu otoritelerine kıyasla daha fazla bilgiye sahip olmaları bu firmaların gerçek anlamda değerlendirilmesini güçleştirmektedir (Laffont & Tirole, 1993). Firmalar ve politika yapıcılar arasındaki bu bilgi asimetrisi teşviklerin tasarımında ve uygulanmasında asil-vekil ilişkisi (principal agent) sorunlarının ortaya çıkmasına ve ahlaki tehlike kaynaklı teşvik problemlerinin belirgin hale gelmesine yol açmaktadır (Berlinger vd. 2017). Ayrıca Berlinger (2019), devlet sübvansiyonlarının girişimcilerin kendi sermaye katkılarını azaltmaları ve mümkün olan en yüksek düzeyde kamu desteği talep etmeleri yönünde teşvikler oluşturabileceğini göstermektedir. Bu durum, kamu kaynaklarının özel yatırım kararlarını etkilerken istenmeyen teşvikler meydana getirebileceğini ve sübvansiyon politikalarının belirlenmesinde bilgi

asimetrisi ile teşvik uyumunun dikkate alınması gerektiğini göstermektedir. İşte bahsedilen bu noktalardan hareketle çalışmamızın amacı kamu otoriteleri tarafından uygulanan teşvik politikalarının özellikle yenilenebilir enerji sektöründeki firma davranışlarına nasıl yansıdığını, ve bu piyasada meydana getirdiği potansiyel aksaklıkları inceleyen akademik birikimin haritasını ortaya koyabilmektir. Çalışmanın bundan sonraki yöntem bölümünde, çalışmanın amacını gerçekleştirmek adına uygulanacak bibliometrik analiz tanıtılacak, bir sonraki aşamada analiz bulguları verilecektir. Son bölümde ise analiz bulguları yorumlanıp tartışılacaktır.

YÖNTEM

Bibliometrik analiz belirli bir literatürdeki akademik çalışmalar arasındaki bibliyografik eşleşmeler ile ilgili çeşitli ilişkileri nicel olarak inceleyen ve bu sayede belirli bir araştırma alanının yapısını ortaya koyan bir yöntem olarak tanımlanmaktadır (Zupic & Čater, 2015). Bu çalışmada da bibliyometrik analiz yöntemi uygulanmıştır. Çalışmanın verileri ("renewable energy" OR "solar" OR "wind") AND ("subsidies" OR "incentives" OR "regulation") AND ("firm behavior" OR "microeconomics" OR "game theory" OR "moral hazard" OR "adverse selection" OR "agency theory" OR "investment decision*") şeklinde kurgulanan tarama kodu çalıştırılarak Web of Science veri tabanından elde edilmiştir. Elde edilen ham veri, sadece "article" ve "review article" biçimindeki yayınlar kalacak şekilde doküman kısıtlamasına ve ayrıca dil birliği sağlanabilmesi için sadece "English" olacak şekilde dil kısıtlamasına tabi tutulmuştur. Bu noktadan sonra elde edilen veri seti R tabanlı Bibliometrix ara yüzü üzerinden analiz edilmiştir (Aria ve Cuccurullo, 2017). Bibliometrix ara yüzünün sunduğu filtreler üzerinden henüz tamamlanmamış olması nedeniyle 2026 yılı da analiz dışı bırakılmıştır. Bu süreç sonucunda 302 yayından oluşan veri setimiz analize hazır hale gelmiştir.

Kelime bulutu ve trend kavramlar analizlerinin yapım aşamasında eşanlamlı olarak işaretlenen kavramlar belirlenerek şu şeklide bir araya getirilmiştir:

- "*renewable energy*" başlığı altında renewable energy sources, renewable, renewables, renewable energies kavramları toplanmıştır.
- "*solar energy*" başlığı altında solar, concentrated solar power, solar power kavramları toplanmıştır.
- "*wind power*" başlığı altında wind ve wind energy ifadeleri toplanmıştır.
- "*game theory*" başlığı altında game, games, game model, game-theory kavramları bir araya getirilmiştir.
- "*evolutionary game*" başlığıa altında evolutionary game theory, evolutionary, evolutionary game model, evolutionary game theoretical model kavramları toplanmıştır.
- "*cooperative game*" başlığı altında cooperative game theory, cooperative, cooperative approach ifadeleri birleştirilmiştir.
- "*investment decision*" başlığı altında investment, investment decisions, investment decision making, investment decision-making, investment planning kavramları toplanmıştır.
- "*real options*" başlığı altında real option, real options (ro), real option method, real option theory, real options valuation, real options valuation (rov) kavramları bir araya getirilmiştir.
- "*subsidies*" başlığı altında subsidy, government subsidy, government subsidies, renewable energy subsidies, bilateral subsidy, electricity price subsidies, energy storage subsidy, financial subsidy, fiscal subsidies, investment subsidy, price subsidy kavramları toplanmıştır.
- "*electricity market*" başlığında altında electricity markets, electricity market design, electricity market mechanisms, retail electricity market, retail electricity markets temaları bir araya getirilmiştir.
- "*energy policy*" başlığında policy uncertainty, government policies, policies, public policy, support policies, energy policies: government temaları bir arada toplulaştırılmıştır.

BULGULAR

Yenilenebilir enerji sektörüne ilişkin kamu politikalarının firma davranışları üzerindeki etkisine yönelik temel bibliometrik bilgiler tablo 1'de gösterilmektedir. Verilerimize baktığımızda, 2008 yılından başlayan bir süreç içerisinde 2025 yılına kadar bu alanda 302 bilimsel yayının yapıldığını ve bu

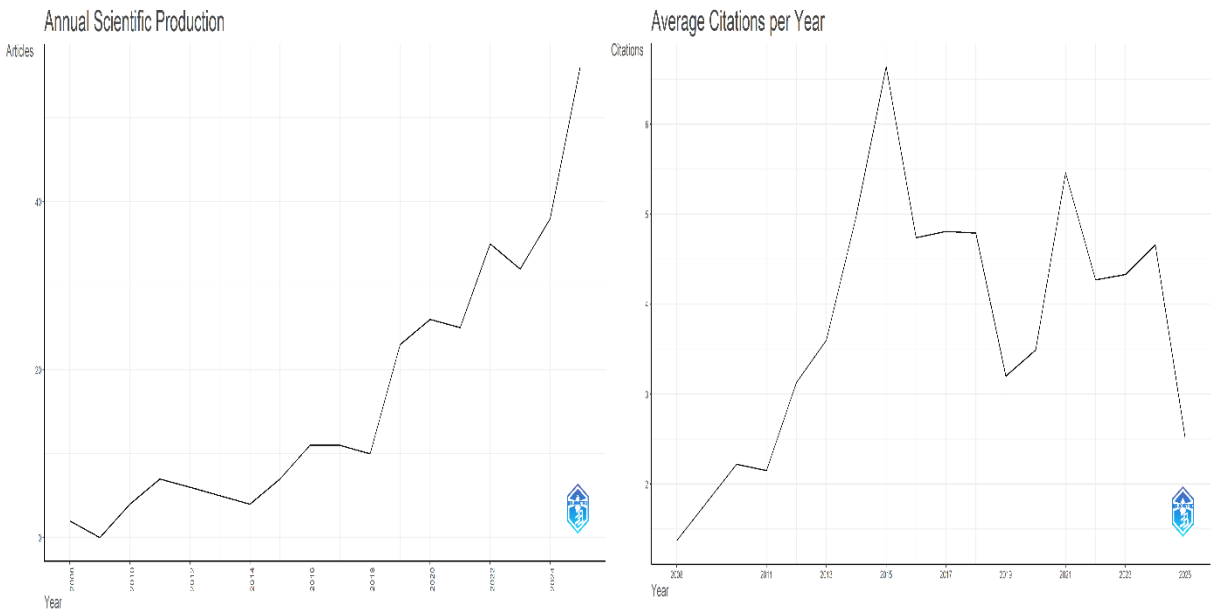
yayınların 137 kaynakta yayımlandığını görmekteyiz. Bahsedilen bu çalışmalar 924 yazar tarafından üretilmiştir. Bu yayınların yıllık büyüme oranı %21,65 olurken, yayınlar ortalama 24,78 atıf almıştır. Üretilen bilimsel çalışmalarda yazarlar 1193 anahtar kelime belirtmişler ve bu çalışmaların kaynakça listelerinde 14169 yayına atıfta bulunmuşlardır. Çalışmaların sadece 24 tanesi tek yazarlı yayın olup, ortak yazarlı çalışmalarda uluslararası ortak çalışma oranı ise %29,47 olarak gerçekleşmiştir.

Tablo 1

Çalışmanın temel bilgileri

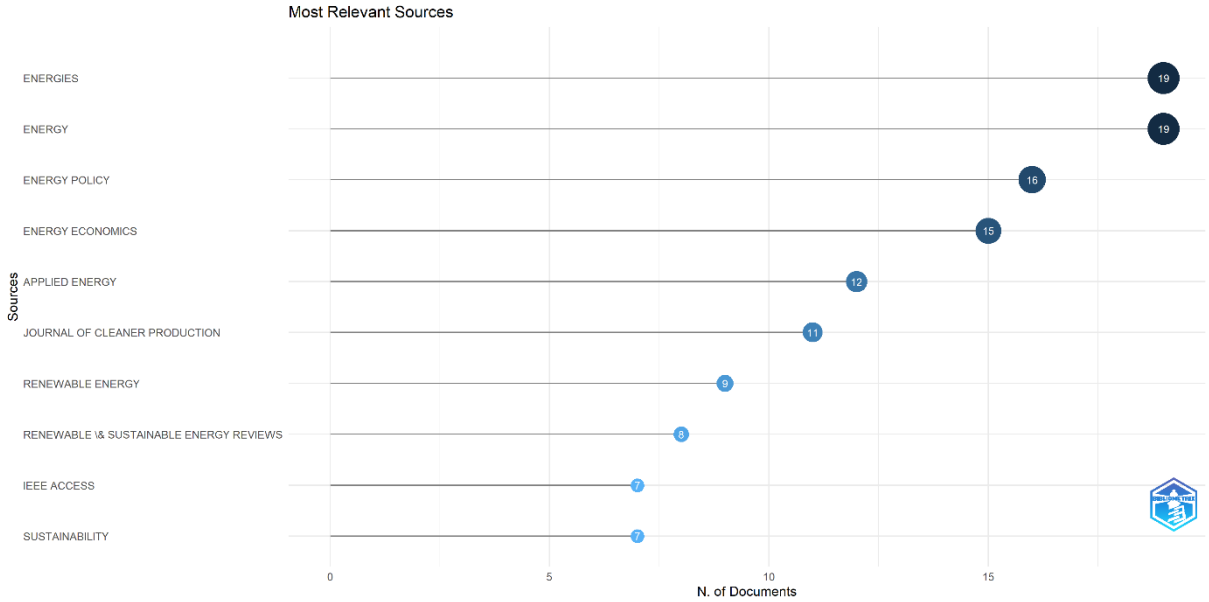
Parametre	Değerler
Zaman aralığı	2008:2025
Kaynaklar	137
Yayınlar	302
Yıllık büyüme oranı %	21,65
Yayın başına ortalama atıf	24,78
Referanslar	14169
Yazar anahtar kelimeleri	1193
Yazarlar	924
Tek yazarlı yayın	24
Uluslararası ortak yazarlık %	29,47

İki bölümden oluşan Şekil 1'in sol bölümü, çalışma alanımız kapsamındaki yayın sayısının yıllar içindeki seyrini gösterirken, şeklin sağ bölümü ise bu yayınlara yıllar içerisinde yapılan ortalama atıfların seyrini göstermektedir. Yıllık bilimsel üretim görseli, WoS veri tabanında ele aldığımız çalışmaların ilk kez 2008 yılında yayımlandığını ve bu tarihten itibaren günümüze kadar çalışma sayısının neredeyse sürekli arttığını göstermektedir. Çalışma konumuz hakkındaki yayın sayısı 2015 yılına kadar tek haneli sayılarda gerçekleşirken, özellikle 2019 yılından itibaren bu alana yönelik akademik ilgi katlanarak artmıştır ve yalnızca 2025 yılında bu alanda 56 çalışma üretilmiştir. Tüm süreç boyunca sadece 2009 yılında hiç çalışma yapılmamıştır. Şekil 1'in sağ tarafında yer alan görsel ise üretilen çalışmalara yapılan atıfların yıllık ortalamasını göstermektedir. Bu görsele baktığımızda, yapılan atıfların ortalamasının 2015 yılına kadar büyük oranda artarak devam ettiğini ancak bir daha aynı seviyeye ulaşamadığını göstermektedir.



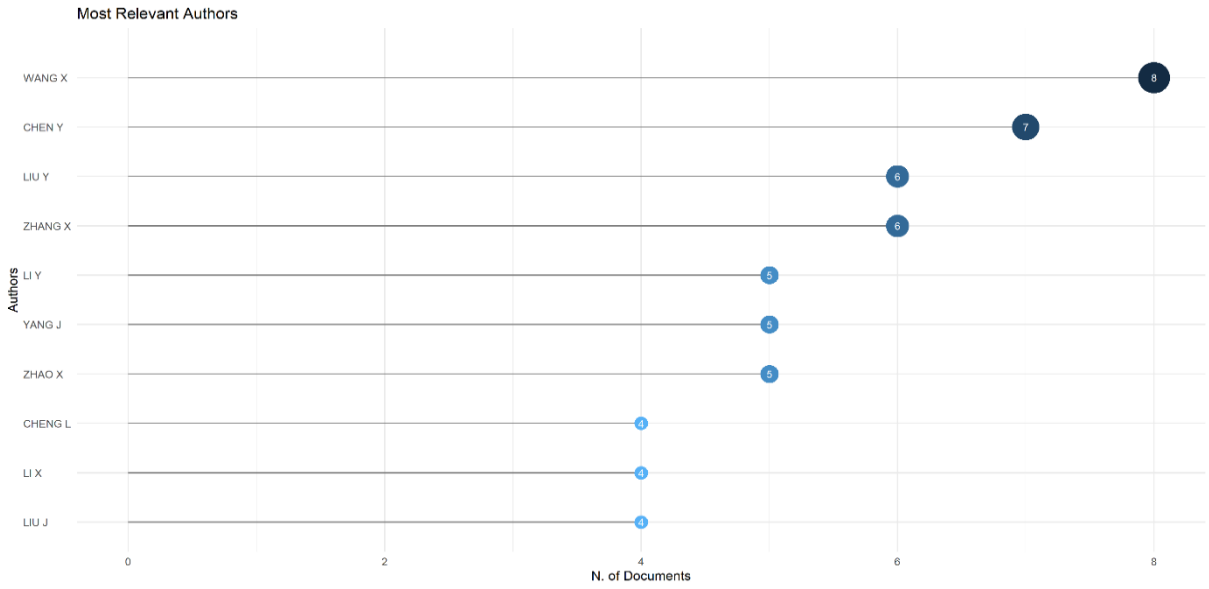
Şekil 1. Yıllık bilimsel üretim ve ortalama atıflar

Şekil 2 çalışma alanımızın en ilgili kaynaklarını göstermektedir. Yapılan analiz başka bir deyişle bu alanda en çok makale yayımlayarak alana yön veren dergileri göstermektedir. Analiz sonuçlarına göre "Energies" ve "Energy" dergileri 19'ar makale ve "Energy Policy" dergisi de 16 makale yayımlayarak çalışma alanımıza yön veren ilk üç dergi olmulardır. Bu dergileri sırasıyla 15 makale ile "Energy Economics", 12 makale ile "Applied Energy" ve 11 makale ile "Journal of Cleaner Production" dergileri takip etmektedir.



Şekil 2. Alanın en ilgili kaynakları

Şekil 3. ilgili çalışma alanı kapsamında en çok yayın üreten yazarları göstermektedir. Bu alanda en çok çalışma "Wang X." tarafından üretilmiştir ve yazarın 8 makalesi bulunmaktadır. Daha sonra "Chen Y." isimli yazar 7 makale, "Liu Y." ve "Zhang X" ise 6'şar makale üretmişlerdir. Bu yazarları 5 makale ile "Li Y.", "Yang J." ve "Zhao X." İsimli yazarlar takip ederken, listenin son sırasında bulunan yazarların 4'er çalışması bulunmaktadır.

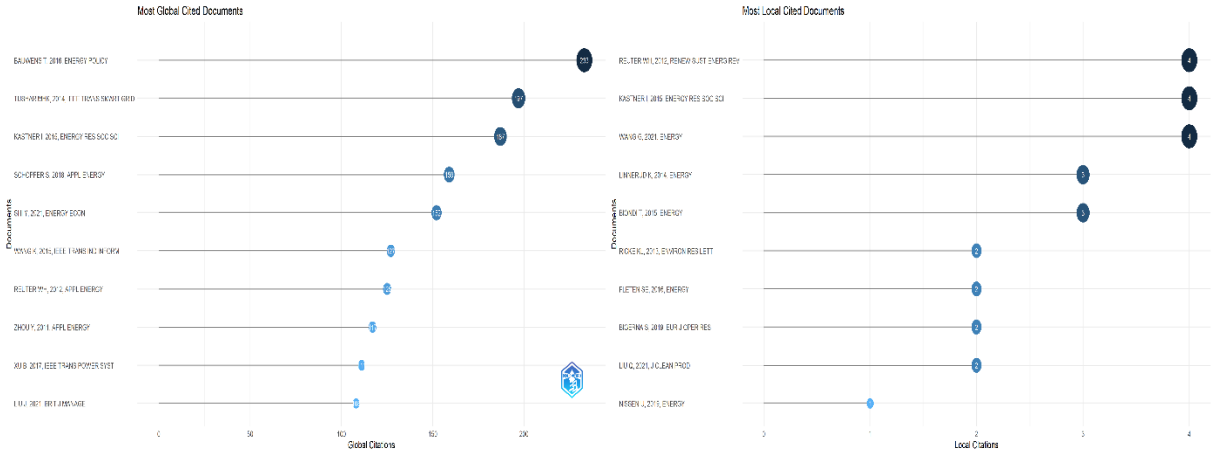


Şekil 3. Çalışma alanının en ilgili yazarları

Şekil 4. Küresel ve yerel olmak üzere iki farklı yönden en çok atıf alan makalelerin listesini göstermektedir. Bibliometrix ara yüzü tüm veri tabanından alınan atıfları "kürsel atıf" ifadesi ile tanımlarken, veri setimiz içindeki çalışmalardan alınan atıfları ise "yerel atıf" olarak tanımlamaktadır.

Buna göre veri setimiz içindeki makalelerin tüm WoS veri tabanından aldığı atıfların listesi Şekli 4'ün sol bölümünde yer almaktadır. Listeye baktığımızda Bauwens T, isimli yazarın 2016 yılında, Energy Policy dergisinde yayımladığı makale aldığı 233 atıfla birinci sıradadır. Tushar Mhk, isimli yazarın 2014 yılında, Ieee Trans Smart Grid isimli dergide yayımlanan makalesi 197 atıf alırken, Kastner I, isimli yazarın 2015 yılında, Energy Res Soc Sci. İsimli dergide yayımlanan çalışması 187 atıf almıştır. Bu çalışmayı 159 atıfla Appl Energy dergisindeki makale ile Schopfer S, isimli yazarın çalışması izlerken, Shi Y, isimli yazarın 2021 yılındaki makalesi ise Energy Econ dergisinde yayımlanmış ve 152 atıf almıştır. Daha eski tarihlerde yayımlanan çalışmaların atıf alabilecekleri potansiyel sürelerin daha uzun olması bu sıralamaların oluşumunda dikkate alınmalıdır. Örneğin ilk sıradaki makale 2016'da yayımlandığından yıl başına ortalama 21,18 atıf alırken, beşinci sırada yayımlanarak toplamda 159 atıf alan makale ise 2021 yılında yayımlandığından yıl başına ortalama atıf sayısı 25,33'e tekabül etmektedir. Bu durum listede beşinci sırada yer alan çalışmayı yıllık ortalamalar bazında tüm listenin en başına taşımaktadır.

Şeklin sağ bölümü veri setimizdeki 302 makaleden alınan yerel atıfları göstermektedir. Yerel atıflar listesinde Reuter Wh, 2012 yılındaki makalesi, Kastner I, isimli yazarın 2015 yılındaki makalesi ve Wang G, 2021 yılındaki makalesi 4'er atıfla ilk sırayı paylaşmaktadır. Bu çalışmalar içerisinde 2021 yılında yayımlanan çalışmanın daha kısa sürede bu atıf sayısına ulaştığı görülmektedir. Bu üç çalışmayı 3'er atıfla Linnerud K'nın 2014 yılında ve Biondi T, 2015 her ikisi de Energy'de yayımlanan makaleleri takip etmektedir. Küresel atıf listesinde yer alan makalelerden yalnızca Kastner'in çalışması en çok yerel atıf alan makaleler listesinde yer bulabilmiştir.



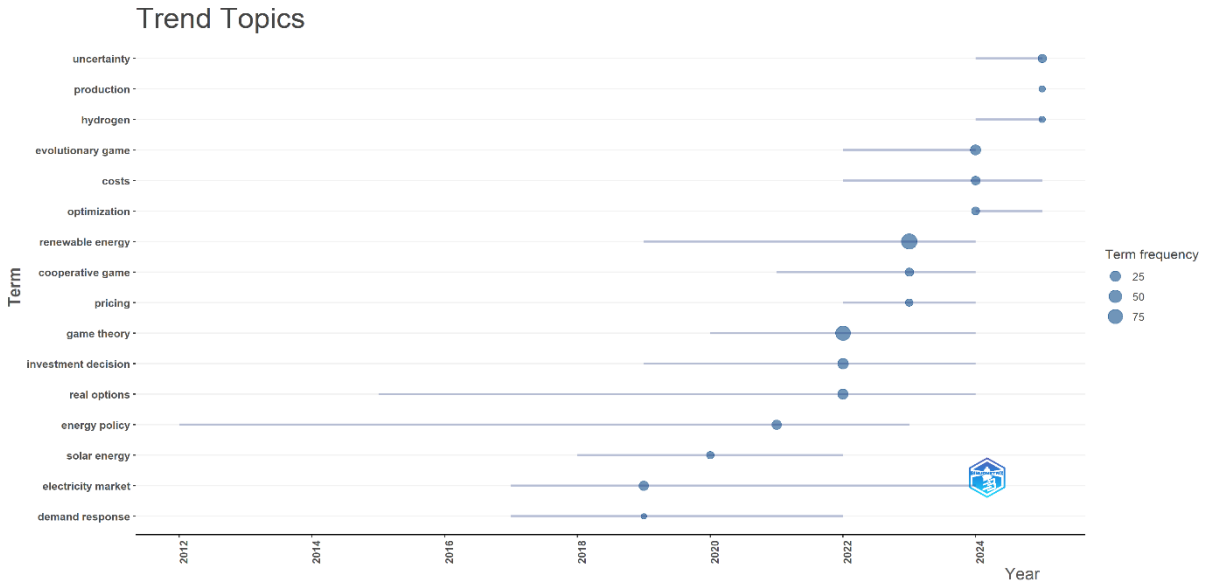
Şekil 4. Küresel ve yerel bazda en çok atıf alan makaleler

Şekil 5 çalışma alanımızda en sık kullanılan kavramlar üzerinden elde edilen kelime bulutunu göstermektedir. Kelime bulutu analizi çalıştırılırken Bibliometrix ara yüzünün kullanıcıya sunmuş olduğu seçeneklerden "yazar anahtar kelimeleri" tercih edilmiştir. Temalar tek tek incelenerek eş anlamlı olanlar tek bir başlık altında toplanmış ve 25 kavram üzerinden analiz tamamlanmıştır. Analizin sonucunda en sık kullanılan kavram 95 frekans ile "renewable energy" olurken, daha sonra sırasıyla 81 frekans ile "game theory", 30 frekansı bulunan "investment decision", 26 frekans ile "real options" ve 25'er frekans ile "evolutionary game" ve "subsidies" kavramları listelenmektedir.



Şekil 5. Kelime bulutu

Şekil 6 çalışma alanımızın temalarını zaman boyutunu da içerecek şekilde analiz eden trend kavramları göstermektedir. Kelime bulutunda sadece frekans odaklı statik bir biçimde çerçevesi çizilen çalışmamızın temaları, trend kavramlar analizinde dinamik bir bakış ile ele alınmaktadır. Analizin yapım sürecinde kavramsal bütünlüğü sağlamak adına kelime bulutunda olduğu gibi yazar anahtar kelimeleri tercih edilmiş ve yine eş anlamlı kelimeler analize tanıtılmıştır. Trend kavramların bulgularına baktığımızda yüksek frekansa sahip olan kavramlardan erken dönemde trend olanlar “energy policy” ve “reel options” kavramlarıdır. Bunlardan “energy policy” hem ilk trend olmuş hem de 11 yıl devam edecek şekilde en uzun süre trend olan kavram olmuştur. Benzer şekilde “reel options” 9 yıl ve “electricity market” 7 yıl trend olarak en uzun süre gündemde olan temalardır. Bu sayılan kavramlar son dönemde yerlerini “uncertainty” , “optimization” ve “hydrogen” gibi güncel kavramlara bırakmışlardır. Listede yer aldığı görülen diğer temalar ise genellikle 2017-2020 döneminden başlayarak günümüze kadar güncel olan kavramlar olarak listelenmişlerdir. Frekansı 95 tekrar ile en yüksek olan “renewable energy” 2019-2024 gibi çok kısa bir süre içinde trend olurken, “game theory” 2020-2024 arasında 81 frekansı yakalamış ve son olarak 30 frekans ile üçüncü sıradaki “investment decision” kavramı da 2019-2024 döneminde trend olmuştur.



Şekil 6. Çalışmanın trend kavramları

SONUÇ VE TARTIŞMA

Kamu politikalarının yenilenebilir enerji sektöründeki firmaların davranışlarını ele aldığımız çalışmamızın kapsamındaki akademik yayınların üretim miktarı ve bu yayınların etki değerlerini gösteren atıf değerleri birlikte değerlendirildiğinde bu çalışma alanına ilişkin önemli sonuçlar karşımıza çıkmaktadır. Buna göre makalelerin üretim sayılarındaki artış ile alınan ortalama atıf değerleri arasında birbirini tamamlamayan bir ilişki bulunmaktadır. 2022 yılından sonra yayın sayısında meydana gelen gözle görünür artışa rağmen, yıllık ortalama atıf oranları en yüksek seviyelerine 2013-2018 arasındaki nispeten durağan üretim döneminde ulaşmıştır. Bu sonuca göre alanın erken döneminde üretilen az sayıdaki çalışma literatürün teorik altyapısını inşa etmiş, son yıllarda üretilen çalışmalar ise henüz olgunlaşma ve atıf döngüsünü inşa edememişlerdir.

Çalışmanın yöntemsel boyutunda kurgulanan tarama kodu alanın mikroiktisadi arka plan düşünerek hazırlanmıştır. Buna rağmen çalışma alanımızı besleyen kaynak dergilere baktığımızda, elde edilen bulgular öne çıkan dergilerin saf iktisat veya finans dergileri olmadığını, teknik ve çok disiplinli dergilerin listede ön sıralarda yer aldığını göstermektedir. Buna göre yenilenebilir enerji kaynaklarına yönelik teşvikler ve firma dinamikleri üzerine çalışılan akademik literatür, teorik iktisat literatüründen ziyade ampirik ve sektörel yansımaların ön planda olduğu uygulamalı enerji dergilerinde daha geniş bir tartışma alanı bulmuştur. Listenin devamında karşımıza çıkan “Energy Economics” ve “Energy Policy” gibi dergilerin varlığı ise ön sıralarda yer alan teknik dergiler ile iktisadi ve politik dengenin sağlanma çabası olarak değerlendirilebilir.

Çalışmanın kavramsal yapısını ifade eden alanın temalarına kelime bulutu analizi ile frekans değerleri üzerinden statik ve trend kavramlar analizi ile zamansallığın ön planda olduğu dinamik bir perspektif üzerinden baktığımızda, alanın kronolojik bir dönüşüm geçirdiği anlaşılmaktadır. Buna göre ilk dönemlerde çalışma alanı “energy policy” ve “reel options” gibi kavramlar üzerinde şekillenirken, orta vadede en yüksek frekans değerlerine ulaşan “renewable energy”, “game theory” ve “investment decision” gibi kavramların üzerinde odaklanmıştır. Güncel dönemde ise firmaların operasyonel işlevlerini temsil eden “cost”, “optimization” ve “hydrogen” gibi yeni nesil teknolojik kavramlara yönelik bir dönüşüm gerçekleşmiştir.

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DETECTION OF ATRIAL FIBRILLATION USING NONLINEAR HEART RATE VARIABILITY PARAMETERS WITHOUT ECG : A MACHINE LEARNING-BASED APPROACH

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ABSTRACT

Atrial fibrillation (AF) is one of the most common cardiac arrhythmias. It is associated with important health risks, including stroke, heart failure, and reduced quality of life. AF is frequently paroxysmal and can remain asymptomatic. Continuous ECG monitoring is often costly and impractical. This study investigates whether AF can be reliably detected using only RR-intervals without analyzing ECG waveform morphology, so supporting non-invasive and wearable screening devices. RR intervals were extracted from two open-access PhysioNet databases, the MIT-BIH Atrial Fibrillation Database and the Long-Term Atrial Fibrillation Database which is including 109 subjects and created 125,269 sixty-second analysis windows. Fifteen HRV features consist of time-domain, frequency-domain, and nonlinear domains which includes Poincaré geometry, Sample Entropy, Permutation Entropy, Detrended Fluctuation Analysis, and Higuchi Fractal Dimension. They were computed for each window. Three classifiers, which are Logistic Regression, Random Forest, and XGBoost, were trained and evaluated using a subject-wise holdout split and five-fold subject-grouped cross-validation.All three classifiers achieved classification accuracy above 93%. XGBoost has achieved the best overall discrimination (Accuracy = 93.73%, ROC-AUC = 0.9708, PR-AUC = 0.9676). Nonlinear HRV features individually performed successfully like as conventional time-domain features. It also combined to time-domain and frequency domain features and improved performance for all models. Permutation Entropy was identified as the single most discriminative nonlinear feature. This study demonstrate that AF can be reliably detected from RR-interval dynamics alone without ECG waveform analysis. It confirm that nonlinear HRV analysis captures information complementary to linear measures. The results show that AF detection is possible with lightweight, wearable and compatible AF screening tools based on nonlinear HRV analysis .

Key Words: Atrial Fibrillation; Heart Rate Variability; Machine Learning; Nonlinear Analysis; RR Intervals

INTRODUCTION

Cardiovascular disease is one of the important public health problems worldwide. Atrial fibrillation (AF) is the most common among cardiac rhythm disorders. It characterized by irregular and uncoordinated electrical activity in the atria. The clinical importance of AF is not only the rhythm disturbance. Irregular atrial contractions significantly increasing the risk of ischemic stroke by triggering blood stasis and clot formation; furthermore, the loss of a regular rhythm can reduce cardiac output over time, leading to fatigue, shortness of breath, and, in long-standing cases, heart failure (Chugh et al., 2014; Wolf et al., 1991).

AF is frequently paroxysmal and, in many patients, largely asymptomatic. It is A major clinical difficulty of AF detection. Because patients may experience attacks at home but present with a normal rhythm during a clinical examination, the condition may go unnoticed until a serious complication arises (Hindricks et al., 2021). Although the electrocardiogram (ECG) remains the gold standard for diagnosing AF due to its reliability in directly visualizing abnormal atrial activity (January et al., 2019), long-term continuous ECG monitoring is generally costly and impractical outside of a hospital setting.

These limitations have led to growing interest in wearable technologies which are providing continuous physiological monitoring outdoors. Wearable devices are lightweight, can be worn during daily activities. They enable a preventive monitoring approach which is becoming increasingly important in cardiovascular care (Patel et al., 2012; Steinhubl et al., 2013). Unlike periodic checkups conducted in a hospital, wearable devices provide a continuous stream of physiological data. This significantly increases the possibility of detecting transient arrhythmia attacks and improves patient compliance with treatment because of their comfort and convenience (Dunn et al., 2018; Smuck et al., 2021).

Most wearable devices which are used in daily life cannot reliably record full multichannel ECG waveforms but many can estimate beat-to-beat (RR) intervals using optical sensors. Therefore, heart rate variability (HRV) which quantitatively measures the variability between successive heartbeats offers a practical approach to arrhythmia screening. The method is using signals that can be realistically obtained from wearable devices (Shaffer & Ginsberg, 2017). HRV patterns are particularly nonlinear measures of complexity and irregularity. Since AF fundamentally disrupts the temporal rhythm of the cardiac cycle HRV are expected to contain important discriminative information about the presence of AF. This application gives more than traditional linear statistics can capture.

The combination of HRV analysis with machine learning enables automatic pattern recognition in physiological time series without requiring ECG signals. The present study investigates whether AF can be accurately detected from RR intervals alone by using nonlinear HRV features together with supervised machine learning classifiers. Specifically examines whether nonlinear HRV features provide an advantage over linear features for this task.

MATERIALS AND METHODS

Study Design and Data Sets

This study used RR-interval sequences derived from ECG annotations rather than raw ECG waveforms. In this way a performance comparison can be done between linear and nonlinear parameters. Data were obtained from two open-access PhysioNet databases: the MIT-BIH Atrial Fibrillation Database (AFDB; 25 records, approximately 10-hour recordings sampled at 250 Hz) and the Long-Term Atrial Fibrillation Database (LTAFDB; 84 records, approximately 24–25-hour recordings sampled at 128 Hz). These data sets provide expert beat and rhythm annotations (Goldberger et al., 2000). Combining the two databases resulted in 109 unique subjects and increased the diversity of rhythm patterns and recording conditions represented in the dataset.

RR intervals were computed from the expert beat annotations. Physiologically unreasonable intervals were filtered out during preprocessing stage. The cleaned RR-interval sequences were segmented into non-overlapping 60-second analysis windows and each window was labeled according to the proportion of AF beats. This process resulted in a final dataset consisting of 125,269 analysis windows. Strict subject-level splitting was applied throughout all training and evaluation procedures. 20% of the subjects were entirely reserved for testing to prevent information leakage between subjects in the training and test sets.

HRV Feature Extraction

For every 60-second window, fifteen HRV features were computed for three group analytical domains. The mean RR interval, the standard deviation of RR intervals (SDNN), the root mean square of successive differences (RMSSD), the percentage of successive RR interval differences greater than 50 ms (pNN50), and the mean heart rate are time-domain features. Frequency-domain features are low-frequency (LF) power, high-frequency (HF) power, and the LF/HF ratio. Nonlinear features are Poincaré

plot descriptors (SD1, SD2, and the SD1/SD2 ratio), Sample Entropy (Richman & Moorman, 2000), Permutation Entropy (Bandt & Pompe, 2002), Detrended Fluctuation Analysis, and the Higuchi Fractal Dimension. AF produces highly irregular and chaotic RR interval dynamics that cannot be fully characterized by classical linear statistics, so nonlinear measures were critical side for this study.

Machine Learning Framework

Three classifiers were trained on the extracted feature vectors: Logistic Regression, Random Forest (Breiman, 2001), and XGBoost which is a gradient boosting ensemble method (Friedman, 2001). Model performance was first assessed on a subject-wise holdout test set. Then model was validated using five-fold GroupKFold cross-validation, in which folds were constructed at the subject level, to account for the strong within-subject correlation of HRV characteristics across adjacent windows. Classification performance was evaluated using accuracy, the area under the receiver operating characteristic curve (ROC-AUC), and the area under the precision–recall curve (PR-AUC) (Fawcett, 2006). In addition to evaluating the full feature set, the classifiers were trained separately on subsets consisting of only time-domain features, only nonlinear features, and a combination of time-domain, frequency domain and nonlinear features. Also each nonlinear feature was evaluated individually to see the contribution of nonlinear HRV analysis to AF classification performance.

RESULTS AND DISCUSSION

All three classifiers achieved strong and closely comparable classification performance on the subject-wise holdout test set. It is summarized in Table 1. XGBoost obtained the best overall discrimination (ROC-AUC = 0.9708, PR-AUC = 0.9676), while Random Forest achieved the highest raw accuracy (93.92%). The narrow performance gap between the classifiers, and the fact that even the simplest linear model exceeded 93% accuracy, indicates that the extracted HRV feature space already contains highly separable class structure. Because of this, the choice of feature representation may more important than classifier complexity for this task.

Model	Accuracy	ROC-AUC	PR-AUC
Logistic Regression	93.77%	0.9601	0.9594
Random Forest	93.92%	0.9670	0.9581
XGBoost	93.73%	0.9708	0.9676

Table 1. Classification performance on the subject-wise holdout test set.

Classifiers were retrained on time-domain-only, nonlinear-only, combined, and full feature sets to determine the contribution of each HRV feature domain as shown in Table 2. Nonlinear HRV features performed similarly to time-domain features for all three classifiers. Combining the two feature groups consistently improved performance. This indicate that they capture complementary physiological information. In contrast, adding frequency-domain features produced only a minor improvement (e.g., ROC-AUC increased from 0.9695 to 0.9708 for XGBoost). This suggest that once nonlinear complexity measures are already included, classical autonomic markers such as LF and HF power add limited discriminative value.

Model	Time Only	Nonlinear Only	Time + Nonlinear	All Features
Logistic Regression	0.9407	0.9503	0.9592	0.9601
Random Forest	0.9632	0.9616	0.9670	0.9670
XGBoost	0.9673	0.9669	0.9695	0.9708

Table 2. ROC-AUC comparison across HRV feature subsets.

Among the individual nonlinear features, Permutation Entropy consistently achieved the highest discriminative power (ROC-AUC up to 0.8399). Sample Entropy and Detrended Fluctuation Analysis followed after. Geometric Poincaré-plot descriptors such as SD1, SD2, and the SD1/SD2 ratio

performed considerably worse. Permutation Entropy depends only on the relative ordering of RR-interval values rather than their absolute magnitudes. Because of this its strong performance suggests that AF disrupts the temporal organization of the cardiac rhythm to a greater extent than it simply increases variability. This is consistent with previous work showing that entropy-based measures are highly sensitive to irregularity in physiological time series (Richman & Moorman, 2000; Bandt & Pompe, 2002).

Five-fold group cross-validation confirmed the stability of these results. All three classifiers achieving mean ROC-AUC values close to 0.99. Low across-fold variance, showing that the models generalize well across subjects and do not exhibit severe overfitting. Overall, these findings show that AF can be detected with high accuracy using only RR-interval derived from HRV features, without any use of ECG waveform morphology. Nonlinear HRV analysis provides discriminative information and complementary with conventional linear HRV statistics. These results support the feasibility of lightweight, wearable-based AF screening tools built on nonlinear HRV analysis rather than full ECG acquisition because RR intervals of this type can realistically be estimated by consumer wearable sensors,

CONCLUSION

This study demonstrates that atrial fibrillation can be accurately detected using only RR-interval-derived heart rate variability features, without requiring analysis of ECG waveform morphology. Three machine learning classifiers were trained and evaluated on 125,269 sixty-second analysis windows derived from 109 subjects at two open-access PhysioNet databases. It is achieving the best overall performance with XGBoost (Accuracy = 93.73%, ROC-AUC = 0.9708, PR-AUC = 0.9676). Nonlinear HRV features, Permutation Entropy in particular, proved to be highly informative, performing comparably to conventional time-domain measures and improving classification when combined with them but frequency-domain features contributed only minimal. These results support the central hypothesis that nonlinear HRV analysis captures clinically relevant information about AF-related rhythm irregularity. Given that the kind of RR intervals used in this study can realistically be obtained from consumer wearable sensors, the proposed approach offers a promising basis for lightweight, continuous, and ECG-independent AF screening tools suitable for real-world wearable health monitoring applications.

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MATERNAL EMPLOYMENT, PARENTING PRACTICES, AND CHILD WELL-BEING: A COMPARATIVE ANALYSIS OF TURKISH AND BRITISH HOUSEHOLD SURVEY DATA

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ABSTRACT

This study examines the relationship between maternal employment, family structure, parenting practices, and child well-being through a comparative analysis of household survey data from Türkiye and the United Kingdom. The Turkish part of the study uses the 2021 Research on Family Structure in Türkiye dataset to evaluate regional differences in maternal employment, maternal education, family happiness, and attitudes toward the role of children in family life. Descriptive findings indicate substantial regional variation in maternal employment, with higher employment rates in more developed regions and lower participation in eastern and southeastern regions. Maternal education and geographic region appear to be important structural factors associated with employment status. However, maternal employment is not strongly associated with family happiness or with the cultural perception that children complete the meaning of family life.

The United Kingdom analysis uses household panel survey data to investigate maternal employment, child routines, child outcomes, and parenting style indicators. Descriptive statistics, chi-square tests, Cramer's V effect sizes, heatmap analysis, and clustering methods are applied to identify meaningful associations and family profiles. The findings suggest that employment status, region, marital status, and parental education are associated with selected parenting practices, reading frequency, school happiness, screen time, and child behavioral indicators. Cluster analysis further reveals distinct parenting profiles characterized by differences in warmth, regulation, conflict, and disciplinary practices. Overall, the study highlights how maternal employment and parenting are shaped by structural, cultural, and regional contexts, while also demonstrating that employment status alone does not fully explain family well-being or child-related outcomes.

Keywords: Maternal employment, parenting practices, child well-being, household survey data

INTRODUCTION

The increase in women's labor force participation since the second half of the twentieth century has been widely recognized as one of the most significant social transformations affecting family life and child-rearing practices (Goldin, 2006; Oláh et al., 2018; Winkler, 2022). Industrialization, rising educational attainment, declining fertility rates, the expansion of the service sector, and changing gender roles have contributed to a substantial increase in women's participation in paid employment. These

transformations have also reshaped the organization of care work within families and the distribution of parenting responsibilities (Broadway & Kalb, 2022; Halim et al., 2023; Liu & Marois, 2024).

However, maternal employment cannot be regarded solely as the outcome of individual choice. Mothers' participation in paid employment is shaped by multiple structural and institutional factors, including the availability and accessibility of childcare services, parental leave policies, flexible working arrangements, and social policies supporting work–family balance (Bergemann & Riphahn, 2023; Hook & Paek, 2020). Moreover, the implications of maternal employment extend beyond economic outcomes. Maternal employment may be associated, directly or indirectly, with patterns of family time use, parenting practices, parent–child interactions, and children's everyday experiences. Accordingly, contemporary research increasingly conceptualizes maternal employment not simply as a labor-market indicator but as a multidimensional social factor associated with family functioning and child development (Heinrich, 2014; Kopp, 2024).

The potential implications of maternal employment for children have consequently received increasing attention in child and family research. Children's living conditions were traditionally evaluated through objective indicators such as physical health, nutritional status, educational achievement, and behavioral problems. More recent studies, however, have increasingly adopted a subjective well-being perspective that emphasizes children's own experiences and evaluations of their lives (Huang et al., 2026; Lippman, 2007; Syafri et al., 2025). This perspective considers children's life satisfaction, happiness, positive emotional experiences, and social relationships to be important indicators of child development, alongside their protection and the fulfillment of their basic needs (Tatlıcıoğlu, 2022).

Within this framework, child happiness is recognized as an important dimension of subjective well-being, reflecting children's life satisfaction, psychological adjustment, family and peer relationships, and sense of security (Holder, 2012; Perez et al., 2016). The family therefore constitutes a primary developmental context for children's subjective well-being. Although the broader implications of maternal employment for children have long been debated, studies directly examining its relationship with children's subjective well-being remain relatively limited. Existing empirical evidence suggests that this relationship cannot be understood as a simple linear association; rather, it is shaped by the interaction of individual, family, cultural, and structural factors.

For example, Bonet et al. (2025) employed a multidimensional measure of child well-being encompassing happiness, worries, temperament, experiences of bullying, and behavioral indicators. Their findings demonstrated a positive association between maternal employment and children's subjective well-being. In contrast, Ökten (2020) showed that the implications of maternal employment for children were not unidirectional. Although children of employed mothers held more positive attitudes toward women's participation in the workforce, they also perceived their mothers as less forgiving than children whose mothers were not employed. These findings indicate that the relationship between maternal employment and child-related outcomes is shaped not only by family dynamics but also by broader social, cultural, and institutional contexts. Examining this relationship comparatively across different welfare regimes and family-policy settings is therefore particularly important.

In this context, Türkiye and the United Kingdom provide two contrasting institutional settings in which to examine the relationships among maternal employment, family life, parenting practices, and child-related outcomes. According to Esping-Andersen's (1990) welfare-regime typology, the United Kingdom is classified as a liberal welfare regime characterized by largely market-oriented childcare provision and selective state support. However, particularly since 1997, family-policy reforms have expanded childcare services and strengthened institutional mechanisms supporting mothers' labor-force participation (Daly, 2010). Türkiye, by contrast, is generally characterized in the comparative welfare literature as having a family-based or familialist welfare system. Childcare is provided primarily within the family, caregiving responsibilities fall disproportionately on women, and public support mechanisms remain relatively limited (Gültekin, 2023; Karagöz, 2025). The two countries, therefore, differ considerably in the distribution of childcare responsibilities among the state, the market, and the family. These institutional differences may also shape the ways in which maternal employment is associated with family functioning and child-related outcomes.

These differences are reflected in maternal employment patterns in the two countries. According to the OECD Family Database, nearly three-quarters of women with at least one child aged 0–14 are employed in the United Kingdom, whereas Türkiye is among the OECD countries in which the maternal employment rate remains below 60%. The United Kingdom also exhibits a more balanced distribution between full-time and part-time maternal employment. In Türkiye, by contrast, employed mothers are predominantly concentrated in full-time employment, while part-time work remains relatively uncommon. Although maternal labor-force participation increases as the youngest child grows older in both countries, employment rates remain substantially lower in Türkiye across all age groups (OECD, 2023). These patterns indicate that differences between the two countries involve not only the overall level of maternal employment but also the broader organization of paid work, childcare, and family responsibilities.

Despite the growing literature on maternal employment and family life, much of the existing evidence is based on single-country studies conducted within specific national contexts. Cross-national studies directly considering countries with different welfare regimes and family-policy arrangements remain relatively scarce. Consequently, it remains unclear how the associations among maternal employment, family well-being, parenting practices, and child-related outcomes vary across institutional and cultural contexts.

This study addresses this gap through a parallel comparative analysis of data from the 2021 Research on Family Structure in Türkiye (TAYA) and the British Household Panel Survey (BHPS). The study examines country-specific dimensions of maternal employment and family life within a common analytical framework. In the Turkish sample, it investigates the associations of maternal employment with geographic region, maternal educational attainment, family happiness, and cultural attitudes toward the role of children in family life. In the United Kingdom sample, it examines the relationships among maternal employment, children's daily routines, early childhood development indicators, behavioral outcomes, and parenting practices. Because the two surveys do not contain fully identical measures, the comparison focuses on how country-specific patterns are embedded within distinct sociocultural and institutional contexts rather than on a direct variable-by-variable comparison.

Across the two analyses, descriptive statistics, chi-square tests of independence, Cramér's V effect-size measures, heatmap analysis, and K-medoids partitioning around medoids clustering are used, as appropriate, to identify meaningful associations and family profiles. These methods allow the study to examine both broad structural patterns and heterogeneity in parenting and family practices.

The study contributes to the literature in three respects. First, it places evidence from two contrasting welfare and family-policy contexts within a common analytical framework, thereby, illustrating how maternal employment is embedded in different structural and cultural environments. Second, it considers maternal employment in relation to regional conditions, educational attainment, family happiness, parenting practices, and child-related outcomes rather than treating it solely as an economic or labor-market variable. Third, the United Kingdom analysis extends conventional descriptive and inferential analyses by using cluster analysis to identify distinct parenting profiles characterized by different combinations of warmth, regulation, conflict, and disciplinary practices.

METHODOLOGY

ANALYSIS OF TAYA DATA

Description of TAYA

This analysis utilizes the use of a comprehensive data set from Turkey. In order to provide information to people about Turkish family structure, the underlying data collection, officially known as TAYA (Research on Family Structure in Türkiye), has been gathered since 2006. This comprehensive and nationally representative investigation was carried out in collaboration with the Ministry of Family, Labor, and Social Services and the Turkish Statistical Institute. Since the 2021 TAYA data set is the most recent survey of the TAYA version, it is used in this study. Accordingly, 22,780 households are included in this survey, which also contains questions for people 15 years of age and older (Turkish Statistical Institute & Ministry of Family, Labor, and Social Services, 2022). A thorough questionnaire

has been used to collect data on a variety of family-related themes, such as household features, marriage, divorce, children, relatives, aging, happiness, and neighbourhood ties. In this study, our goal is to examine the descriptive statistics and trends of working and non-working mothers, elementary family relationships in terms of their happiness.

Accordingly, an exploratory data analysis was conducted to investigate the age-related and regional dynamics of maternal employment. It is decided to limit and use moms who were 90 years of age or younger because the dataset does not explicitly indicate whether the mothers are still alive. Below you can find the table of descriptive statistics related with maternal employment, age and region.

The above investigation explores at the age distribution and work status of employed mothers (under 90) in different statistical regions of Turkey based on the TAYA 21 dataset. Working and non-working mother's average age profiles and involvement in the workforce demonstrate clear regional trends. It is seen that Western Anatolia (N=3,730), Istanbul (N=3,402), and Southeastern Anatolia (N=3,338) have the highest average of moms who are not employed. Whereas, the Aegean area has the largest overall total number of employed mothers (N=1,814), subsequently being followed by Istanbul (N=1,167) and the Mediterranean (N=1,082).

Table 1. Mothers' Age Distribution by Region and Employment Status in Turkey

Region	Employment Status	N (Count)	Mean Age	Min Age
İstanbul	Not Working	3402	65.2	33
İstanbul	Working	1167	58.4	35
Western Marmara	Not Working	980	66.3	35
Western Marmara	Working	914	65	33
Aegean	Not Working	3039	66.1	32
Aegean	Working	1814	65.1	32
Eastern Marmara	Not Working	2373	65	32
Eastern Marmara	Working	949	61.8	35
Western Anatolia	Not Working	3730	64.8	33
Western Anatolia	Working	976	61.2	32
Mediterranean	Not Working	2345	65.6	31
Mediterranean	Working	1082	62.9	32
Central Anatolia	Not Working	1539	65.9	33
Central Anatolia	Working	432	64.1	34
Western Black Sea	Not Working	1487	66.4	31
Western Black Sea	Working	785	65.6	35
Eastern Black Sea	Not Working	773	67.6	31
Eastern Black Sea	Working	334	65.6	36
Northeastern Anatolia	Not Working	1378	63.1	32
Northeastern Anatolia	Working	218	63.2	35
Middle East Anatolia	Not Working	2019	63.2	32
Middle East Anatolia	Working	333	61.2	36
Southeastern Anatolia	Not Working	3338	61.1	33
Southeastern Anatolia	Working	289	63	32

According to Figure 1, the proportional percentage of employed versus unemployed mothers among different statistical regions in Turkey is illustrated in the bar chart. Western Marmara has nearly complete symmetry, making it a distinguishing feature in the dataset and stands out as the highest employment rate. The maternal employment rate (49.8%) and the non-working rate (50.2%) are statistically equal exclusively in this region. On the other hand, in the Eastern and Southern East regions of Turkey, where mother employment falls to extremely low levels, demonstrate the most severe difference. Southeastern Anatolia has the lowest workforce engagement with a 91.7% of mothers not working and only 8.3% employed. Similar variations can be seen in Middle East Anatolia (85.9% non-working) and Northeastern Anatolia (86.0% non-working). In addition to that, percentages are

comparatively low in populated or developed regions like Western Anatolia (20.3%) and Istanbul (24.5%).

Moreover, from the bar graph in Figure 2, the results indicates that while the 50–65 age group dominates the overall workforce volume, maternal employment spikes proportionately during the 40–49 life period. Additionally, the substantial number of working mothers over 66 indicates unique structural features of Turkey's female labour market.

Additionally, from the outputs of the Table 2, it is seen that most notably, non-working mothers, 92.2% have either no formal education (54.4%) or only a primary school education (37.8%). Furthermore, majority of the employed mothers with 78.8% fall into both of the lowest educational groups. This suggests that low-skill, informal, or agricultural labour accounts up a substantial portion of maternal employment. Moreover, at the secondary education level, the two groups start to diverge more. High school graduates represent 8.7% of the working population but just 3.5% of the non-working population. Whereas highly educated mothers correspond to only 0.5% of the non-working group. Particularly, fundamental twist is revealed by examining the total counts (N). The only group in which the total number of working mother's (N=878) greatly outweighs the number of non-working mothers (N=159) is higher education. Below, the regional differences in education level plot is given.

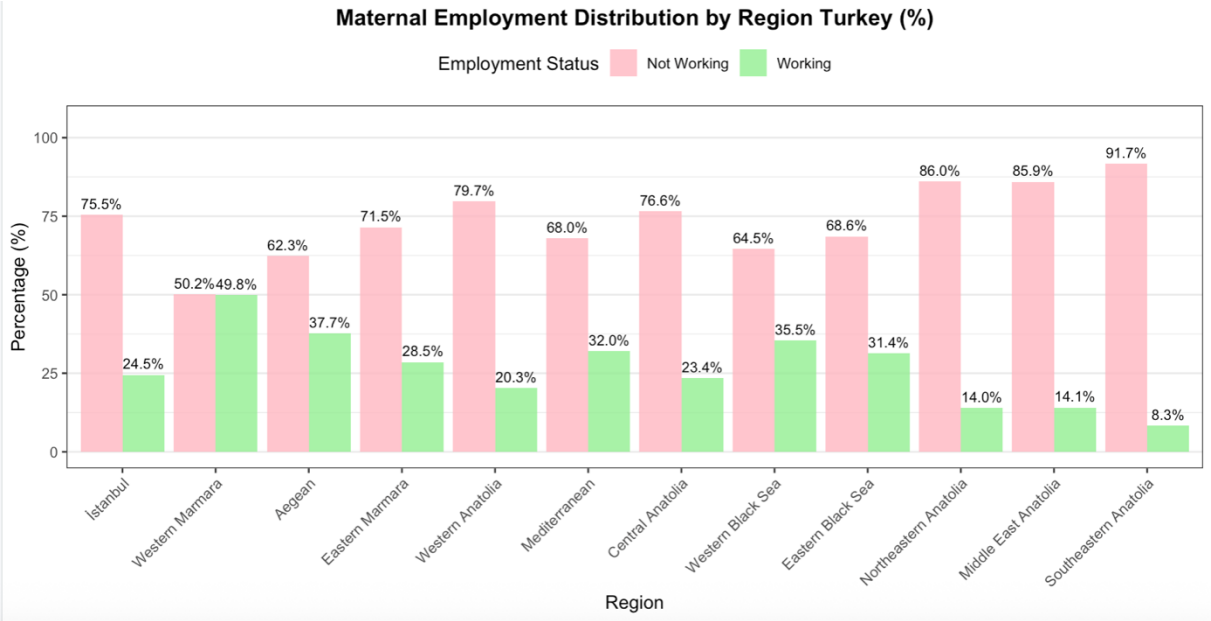

Figure 1. Maternal Employment Distribution by Region in Turkey

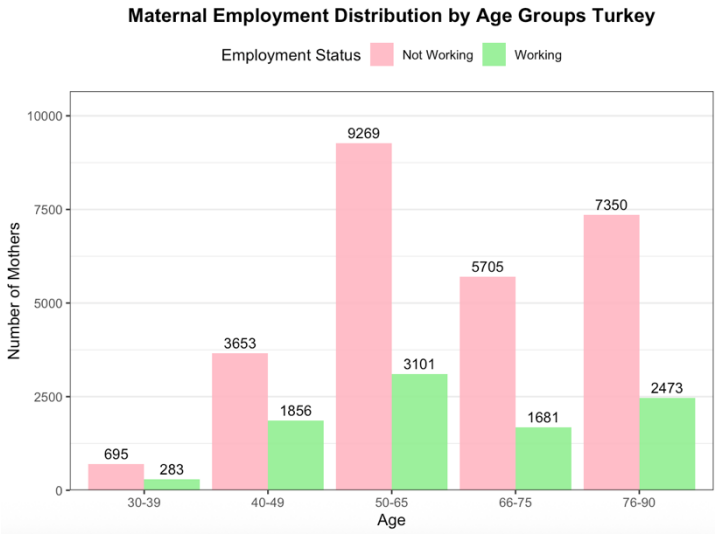

Figure 2: Maternal Employment Distribution by Age Groups. Mothers are categorized into five age brackets to demonstrate workforce participation across different life stages.

From the associated figure, it is observed that a combination of "No Formal Education" and "Primary School" contributes to composed between 80% and 95% of all mothers, even among those living in the most developed areas. The percentage of mothers without formal education is lowest in Western Anatolia (38.2%), then followed by Istanbul (41.1%). Furthermore, the highly dense fundamental bars of middle school, high school, and higher education are displayed in these areas. These western regions are only regions where secondary and postsecondary education continue to have substantial presence, despite the fact that these educational tiers are still relatively small. On the other hand, Southeastern Anatolia has a remarkably low 78.0% of mothers lack formal education while another 17.2% have barely finished elementary school. The observed differences in maternal employment engagement are precisely reflected in the regional distribution of maternal education.

Table 2. Maternal Education Levels

	Working		**Not-Working**	
Education Level	Percentage %	N (Count)	Percentage %	N (Count)
No Formal Education	44.8 %	5022	54.4 %	16777
Primary School	34 %	3805	37.8 %	11663
Middle School	4.7 %	523	3.8 %	1162
High School	8.7 %	975	3.5 %	1079
Higher Education	7.8 %	878	0.5 %	159

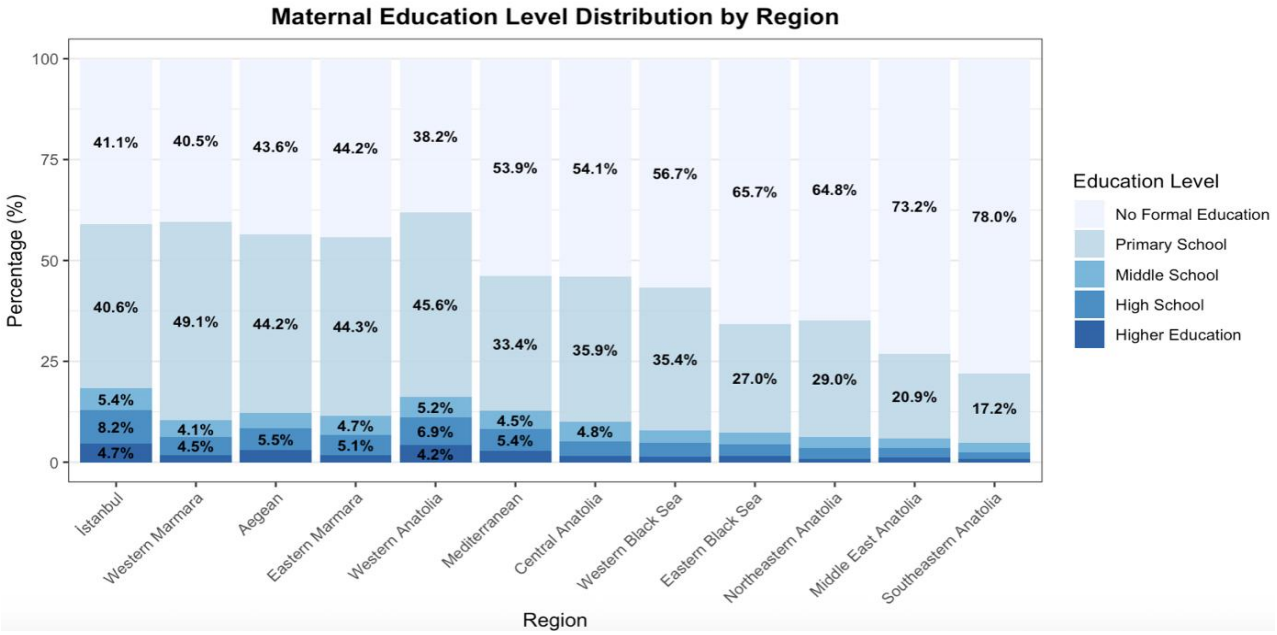

Figure 3. Maternal Education Distribution by Regional Groups

Furthermore, as seen in the Table 3, we have examined the number of families with children. In the TAYA data set, there exists three different categories for that. Thus, three survey questions were used to produce a binary variable representing child status: biological child, stepchild, and adopted child. If a respondent stated that they had at least one biological, step, or adoptive child, they were categorized as having children.

Table 3. Having a Child

	Biological Child		**Step-Child**		**Adopted Child**	
	N (Count)	%	N (Count)	%	N (Count)	%
Yes	30087	71.6%	889	2.1%	142	0.3%
No	11956	28.4%	41154	97.9%	41901	99.7%

Biological child ownership serves as the main criterion for creating the family-centred sample. Among the respondents in the larger sample, 71.6% (N = 30,087) confirmed they had at least one biological kid. On the other hand, childless households are represented by the 28.4% (N = 11,956) are not included in family analysis. Only 2.1% (N = 889) of the participants reported having a stepchild, which makes blended households a small portion of the sample. Lastly, adoptive households are the most uncommon family pattern in the population with 0.3%. After that we examined the happiness level across families who has a child. In order to investigate whether family happiness varied based on child status, a five-point rating system was used to determine family well-being, with 1 being “very happy” and 5 representing “unhappy”. Figure 4 represents the bar graph of this examination assessment.

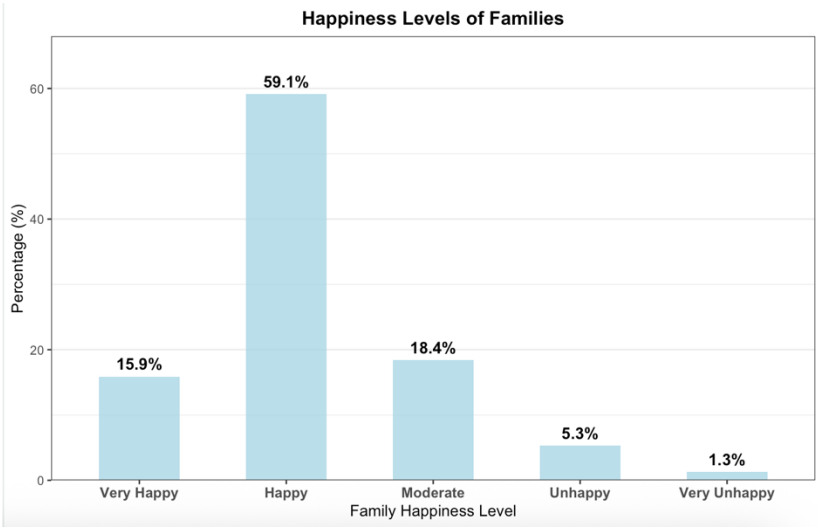

Figure 4. Family Happiness Levels

In the same figure, it is also seen that 59.1%, more than half of the sample, indicate that they are "Happy" in their family life. Alongside with the 15.9% who describe themselves as "Very Happy," precisely three-quarters (75.0%) of families with children have a positive opinion of their household setting. The above implies that the basic notion of family well-being is still robustly high, regardless of any socioeconomic or workforce disparities previously highlighted. Moreover, the "Moderate" category accounts for a large proportion of the population (18.4%), this group stands for neutrality. On the other hand, there is statistically little expressed unhappiness inside the family system. Only 5.3% of participants categorize their families as "Unhappy," while a negligible 1.3% say they are "Very Unhappy." Only 6.6% of the sample as a whole is accounted for in the corresponding negative end of the distribution. Furthermore, there existed one more variable, that called “Being a Family”. They asked to the participants following question: "A child completes the essence of being a family," using a typical 5-point Likert scale that corresponds to (1) "Strongly Disagree" to (5) "Strongly Agree." This psychological and cultural aspect enables a more thorough analysis of the traditions surrounding parenthood in Turkey. Figure 5 illustrates the distribution of the answers to the question.

From the plot, it is seen that the distribution's most notable feature is the substantial number of respondents in the agreement groups. Overall, 91.7% of respondents from families with children believe that a child is crucial to complete the meaning of a family, including a clear majority of 76.3% "Agree" and an additional 15.4% "Strongly Agree." This severe difference draws attention to a deeply established cultural norm that views childbearing as the essential completeness of the household unit rather than just a stage of life. On the other hand, the data shows that there is almost no cultural disagreement with the statement. Nevertheless 3.1% of the families "Disagree," and a low 0.4% "Strongly Disagree." Hence, across typical family units in Turkey, a child's pivotal role is observed.

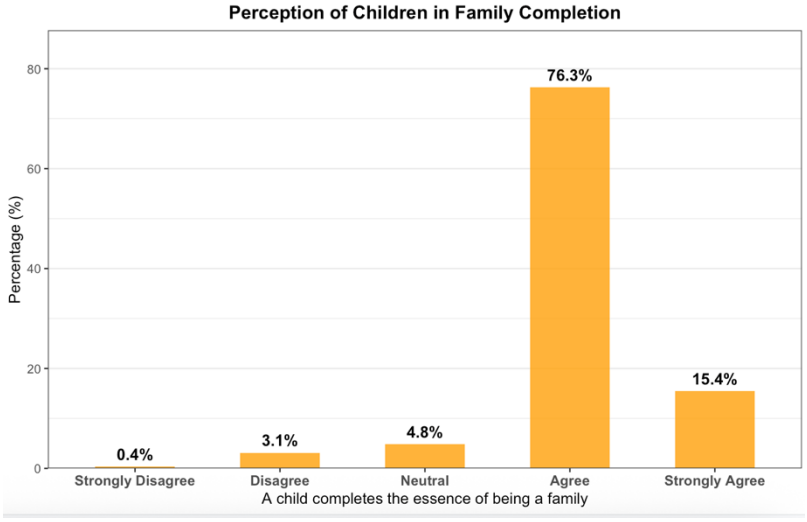

Figure 5. Being a Family

Inferential Statistical Analysis

In order to statistically confirm the descriptive data, a number of Chi-Square tests for independence were performed. Each pair's effect size was measured using Cramer's V and classified as either negligible ($V < 0.10$) or moderate ($V > 0.10$). The findings clearly distinguish between sociocultural attitudes and the structural factors that influence employment and family happiness. Table 4 lists the associated statistics.

Table 4. Statistical Results

Predictor	Outcome	Chi-Square	p-value	Cramer's V	Strength
Region	Mother's Employment	1854	<0.001	0.247	Moderate
Mother's Education	Mother's Employment	767	<0.001	0.159	Moderate
Region	Mother's Education	2194	<0.001	0.135	Moderate
Mother's Employment	Family Happiness	53.4	<0.001	0.042	Negligible
Mother's Employment	Being a Family	4.16	0.3848	0.012	Negligible

The structural factors and sociocultural reality of working mothers in Turkey are clearly in contrast according to the inferential study. The greatest impact is shown by structural characteristics; maternal educational ($V = 0.159$, $p < 0.001$) and geographic region ($V = 0.247$, $p < 0.001$) both have a statistically significant and moderate relationship within employment involvement. On the other hand, the analysis implies that fundamental family dynamics are essentially unaffected by a mother's employment level. Although there is a mathematical difference in individual family satisfaction, the real effect size is extremely small ($V = 0.042$). Furthermore, when it comes to the argument that a child completes the essence of a family, there is no statistically significant difference ($p = 0.3848$) between working and non-working mothers. These findings display that although systemic socioeconomic limitations significantly influence maternal employment status, working is not associated with a significant difference in overall household happiness or deviation from standard family values. Thus, Figure 6 shows the heat map of the significant variables.

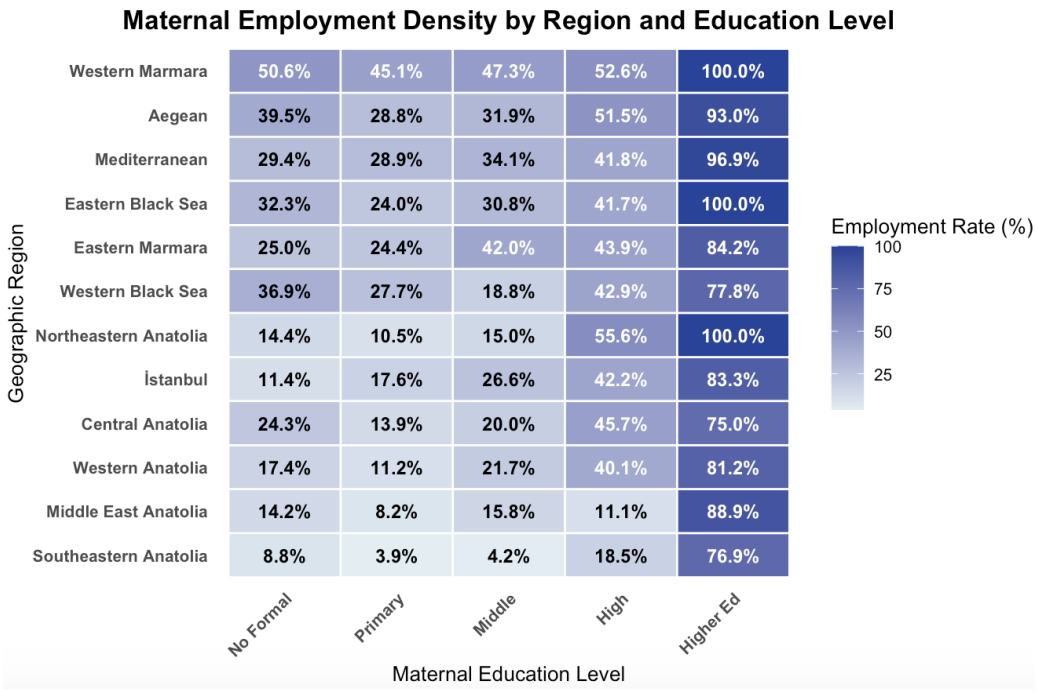

Figure 6. Heat Map of the Significant Variables

Thereby, from Figure 6 is it observed that having a higher education degree provides extremely high maternal employment rates, ranging from 75.0% to 100.0%, regardless of the location whether in the less developed Southeastern Anatolia or the highly industrialized Western Marmara. This graphically demonstrates how postsecondary education is the ultimate driver of workforce participation, successfully overcoming regional disadvantages. Unfortunately, mothers with "Primary" or "No Formal" education in Southeastern and Middle East Anatolia are facing very low employment rates. In some regions, being uneducated is equivalent to being almost completely excluded from the official work force. In conclusion, Maternal employment is driven by a variety of factors, including education and geographic location.

STATISTICAL ANALYSIS OF BHPS DATA

Description of BHPS Data

In the British Household Panel Survey there are 9 different datasets of different type of information: indresp, child, parstyle, hhresp, egoalt, newborn. We only consider mother demographics to define their work status and their linked child and all information about child with focusing on child's well-being questions. The people in a household over 15 years old are considered as responsible individuals. In our project we are focusing on the women who has child under age 15 and their children in the same house. The aim is to discover the relation about mother's job status with the child's overall well-being in the house. We collect only the children's data whose age is under 15 since British Household Panel Survey (BHPS) consider children over 15 as capable of making decisions and responsible in the society.

Hereby, firstly, we observe the descriptive statistics regarding maternal employment status. We also classify the sample by geographical region across the UK to consider potential regional differences in workforce participation.

As shown in Table 5 there are overall 6,867 women in the 4 regions across the UK. In England we have the majority of the dataset, while in Northern Ireland, Scotland, Wales contain 398, 465, 405 data, respectively. We see the mean age of each group regarding their employment status and regions. We can observe that the mean age of working mothers across all groups is approximately 40 years.

Also, in Table 5 we can observe an important outlier where we can see the mother in 90 years of age as the maximum value. There are a few possible explanations for this anomaly. The first is that sometimes the biological grandmother is the main responsible for their grandchild. Therefore, they are linked with them as their main parent, so we see them as their mothers since we filtered all the parents as if they are female and they adopt or have a child. Second, this extreme value could be the result of a data entry error regarding the mother's age. Third, it is possible that the individual legally adopted the child at an advanced age. There are only 7 such pair and 4 of them is the grandmothers.

Table 5: Maternal Age Distribution by Region and Employment Status

Region	Employment Status	N (Count)	Mean Age	Std. Dev.	Min Age	Max Age
England	Not Working	1934	37.84	8.78	16	90
	Working	3665	40.60	7.10	19	73
Northern Ireland	Not Working	105	37.21	10.41	18	70
	Working	293	40.01	7.41	21	59
Scotland	Not Working	110	37.72	7.54	17	56
	Working	355	41.12	7.02	25	73
Wales	Not Working	123	39.13	9.43	17	63
	Working	282	39.20	6.29	23	61

In Figure 7 the amount of employed and non-employed mother distribution is shown. Furthermore, we can get from the figure that 67.5% of mothers are working while 32.5% is not working. In each region in UK, we can see that 3658 of mothers works while 1915 are not in England, 354 of mothers work while 110 are not in Scotland, and for Wales and Northern Ireland, the employed mothers are 282, 293 and 123, 100 of them are not working, respectively.

In Figure 8 there exists 4 different age groups to consider the distribution of age. In the dataset the majority of women are in 30-39 and 40-49 years old. In order, 282 women under 30, 1713 women between ages 30-39, 2150 women between ages 40-49 and 441 women over 50 are working. However, 342 women under 30, 1052 women in 30-39, 709 women in 40-49, 145 women in 50-65 are not in workforce.

In Table 6 we look at the percentages of working and not working mothers, respectively, to their other characteristics. Firstly, if we look at the percentage of single parent in a household with their employment status (where the BHPS takes single mothers and their child in a house as a family and consider them as household responsible in such case), we see 31% of single women are working. Secondly, we categorize the health variable whether the adult has a Long-standing Illness/Disability so that we can also link these participants as chronic patients when their answers are yes. We can see in total 20% of working mothers suffer from a long-standing disease. In the third row, we look at the variable klm_hiqual_dv / klm_higheduk to determine whether women have a college degree. We find that in total 62.3% of them have a degree in the dataset of employed mothers. Finally, in the last row we check the working hours (using jbhrs variable) and they are checked if it is higher than 30 hours in a week or not in order to understand whether their job is a full time or part time job.

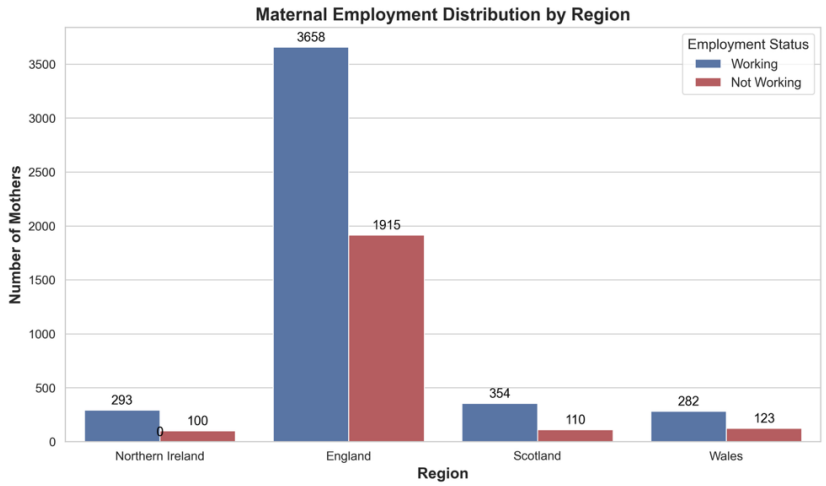

Figure 7: Maternal Employment Distribution Across UK Regions.

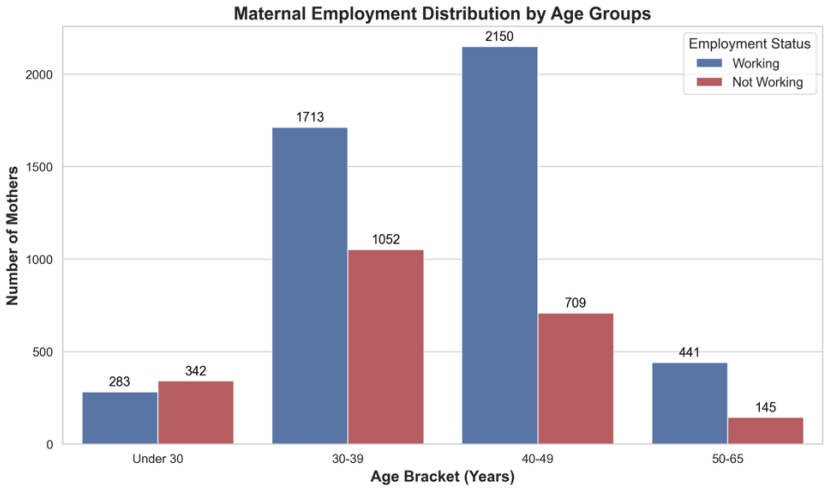

Figure 8: Maternal Employment Distribution by Age Groups.

Table 6: Maternal Characteristics by Employment Status

	Working Mothers		Not Working Mothers	
Characteristic	**%**	**N**	**%**	**N**
Single Parent Household	31%	824	38.4%	430
Long-standing Illness/Disability	20.1%	538	29.6%	333
Higher Education (Degree)	62.3%	1656	40.1%	437
Full-Time (30+ hours/week)	53.4%	1190	–	–

Description of Child Data

In this section the child data and all questionnaires are described by using descriptive statistics. The full description of variables used in the analysis is presented in Table 7.

Table 7: Description of Variables in BHPS Dataset

Category	Variable Name	Description / Item Label
Identifiers	pidp_child	Unique cross-wave personal identifier for the child
	pidp_mother	Unique cross-wave personal identifier for the mother
	fimnnet_dv	Unique cross-wave household identifier
Demographics	klm_hiqual_dv	Mother's highest qualification (Education Level)
	Edu_Group	"Derived: Categorical maternal education (Low
	klm_jbstat	Current economic activity / Employment status
	Emp_Status	"Derived: Categorical employment status (Working
	klm_jbhrs	Total weekly hours worked in all jobs
	klm_fimnnet_dv	Total household net monthly income
	klm_sclfsato	Overall life satisfaction score
Child Routines	klm_bedreg	Regularity of child's bedtime
	klm_mealsreg	Regularity of child's mealtimes
	klm_cdcread	Frequency of reading to the child
	klm_cdoread	Frequency of telling stories to the child
	klm_cdtvvidhrs	TV/Video hours on weekdays
	klm_cdtvvidhrw	TV/Video hours on weekends
Child Outcomes	klm_chsdqa	SDQ: Emotional symptoms score
	klm_chsdqd	SDQ: Conduct problems score
	klm_chsdqe	SDQ: Hyperactivity/inattention score
	klm_chsdqf	SDQ: Peer relationship problems score
Parenting (DV)	klm_psdqa_dv	"Derived: Maternal Warmth and Support score (Authoritative)"
	klm_psdqb_dv	"Derived: Maternal Regulation / Control score (Authoritarian)"
	klm_psdqc_dv	"Derived: Maternal Physical/Verbal Conflict score (Authoritarian)"
PSDQ Items	klm_ps1	I am responsive to our child's feelings or needs
	klm_ps2	I yell or shout when our child misbehaves
	klm_ps3	I have warm and intimate times together with our child
	klm_ps4	I spank when our child is disobedient
	klm_ps5	I give praise when our child is good
	klm_ps6	I allow our child to give input into family rules
	klm_ps7	I grab our child when being disobedient
	klm_ps8	I help our child to understand the impact of behavior
	klm_ps9	I encourage our child to talk about his/her troubles
	klm_ps10	I use physical punishment as a way of disciplining
	klm_ps11	I give comfort and understanding when our child is upset
	klm_ps12	I scold and criticize to make our child improve
	klm_ps13	I give our child reasons why rules should be obeyed
	klm_ps14	I punish by taking privileges away with little explanation
	klm_ps15	I express affection by hugging
	klm_ps16	I punish by putting our child off somewhere alone
	klm_ps17	I take our child's desires into account
	klm_ps18	I slap our child when the child misbehaves
	klm_ps19	I emphasize the reasons for rules
	klm_ps20	"I state: ""because I said so
	klm_ps21	I explain how we feel about good/bad behaviour
	klm_ps22	I threaten our child with punishment more often than giving it
	klm_ps23	I take into account our child's preferences in family plans
	klm_ps24	I explode in anger towards our child
	klm_ps25	I encourage our child to freely express themselves
	klm_ps26	I scold or criticize when behaviour doesn't meet expectations
	klm_ps27	I state punishments and do not actually do them
	klm_ps28	I give in to our child when the child causes a commotion
	klm_ps29	I show respect for our child's opinions
	klm_ps30	I spoil our child
	klm_ps31	I ignore our child's misbehaviour
	klm_ps32	I bribe our child with rewards to bring about compliance
Development	klm_brfedstill	Infant still being breastfed (0-5 age group)
	klm_cdvlq	Child participates in games with others
	klm_cdvlr	"Child engages in ""playing pretend"""

Category	Variable Name	Description / Item Label
	klm_chrisk	General child health risk indicator
	klm_chdelay	Concerns regarding developmental delay

In Table 8 the child's general information about age and region are given. Since questions in the dataset are separated for different age groups via children between ages 0 to 15 and since they categorized them as 0-4, 5-10, 11-15 years old in the variable klm-agegr5, we used the same classes in our analyses. We also looked at their demographics by looking at differences of their mothers' employment status. Firstly, for children of working mothers, 883 of them are under 5, 1727 of them between 5-10, 1757 of them are between 11-15. For non-working mothers, it is observed that 692 of their children are under 5, 741 of them are between 5-10, and 669 of them are between 11-15, which corresponds to totally 6469 children.

Table 8: Child Demographics by Mother's Employment Status

Characteristic	Working Mothers		Not Working Mothers	
	%	N	%	N
Age Group				
0-4 Years (Pre-school)	20.2%	883	32.9%	692
5-10 Years (Primary)	39.5%	1727	35.3%	741
11-15 Years (Adolescence)	40.2%	1757	31.8%	669
Region				
England	79.8%	3486	84.5%	1777
Wales	6.0%	264	5.6%	118
Scotland	7.6%	333	4.9%	103
Northern Ireland	6.5%	284	4.9%	104

Note: N represents the actual number of children in each category. Percentages (%) are calculated within the respective maternal employment group (Working vs. Not Working). Children over 15 years of age are excluded from this dataset.

In Table 9 we look at child routines questions for different age groups since not all questions are asked for all age groups. For the questions as child meal and sleeping routines (looking at variable mealsreg and bedregs) there are only children between ages 0 and 10. We can see for children under age 5 the answer for the question" Children has meals at regular time" is yes for the 47%. Also, for reading routines described as "cdcread" in the questionnaire only children under 10 years old are considered.

Table 9: Distribution of Child Routines by Age Group Percentage (%)

Routine Category	0-4 Years (%)	5-10 Years (%)	11-15 Years (%)
Child has meals at regular times			
Yes, always	47.0%	52.5%	-
Yes, usually	42.8%	39.7%	-
Yes, sometimes	9.5%	7.7%	-
No, never or almost never	0.7%	0.2%	-
Child goes to bed at regular time			
Yes, always	44.1%	44.0%	-
Yes, usually	44.7%	46.0%	-
Yes, sometimes	8.9%	8.5%	-
No, never or almost never	2.3%	1.5%	-
Parent reads to child			
Every day	63.3%	42.1%	-
Several times a week	21.1%	30.9%	-
Once or twice a week	10.4%	14.0%	-
Once or twice a month	2.6%	5.1%	-
Less often	2.3%	4.9%	-

Not at all	0.3%	2.9%	-

Note: Percentages are calculated within each age group based on valid responses. Each column section sums to 100%. Hyphens (-) indicate that the specific question was not asked for that age group due to survey skip logic.

Table 10: Comprehensive Early Childhood Markers (0-4 Years) by Maternal Employment

Characteristic	Working (N)	Not Working (N)
Still Breastfed		
Yes	24	13
No	43	15
Learn: Participates in games		
Yes	174	95
To some extent	19	9
No	2	5
Learn: Playing pretend		
Yes	177	90
To some extent	15	14
No	3	5
Concern about developmental delay		
Yes	3	7
No	5	3
Child has health risk/disability		
Yes	2	4
No	6	3
Parent reads to child		
Every day	130	65
Several/week	44	21
Once/twice/week	16	16
Not at all	1	0
Goes to bed at regular time		
Never	4	3
Sometimes	15	12
Usually	86	50
Always	90	44

In Table 10, we look at babies' routines. In the dataset newborn some mothers are asked for their babies' general routines. This part of the dataset is small since it can be expected that children under age 5 is not a big part of dataset. Either the child is still breastfed (looking at variable brfedstill), or if the children has learned to participate in games, playing pretend has been asked. Also, there are some general questions as concerns about development delay, and health risks. In the table it is separated again for working and not working mothers. Also, this table contains all the possible child well-being questions for children under age 5.

Inferential Statistical Analysis of BHPS

First of all, Chi-square goodness of fit test applied to a dataset of parenting style questions on Table 11 by using the following null hypothesis.

- **Null Hypothesis** (H_0): The observed data follows the expected theoretical distribution (e.g., a uniform or normal distribution).

- **Statistical Result** ($p < 0.001$): This result indicates that the null hypothesis is strongly rejected. In the context of this study, it implies that the participants' responses do not show a random distribution; instead, they exhibit specific patterns or clusters related to Parenting Styles.

Table 11: Chi-square Goodness-of-Fit Test on Parenting Style Questions

Question	Valid N	Categories Answered	Chi-Square
KLM_PS1	2955	5	4540.34
KLM_PS2	2827	5	9472.79
KLM_PS3	2824	5	1322.83
KLM_PS4	2824	5	1577.12
KLM_PS5	2824	5	3251.46
KLM_PS6	2824	5	10607.29
KLM_PS7	2824	5	4717.13
KLM_PS8	2821	5	1367.05
KLM_PS9	2824	5	1140.31
KLM_PS10	2824	5	9348.49
KLM_PS11	2821	5	1713.21
KLM_PS12	2821	5	6343.63
KLM_PS13	2821	5	2315.27
KLM_PS14	2821	5	3370.63
KLM_PS15	2821	5	4241.69
KLM_PS16	2821	5	3615.72
KLM_PS17	2820	5	1553.63
KLM_PS18	2821	5	3134.74
KLM_PS19	2821	4	6604.00
KLM_PS20	2821	5	3735.23
KLM_PS21	2821	5	3529.10
KLM_PS22	2819	5	1515.94
KLM_PS23	2817	5	2486.03
KLM_PS24	2821	5	1187.24
KLM_PS25	2821	5	5995.73
KLM_PS26	2819	5	6024.16
KLM_PS27	2821	4	2257.16
KLM_PS28	2819	5	10588.77
KLM_PS29	2821	5	2636.63
KLM_PS30	2819	5	3028.67
KLM_PS31	2821	5	4973.78
KLM_PS32	2821	4	8131.14

Chi-Square Goodness-of-Fit test evaluate whether the observed responses of parenting styles questions distributed evenly. We found that p-values are less than 0.001 which is the significance level for all questions. This means that all values of parenting style questions in the dataset is not evenly distributed, null hypothesis rejected, so there are some statistically significant concentrations of preferences toward specific options for every question.

Table 12: Chi-square Goodness-of-Fit Test for General Variables

Variable	Original Column	Valid N	Categories	Chi-Square	p-value
Employment Status	klm_jbstat	22091	2	1369.83	< 0.001
Marital Status	klm_marstat	21982	2	6535.54	< 0.001
Higher Education	klm_highed uk	14	2	2.57	0.1088

Urban/Rural	klm_urban_dv	20987	2	9980.83	< 0.001
Parent Illness	klm_health	21899	2	8412.55	< 0.001
Life Satisfaction	klm_sclfsato	21475	7	20038.96	< 0.001
Highest Qualification	klm_qfhighoth	10	5	2.00	0.7358
Child Sex	klm_sex_child	22116	2	45.22	< 0.001
Living w/ Parents	klm_livpar	22119	2	20621.25	< 0.001
Child Illness	klm_cddis	1845	2	951.56	< 0.001
Region	klm_region_child	22119	4	39432.22	< 0.001
Child Age Group	klm_agegr5_dv	20549	3	1490.86	< 0.001
Still Breastfeeding	klm_brfedstill	348	2	62.94	< 0.001
Child Health	klm_cdcond	2038	5	1770.57	< 0.001
Regular Meals	klm_mealsreg	1846	4	1539.94	< 0.001
Regular Bedtime	klm_bedreg	1844	4	834.85	< 0.001
Screen Time (Wd)	klm_cdtvvidhrs	1838	5	2545.77	< 0.001
Screen Time (We)	klm_cdtvvidhrw	1839	5	1169.25	< 0.001
Happy in School	klm_cdphsc	1539	8	1732.58	< 0.001
Reading Freq	klm_cdcread	2033	6	2158.40	< 0.001
SDQ Behavior (A)	klm_chsdqa	1596	3	784.56	< 0.001
SDQ Behavior (D)	klm_chsdqd	1663	3	839.55	< 0.001
SDQ Behavior (E)	klm_chsdqe	1661	3	134.58	< 0.001
SDQ Behavior (F)	klm_chsdqf	1664	3	1181.92	< 0.001
SDQ Behavior (G)	klm_chsdqg	1664	3	419.19	< 0.001
SDQ Behavior (I)	klm_chsdqi	1665	3	1159.31	< 0.001
SDQ Behavior (K)	klm_chsdqk	1657	3	1289.37	< 0.001
SDQ Behavior (L)	klm_chsdql	1660	3	2058.08	< 0.001
SDQ Behavior (M)	klm_chsdqm	1658	3	1241.65	< 0.001
SDQ Behavior (N)	klm_chsdqn	1659	3	1545.59	< 0.001
SDQ Behavior (P)	klm_chsdqp	1591	3	222.31	< 0.001
SDQ Behavior (R)	klm_chsdqr	1657	3	1917.41	< 0.001
SDQ Behavior (X)	klm_chsdqx	1657	3	674.87	< 0.001
SDQ Behavior (W)	klm_chsdqw	1573	3	1342.03	< 0.001
SDQ Behavior (Y)	klm_chsdqy	1588	3	291.63	< 0.001

For general information that we have throughout the project, again chi-square test is applied on Table 12. Only for Higher Education and Highest Qualification the p-value shows a higher result due to valid amount of data.

For this table, also we can see the similar result except for the highest qualification and higher education questions. Such result is observed due to lack of information (small amount of dataset for these questions).

Then, a series of Chi-square tests of independence was applied to understand the relationship between socio-demographic variables (Employment, Region, and Marital Status) and parenting style dimensions (parenting style questions and parenting score questionnaires). Also, the Cramer's V results calculated to see the effect more clearly Cramer's V results are between 0 and 1.

The results indicate that socio-demographic factors have a statistically significant impact on parenting styles, since most p-values are less than 0.001. In particular, *Employment* and *Region* can be seen as the most influential predictors, showing a strong association with questions such as PS3 and PS4 (Cramer's V ranging from 0.384 to 0.682). However, while *Marital Status* remains statistically significant, its relationship with parenting styles is generally negligible, showing that employment status and region play a more significant role in parenting style questions in the dataset. Later, a similar test was applied to Employment Status to Reading Frequency, School Happiness, Marital Status, and SDQ test results.

Similar test is applied to SDQ for parents (in our case, for mothers). We found that the strongest associations were observed between Employment status and Reading Frequency (V=0.336). Similar result obtained for between Region and Reading Frequency (V=0.308). Other relationships, such as the impact of Marital Status on Behaviour (SDQA) or Employment on School Happiness, has shown more moderate, negligible, effect.

Table 13: Cross-Tabulation Test on Parenting Styles

Predictor	**PS Question**	**Valid N**	**Chi-Square**	**p-value**	**Cramer's V**	**Strength**
Employment	KLM_PS3	2823	1318.07	< 0.001	0.682	Strong
Employment	KLM_PS4	2823	933.67	< 0.001	0.574	Strong
Region	KLM_PS3	2792	883.20	< 0.001	0.561	Strong
Employment	KLM_PS1	2954	904.81	< 0.001	0.552	Strong
Region	KLM_PS4	2792	414.69	< 0.001	0.384	Strong
Marital Status	KLM_PS3	2823	155.96	< 0.001	0.232	Moderate
Marital Status	KLM_PS4	2823	104.26	< 0.001	0.188	Moderate
Region	KLM_PS1	2923	94.87	< 0.001	0.176	Moderate
Employment	KLM_PS2	2826	41.11	< 0.001	0.115	Moderate
Marital Status	KLM_PS1	2954	26.69	< 0.001	0.088	Negligible
Marital Status	KLM_PS2	2826	15.93	0.0031	0.065	Negligible
Region	KLM_PS2	2795	14.85	0.0050	0.062	Negligible

Table 14: Significant Cross-Tabulations and Effect Sizes

Predictor **Employment**	**Outcome** **Reading Freq**	**Valid N** **2032**	**Chi-Square** **234.89**	**p-value** **< 0.001**	**Cramer's V** **0.336**	**Strength** **Strong**
Region	Reading Freq	1876	182.39	< 0.001	0.308	Strong
Employment	School Happy	1372	62.40	< 0.001	0.212	Moderate
Marital Status	SDQ_A (Behavior)	1588	68.95	< 0.001	0.205	Moderate
Region	School Happy	1101	41.05	< 0.001	0.191	Moderate
Marital Status	School Happy	1365	29.67	< 0.001	0.145	Moderate
Marital Status	Reading Freq	2023	43.36	< 0.001	0.138	Moderate
Marital Status	SDQ_D (Behaviour)	1654	25.19	< 0.001	0.118	Moderate
Region	SDQ_D (Behaviour)	1515	19.04	< 0.001	0.106	Moderate
Employment	Screen Time	1837	23.48	< 0.001	0.103	Moderate
Marital Status	Screen Time	1828	22.12	< 0.001	0.100	Negligible
Region	SDQ_A (Behaviour)	1449	11.35	0.0034	0.080	Negligible

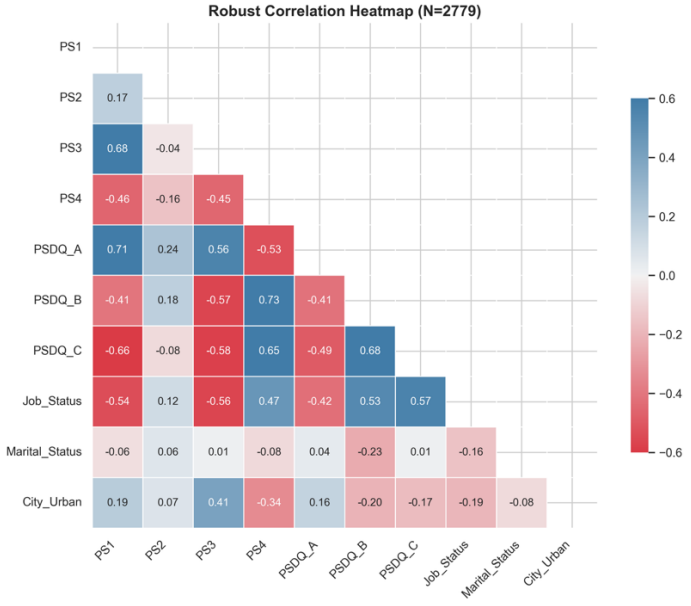

Figure 9: Heatmap analysis for the significant variables we have conducted from Chi-square tests

Additionally, we can see in Figure 9, the most correlated variables are between PSDQB (Maternal Regulation Score) and PS4 (Question: I spank when our child is disobedient) which score is highest (positive relation). Furthermore, the following are also highly positively related: between PSDQA (Maternal Warmth and Support Score) and PS1 (Question: I am responsive to our child's feelings or needs), between PSDQC (Maternal Physical/Verbal Conflict Score) and PSDQB (Maternal Regulation Score), between PSDQC and PS4, between Job Status and PSDQC. Also, there are some negative relations, which is also important, such as between PSDQC and PS1. Similarly, we can see negative correlations between PSDQC with PS3 (Question: I have warm and intimate times together with our child) and with PSDQA. We can also detect negative correlation between PSDQA with PS4, between Job Status with PS1 and PS3 and so on. Other relations closer to 0 either in negative or positive direction which implies no correlation.

On the other hand, in this study, the K-Medoids (Partitioning Around Medoids - PAM) clustering algorithm was applied to understand the natural profiles of the cluster of the dataset. Basically, unlike generally used K-Means algorithm, K-Medoids selects the cluster centres from actual observations (medoids) within the dataset rather than using calculated virtual mean values. Accordingly, K-Medoids makes the algorithm much more resilient to outliers, which typically cause a problem with such large survey data. To determine the optimal number of clusters (K), Silhouette analysis—a fundamental evaluation method in the literature—was applied. See Figure 10)

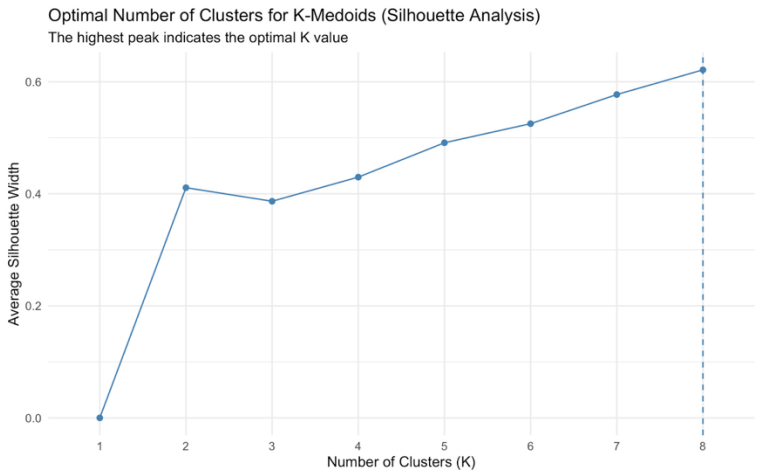

Figure 10: Distance due to different number of clusters

To understand the structural stability and separation of the data, we used the Elbow Method. In this approach we select a range of k values, i.e., number of clusters, and then for each k we run K-Means and calculate WCSS (Within-Cluster Sum of Squares) and determine how far the data point to the cluster centres.

$$WCSS = \sum_{\{i=1\}}^{k} \sum_{\{j=1\}}^{n_i} distance\left(x_j^{(i)}, c_i\right)^2$$

In Figure 11, we observe a sharp change in the direction of k = 4 and k = 5. Whereas due to simplicity in the interpretation of result we selected k = 4 rather than k = 5. Then, for the questions related to parenting style, SDQ scores with job status we applied PAM algorithm using 4 clusters. Moreover, we performed principal component analysis PCA to visualize the high dimensional data onto xy- plane by reducing the dimensions. To address this, Principal Component Analysis (PCA) was employed as a dimensionality reduction technique to project

the n-dimensional data onto a 2D plane.

Thus, in order to understand the Cluster's profiles, we implemented some graphing methods on clusters using original large data.

Figure 13 provides a visualization of mean values of each cluster for each survey question. The middle value 0 gives the overall sample average for the given question, so that we can use standardized scores. Therefore, if mean goes toward to 1 or higher, it means cluster scores higher than the average population on that particular parental behaviour. Similarly, if it goes toward -1 it represents the opposite, that is the cluster tends to have lower than average population on that specific behaviour.

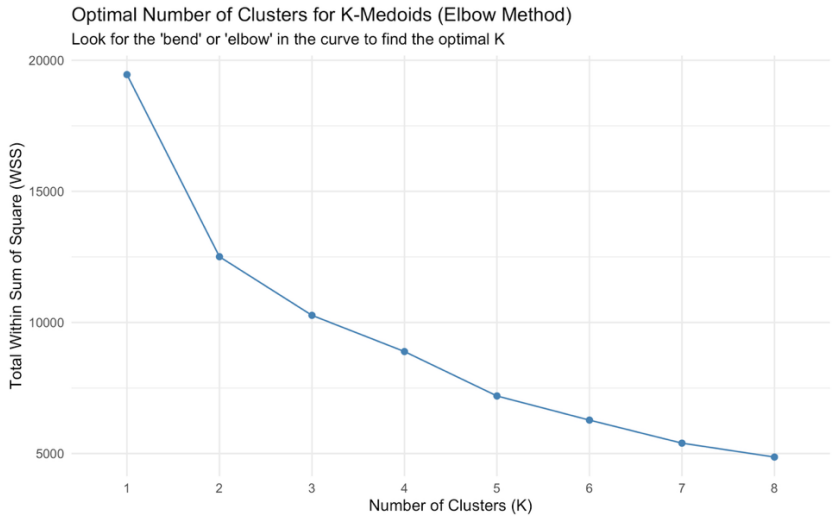

Figure 11: Elbow Curve

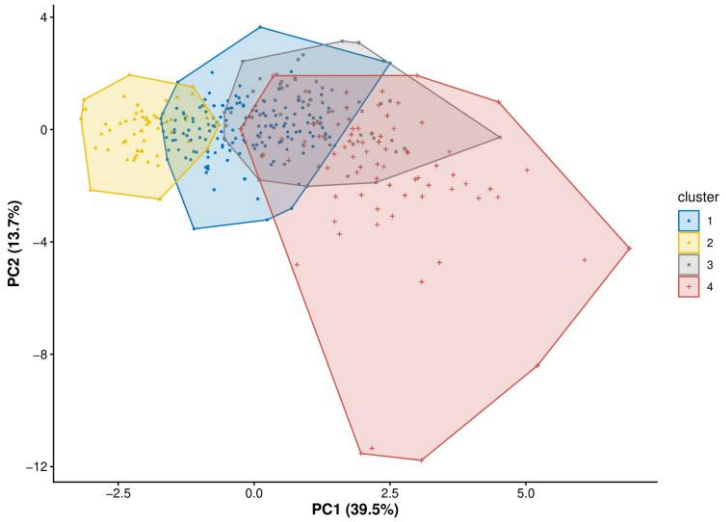

Figure 12: Clustering Result for k = 4

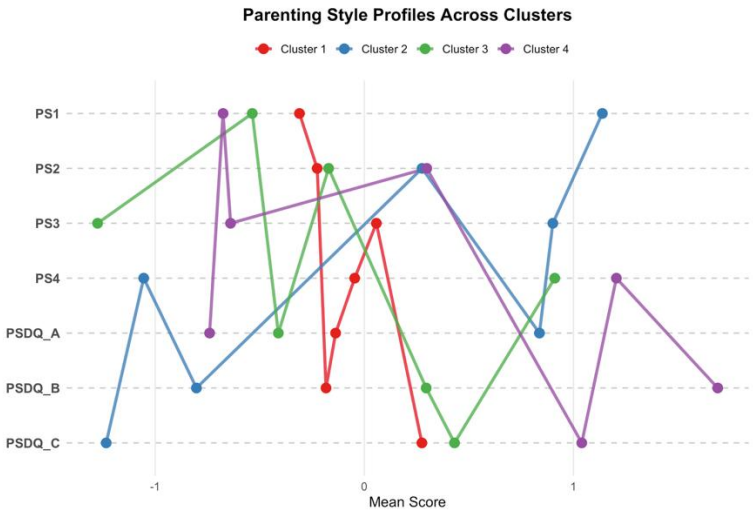

Figure 13: Clustering Profiles

We can then investigate the clusters:

- *The first cluster* (red line) answered all the questions close to the mean value, which means answers closer to the original mean values. Therefore, this cluster might represent a normative group.
- *The second cluster* (the blue line) is characterized by below-average on physical punishment (PS4) and physical/verbal conflict (PSDQC) as well as the lower maternal regulation and control (PSDQB). Whereas they answered high valued answers to maternal warmth (PSDQA) and PS1 (responsiveness to the child's needs), PS2(warm/intimate times) questions.
- *The third cluster* (the green line) answered lower than average to PS3 and PS1 (warmth and intimacy questions). For PSDQA, PSDQB, PSQDC they answered close to 0. On the other hand, they answered a little bit higher to physical punishment survey question PS4.
- *The fourth cluster* (the purple one) answered lower to PS1, PS3, and PSDQA. However, they answered higher to PSDQB, PSQDC and PS4. To understand the other demographic profiles for each cluster we drawn bar charts.

In Figure 14, we can observe that Job Status, Marital Status, Region values are related to each other, and we see the majority of each answer of each survey value. The most obvious difference is, for example, the cluster 4 contain much more single mothers than all other 3 clusters.

DISCUSSION

This study draws on data from the 2021 Research on Family Structure in Türkiye (TAYA) and the British Household Panel Survey (BHPS) to examine the associations of maternal employment with family life, parenting practices, and child-related outcomes in two distinct socioeconomic and institutional contexts. The parallel comparative design provides insight into how these associations are embedded within different national settings. However, because the two datasets do not contain fully equivalent measures, the findings should be interpreted as a contextual comparison rather than as a direct variable-by-variable comparison between the two countries.

Overall, the findings indicate that maternal employment is an important component of family life in both contexts, but its associations with family and child outcomes do not follow a simple or unidirectional pattern. Instead, these associations appear to vary according to educational attainment, geographic region, family structure, parenting practices, and the broader institutional environment. The findings therefore move beyond approaches that treat maternal employment solely as an economic activity and

indicate that its implications for family life should be considered within broader structural and familial conditions.

The findings from the Turkish sample particularly demonstrate the importance of structural inequalities in maternal employment. Maternal employment showed moderate associations with both geographic region and maternal educational attainment. These results indicate that mothers' labor-force participation cannot be explained solely by individual preferences. Rather, it is associated with a broader structural context that includes educational opportunities, regional development, economic conditions, employment opportunities, and prevailing gender norms.

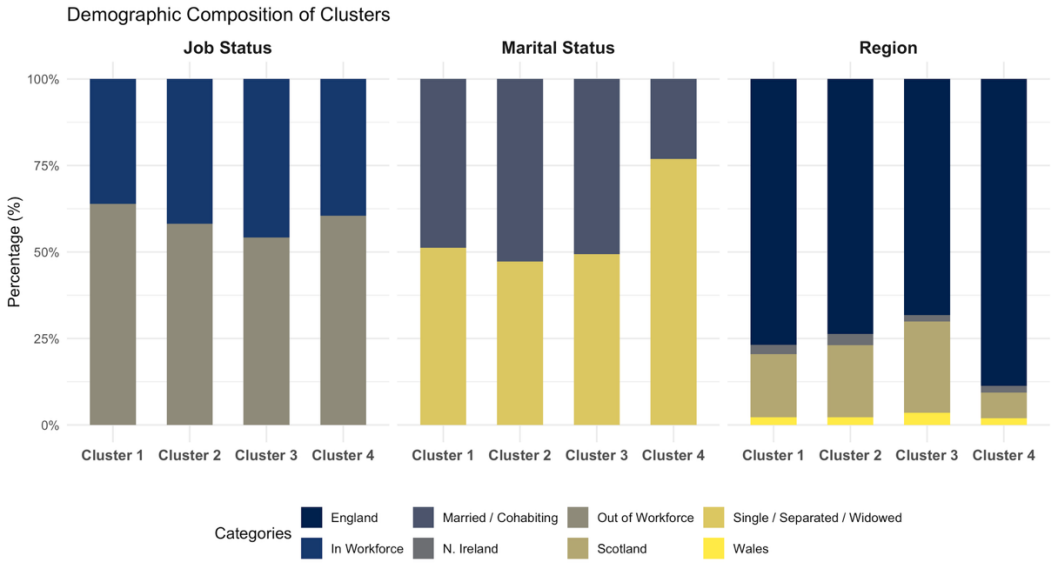

Figure 14: Clustering Demographic Profiles

Although the literature directly examining regional differences in maternal employment in Türkiye remains limited, the role of regional disparities and educational attainment in women's employment and labor-force participation has been widely documented. This general pattern is also consistent with recent statistics reported by the Turkish Statistical Institute. According to TurkStat (2025), women's employment rates vary considerably across geographic regions, with particularly low rates in Eastern and Southeastern Anatolia. The present findings similarly show substantial regional variation and identify the lowest levels of maternal employment in the eastern and southeastern regions of Türkiye.

Another notable finding from the Turkish sample is the prominent role of maternal educational attainment. The heatmap analysis showed that mothers with higher education had relatively high employment rates even in less developed regions. This result suggests that higher educational attainment may help women overcome some of the disadvantages associated with regional inequalities. Education may therefore function not only as a component of individual human capital but also as an important resource that facilitates women's participation in paid employment. This interpretation is consistent with evidence reported by TurkStat (2025), according to which women's labor-force participation and employment rates increase with educational attainment, whereas substantially lower rates are observed among women with lower levels of education.

Nevertheless, educational attainment does not appear to eliminate regional inequalities completely. Mothers with no formal education or only primary education had especially low employment rates in Southeastern and Middle East Anatolia. Maternal employment should therefore be understood as the outcome of the interaction between education and regional conditions rather than as the consequence of either factor alone. Access to employment opportunities, the availability of childcare, local labor-market structures, and gendered expectations regarding care work may contribute to these regional differences.

In contrast to its moderate associations with region and education, maternal employment had only a negligible association with family happiness in the Turkish sample. Although the chi-square test for family happiness was statistically significant, the corresponding Cramér's V value was very small. The statistical significance of this relationship may partly reflect the large sample size and should not be interpreted as evidence of a substantively important difference between employed and non-employed mothers.

Maternal employment was also not significantly associated with the belief that a child completes the meaning of family life. This finding indicates that this cultural attitude did not differ according to mothers' employment status in the present sample. The findings therefore do not support the assumption that women's participation in paid employment necessarily weakens established attitudes toward children and family life. Instead, employment status and traditional family-related values appear to coexist among many respondents.

The findings from the United Kingdom reveal a different pattern. Maternal employment was common in the British sample and was associated with selected parenting practices and child-related outcomes. Employment status was particularly associated with reading frequency and also showed associations with school happiness and screen time. However, these relationships varied in strength, indicating that maternal employment alone does not provide a sufficient explanation of children's routines or well-being.

The association between maternal employment and reading frequency was one of the strongest relationships identified in the British analysis. This finding suggests that employment does not necessarily prevent mothers from engaging in developmentally supportive activities with their children. It may also indicate that the organization and quality of parent–child time are as important as the total amount of time available. Nevertheless, the present analysis does not directly measure either the quality or duration of parent–child interaction. This interpretation should therefore be regarded as a possible explanation rather than as a conclusion directly established by the data.

The implications of maternal employment for child development have long been debated in the literature. Some studies suggest that maternal employment may support children's cognitive, social, and emotional development, whereas others identify potentially adverse associations depending on working hours, employment quality, childcare arrangements, and the child's developmental stage (Bishnoi et al., 2020; Hsin & Felfe, 2014). The present findings are consistent with the argument that maternal employment should not be classified as uniformly beneficial or harmful. Its associations with children's experiences are likely to depend on the conditions under which mothers work and the resources available to families.

The findings also revealed a relatively limited association between maternal employment and children's screen time. This result indicates that children's screen use cannot be explained solely by whether their mothers are employed. Previous research suggests that children's digital-media use is associated with several individual and family-level factors, including parental monitoring, household rules, socioeconomic status, and the child's age (Güven & Yumugan, 2026; Li et al., 2024). Approaches addressing children's screen use should therefore focus on family-wide digital practices and parental guidance rather than treating maternal employment as the principal explanatory factor.

Parenting practices were further examined using PAM cluster analysis, which identified four distinct profiles. These profiles indicate that parenting behaviors cannot be adequately characterized along a single linear continuum. Instead, warmth, responsiveness, regulation, conflict, and disciplinary practices may occur in different combinations.

The second cluster was characterized by relatively high levels of warmth and support and relatively low levels of physical discipline and conflict. This profile resembles the authoritative parenting style described in the literature. In contrast, the fourth cluster combined relatively low warmth with higher levels of control, conflict, and physical discipline and therefore more closely resembled an authoritarian parenting pattern. These labels should nevertheless be interpreted cautiously because the clusters are empirical profiles derived from the variables included in the analysis rather than definitive classifications of individual families.

The cluster analysis also demonstrates that employment status does not correspond to a single parenting pattern. Mothers with similar employment characteristics may differ considerably in warmth, regulation, conflict, and disciplinary practices. Parenting behavior is therefore likely to reflect the interaction of employment conditions with marital status, socioeconomic resources, family relationships, parental beliefs, and other contextual characteristics. This heterogeneity would have been obscured if maternal employment had been examined only as a binary distinction between employed and non-employed mothers.

At a broader level, the findings from Türkiye and the United Kingdom point to a common conclusion despite the differences between the datasets and welfare contexts. Maternal employment is associated with family life and selected child-related outcomes, but it does not operate independently of education, geographic inequalities, family structure, and parenting practices. In Türkiye, the clearest pattern concerns the structural distribution of employment according to education and region. In the United Kingdom, maternal employment is associated with selected dimensions of parenting and children's daily experiences, but these associations vary across outcomes.

These similarities should not be interpreted as evidence that maternal employment functions identically in the two countries. The Turkish and British analyses use different variables, samples, and child- and family-related indicators. Consequently, the study does not establish that the same mechanisms operate in both countries or that the magnitudes of the associations can be directly compared. Rather, the findings show that maternal employment is embedded within country-specific structural and family contexts.

Overall, the study suggests that the relationships among maternal employment, parenting, family functioning, and child well-being are most appropriately understood within a multilayered ecological framework. At the individual level, maternal education and employment characteristics may shape women's opportunities and resources. At the family level, parenting practices, marital status, routines, and parent–child interactions are relevant. At the structural level, regional inequalities, labor-market conditions, childcare provision, and welfare policies influence the conditions under which mothers combine paid employment and family responsibilities. Maternal employment should therefore be understood not as an isolated determinant of family or child outcomes but as one component of a broader system of interacting social, familial, and institutional factors.

CONCLUSION

This study analyzed data from the 2021 Research on Family Structure in Türkiye (TAYA) and the British Household Panel Survey (BHPS) to examine the associations among maternal employment, family characteristics, parenting practices, and selected family- and child-related outcomes in two distinct social and institutional contexts. Because the two datasets do not include fully equivalent variables, the study provides a parallel contextual comparison rather than a direct variable-by-variable comparison between Türkiye and the United Kingdom.

The findings indicate that maternal employment constitutes an important component of family life; however, employment status alone does not adequately explain variation in family functioning, parenting practices, or child-related outcomes. Instead, the observed associations appear to be embedded within a broader context involving educational attainment, geographic region, family structure, parenting practices, and institutional conditions.

The literature has reported both positive and negative associations between maternal employment and child development. The present findings similarly suggest that the relationship is neither simple nor unidirectional. In the Turkish sample, maternal employment was moderately associated with maternal educational attainment and geographic region. By contrast, its association with family happiness was negligible, and it was not significantly associated with the belief that a child completes the meaning of family life. These findings indicate that structural conditions are particularly relevant to understanding differences in maternal employment in Türkiye, whereas employment status does not appear to produce substantial differences in the family-related attitudes examined in this study.

In the United Kingdom sample, maternal employment was associated with selected parenting practices, children's routines, and child-related outcomes, particularly reading frequency. Employment status was also associated with school happiness and screen time, although these relationships varied in strength. Region, marital status, and parenting practices were also associated with several outcomes. In addition, the cluster analysis identified distinct parenting profiles characterized by different combinations of warmth, responsiveness, regulation, conflict, and disciplinary practices. These findings demonstrate that mothers with similar employment characteristics may nevertheless differ considerably in their parenting behaviors.

Taken together, the findings suggest that maternal employment operates within a broader structural and family context rather than functioning as an independent determinant of family or child outcomes. The institutional differences between Türkiye and the United Kingdom provide an important context for interpreting the observed patterns. However, because welfare-regime characteristics were not directly measured or statistically tested, the findings should not be interpreted as demonstrating the effects of welfare regimes themselves.

This study contributes to the comparative family studies literature in several respects. Existing research on maternal employment has frequently relied on single-country data or focused primarily on labor-market and economic outcomes. In contrast, the present study considers evidence from two countries with different family-policy and welfare contexts and examines maternal employment in relation to education, region, family happiness, cultural attitudes, parenting practices, children's routines, and selected child-related outcomes. The use of cluster analysis also contributes to identifying heterogeneity in parenting practices that may be overlooked when maternal employment is treated only as a binary distinction between employed and non-employed mothers.

The findings also offer several implications for social policy. In Türkiye, reducing regional disparities in women's labor-force participation is unlikely to be achieved through employment incentives alone. The findings suggest the importance of increasing women's educational opportunities, expanding access to affordable and accessible early childhood care services, promoting formal and secure employment, and strengthening policies supporting gender equality in paid and unpaid work. Regional differences should also be considered when designing employment and family-support policies.

The findings from the United Kingdom indicate that policies focusing exclusively on maternal employment may be insufficient to support children's well-being. Family-support programs and parent-education initiatives may contribute to strengthening positive parenting practices and parent–child relationships. Policies supporting work–family balance and enabling parents to spend meaningful time with their children may also be relevant. Nevertheless, the present analyses do not directly evaluate the effectiveness of these interventions, and these recommendations should therefore be interpreted as policy implications rather than demonstrated causal solutions.

Despite its contributions, the study has several limitations. First, the analyses are restricted to the variables available in the existing datasets. Consequently, potentially relevant factors—including employment quality, job satisfaction, working schedules, employment security, paternal involvement, household division of labor, childcare quality, and access to informal support—could not be fully incorporated into the analyses.

Second, the Turkish and British datasets differ in their measurement structures, target populations, and available family- and child-related indicators. The findings from the two countries cannot therefore be compared as though they were based on harmonized measures. The Turkish component focuses primarily on maternal employment, family happiness, and cultural attitudes, whereas the British component includes more detailed measures of parenting practices, children's routines, and behavioral outcomes.

Third, the analyses are observational. The Turkish data are cross-sectional, and the present use of the BHPS data does not establish causal relationships. Moreover, many of the reported relationships are based on bivariate chi-square tests and do not control simultaneously for potential confounding factors. Statistically significant associations should therefore not be interpreted as evidence that maternal employment causes the corresponding family or child outcomes. The parenting profiles generated

through cluster analysis are also exploratory and may vary according to the selected variables, coding decisions, and number of clusters.

Finally, the study is limited to two countries. Although Türkiye and the United Kingdom represent contrasting social-policy and family contexts, the inclusion of additional countries with different cultural, labor-market, childcare, and welfare arrangements would allow more comprehensive cross-national analysis. Future research should use harmonized longitudinal data and multivariable models to examine how employment conditions, childcare arrangements, paternal involvement, parenting practices, and family-policy support interact over time.

Overall, the findings suggest that maternal employment alone is not sufficient to explain family functioning or child-related outcomes. Greater attention should be given to the structural conditions shaping women's employment opportunities, families' access to formal and informal support, and the quality of parenting and parent–child relationships. Family and employment policies should therefore adopt a holistic approach that considers the interaction of labor-market conditions, educational opportunities, childcare provision, gender equality, and family support.

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WOMEN'S INTRA-HOUSEHOLD DECISION-MAKING POWER: TURKEY AND THE UNITED KINGDOM

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ABSTRACT

This study examines women's positions within the household in Türkiye and the United Kingdom using two nationally representative datasets: the Turkish Family Structure Survey (TAYA) and the UK Household Longitudinal Study (Understanding Society). Based on approximately 14,400 observations from Türkiye and 16,000 female respondents from the United Kingdom, the study employs descriptive and inferential statistical analyses to examine women's household roles. The Turkish data assess women's participation in household decision-making across housing, expenditures, childcare, and social relations, whereas the UK data evaluate women's household position through indicators of employment, financial wellbeing, family interaction, parenting practices, and housing conditions. The findings show that women occupy active positions within households in both countries, although the nature of their involvement differs. In Türkiye, women participate extensively in household decision-making, but their role is primarily characterized by joint decision-making with spouses. In the United Kingdom, women generally report high levels of socioeconomic and family engagement, while financial hardship and health-related challenges remain important sources of inequality. Socioeconomic characteristics are significantly associated with women's household position in both countries, although their effects differ. In Türkiye, most socioeconomic factors have relatively weak practical effects, with income emerging as the strongest predictor of women's decision-making power. In contrast, age, education, employment status, and income exert more substantial influences in the United Kingdom. Overall, women's household roles are shaped by economic resources and labour-market participation in both societies, although these factors operate differently across institutional and cultural contexts. Despite improvements in women's education, employment, and legal rights, inequalities in household power relations continue to persist.

INTRODUCTION

Recent decades have witnessed substantial improvements in women's educational attainment, labor force participation, and legal rights, all of which have been recognized as important advances toward gender equality. However, women's empowerment in the public sphere does not necessarily imply a corresponding transformation of power relations within the family (Mawa, 2021). The family is more than an institution in which individuals share economic resources; it is a fundamental

social institution where gender roles are produced and reshaped (Oláh et al., 2021). Therefore, the allocation of decision-making authority, the distribution of resources, and the sharing of caregiving responsibilities within the family are widely regarded as key indicators of women's social status.

Family structures and intra-family relationships have undergone significant transformations under the influence of various social change processes, particularly industrialization, urbanization, and globalization (Haq, 2024; Nabirye, 2025). This structural transformation has influenced not only economic and demographic patterns but also the redefinition of gender norms. In this context, women's position within the household has emerged as a key indicator of gender equality, economic empowerment, and intergenerational well-being. The United Nations Sustainable Development Goals also emphasize that social progress is not limited to women's access to education and employment but also requires their meaningful participation in key household decisions concerning resource allocation, expenditure patterns, children's education, health investments, and household management (United Nations, 2015). Therefore, women's decision-making power within the household is regarded as a key determinant not only of individual empowerment but also of household economic functioning, intergenerational equality of opportunity, and the sustainability of social well-being (Modiri et al., 2024).

Traditional modernization perspectives are based on the assumption that economic development, urbanization, and improvements in educational attainment enhance women's status and position within the household (Rimkute & Sugiharti, 2024; Banerjee et al., 2023). However, empirical evidence suggests that increases in women's educational attainment, labor force participation, and legal rights do not necessarily lead to corresponding changes in intra-household power relations (Rana et al., 2024; Marcus & Somji, 2024). In other words, women's increasing visibility in the public sphere does not necessarily imply equal influence over the control of household resources, financial decision-making, or the distribution of caregiving responsibilities within the family. This suggests that women's decision-making capacity cannot be explained solely by their access to economic resources. Instead, decision-making power is also shaped by cultural norms, social expectations, and intra-household power dynamics, alongside access to economic resources.

These theoretical debates provide an important foundation for comparative research across countries with different social and institutional structures. Comparative studies indicate that women's position within the family is influenced not only by individual characteristics but also by national social policy regimes, welfare systems, labor market structures, and prevailing gender norms. Therefore, examining societies that have experienced similar economic transformations but differ in their cultural and institutional characteristics contributes to a more comprehensive understanding of the mechanisms shaping women's decision-making processes. In this regard, Türkiye and the United Kingdom represent two compelling cases for a comparative analysis of women's intra-household decision-making processes. Over the past few decades, both countries have experienced similar processes of social change, including urbanization, rising educational attainment, increased female labor force participation, and transformations in family structures (Aracı, 2024; Macit, 2020; Murphy et al., 2022; Woods, 2012). However, they differ substantially in the institutional arrangements, welfare regimes, gender norms, and cultural values that shape women's position within the family. These differences suggest that women's decision-making processes cannot be explained solely by individual characteristics or the level of economic development; rather, they are also shaped by broader social contexts and institutional structures. Therefore, examining these two countries together provides an important comparative framework for understanding how women's intra-household decision-making experiences are shaped under different social conditions. The United Kingdom is widely recognized as one of the countries in which women's position in the public sphere has been significantly strengthened by high levels of female labor force participation, broad access to higher education, a comprehensive welfaresystem, and long-standing gender equality policies. In particular, the growing prevalence of dual-earner households, the increasing participation of women in the professional workforce, and the institutionalization of family policies have supported the transformation of traditional divisions of labor and gender roles within the family. Nevertheless, recent studies indicate that, despite these advances in the public sphere, women have not yet achieved full equality in intra-household

decision-making processes. Gender-based inequalities continue to persist in various forms in areas such as the sharing of caregiving responsibilities, the management of financial resources, savings decisions, and child-rearing practices (Schmid et al., 2025; Leoncini et al., 2023). Furthermore, the post-pandemic cost-of-living crisis, rising economic uncertainty, and the expansion of flexible working arrangements have brought renewed attention to household resource management and intra-household decision-making processes (Johnston, 2021; Oreffice et al., 2021).

In recent years, Türkiye has undergone a significant process of social transformation characterized by rising educational attainment, urbanization, increasing female participation in paid employment, and changes in family structures. Nevertheless, despite the effects of modernization, traditional family structures, patriarchal values, and gender role expectations continue to shape power relations within the family (Özçelik, 2025; Engin, 2022; Kaplan, 2021). This suggests that women's position within the family is shaped by the coexistence of forces of change and continuity. While women's educational attainment, participation in economic life, and individual autonomy have continued to expand, traditional family authority structures and gender norms remain influential, particularly in strategic domains of household decision-making. Therefore, Türkiye represents an important case in which modernization and traditional family patterns coexist, making it particularly well suited for a multidimensional examination of women's intra-household decision-making processes.

The literature examining women's experiences across different domains of decision-making from a holistic perspective remains limited. Existing research has primarily conceptualized women's participation in decision-making through unidimensional indicators, while paying insufficient attention to the domain-specific nature of decision-making power.

The primary aim of this study is to comparatively examine women's position within the household and the socioeconomic and social factors shaping their decision-making processes in Türkiye and the United Kingdom. Accordingly, the study aims to examine how women's decision-making roles vary across different domains of household decision-making and the extent to which their empowerment in the public sphere is reflected in power relations within the family.

While the TAYA dataset is used to examine women's roles across different domains of household decision-making in Türkiye, including housing choice, food expenditures, shopping, children's education, childcare, social relationships, vacation planning and expenditure priorities, the analysis of the United Kingdom relies on the Understanding Society dataset. Because this dataset does not include a direct measure of household decision-making, the analysis focuses on indicators reflecting women's position within the household, including subjective financial well-being, employment status, the frequency of family meals, perceived family support, self-rated health, parenting style, and homeownership. Accordingly, this study aims to demonstrate that women's roles within the household are not uniform across all domains of decision-making but instead differ according to the routine, economic, and strategic nature of the decisions. Accordingly, women's intra-household decision-making experiences are understood not as a unidimensional construct but as a dynamic process that is continuously shaped and reshaped through the interplay of gender norms, family structure, economic resources, socioeconomic conditions, and intra-household power negotiations. The study also aims to contribute to the literature from a methodological perspective. Accordingly, descriptive statistics and exploratory data analysis, together with Chi-square tests, Cramér's V, Kendall's Tau correlation, and one-way analysis of variance (ANOVA), are employed to comparatively examine the socioeconomic factors associated with women's position within the household in both countries.

METHODOLOGY

ANALYSES OF TAYA

Descriptive Statistics and Demographic Structure of TAYA

The analysis for Turkey has been carried out using the results of the Turkish Family Structure Survey (TAYA), which is a household survey conducted nationally by the Ministry of Family and Social Services in Turkey in 2021. The survey seeks to gather data on family structure and family living

conditions in Türkiye and includes various family and related questions addressing various demographic, socioeconomic, and family issues. The questionnaires contain sections on family structure, marriage and family life, education, work, income, housing situation, health, social relations and intra-household decision making. TAYA has been carried out at regular intervals to track trends in family structure over time; the data in this study come from the 2021 wave.

Table 1 shows that 14,401 respondents are included in the data and a wide range of demographic, socioeconomic and household decision-making attributes are included in the analysis. The main variables are summarized in the table including the median, minimum, maximum, mean and SD values, and also including the kurtosis of the data (kurt). Demographic data (age, marital status, type of settlement) is given with socioeconomic data (education, employment, housing facilities and income). A number of variables related to household decision making in different areas are also included in the data. The average age of respondents is about 40 years, at which age the concerns of the household and family are of particular concern.

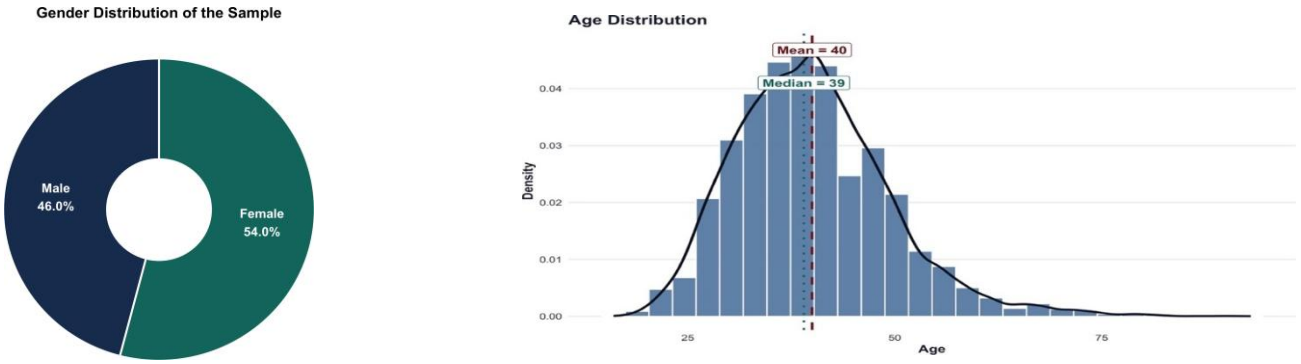
Table 1. Descriptive Statistics of the Main Variables

Variable	Mean	SD	Med.	Min	Max	Range	Skew	Kurt.
RelationshipToHouseholdHead	1.46	0.5	1	1	2	1	0.18	-1.97
GenderCode	1.54	0.5	2	1	2	1	-0.16	-1.97
Age	40	9.41	39	16	93	77	0.76	1.28
CountryOfBirth	1	0	1	1	1	0	-	-
RegisteredProvince	35.71	20.73	35	0	81	81	0.11	-0.86
HouseholdType	20.17	5.68	22	3	23	20	-2.69	5.23
EmploymentStatusCode	1.95	1	1	1	3	2	0.1	-1.99
JobContinuityCode	0.93	0.99	0	0	2	2	0.14	-1.96
EmploymentTypeCode	5.2	5.28	3	0	12	12	0.18	-1.88
WeeklyWorkingHours	25.5	25.61	30	0	110	110	0.26	-1.42
HealthStatusScale	2.06	0.6	2	1	3	2	-0.02	-0.2
CompletedSchool	136.65	209.03	33	1	522	521	1.23	-0.45
MaritalStatusCode	23.77	4.34	25	1	25	24	-4.25	17.17
SettlementType	24.96	5.21	22	4	32	28	0.32	-0.53
YearsInCurrentResidence	2000	15.68	2003	1930	2021	91	-0.63	-0.37
IncompleteEducation	1.86	0.35	2	1	2	1	-2.04	2.17
Variable	Mean	SD	Med.	Min	Max	Range	Skew	Kurt.
Housing Tenure	1.73	0.99	1	1	4	3	1.33	0.66
ParentsInSameBuilding	1.82	0.39	2	1	2	1	-1.64	0.68
NetAverageIncome	6377.38	5908.54	5000	100	150000	149900	5.76	73.22
HouseholdNeedsScale	3.53	0.97	4	1	5	4	-0.26	-0.44
HousingChoiceDecisionMode	1.89	0.31	2	1	2	1	-2.48	4.14
HousingChoiceDecisionMakerID	0.18	0.55	0	0	7	7	3.73	17.27
FoodDecisionMode	1.71	0.46	2	1	2	1	-0.9	-1.19
FoodDecisionMakerID	0.56	0.95	0	0	8	8	1.73	3.58
HouseholdGoodsDecisionMode	1.89	0.31	2	1	2	1	-2.5	4.26
HouseholdGoodsDecisionMakerID	0.19	0.58	0	0	7	7	3.62	16.04
ShoppingDecisionMode	1.82	0.38	2	1	2	1	-1.68	0.83
ShoppingDecisionMakerID	0.32	0.75	0	0	8	8	2.61	8.42
ExpenditurePriorityDecisionMode	1.86	0.34	2	1	2	1	-2.1	2.41
ExpenditurePriorityDecisionMakerID	0.21	0.61	0	0	10	10	4	26.16
ChildEducationDecisionMode	1.91	0.28	2	1	2	1	-2.97	6.8
ChildEducationDecisionMakerID	0.14	0.51	0	0	7	7	4.31	22.63
ChildClothingDecisionMode	1.87	0.33	2	1	2	1	-2.22	2.93
ChildClothingDecisionMakerID	0.23	0.67	0	0	8	8	3.23	12.68
RelationsWithRelativesDecisionMode	1.94	0.24	2	1	2	1	-3.68	11.52
RelationsWithRelativesDecisionMakerID	0.09	0.4	0	0	7	7	5.6	40.88
RelationsWithNeighborsDecisionMode	1.93	0.25	2	1	2	1	-3.51	10.36

RelationsWithNeighborsDecisionMaker ID	0.1	0.42	0	0	7	7	4.77	27.04
SocialActivitiesDecisionMode	1.94	0.23	2	1	2	1	-3.79	12.35
SocialActivitiesDecisionMakerID	0.09	0.42	0	0	14	14	9.29	190.59
VacationDecisionMode	1.95	0.23	2	1	2	1	-3.94	13.52
VacationDecisionMakerID	0.08	0.39	0	0	7	7	6.56	59.59

On the other hand, the distribution of gender and age groups show the demographic structure of the sample as in Figure 1. As revealed in Figure 1(a), females made up 54% of the respondents, and males made up 46% which is good as the sample is relatively balanced with a slight majority of females. The higher number of female respondents in the study is also important in its relevance to the study in regard to decision making power within the households. The age distribution of all respondents is shown in Figure 1(b). The average age is about 40 years and the median age is 39 years, indicating that the population is mostly middle aged. The distribution is slightly right-skewed with a majority in the age group 30 to 45 years, and relatively fewer in the older age groups.

Moreover, Figure 2 shows the regional distribution of the sample by IBBS Level 1 regions. The highest proportions are observed in West Anatolia (13.2%), the Aegean region (12.6%), and Istanbul (12.6%), followed by Southeast Anatolia (11.7%) and the Mediterranean region (10.0%). The Central East Anatolia region, West Black Sea, Central Anatolia, West Marmara, and East Marmara also have moderate shares (6.8%, 5.4%, 5.4%, 5.2%, and 9.3%, respectively). Northeast Anatolia (4.7%) and East Black Sea (3.2%) have the lowest shares. These regional differences reflect the survey's two-stage stratified cluster sampling design and the allocation of the sample across IBBS Level 1 regions based on their regional populations.



(a) (b)

Figure 1: (a) Gender and (b) Age Distributions.

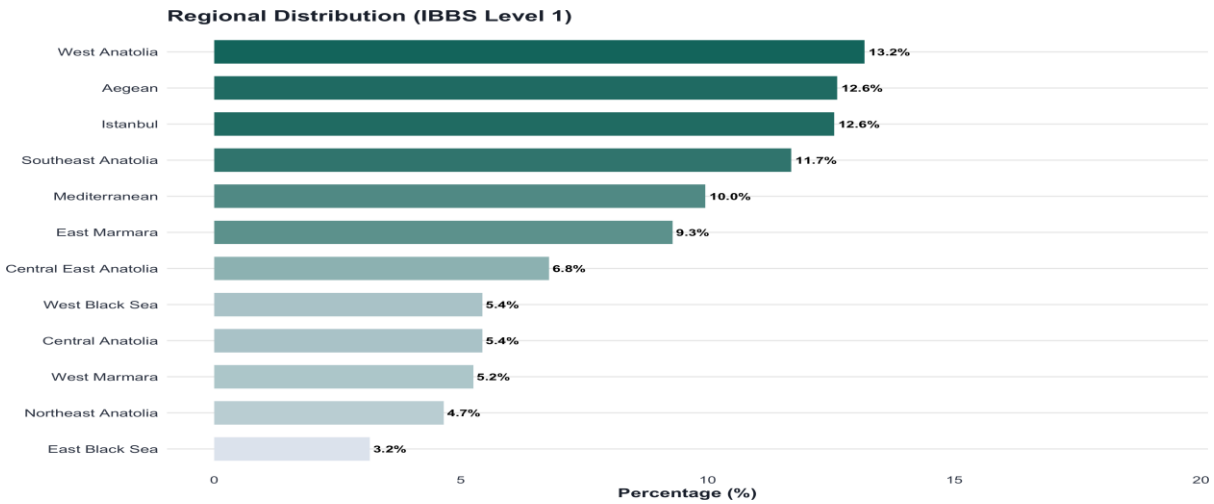


Figure 2: Regional Distribution (IBBS Level 1)

Women-only Socioeconomic Profile of TAYA

Figure 3 shows the marital status distribution in the sample of women. Most women (83.6%) are married, of which very few are married only by civil marriage (7.9%), divorced (3.2%) or widowed (2.7%). This means that the bulk of the sample in which women reside are in formally organised marital households, a factor of great importance when examining intra-household decision making power.

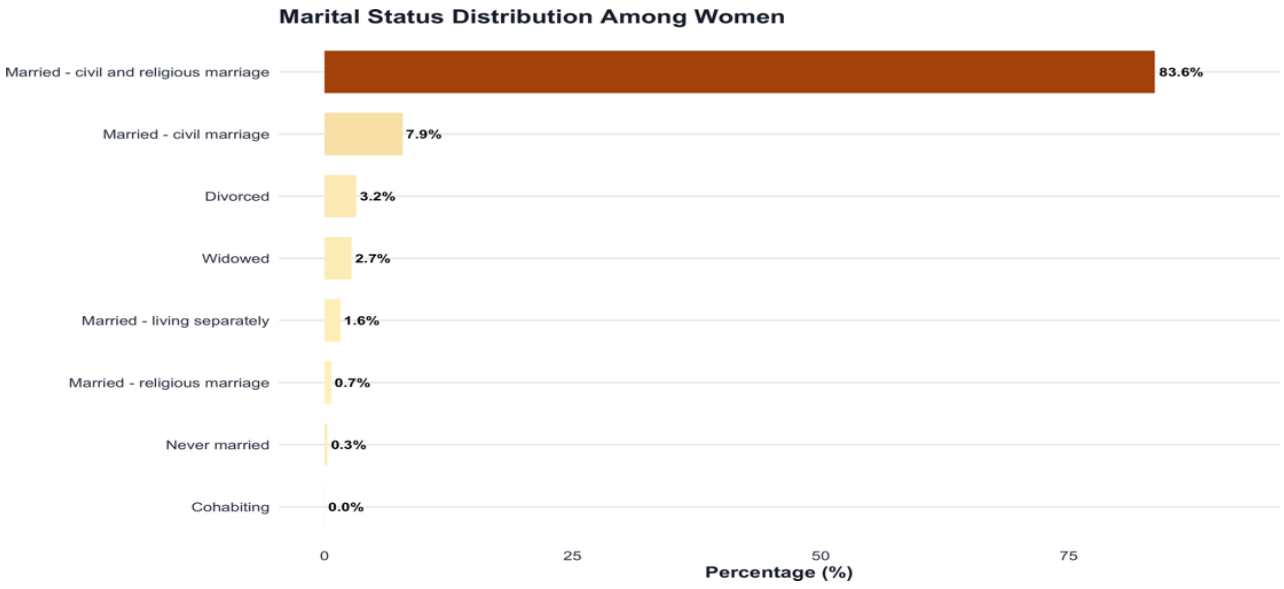


Figure 3: Marital Status Distribution Among Women

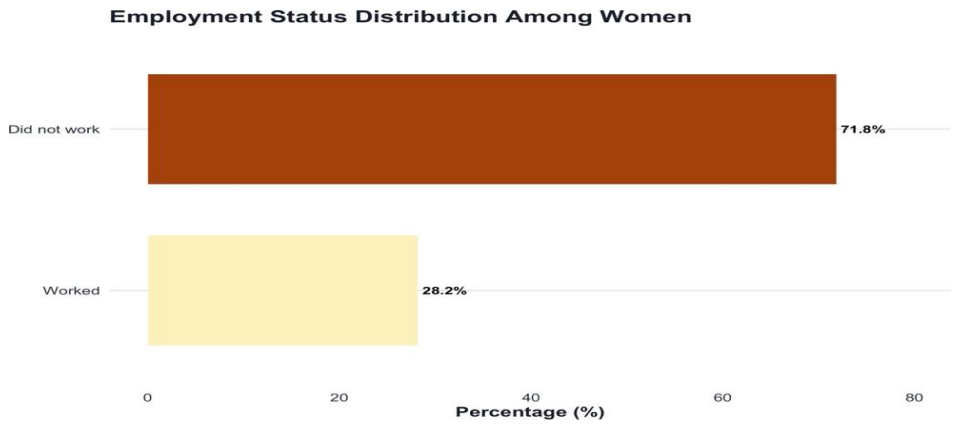


Figure 4: Employment Status Distribution Among Women

Moreover, Figure 4 shows the employment status distribution among women in the sample. Most women (71.8%) did not work, while 28.2% were employed. This indicates that the majority of women in the dataset were not participating in paid employment during the survey period.

Additionally, Figure 5 represents the employment type distribution among working women. The majority of working women (74.5%) are wage or salary workers, while smaller proportions are self-employed (8.1%), unpaid family workers (7.9%), and daily wage workers (7.0%). This indicates that most employed women in the sample work in regular wage-based jobs.

Figure 6 shows the distribution of education levels among women. Primary school is the most common category, representing about 27.3% of the sample. This is followed by general high school (13.0%) and 4-year higher education (12.9%). Women with no formal schooling (12.5%) and those with general middle school education (11.8%) also make up a notable portion of the sample. Vocational/technical high school (6.0%) and 2–3 year higher education (5.9%) have moderate representation. At the upper end of the distribution, advanced degrees are relatively rare, with master's degree holders accounting for 1.8% and doctorate holders only 0.5%. Overall, the distribution is concentrated around primary and mid-level education categories, with fewer women at higher education levels.

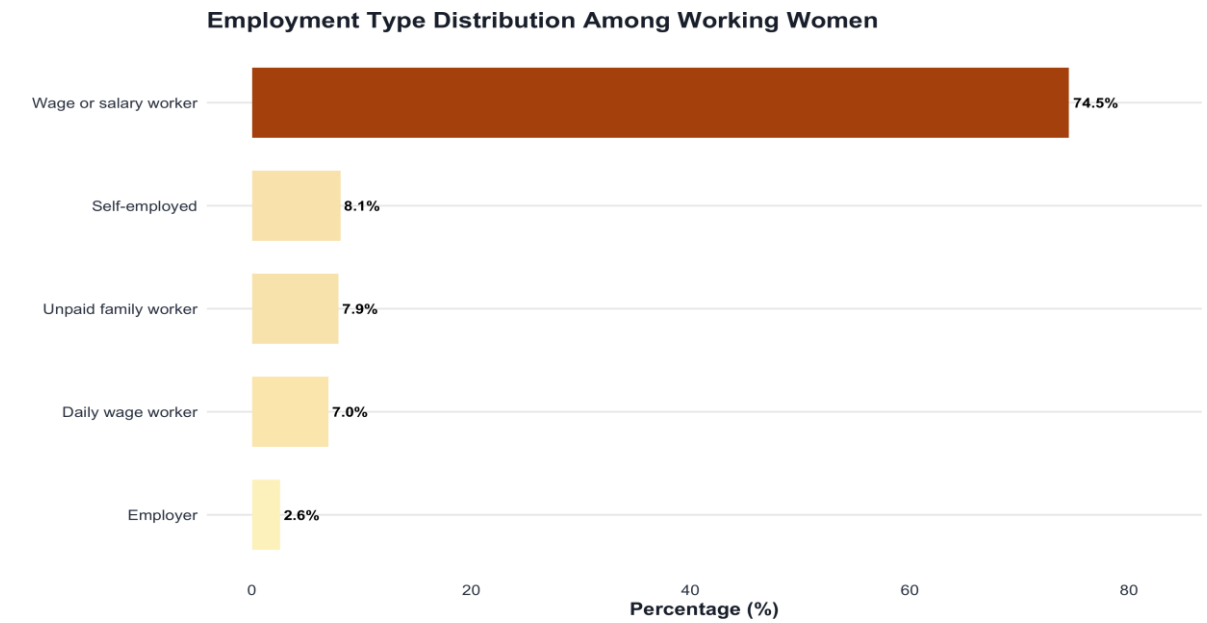


Figure 5: Employment Type Distribution Among Working Women

As a supporting finding, Figure 7 shows the percentage of women in each education group in the sample. Education levels were combined into three groups: low (no school completed, primary school, middle/higher vocational school), middle (high school, 2-3 year higher education, 4-year higher education / faculty), and high (5-6 year faculty, master's, doctorate). Most women (59.7%) have low education, and 24.9% have middle education. There are relatively few women in the higher education group (15.5%).

On the other hand, Figure 8 shows the weekly working hours distribution among working women. Both the mean (42.5 hours) and the median (45 hours) are close to each other, indicating a relatively balanced distribution. Most working women are concentrated around 40–45 hours per week, suggesting that full-time work is common in the sample.

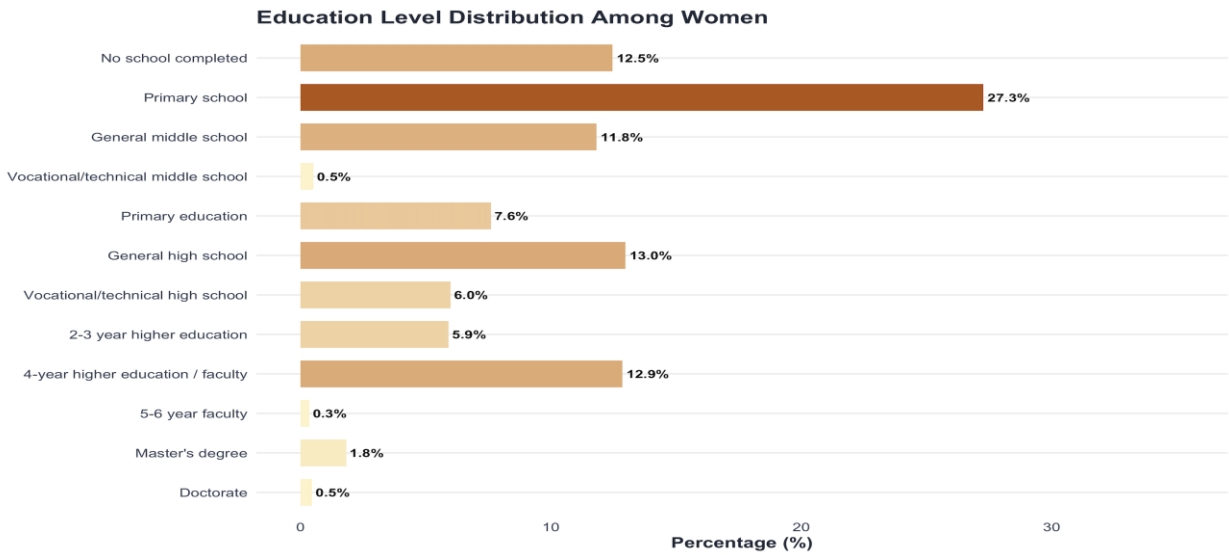


Figure 6: Education Level Distribution Among Women

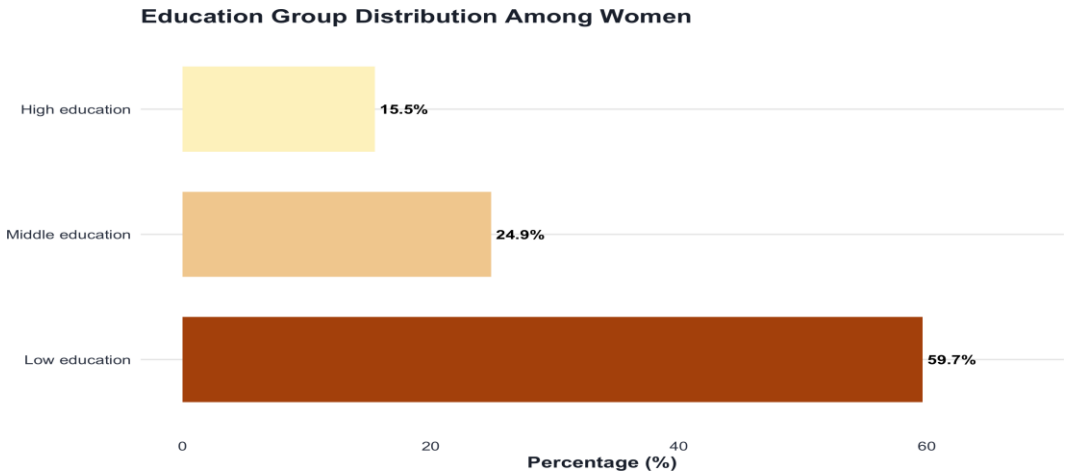


Figure 7: Education Group Distribution Among Women

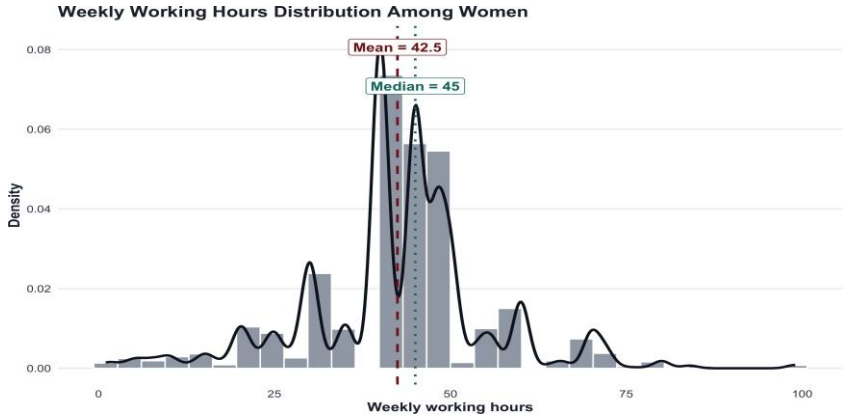


Figure 8: Weekly Working Hours Distribution Among Working Women

Finally, Figure 9 represents the net average income distribution among women on a log scale. Most observations are concentrated in the middle-income range, while very low and very high-income levels appear less frequently. This indicates that the sample mainly consists of women with moderate income levels, with fewer observations at the extreme ends of the income distribution.

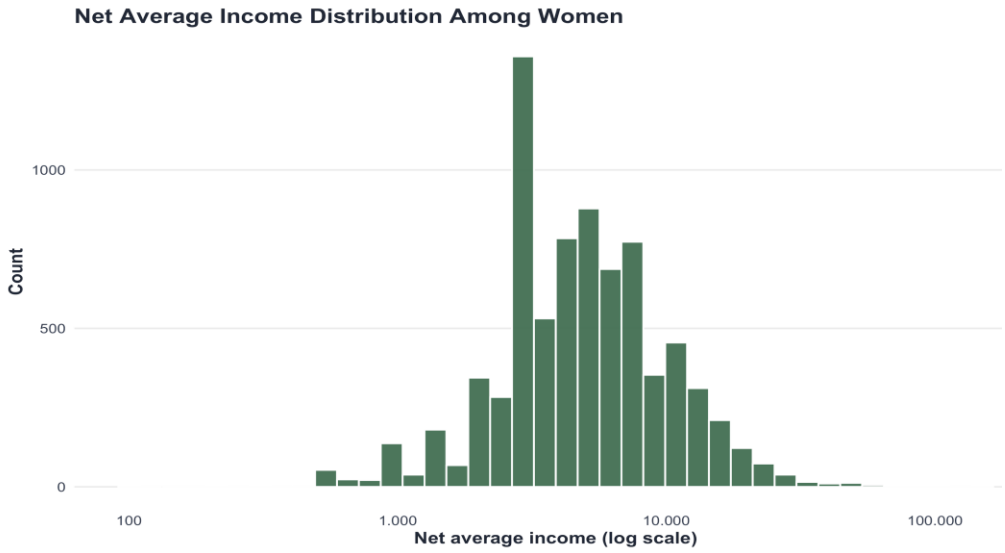


Figure 9: Net Average Income Distribution Among Women

Women's Household Decision-Making Structure of TAYA

Figure 10 shows women's power in decision making in various areas of the household including choice of housing, food, shopping, child education, and planning vacations. In nearly every field, the majority of women are co-participants, meaning that family decisions are not made alone but rather, decisions are made in concert with other family members. Women's influence is higher in food related decisions, shopping, decisions related to children etc., where sole decision making is more prevalent. Housing choice, vacation planning, and social activities, on the other hand, exhibit less sole decision-making and relatively more family-level joint participation, suggesting a more distributed decision-making process in families on these other decisions. In most domains, the percentage of women who are not engaged in decision making is relatively low. The overall figure indicates that women make an active contribution to family decision making, although the contribution is usually on a mutual basis and not as complete an individual.

Figure 11 represents women's participation rates across different household decision domains. Participation rates are very high in all areas, with all values above 90%, showing that women are actively involved in most household decisions. The highest participation rates are observed in food decisions (98.2%), relations with neighbors (98.2%), and child clothing (97.9%). This suggests that women play a particularly strong role in daily household management and family-related responsibilities. Participation is also high in social activities, relations with relatives, and child education. Although participation remains high in all domains, slightly lower rates are seen in housing choice (95.4%) and expenditure priority (92.6%). These areas may involve more shared responsibility with other household members. Overall, the graph shows that women are rarely excluded from household decision-making processes and are highly involved across both daily and major household decisions.

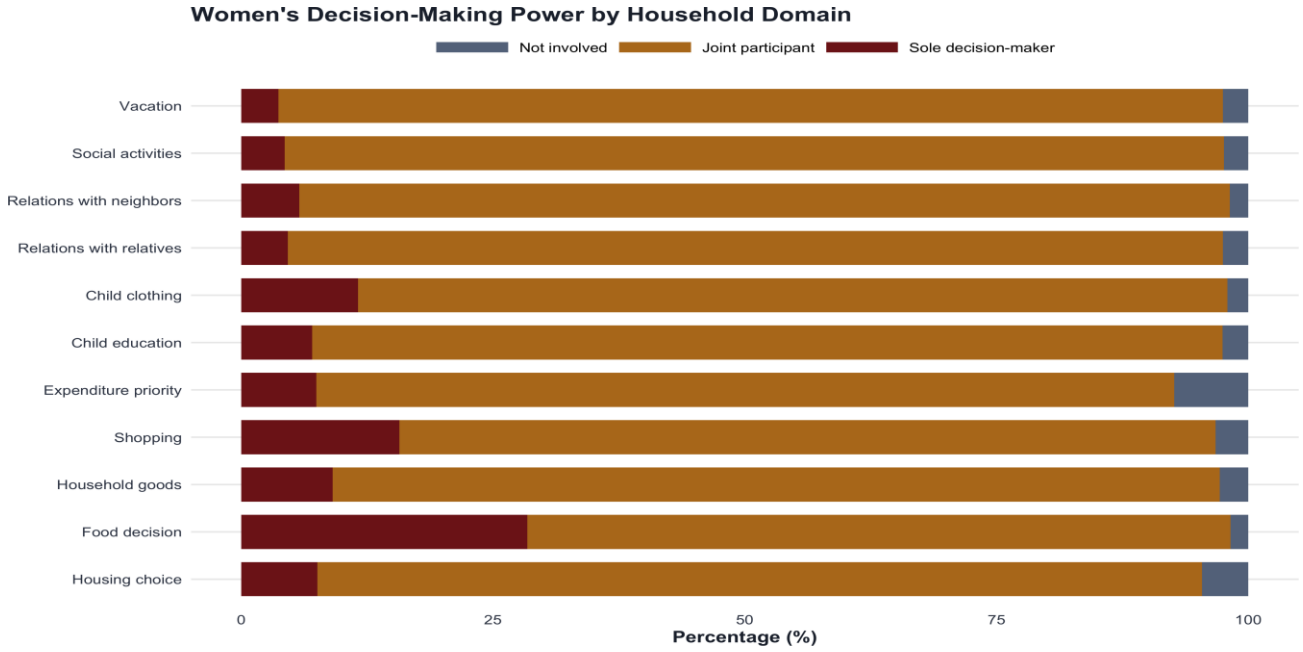


Figure 10: Women's Decision-Making Power by Household Domain

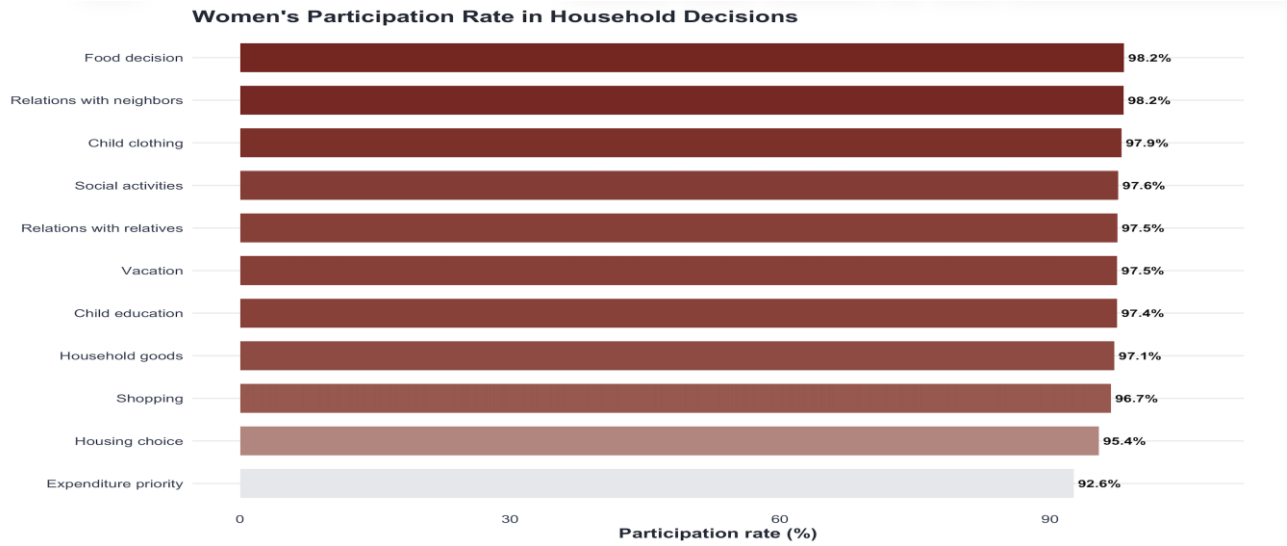


Figure 11: Women's Participation Rate in Household Decisions

Inferential Statistical Analysis of TAYA

Table 2 shows the outcomes of the Chi-square Goodness-of-Fit test with the 1 degree of freedom for females' participation in various household decision areas including housing choice, food decisions, shopping, child education and vacation planning. In all decision areas, the p-values are less than 0.05 ($p < 0.001$) and indicate that the null hypothesis: in the populations the domains have the same distribution is rejected. What means that the distribution of women's participation is not even across decision categories. That is, women are not equally involved in decision making processes as primary decision makers, as co-decision makers or as non-decision makers. There are also high Chi-square values indicating that there are significant discrepancies between the observed and the expected frequencies. But it is not a test of how much representation in the group the

differences have or whether they are more prevalent among one group or another. In general, results support the notion that women's power to make decisions in the household is not symmetrical in all aspects of the household, but depends on the specific decision.

Decision domain	Chi-square	P-value
Housing choice	4464.05	< 0.001*
Food decision	1223.772	< 0.001*
Household goods	4518.748	< 0.001*
Shopping	3002.77	< 0.001*
Expenditure priority	3850.511	< 0.001*
Child education	5077.589	< 0.001*
Child clothing	4113.719	< 0.001*
Relations with relatives	5720.327	< 0.001*
Relations with neighbors	5600.926	< 0.001*
Social activities	5827.134	< 0.001*
Vacation	5962.907	< 0.001*

Table 2: Goodness-of-Fit Tests for Decision Mode Variables

Then, to examine whether decision domains can be grouped, each domain was represented by its distribution of women's decision power levels. Pairwise similarities were calculated between domains, and the method of Partitioning Around Medoids (PAM) was used to cluster similar domains. Shortly, *Partitioning Around Medoids (PAM)* is a clustering algorithm in the *k*-medoids family. Unlike *k*-means, which represents each cluster by an arithmetic mean (a synthetic point), PAM represents each cluster by an actual observation (the medoid) with the smallest total distance to all other points in its cluster. This makes PAM more robust to outliers and produces directly interpretable cluster representatives.

The optimal number of clusters k was selected using the average silhouette weight (ASW) score, evaluated for $k \in \{2, 3, 4, 5, 6\}$. The silhouette score measures how well each observation fits its assigned cluster relative to the next-closest cluster, ranging from -1 (poor fit) to $+1$ (excellent fit), with values above 0.4 indicating substantial structure.

Accordingly, for TAYA dataset, the optimal cluster number was identified as $k = 2$ with ASW= 0.661. A direct comparison of $k = 2$ and $k = 3$ was also conducted; the lower silhouette value for $k = 3$ indicates that adding an extra cluster does not improve clustering quality. As stated prevşously, similarity values range from 0 to 1, where 0 indicates no similarity and 1 indicates perfect similarity between decision domains. Figure 12 shows the similarity heat map of the household decision domains. The results show that the pairwise similarity values are very high, at least 0.90 for the most part, which suggests that the participation patterns of women are more or less the same across the various types of decisions. But, food decision is the one with relatively lower similarity scores, suggesting a different structure in decision making.

Figure 13 illustrates the PAM clustering results based on these similarity patterns. The clustering analysis identifies two distinct groups of decision domains. Most domains are grouped together in a single cluster, while food decision is clearly separated from the rest. This separation is also visually evident in the PCA-based cluster plot, where food decision appears distant from other domains along the principal component axis.

Table 3 further clarifies the underlying reason for this distinction. While most domains are characterized by a high proportion of joint decision-making (generally above 85%), food decision shows a substantially lower joint participation rate and a notably higher proportion of sole decision-making. Overall, these findings suggest that household decision domains do not follow a uniform participation structure. Instead, most decisions are made collectively, whereas food-related decisions are more individualized, making food decision a distinct category within the clustering framework.

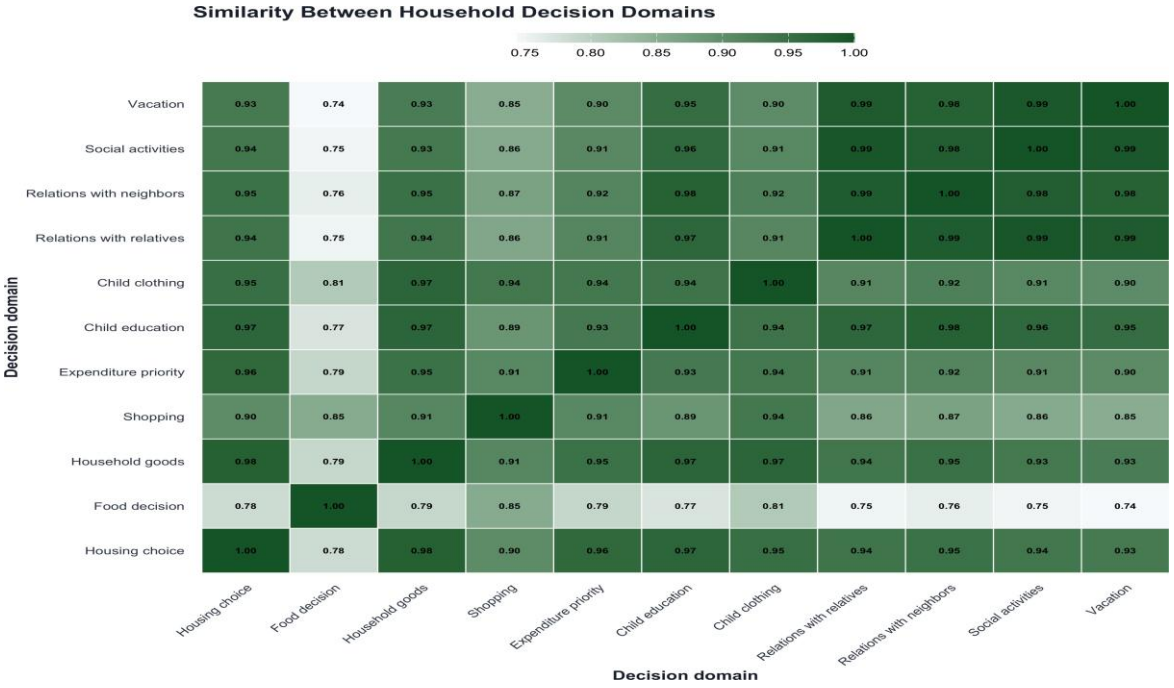


Figure 12: Similarity Heatmap Between Household Decision Domain

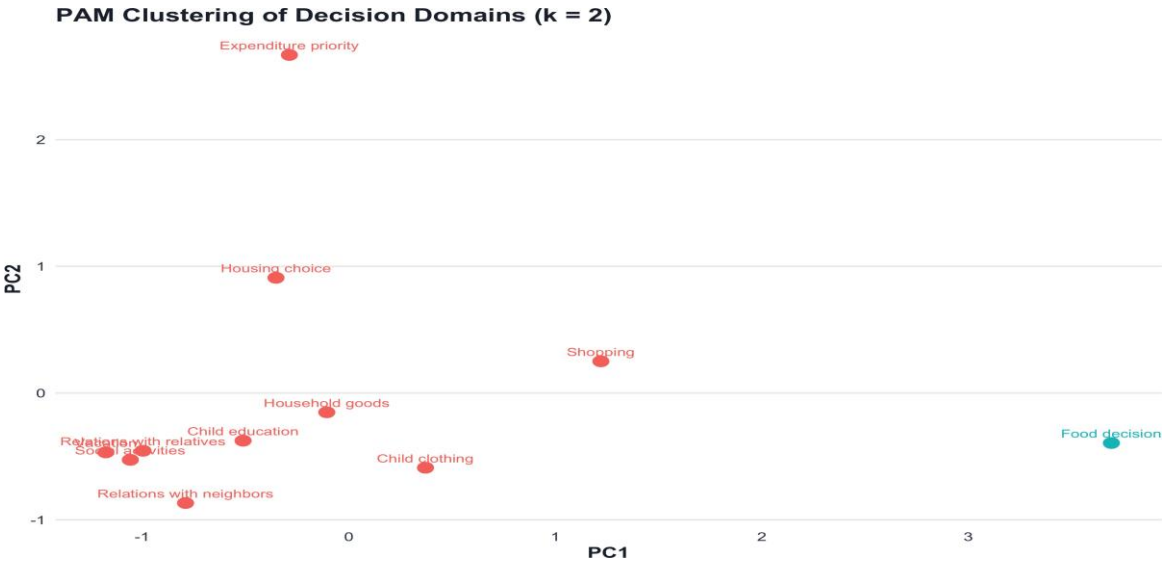


Figure 13: PAM Clustering of Household Decision Domains

Table 3: PAM Clusters of Decision Domains

PAM cluster	Decision domain	Not involved (%)	Joint participant (%)	Sole decision-maker (%)
1	Child clothing	2.1	86.4	11.6
1	Child education	2.6	90.4	7
1	Expenditure priority	7.4	85.2	7.5
1	Household goods	2.9	88.1	9
1	Housing choice	4.6	87.9	7.5
1	Relations with neighbors	1.8	92.4	5.7
1	Relations with relatives	2.5	92.9	4.6
1	Shopping	3.3	81.1	15.7
1	Social activities	2.4	93.3	4.3
1	Vacation	2.5	93.8	3.7
2	Food decision	1.8	69.8	28.4

In order to investigate whether socioeconomic groups differ in decision-making patterns, women were clustered based on their decision-power scores across all household decision domains. The optimal number of clusters was determined using ASW as used previously, with the highest value obtained for k = 2 with ASW = 0.716. The clustering results show that only **4.9%** of women belong to the high decision-power cluster, whereas, **95.1%** are classified into the lower decision-power cluster. This two-cluster solution was used in the subsequent analysis, and chi-square tests were then conducted to examine differences in cluster membership by education, employment, income, and region.

Table 4: Chi-square Tests: Socioeconomic Groups and Individual Decision Pattern Clusters

Predictor	Chi-square	P-value	Cramer's V
EducationGroup	9.291	0.010*	0.035
EmploymentGroup	19.819	< 0.001*	0.050
IncomeGroup3	10.548	0.005*	0.037
RegionGroup	20.504	< 0.001*	0.051

Finally, the results presented in Table 4 indicate that while the chi-square tests reveal statistically significant differences across socioeconomic groups, the very low Cramer's V values suggest that these factors explain only a negligible portion of variation in decision-making patterns. All tests were conducted with 2 degrees of freedom (DF = 2) and a sample size of N = 7,782 participants.

The results of Chi-square tests of independence and Cramer's V values for the association between socioeconomic predictors and women's decision making participation are presented in Figure 14 and Table 5. The reported associations are significant ($p < 0.05$) and evidence that the null hypothesis that there was no association between the socioeconomic predictor and women's decision participation was rejected. The values of Cramer's V are typically low, however, suggesting low correlation or association. Relatively higher Cramer's V values for the Education Group indicate that this group had a slightly higher association with women's participation in several decision domains compared to other predictors. Some significant relationships also exist between employment and region groups, but the effects are small. In total, a large range of socioeconomic factors is statistically related to women's involvement in the decision-making process, but it seems their influence is not extensive in practice.

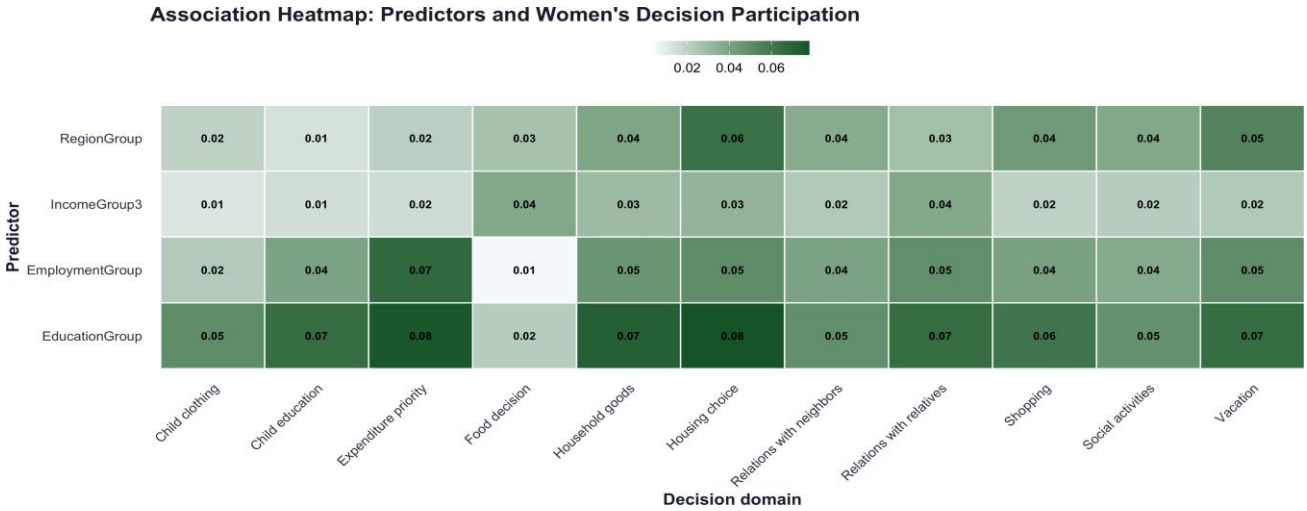


Figure 14: Cramer's V Heatmap: Predictors and Decision Participation

Table 5: Significant Associations Based on Cramer's V

Predictor	Decision domain	Chi-square	P-value	Cramer's V	N
EducationGroup	Housing choice	47.574	< 0.001*	0.078	7782
EducationGroup	Expenditure priority	45.07	< 0.001*	0.076	7782
EducationGroup	Household goods	40.189	< 0.001*	0.072	7782
EmploymentGroup	Expenditure priority	34.437	< 0.001*	0.067	7782
EducationGroup	Child education	32.844	< 0.001*	0.065	7782
EducationGroup	Relations with relatives	32.453	< 0.001*	0.065	7782
EducationGroup	Vacation	32.732	< 0.001*	0.065	7782
RegionGroup	Housing choice	30.887	< 0.001*	0.063	7782
EducationGroup	Shopping	28.899	< 0.001*	0.061	7782
RegionGroup	Vacation	22.636	< 0.001*	0.054	7782
EmploymentGroup	Housing choice	19.814	< 0.001*	0.05	7782
EducationGroup	Child clothing	19.545	< 0.001*	0.05	7782
EmploymentGroup	Vacation	19.767	< 0.001*	0.05	7782
EmploymentGroup	Relations with relatives	18.818	< 0.001*	0.049	7782
EducationGroup	Relations with neighbors	18.587	< 0.001*	0.049	7782

As seen in Table 6, The Kendall's Tau results for N=7782 in every domain indicate that while some ordinal associations between socioeconomic variables and women's decision power are statistically significant, supporting the rejection of the null hypothesis stating no ordinal association between the predictor and women's decision power score, the magnitude of these

relationships remains very small. This confirms the earlier findings that socioeconomic factors have only a weak influence on women's decision-making power.

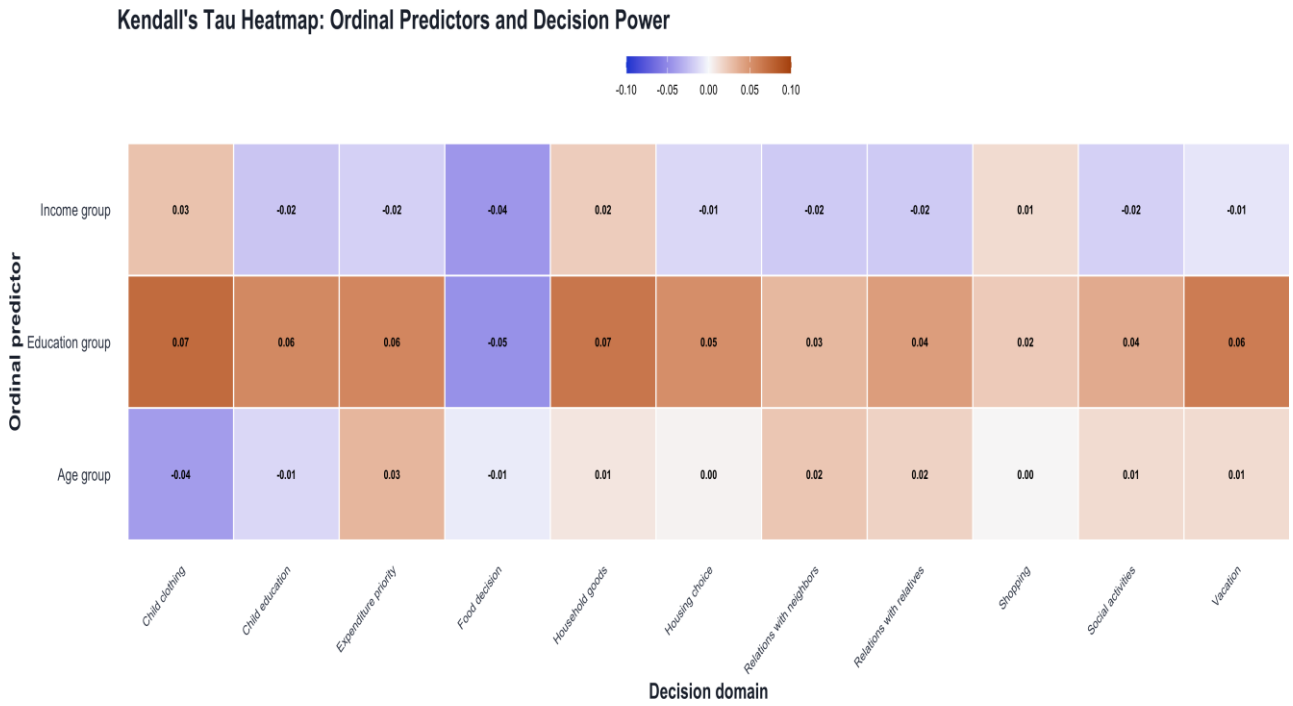


Figure 15: Kendall's Tau Heatmap

Table 6: Kendall's Tau Tests for Ordinal Predictors

Decision domain	Predictor	Kendall's tau	P-value
Housing choice	Age group	0.003	0.778
Housing choice	Income group	-0.014	0.174
Housing choice	Education group	0.053	< 0.001*
Food decision	Age group	-0.006	0.556
Food decision	Income group	-0.044	< 0.001*
Food decision	Education group	-0.047	< 0.001*
Household goods	Age group	0.009	0.388
Household goods	Income group	0.021	0.047*
Household goods	Education group	0.066	< 0.001*
Shopping	Age group	0.002	0.822
Shopping	Income group	0.014	0.183
Shopping	Education group	0.022	0.043*
Expenditure priority	Age group	0.032	0.002*
Expenditure priority	Income group	-0.017	0.107
Expenditure priority	Education group	0.057	< 0.001*
Child education	Age group	-0.014	0.179
Child education	Income group	-0.022	0.037*
Child education	Education group	0.056	< 0.001*
Child clothing	Age group	-0.041	< 0.001*
Child clothing	Income group	0.026	0.013*

Child clothing	Education group	0.073	< 0.001*
Relations with relatives	Age group	0.018	0.080
Relations with relatives	Income group	-0.02	0.066
Relations with relatives	Education group	0.045	< 0.001*
Relations with neighbors	Age group	0.024	0.024*
Relations with neighbors	Income group	-0.02	0.066
Relations with neighbors	Education group	0.031	0.004*
Social activities	Age group	0.014	0.189
Social activities	Income group	-0.017	0.102
Social activities	Education group	0.038	< 0.001*
Vacation	Age group	0.014	0.187
Vacation	Income group	-0.008	0.453
Vacation	Education group	0.063	< 0.001*

Furthermore, the Decision Power Index was compared across socioeconomic groups. before selecting the final test, normality of residuals and homogeneity of variance were checked. If both assumptions were met, one-way ANOVA could be used for the comparison of the mean equality of decision power index. If only equal variance failed, Welch ANOVA would be used. On the other side as normality failed, Kruskal-Wallis was used.

Table 7: Group Comparison Results for Decision Power Index

Predictor	Test used	Normality p	Variance p	Statistic	P-value	N
EducationGroup	Kruskal-Wallis	0	0.042	25.356	< 0.001*	7782
EmploymentGroup	Kruskal-Wallis	0	0.009	13.166	0.001*	7782
IncomeGroup3	Kruskal-Wallis	0	0.165	4.789	0.091	7782
RegionGroup	Kruskal-Wallis	0	0	167.653	< 0.001*	7782

Discussion about TAYA Findings

This study examines women's intra-household decision-making power in Türkiye using the large-scale, nationally representative TAYA dataset and aims to reveal women's positions across different domains of household decision-making. While women's empowerment is often explained in the literature through individual resources such as education, income, and employment, this study shows that decision-making processes have a complexity that cannot be explained solely by individual resources. Therefore, the study makes a distinctive contribution to the existing literature by evaluating women's intra-household decision-making power through both the nature of decision domains and the extent to which decisions are made jointly within the household.

The findings of the study indicate that women are not largely excluded from intra-household decision-making processes; rather, they demonstrate high levels of participation across nearly all decision domains. However, the dominant form of participation is not individual decision-making but joint decision-making. This finding suggests that women are visible and active actors within the household, while decision-making processes are largely shaped through negotiation and shared responsibility. Moreover, the results show that women's participation in household decision-making is both widespread and structurally patterned across different domains. The clustering analysis further reveals that decision domains are not homogeneous. Most domains form a group characterized by collective decision-making patterns, while food-related decisions emerge as a distinct category with a higher prevalence of individual decision-making. This distinction highlights that women's decision-making roles vary depending on the nature of the decision, with

greater autonomy observed in routine, day-to-day activities. The distinctiveness of food-related decisions compared to other domains suggests that women possess greater individual authority in matters associated with the management of daily life and caregiving responsibilities. However, this finding is not entirely consistent with some previous studies in the literature. Although Kitapcı and Dörtyol (2009) reported that women play an influential role in food purchasing decisions, they argued that this influence is shaped primarily by intra-family role allocation and domestic responsibilities. The study emphasizes that rather than possessing completely independent authority in decision-making processes, women function as more visible and influential actors within specific domains of consumption. Therefore, the finding that food-related decisions exhibit a higher degree of individual decision-making in the present study diverges from some of the findings reported in the existing literature.

In contrast, the predominance of joint decision-making in more strategic and high-cost decision domains, such as housing choice, spending priorities, and vacation planning, suggests that intra-household power relations may vary according to the nature of decisions. The inferential analysis shows that socioeconomic factors such as education, employment, income, and region are statistically associated with women's participation. However, the strength of these relationships is generally weak, as indicated by low Cram´er's V and Kendall's tau values. Group comparison tests further confirm that, with the exception of income, these factors do not lead to significant differences in overall decision-making power.

However, the literature indicates that findings on women's intra-household decision-making processes are not entirely consistent. While some studies demonstrate that women actively participate in decision-making processes, others highlight the continued influence of male dominance, especially in economic and strategic domains of decision-making. In this context, the study conducted by Vural and Güllü (2017) demonstrates that women's position in decision-making processes varies according to the nature of decision domains. In this context, the study conducted by Vural and Güllü (2017) demonstrates that women's position in decision-making processes varies according to the nature of decision domains. Although the study found that women participate extensively in intra-household decision-making processes, this participation was reported to occur predominantly through joint decision-making between spouses. This finding is particularly important, as it indicates that women's increased visibility within the family does not necessarily correspond to greater independent decision-making authority. Therefore, women's position in decision-making processes should be evaluated not only in terms of participation levels, but also with regard to decision-making influence, bargaining power, and final decision-making authority. Nevertheless, the study conducted by Dilek and Yılmaz (2023) reveals that the influence of patriarchal structures remains clearly evident in intra-family decision-making processes. According to the findings, fathers and elder family members predominantly occupy decision-making positions within the family, whereas women are found to be more influential in decisions related to everyday practices such as the selection of household items, grocery shopping, and social visits. These findings show that women participate in intra-family decision-making processes, but that such participation varies according to the nature of decision domains.

Among all predictors, income stands out as the only variable with a statistically significant effect on the Decision Power Index. Nevertheless, even in this case, the magnitude of the observed differences remains limited, suggesting that economic resources play a role, but do not fully explain variations in decision-making power. Nevertheless, inconsistencies have been observed in the literature. Castells (2010) argues that women's participation in economic life enhances their bargaining power. However, some studies indicate that women's employment, property ownership, income, or education do not always increase their decision-making authority within the household; in some cases, these factors may even reduce it (Mabsout & Van Staveren, 2010).

ANALYSES OF UK SURVEY

Descriptive Statistics and Explanatory Data Analysis of UK Survey

Table 8: Comprehensive Descriptive Statistics (UK Women)

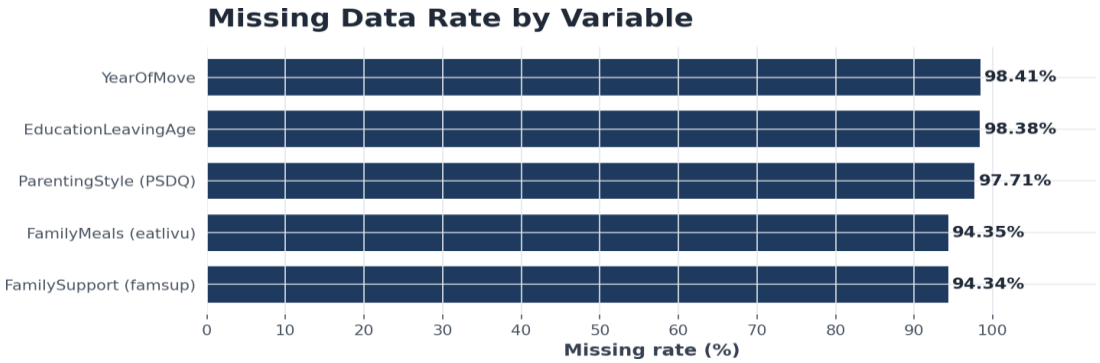
Variable	N	Mean	SD	Med.	Min	Max	Range	Skew	Kurt.
RelationshipToHouseholdHead	8618	2.51	3.87	1	1	30	29	5.15	30.34
Age	16239	50.28	18.62	51	16	100	84	-0.02	-0.91
RegisteredRegion (GOR)	16234	6.62	3.17	7	1	12	11	-0.03	-1.05
HouseholdType	16241	11.02	6.47	10	2	23	21	0.25	-1.31
EmploymentStatusCode	16197	4.28	9.12	2	1	97	96	9.53	93.81
EmploymentTypeCode	8466	1.09	0.28	1	1	2	1	2.92	6.55
WeeklyWorkingHours	7494	29.7	10.75	34	0.1	97	96.9	-0.4	0.77
HealthStatusScale	16054	2.79	1.03	3	1	5	4	0.27	-0.43
CompletedSchool	15992	3.09	2.21	3	1	9	8	1.38	1.57
MaritalStatusCode	16062	2.38	1.57	2	1	9	8	1.33	0.5
SettlementType	16234	1.25	0.44	1	1	2	1	1.13	-0.72
YearsInCurrentResidence	259	2014.28	7.43	2017	1967	2021	54	-2.75	10.92
EducationLeavingAge	263	16.38	1.28	16	11	20	9	-0.29	2.41
Variable	N	Mean	SD	Med.	Min	Max	Range	Skew	Kurt.
HousingTenure	15651	2.23	1.52	2	1	8	7	1.53	1.59
NetAverageIncome (£)	15706	3780.98	3467.11	3232.5	0	173638	173638	15.94	559.05
HouseholdNeedsScale	16059	1.99	0.9	2	1	5	4	0.9	0.83
HRP PNO	16241	1.39	0.62	1	1	7	6	2.25	8.98
ParentingAuthoritative	372	62.27	7.35	63	34	75	41	-0.39	-0.05
ParentingAuthoritarian	371	20.49	4.23	19	13	40	27	1.79	4.5
ParentingPermissive	371	10.23	3.14	10	5	21	16	0.67	0.18
FamilyMealsFreq	918	2.86	1.05	3	1	4	3	-0.42	-1.07
FoodSpending (£)	14574	353.54	291.65	320	0	25000	25000	42.63	3510.75
FamilySupport	919	1.31	0.51	1	1	3	2	1.34	0.77

The analysis for the United Kingdom has been conducted using data from the Understanding Society survey, also known as the UK Household Longitudinal Study (UKHLS). Understanding Society is a nationally representative longitudinal household survey designed to collect information on the social, economic, and demographic circumstances of individuals and households across the United Kingdom. The survey covers a broad range of topics, including education, employment, income, housing, health, family life, and social relationships, providing comprehensive information on living conditions and family dynamics. Data are collected regularly to monitor changes in household and individual circumstances over time, and the analyses presented in this study are based on the selected wave used for the comparative analysis. The selected variables provide a broad overview of the demographic, socioeconomic, and family-related characteristics of women included in the UK sample. Table 1 represents the descriptive statistics of the main variables for the UK female sample drawn from Understanding Society. The dataset includes between approximately 260 and 16,200 observations across variables, with most individual-level measures based on around 16,000 women. The average age of women is approximately 50 years, considerably higher than in the Turkish sample, reflecting the broader age coverage of the UK panel which includes older adults. Marital status, employment, education, and housing tenure variables show substantial variation, indicating socioeconomic heterogeneity across UK

households. The mean household net monthly income is approximately £3,780 with a wide standard deviation, suggesting considerable income disparity. Subjective financial situation has a mean close to 2, indicating that most women report "living comfortably" or "doing alright" financially. Parenting-style scales (PSDQ) are observed only for the subset of mothers participating in the parenting module (N ≈ 370). Overall, the descriptive picture suggests that UK women in the sample are concentrated in middle-to-older adulthood, with high levels of employment and home ownership but considerable variability in financial wellbeing.

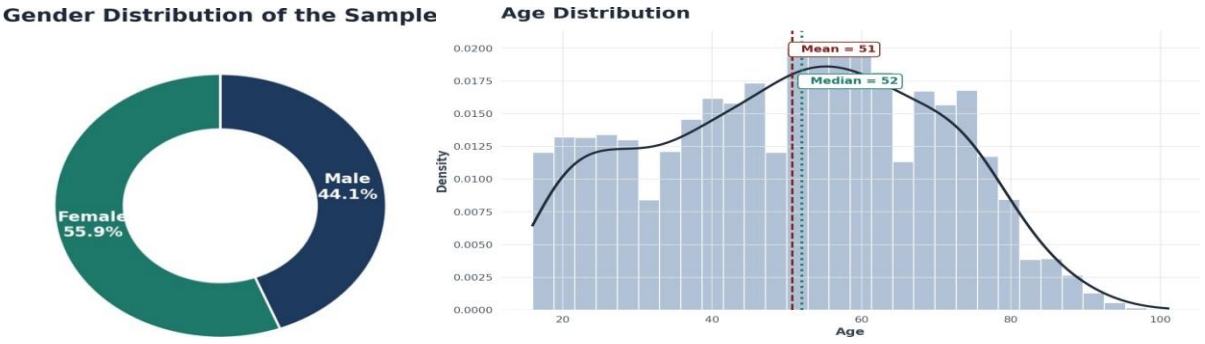
Figure 16 shows that several module-specific variables (parenting style, family meals, family support) have very high missing rates above 90%, because they were administered only to specific subgroups (e.g., parents of children under 16 for the PSDQ module). The high missingness in these variables is therefore structural rather than random, and the relevant analyses below are conditioned on the appropriate subsample.

2.2.



2.3. Figure 16: Missing Data Rate by Variable (UK Women)

The socio-demographic profile of the whole UK sample is provided in Figure 17. The female respondents make up 55.9 percent of the respondents while the male respondents make up 44.1 percent of the respondents as shown in Figure 17a, the females were slightly more in number than the males. Because this study is focused on women, the analysis of the female subsample (about 16,000) is presented for all subsequent analyses. The age distribution of the entire sample is shown for the full sample in figure 17b. The mean is around 51 years and the median is around 52 years, suggesting that the sample consists of middle to older aged adults. The proximity of mean and median indicates that the age distribution is fairly symmetrical and the majority of respondents were between 30 and 70 years of age.



(a) (b)

Figure 17: (a) Gender and (b) Age Distributions

Furthermore, Figure 18 shows the regional distribution of the UK sample based on the Government Office Region (GOR) classification. The largest regional shares are in the South East, North West, and London, while Northern Ireland and Wales have the smallest shares.

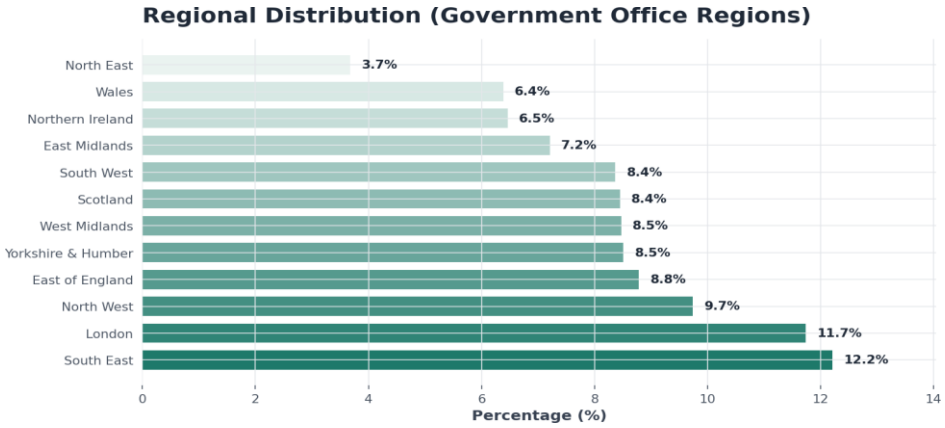


Figure 18: Regional Distribution (Government Office Regions)

Women-only Socioeconomic Profile of UK Survey

Figure 19 represents the marital status distribution among UK women. The largest group is married, followed by single (never married), divorced, and widowed. Compared to the Turkish sample, the UK distribution is more diverse: a substantial share of women have never married or are formerly married, reflecting different demographic patterns of partnership formation.

Additionally, Figure 20 shows the employment status distribution among UK women. Roughly half of women are in paid work, while the remainder are not currently employed (which includes retirees, given the older age profile of the UK sample). This is markedly higher than the female employment rate observed in the Turkish data.

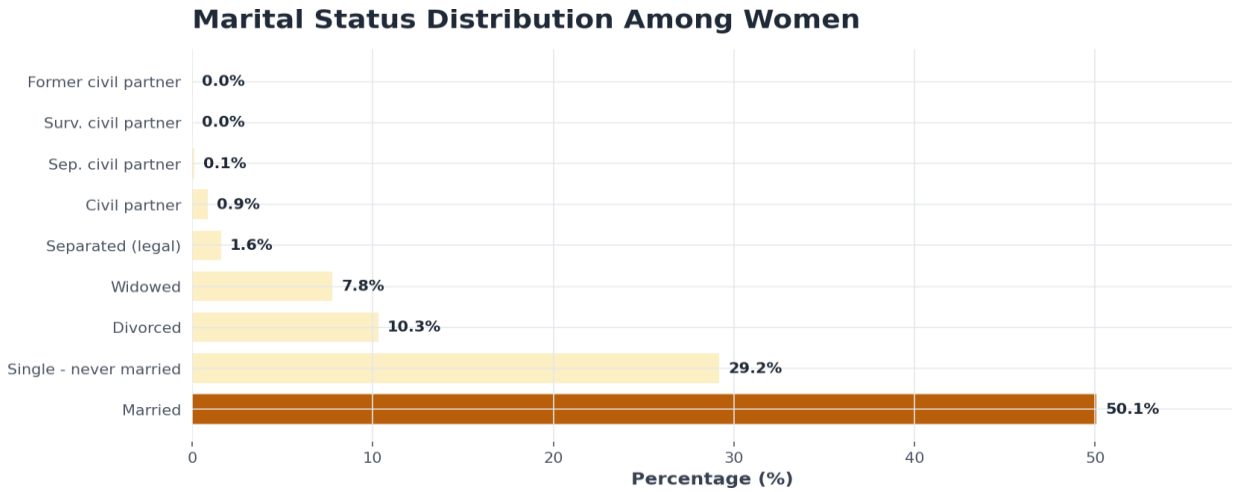


Figure 19: Marital Status Distribution Among Women (UK)

Figure 21 represents the employment type among working UK women. The vast majority work as paid employees, while a much smaller share are self-employed, indicating that wage employment is the dominant mode of female labour-market participation. Note that the UK survey provides only a binary self-employed vs. paid-employee distinction, unlike the Turkish data which distinguishes wage workers, daily-wage workers, employers, and unpaid family workers separately.

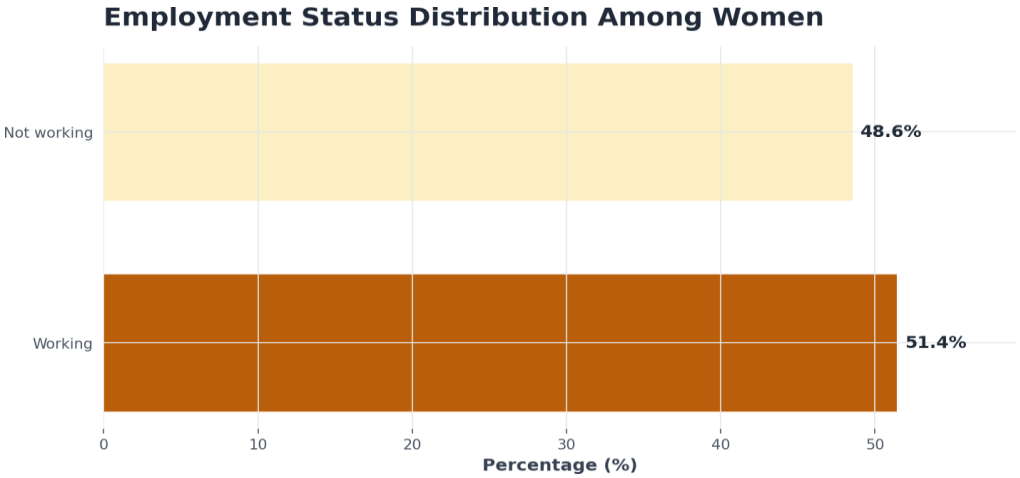


Figure 20: Employment Status Distribution Among Women (UK)

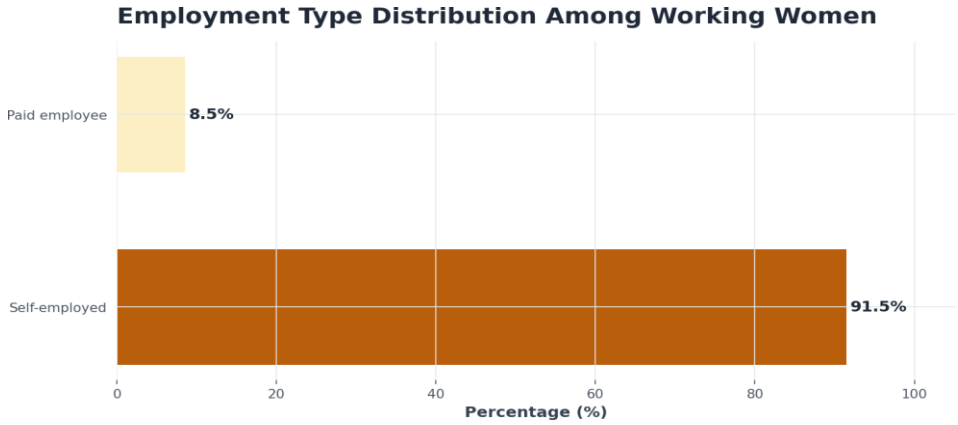


Figure 21: Employment Type Distribution Among Working Women (UK)

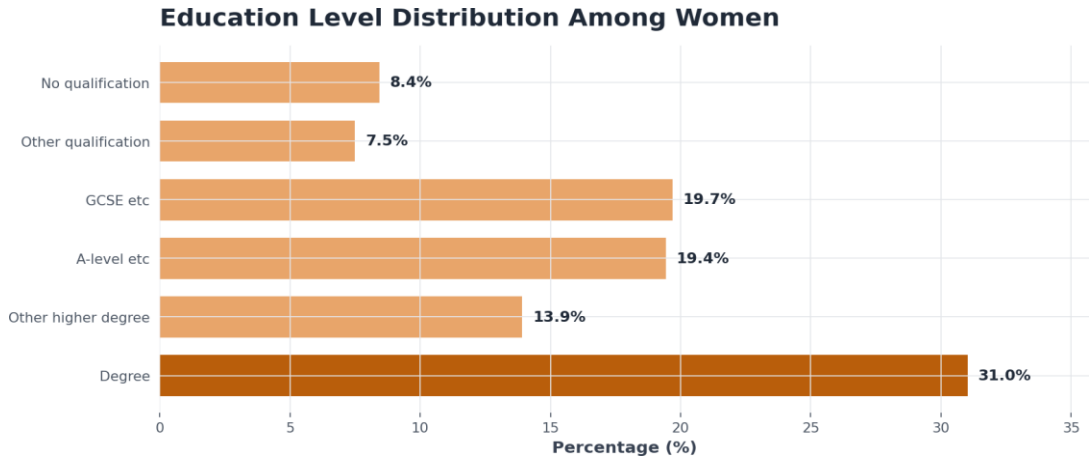


Figure 22: Education Level Distribution Among Women (UK)

Moreover, Figure 22 shows the distribution of detailed education categories among UK women. “Degree”, “A-level”, and “GCSE” represent the largest categories, with smaller shares for other higher qualifications and “no qualification”. UK women are substantially better-educated on average than their Turkish counterparts.

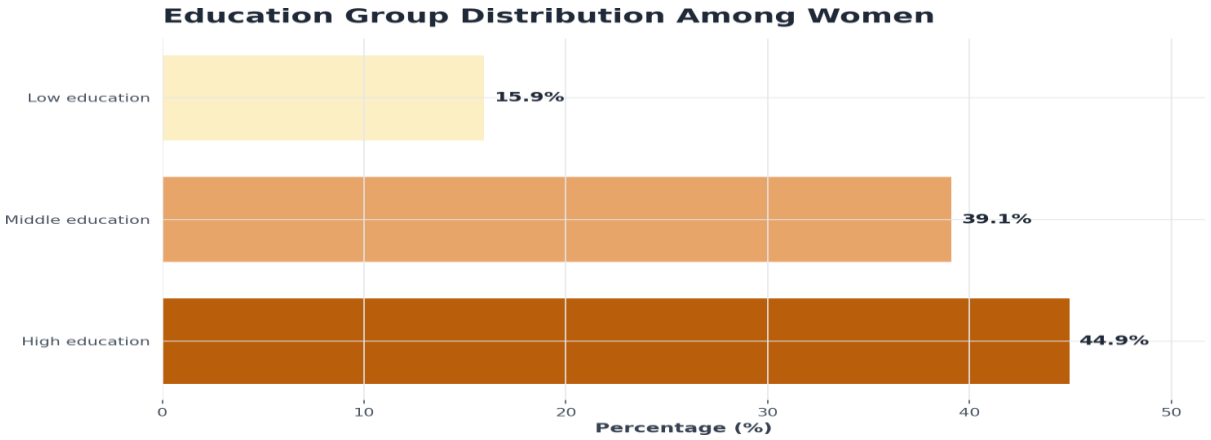


Figure 23: Education Group Distribution Among Women (UK)

Figure 23 represents the three-category education grouping. The “high” education group (degree and other higher degrees) is the largest, followed by “middle” (A-level and GCSE) and “low” (no qualification or other). This distribution is essentially the inverse of the Turkish sample, where the “low” group dominated. Also, Figure 24 represents the three-category income grouping based on tertiles of household net monthly income. The three groups are roughly balanced by construction (tertile-based split), with the low-income tertile slightly larger than the middle and high tertiles due to ties at the lower bound. This grouping is used in the inferential analyses below.

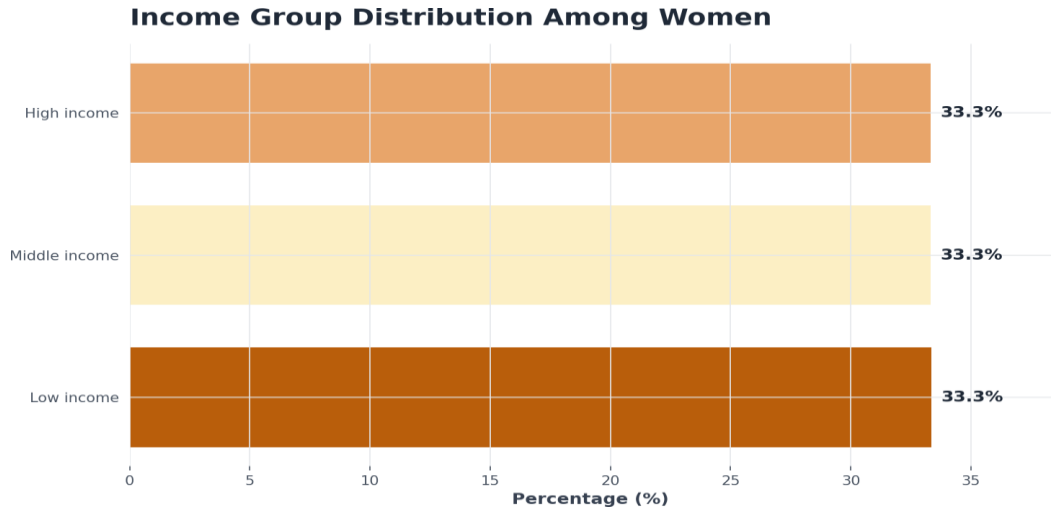


Figure 24: Income Group Distribution Among Women (UK)

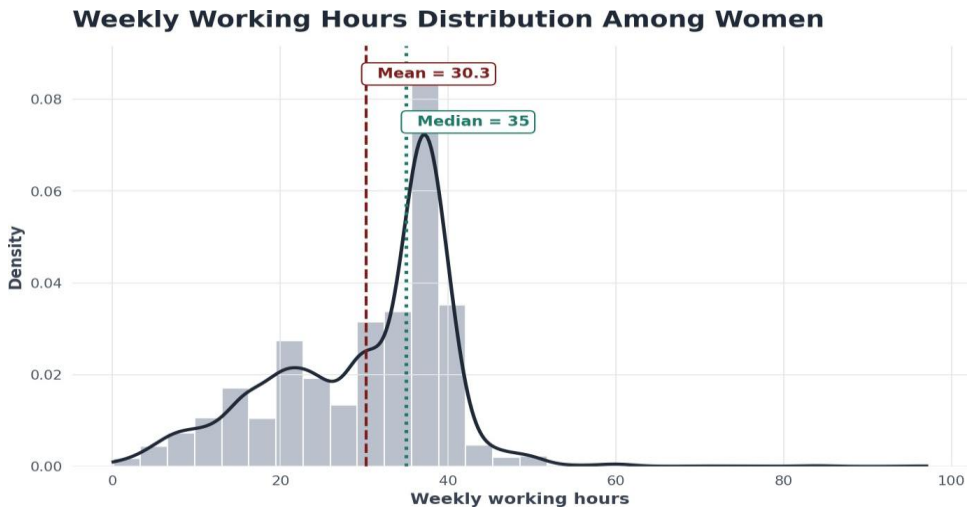


Figure 25: Weekly Working Hours Distribution Among Working Women (UK)

Furthermore, Figure 25 shows the weekly working hours of working UK women. The distribution is bimodal, with peaks around full-time (35–40 hours) and part-time (16–25 hours) employment, indicating that part-time work is widespread among UK women.

Finally, Figure 26 indicates the log-scale net average household income distribution among UK women. The distribution is approximately log-normal, with most households concentrated around the median monthly net income, and a long right tail of high-income households.

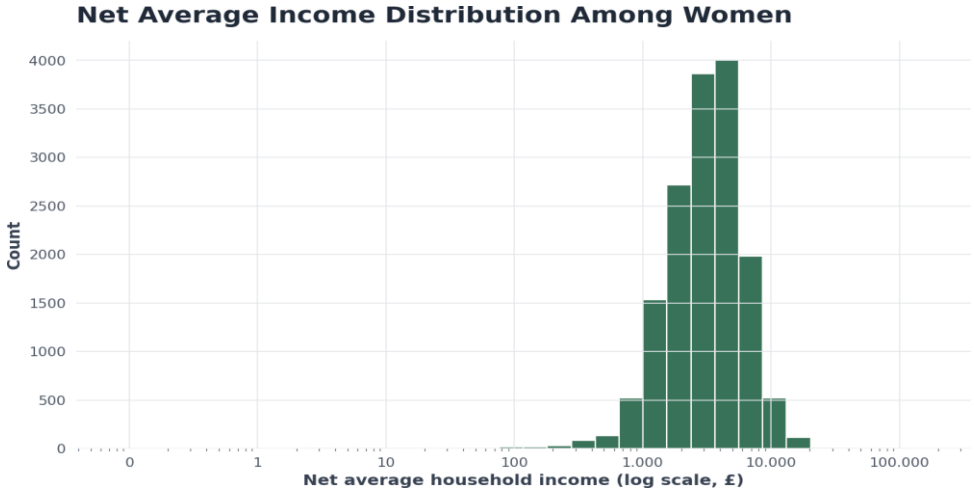


Figure 26: Net Average Household Income Distribution Among Women (log scale, UK)

Inferential Statistical Analysis of UK Survey

As the UK Understanding Society survey lacks household decision-making questions comparable to the Turkish TAYA module, the analyses use seven UK-available outcomes reflecting women's household engagement. A composite Family Engagement Index (FEI) was created by summing positive outcomes across these domains.

Table 9: Goodness-of-Fit Tests for Engagement Variables (UK)

Decision domain	Chi-square	DF	P-value	Decision at alpha = 0.05	N
Financial wellbeing	4517.049	1	< 0.001	Reject H0	16059
Family meals freq	73.638	1	< 0.001	Reject H0	918
Family support	207.801	1	< 0.001	Reject H0	919
Health status	4585.549	1	< 0.001	Reject H0	16054
Authoritative parent	0.269	1	0.604	Fail to reject	372
Employment status	13.350	1	< 0.001	Reject H0	16197
Home ownership	3918.252	1	< 0.001	Reject H0	15651

Table 9 represents the Chi-square Goodness-of-Fit test results for women's engagement across the analysed UK domains. For all domains except authoritative parenting, the p-values are below 0.05, leading to rejection of the null hypothesis and indicating that engagement categories do not follow the same distribution. In most domains, one category (typically positive engagement) clearly dominates. The only exception is authoritative parenting, where the median split produces nearly equal group sizes by construction. Overall, the findings show that women's engagement varies across household domains rather than being uniformly distributed.

Figure 27 and Table 10 represent the results of the Chi-square tests of independence with Cramer's V values for the UK sample. The analysis examines whether there is an association between socioeconomic predictors and women's engagement. The results show that several associations reach moderate or even strong effect sizes. Age, education, and income are strongly associated with employment status, while income is moderately associated with home ownership. Employment, education, and income also show meaningful associations with health status. In contrast, family meal frequency, family support, and authoritative parenting exhibit only negligible associations with the socioeconomic predictors, suggesting that these aspects of family interaction are relatively independent of broad socioeconomic characteristics. Overall, the findings indicate that socioeconomic stratification has a meaningful influence on women's structural household outcomes, while having little effect on family interaction quality.

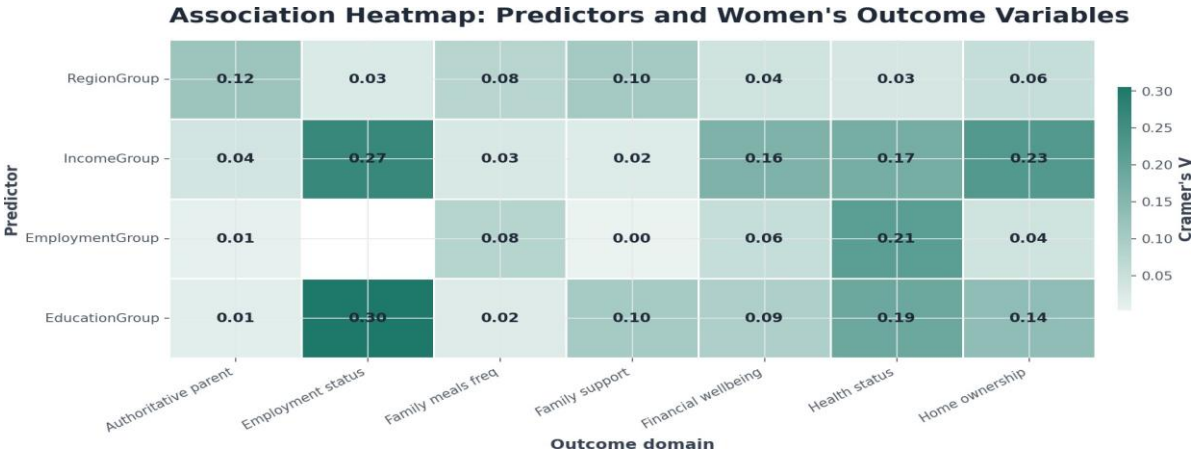


Figure 27: Cramer's V Heatmap: Predictors and Outcome Variables (UK Women)

Table 10: Significant Associations Based on Cramer's V (UK)

Predictor	Decision domain	Chi-square	P-value	Cramer's V	Strength	N
AgeGroup	Employment status	2786.709	< 0.001	0.415	Strong	16195
EducationGroup	Employment status	1485.736	< 0.001	0.305	Relatively strong	15951
IncomeGroup	Employment status	1098.490	< 0.001	0.265	Moderate	15673
IncomeGroup	Home ownership	789.103	< 0.001	0.225	Moderate	15647
EmploymentGroup	Health status	723.559	< 0.001	0.213	Moderate	16023
EducationGroup	Health status	567.659	< 0.001	0.189	Weak	15819
AgeGroup	Home ownership	498.894	< 0.001	0.179	Weak	15649
IncomeGroup	Health status	469.251	< 0.001	0.174	Weak	15530
AgeGroup	Health status	481.082	< 0.001	0.173	Weak	16052
IncomeGroup	Financial wellbeing	397.457	< 0.001	0.160	Weak	15544
EducationGroup	Home ownership	283.730	< 0.001	0.136	Weak	15418
AgeGroup	Financial wellbeing	261.856	< 0.001	0.128	Weak	16057
EducationGroup	Family support	9.620	0.008	0.104	Weak	895
EducationGroup	Financial wellbeing	127.570	< 0.001	0.090	Negligible	15826
EmploymentGroup	Family meals freq	5.521	0.019	0.078	Negligible	914

Figure 28 and Table 11 represent the Kendall's Tau correlation results between ordinal predictors (age, income, education) and women's engagement outcomes. Several relationships are statistically significant and reach weak-to-moderate magnitudes. Age is negatively associated with employment ($\tau \approx -0.29$) and health ($\tau \approx -0.16$), reflecting the older age structure of unemployed and less healthy women. Income shows positive associations with employment, home ownership, financial wellbeing, and health. Education exhibits its strongest association with employment ($\tau \approx 0.28$), followed by health, home ownership, and financial wellbeing. Family-related outcomes (meals, support, authoritative parenting) show only weak or non-significant relationships. Overall, the ordinal correlation pattern reinforces the Cramer's V findings: structural outcomes (employment, housing, finances, health) are systematically related to socioeconomic position, while family-interaction outcomes are largely independent of these factors.

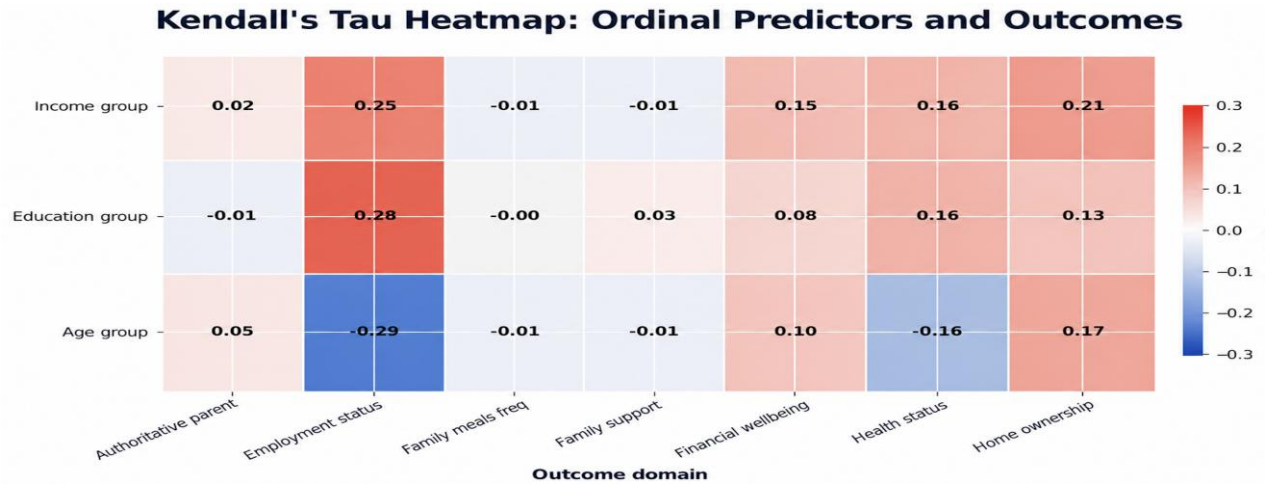


Figure 28: Kendall's Tau Heatmap (UK)

Table 11: Kendall's Tau Tests for Ordinal Predictors (UK)

Predictor	Decision domain	Kendall's tau	P-value	Direction	Strength	Decision at alpha = 0.05	N
Age group	Financial wellbeing	0.098	< 0.001	Positive	Negligible	Significant	16057
Age group	Family meals freq	–	–	Negative	Strong	Not significant	918
Age group	Family support	–	–	Negative	Strong	Not significant	919
Age group	Health status	-0.164	< 0.001	Negative	Weak	Significant	16052
Age group	Authoritative parent	0.054	0.296	Positive	Negligible	Not significant	372
Age group	Employment status	-0.291	< 0.001	Negative	Moderate	Significant	16195
Age group	Home ownership	0.169	< 0.001	Positive	Weak	Significant	15649
Income group	Financial wellbeing	0.151	< 0.001	Positive	Weak	Significant	15544
Income group	Family meals freq	-0.008	0.800	Negative	Negligible	Not significant	845
Income group	Family support	-0.008	0.818	Negative	Negligible	Not significant	845
Income group	Health status	0.163	< 0.001	Positive	Weak	Significant	15530
Income group	Authoritative parent	0.022	0.661	Positive	Negligible	Not significant	359
Income group	Home ownership	0.211	< 0.001	Positive	Moderate	Significant	15647
Education group	Financial wellbeing	0.082	< 0.001	Positive	Negligible	Significant	15826
Education group	Family meals freq	-0.004	0.893	Negative	Negligible	Not significant	894
Education group	Family support	0.026	0.432	Positive	Negligible	Not significant	895
Education group	Health status	0.161	< 0.001	Positive	Weak	Significant	15819
Education group	Authoritative parent	-0.005	0.923	Negative	Negligible	Not significant	363
Education group	Employment status	0.279	< 0.001	Positive	Moderate	Significant	15951

Education group	Home ownership	0.129	< 0.001	Positive	Weak	Significant	15418

Additionally, a composite Family Engagement Index (FEI, range 0–7) was constructed by summing positive outcomes across the seven engagement domains. One-way ANOVA was used to test whether the mean FEI differs across socioeconomic groups

Table 12: One-Way ANOVA Results for Family Engagement Index (UK)

Predictor	F statistic	DF1	DF2	P-value	Decision at alpha = 0.05	N
EducationGroup	701.012	2	15969	< 0.001	Significant	15972
EmploymentGroup	7374.795	1	16187	< 0.001	Significant	16189
IncomeGroup	1085.995	2	15691	< 0.001	Significant	15694
RegionGroup	3.034	5	16206	0.010	Significant	16212
AgeGroup	204.871	2	16214	< 0.001	Significant	16217

Table 12 represent the one-way ANOVA results for the Family Engagement Index across socioeconomic groups in the UK. All five predictors—education, employment, income, region, and age—show statistically significant differences. The F-statistics for employment, income, and education are particularly large, indicating substantial mean differences in the FEI between groups. Region also shows a significant but smaller effect. Unlike the Turkish data, where only income was significant, the UK results reveal that all major socioeconomic dimensions matter for women's overall household engagement, with employment status and income being the most influential. The boxplot results support these findings, with clear visual separation across employment, income, and education groups.

Furthermore, the bivariate inferential tests above detect pairing associations, multivariate cluster analysis detects natural groupings of women based on their association on multiple variables. This section uses the Partitioning Around Medoids (PAM) algorithm on the UK sample for women to create empirically informed woman profiles.

Hereby, the clustering was performed on a set of nine variables combining four engagement indicators (financial wellbeing, good health, employment, home ownership) and five socioeconomic indicators (age, log income, education, working status, region). Because the variables include a mix of binary, ordinal, and continuous types, the *Gower distance* metric was used to construct the pairwise distance matrix. Clustering was applied to a random sample of 4,000 women drawn from the 15,172 complete-case female respondents to keep the distance matrix computationally tractable.

The optimal number of clusters was determined using ASW. The highest ASW score was obtained for $k = 2$ with ASW $= 0.467$, whereas, all alternative solutions ($k \geq 3$) produced substantially lower scores (all below 0.27). Therefore, the two-cluster solution was selected for the subsequent clustering analysis.

2.4.

On the other hand, the two clusters were relatively balanced in size. Cluster 1 included 2,140 women (53.5% of the sample), while Cluster 2 included 1,860 women (46.5%). This balanced distribution indicates that the clustering solution did not produce a small or isolated subgroup, supporting the stability of the two-cluster solution.

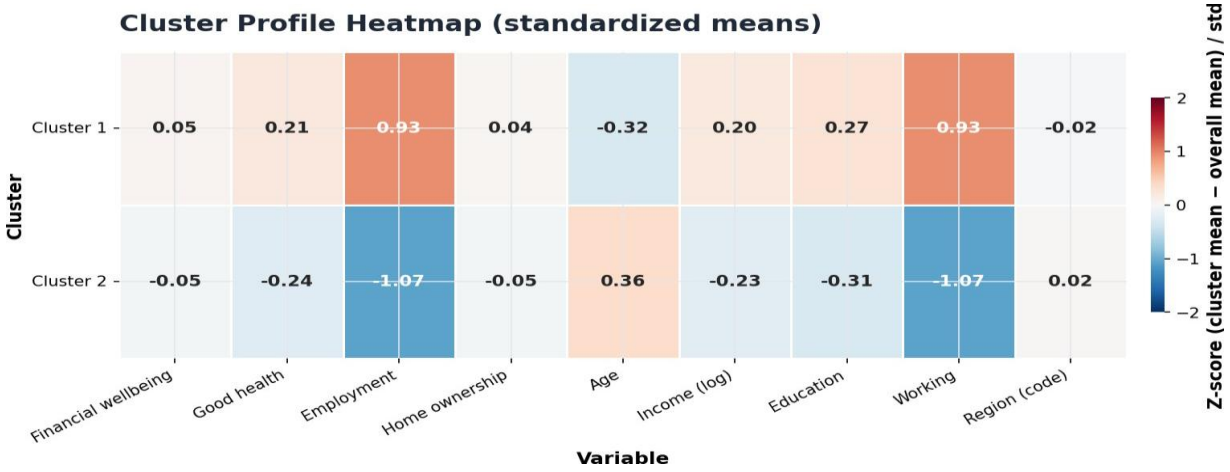


Figure 29: Standardized profile heatmap. Z-scores show how each cluster mean deviates from the overall sample mean, in standard-deviation units.

Accordingly, cluster profiles show two distinct clusters. Cluster 1 includes 2140 women (53.5% of the sample) who have slightly higher financial wellbeing scores (78.6%), higher home ownership rates (77.1%), a slightly better health score (85.9%) and are slightly younger (27.5 years old on average), with higher ePAMducational attainment and higher average household income (£3,512). By contrast, Cluster 2 consists of 1,860 women (46.5% of the sample) and is composed of older women who are not currently in the labour force, and have lower levels of education and lower average household income (£2,349). This cluster also has below average levels of good health (67.4%), financial wellbeing (74.2%) and home ownership (73.3%). The overall size of the two clusters is fairly even, the difference between the employment rates and the ages being the most obvious.

The PAM analysis shows that the most prominent structural division within the UK female sample is essentially a labour-market activity division, which is also linked to age. The clustering does not form a fine-grained socioeconomic gradient (low, middle, and high) but rather a binary contrast between an active and employed (with a somewhat younger population) with a non-working and older population that had weaker health outcomes. This is similar to the bivariate results presented above – where employment, income and age were most significant – but also provides a multivariate validation: when all features are analysed together, employment becomes the major one explaining the variability among UK women. However, it should be noted that this two cluster structure, to some extent, is a result of the wide age spread of the UK panel, which contains a significant proportion of retired women. A clustering that is limited to working age women (such as 25 – 65) may show a more subtle partition which could be investigated in future work.

Discussion about UK Survey's Findings

This part of the study aimed to examine women's position within household and family life in the contexts of Türkiye and the United Kingdom and to explore how women's empowerment is shaped across different social and institutional settings. The study analyzed women's position within the family through direct measures of intra-household decision-making processes in Türkiye and multidimensional indicators reflecting participation in family life and well-being in the United Kingdom, rather than relying solely on economic indicators. In this respect, the study offers a critical contribution to the literature by demonstrating that women's empowerment may take different forms across different social contexts, thereby challenging the often-assumed unidimensional understanding of empowerment.

The findings suggest that women occupy active and visible roles within family life in both countries; however, the nature and expression of this involvement vary considerably across national contexts. In Türkiye, women demonstrate high levels of participation in intra-household decision-making processes, however, this participation occurs primarily through joint decision-making

mechanisms. While women tend to possess greater individual authority in areas associated with the management of everyday life, joint decision-making arrangements predominate in more strategic and resource-intensive domains. In the United Kingdom, women generally report high levels of positive outcomes in family life; however, these outcomes appear to be shaped to a considerable extent by socioeconomic factors such as education, income, employment, and life-course position. In contrast, everyday family interactions, such as family support, family meals, and parenting style, appear to remain relatively independent of socioeconomic position. When considered together, these findings suggest that women's position within the family is shaped not only by the availability of economic resources, but also by the nature of decision domains, social norms, and patterns of family interaction, reflecting a multilayered process.

The comparative analysis reveals that the mechanisms underlying women's position within the family vary across the two national contexts. In the Turkish sample, the relationships between decision-making power and socioeconomic factors such as education, income, and employment were statistically significant; however, their influence remained relatively limited. This suggests that women's decision-making processes cannot be explained solely by individual resources. By contrast, in the United Kingdom sample, employment, income, education, and age were found to have a more pronounced influence on women's living conditions. However, the relative independence of indicators reflecting the quality of intra-family relationships from socioeconomic position suggests that economic resources do not always determine family relationships. Therefore, when the findings from both countries are considered together, women's empowerment cannot be explained solely by increases in economic capital; rather, it emerges as a complex process that requires the joint consideration of economic, cultural, relational, and institutional dimensions.

The Chi-square Goodness-of-Fit results confirm that women's engagement is not equally distributed across cat-egories. In most domains, the positive category is dominant, but the strength of this dominance varies considerably across outcomes. Authoritative parenting is the only domain showing roughly equal split, reflecting the median-split definition used.

The Chi-square Tests of Independence and Cramer's V analysis reveal a markedly stronger pattern of associations than in the Turkish data. Age, education, and income are strongly or moderately associated with employment status; income with home ownership; and employment, education, and income with health status. These effect sizes are practically meaningful and not merely artefacts of the large sample. By contrast, family-interaction outcomes (meals, support, parenting) show only negligible associations with socioeconomic predictors, suggesting that family-level dynamics are relatively independent of structural socioeconomic position. This finding is consistent with previous research suggesting that women's empowerment is not a homogeneous process that unfolds equally and linearly across all spheres of life; rather, it consists of economic, relational, and familial dimensions that operate at different levels. Indeed, the existing literature emphasizes that empowerment in one domain does not necessarily lead to a similar level of empowerment in other domains. This suggests that power relations may vary across different decision domains, social norms, and institutional contexts (Abdulai et al., 2024; Nacka et al., 2024; UNECE, 2020).

Kendall's Tau results reinforce this picture: structural outcomes (employment, housing, financial wellbeing, health) are systematically and ordinally related to age, education, and income, while family-interaction outcomes are essentially independent of these ordinal predictors. Education and income are the most consistent positive predictors, while age has divergent effects (negative for employment and health, positive for home ownership and financial wellbeing).

The ANOVA results provide an important comparative finding: unlike the Turkish data, in which only income produced a statistically significant ANOVA result, in the UK *all* five socioeconomic predictors significantly affect the Family Engagement Index. Employment, income, and education produce the largest F-statistics, indicating that these three dimensions are the most powerful socioeconomic shapers of women's overall household engagement in the UK.

The PAM cluster analysis adds a multivariate dimension to these findings. Rather than a fine-grained gradient, the UK female sample partitions cleanly into two profiles: a younger, employed,

financially comfortable, and healthier group (Cluster 1, 53.5%) and an older, non-working group with weaker health outcomes (Cluster 2, 46.5%). The high silhouette score (0.467) at $k = 2$ confirms that this binary employment-and-age division captures the dominant structure of the data, reinforcing the conclusion that labour-market participation is the most consequential axis of variation among UK women.

CONCLUSION

This study comparatively examined the socioeconomic determinants of women's position within the household in Türkiye and the United Kingdom and demonstrated that women's intra-household power and decision-making processes are shaped by different social and structural dynamics across the two countries. The findings suggest that women's active participation in family life does not necessarily result in autonomous decision-making authority. Instead, joint decision-making remains the predominant pattern, particularly in strategic and economically significant domains of household decision-making. These findings suggest that assessing women's position within the household solely in terms of their level of participation in decision-making is insufficient and that a multidimensional approach, which also takes into account the nature of decisions and the structure of decision-making domains, is required.

The comparative analysis highlights both shared patterns and distinct differences between the two countries. In Türkiye, women's position within the household cannot be explained solely by conventional socioeconomic indicators such as education, income, and employment. Rather, the social context, in which traditional family structures coexist with processes of modernization, renders household decision-making mechanisms considerably more complex. In contrast, women's position within the household in the United Kingdom appears to be more strongly determined by economic resources and labor market participation. While educational attainment supports more consistent engagement in family life, employment strengthens women's structural position within the household, and income emerges as a particularly important determinant of housing conditions and economic security. By contrast, the relative stability of family interaction quality across socioeconomic groups suggests that structural indicators of power and family processes are shaped by different dynamics.

These findings suggest that women's empowerment is not a universal process independent of a country's social context; rather, it is shaped by each society's institutional arrangements, welfare regime, gender norms, and family model. Therefore, policies and interventions aimed at strengthening women's position within the household should not be limited to improving women's access to education and employment. They should also incorporate comprehensive approaches that seek to transform intra-household power relations, gender roles, and decision-making processes.

Nevertheless, this study has several limitations. First, the cross-sectional nature of the data does not allow causal inferences regarding the relationships among the variables. Furthermore, the indicators used to assess women's position within the household are not fully comparable across the Türkiye and United Kingdom datasets. While the Turkish data provide direct measures of intra-household decision-making, the United Kingdom data rely on indirect indicators reflecting women's engagement in family life and well-being. Therefore, while the comparison between the two countries is conceptually meaningful, the measures employed cannot be assumed to be fully equivalent. Moreover, because the variables are largely based on women's self-assessments, the findings may reflect perceived power and decision-making processes. Finally, the absence of variables that may directly influence intra-household power relations—such as gender norms, spousal negotiation processes, relationship quality, and individuals' perceptions of power—limits the interpretation of the findings to some extent.

Future research should adopt longitudinal designs to examine women's empowerment within the household from a life-course perspective. Examining how changes in education, employment, and income over time influence women's decision-making processes and their position within the household would strengthen the causal inferences that can be drawn from the current findings. In addition, qualitative research could provide a deeper understanding of the negotiation processes underlying joint decision-making, the less visible dimensions of intra-household power relations, and the ways in which gender norms are reflected in everyday family practices. Comparative studies conducted across

countries with different welfare regimes, family models, and gender orders would contribute to a more comprehensive understanding of both the universal and context-specific dimensions of women's empowerment. In conclusion, advancing our understanding of women's position within the household requires a holistic perspective that extends beyond individual socioeconomic characteristics to encompass the social, cultural, and institutional contexts in which they are embedded. Such an approach would contribute not only to the advancement of the literature but also to the development of more effective policies for promoting gender equality. In conclusion, understanding women's position within the household requires a holistic perspective that considers not only individual socioeconomic characteristics but also the broader social, cultural, and institutional contexts in which they are embedded. This perspective would contribute to the advancement of the literature and support the development of more effective policies for promoting gender equality.

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EFFECT OF THROUGH-THICKNESS ABS LAYER PLACEMENT ON THE TENSILE BEHAVIOR AND ENERGY ABSORPTION OF MULTI-MATERIAL FDM-PRINTED SILK PLA/ABS STRUCTURES

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ABSTRACT

Multi-material fused deposition modeling (FDM) allows dissimilar polymers to be combined within a single printed part. When stiff PLA and tough ABS are deposited as alternating bands through the thickness, the weakly bonded PLA/ABS interfaces and the spatial arrangement of the phases jointly govern the mechanical response. Previous work has mostly addressed the total amount of the secondary material, whereas the question of where an identical amount of ABS should be placed through the thickness has remained largely open. In this study, the effect of through-thickness ABS placement at constant ABS content on the tensile behavior, ductility, and energy absorption of silk PLA/ABS structures was investigated experimentally. Dogbone specimens with an ASTM D638 Type I planform and 6 mm total thickness were produced in a single job on a single-nozzle multi-material FDM printer (silk PLA at 220 °C, ABS at 260 °C, bed temperature 55 °C, printing speed 150 mm/s). All specimens had 0.6 mm fully dense PLA skins and a 40% honeycomb interior; the 2.4 mm total ABS thickness was placed as (M) a single central core, (K) two 1.2 mm bands adjacent to the skins, and (G) three 0.8 mm distributed bands forming a functionally graded arrangement. Three replicates per configuration were tested at 5 mm/min with a 106 mm grip separation. All three configurations reached peak loads of about 1000 N (about 13 MPa apparent strength; ANOVA $p = 0.809$) with similar apparent moduli (383-415 MPa, $p = 0.077$). The post-peak response, however, differed drastically: the ABS bands fractured while the silk PLA kept deforming by extensive cold drawing and fibrillation; the displacement at failure ranked K (137 ± 21 mm) > M (79 ± 14 mm) > G (15 ± 16 mm) and the absorbed energy K (22.5 ± 2.5 J) > M (13.9 ± 0.5 J) > G (4.5 ± 3.0 J), with all pairwise differences significant (Tukey $p < 0.05$). At fixed composition, layer placement therefore acts as a design variable that changes ductility by roughly nine-fold and energy absorption by roughly five-fold at no additional material or equipment cost.

Keywords: Additive Manufacturing; FDM; Multi-material Printing; PLA/ABS; Silk PLA; Layer Placement; Functionally Graded Structures; Energy Absorption; Tensile Behavior

INTRODUCTION

Fused deposition modeling (FDM) has become one of the most widely used additive manufacturing processes thanks to its low cost and design flexibility; the mechanical properties of printed parts depend strongly on process parameters such as layer thickness, build orientation, raster angle, and infill [1, 2]. Infill density and pattern are among the main determinants of stiffness and strength, particularly in parts with cellular interiors [7], and raster- and geometry-dependent failure behavior has been documented in detail [8].

Multi-material FDM allows dissimilar polymers to be combined within a single print job, opening the door to property combinations that no single material offers. The PLA/ABS pair is frequently studied in this context: PLA is stiff but prone to brittle failure [6], whereas ABS is more compliant and tough [1]. However, PLA and ABS do not fuse well chemically; the interface strength is limited by inter-molecular diffusion, and PLA/ABS interfaces constitute the weakest link in multi-material prints [3, 4].

Graded (functionally graded) through-thickness transitions are one of the unique design freedoms offered by additive manufacturing, allowing the material distribution to be tailored with position inside a part [5]. It is not clear, however, whether graded architectures are always beneficial for polymer pairs with weak interfaces; grading smooths the transitions but also multiplies the number of weak interfaces.

The behavior of multi-material PLA/ABS structures has mostly been addressed in terms of the total fraction of the secondary phase, the interfacial bond strength, and the printing parameters [3, 4]. In contrast, the question of where an identical amount of ABS should be placed through the thickness, that is, the effect of phase placement (architecture) at constant composition, has received comparatively little attention. Yet placement directly changes the number of interfaces, the thickness of the continuous PLA ligaments, and the path along which damage propagates.

The aim of this study is to determine experimentally the effect of through-thickness ABS placement, at constant ABS content (2.4 mm in a 6 mm thickness), on the tensile behavior, ductility, and energy absorption of silk PLA/ABS multi-material structures. Three architectures are compared: a single central ABS core (M), two ABS bands adjacent to the skins (K), and a graded arrangement of three ABS bands distributed through the thickness (G). Silk PLA, a decorative filament that exhibits pronounced ductile drawing, was used as the bulk material, and its post-peak behavior in multi-material structures is also documented.

MATERIALS AND METHODS

Specimen Design and Architectures

The specimens were designed with an ASTM D638 Type I planform [9], a total thickness of 6 mm, and a flat build orientation (thickness = printing z axis). In all configurations, 0.6 mm thick fully dense (rectilinear, 45°) silk PLA skins were used at the bottom and top faces, and the interior was printed with 40% honeycomb infill. The total ABS thickness was kept constant at 2.4 mm in all three architectures, and only its placement through the thickness was varied (Table 1, Figure 1): (i) M (Center): a single 2.4 mm central ABS core; (ii) K (Edge): two 1.2 mm ABS bands adjacent to the skins; (iii) G (Graded): three 0.8 mm ABS bands distributed through the thickness. This design fixes the composition and isolates the effect of placement alone. The architectures differ systematically in the number of PLA/ABS interfaces (M: 2, K: 4, G: 6) and in the thickest continuous PLA block (K: 2.4 mm, M: 1.8 mm, G: 1.2 mm).

Table 1. Through-thickness stacking of the configurations (z = 0 at the build plate).

Configuration	z range (mm)	Material	Infill (%)	Pattern
M	0-0.6	PLA	100	Rectilinear (45°)
	0.6-1.8	PLA	40	Honeycomb (0°)
	1.8-4.2	ABS	40	Honeycomb (0°)
	4.2-5.4	PLA	40	Honeycomb (0°)
	5.4-6.0	PLA	100	Rectilinear (45°)
K	0-0.6	PLA	100	Rectilinear (45°)
	0.6-1.8	ABS	40	Honeycomb (0°)
	1.8-4.2	PLA	40	Honeycomb (0°)
	4.2-5.4	ABS	40	Honeycomb (0°)
	5.4-6.0	PLA	100	Rectilinear (45°)

Configuration	z range (mm)	Material	Infill (%)	Pattern
G	0-0.6	PLA	100	Rectilinear (45°)
	0.6-1.4	ABS	40	Honeycomb (0°)
	1.4-2.6	PLA	40	Honeycomb (0°)
	2.6-3.4	ABS	40	Honeycomb (0°)
	3.4-4.6	PLA	40	Honeycomb (0°)
	4.6-5.4	ABS	40	Honeycomb (0°)
	5.4-6.0	PLA	100	Rectilinear (45°)

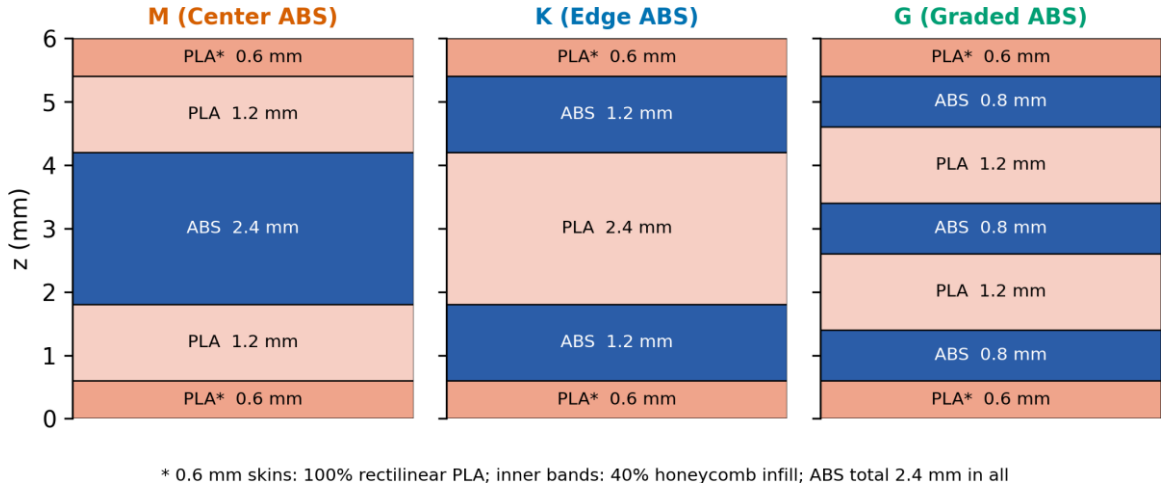


Figure 1. Schematic representation of the three ABS placement architectures through the thickness.

Fabrication

The specimens were produced in a single job on a single-nozzle multi-material FDM printer with an automatic material system (Bambu Lab X1 Carbon, Bambu Lab, China). Pink silk PLA was printed at a nozzle temperature of 220 °C and ABS at 260 °C, with a bed temperature of 55 °C, a printing speed of 150 mm/s, one wall loop, and a layer thickness of 0.2 mm (Table 2). Nozzle purging (prime tower) was enabled at material changes to prevent cross-contamination of the sections, and the stacking was verified in the slicer preview and from edge views of the printed specimens (Figure 2).

Table 2. Fabrication parameters.

Parameter	Value
Bed temperature	55 °C
Printing speed	150 mm/s
Wall loops	1
PLA nozzle temperature	220 °C
ABS nozzle temperature	260 °C
Layer thickness	0.2 mm
Skin infill	100%, rectilinear, 45°
Interior infill	40%, honeycomb, 0°

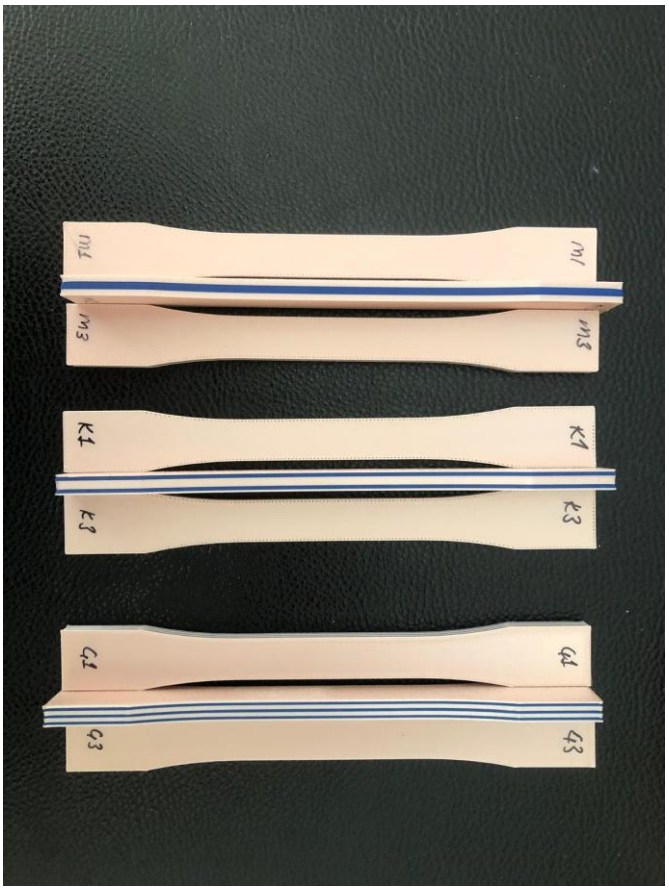


Figure 2. Edge views of the printed multi-material specimens: placement of the blue ABS bands in the M (top), K (middle), and G (bottom) architectures.

Tensile Tests

Tensile tests were carried out on a universal testing machine at a constant crosshead speed of 5 mm/min with a grip separation of 106 mm and three replicates per configuration (n = 3); force and displacement were recorded at 200 Hz. Because of the very large elongation of silk PLA, a single test on the ductile specimens took about 30 minutes. Image-based strain measurement (DIC) with a speckle pattern on the gauge section was initially planned; however, the correlation could not be maintained because of the excessive elongation and flaking of the paint layer, so this measurement was abandoned and the evaluation was based on the load-displacement data and on visual damage inspection. The apparent stress was computed by dividing the force by the gross cross-sectional area (13 mm × 6 mm = 78 mm²), and the nominal strain as the crosshead displacement divided by the initial grip separation. Since the interior is cellular (40% infill), these values should be interpreted as apparent, structure-level quantities rather than material properties.

. Data Analysis and Statistics

For each specimen, the peak load and the corresponding apparent strength were determined; the apparent elastic modulus was obtained by a linear fit over the 0.10-0.40 peak-load range on the rising branch; the displacement at failure (separation) was taken as the last point at which the load remained above a 10 N threshold; and the absorbed energy was computed as the area under the load-displacement curve. Since final separation occurred gradually due to bridging by thin silk PLA fibrils, the displacement at failure is represented by the end of the record, where the load had decayed to roughly 5-12% of the peak value. The configurations were compared using one-way analysis of variance (ANOVA) and Tukey HSD multiple comparison tests ($\alpha = 0.05$); the analyses were performed in MATLAB.

RESULTS AND DISCUSSION

Stress - Strain Behavior

Figure 3 shows the apparent stress-nominal strain curves of the nine specimens. All three architectures exhibited nearly coincident behavior in the initial region, reaching a peak of 12.2-13.4 MPa apparent stress at approximately 4% strain. Immediately after the peak, the load dropped sharply to roughly 35-55% of its peak value; this drop is associated with cracking of the brittle ABS bands and of the fully dense skins. The behavior then took the form of a long, slowly decaying plateau sustained by cold drawing of the silk PLA. The differences between the architectures emerged in this second stage: the K specimens sustained the plateau up to nominal strains as high as 151%, whereas two of the G specimens separated immediately after the peak (at about 5.5% elongation).

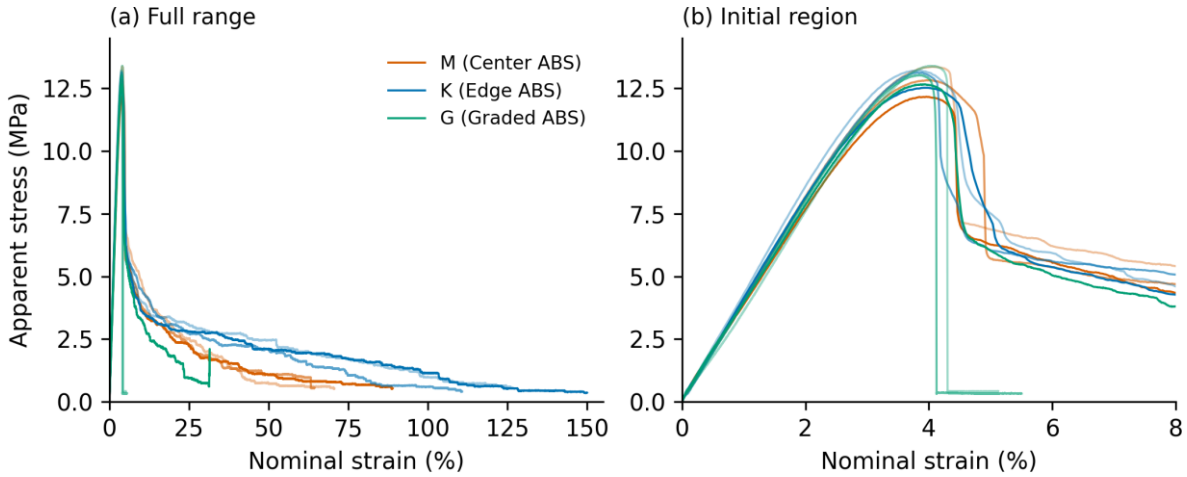


Figure 3. Apparent stress - nominal strain curves: (a) full range, (b) initial region (three replicates per architecture).

Mechanical Properties and Statistical Evaluation

Table 3 and Figure 4 summarize the results. The peak load (M: 998 ± 47 N, K: 1011 ± 29 N, G: 1016 ± 29 N) and the corresponding apparent strength were independent of the architecture (ANOVA $p = 0.809$), and the differences in apparent modulus did not reach significance ($p = 0.077$). This finding is consistent with the expectation that, in tension, the load is carried parallel to the layers (approximately under an iso-strain condition) and the peak load is set by the composition, which was kept constant, rather than by the placement.

In contrast, the displacement at failure ($p < 0.001$) and the absorbed energy ($p < 0.001$) were strongly affected by the architecture, and all pairwise differences were significant according to the Tukey test (for displacement at failure, M-K $p = 0.014$, M-G $p = 0.009$, K-G $p < 0.001$; for energy, M-K $p = 0.008$, M-G $p = 0.005$, K-G $p < 0.001$). The K architecture was the most ductile and energy-absorbing structure, with an average failure displacement of 137 mm and an energy of 22.5 J, whereas the graded G architecture was the most brittle, with 15 mm and 4.5 J; the difference between the two extremes is roughly nine-fold in ductility and roughly five-fold in energy.

Table 3. Tensile test results (mean ± standard deviation, n = 3). Different letters within a row indicate a significant difference according to the Tukey test ($p < 0.05$).

Property	M (Center)	K (Edge)	G (Graded)	ANOVA p
Peak load (N)	998 ± 47 (a)	1011 ± 29 (a)	1016 ± 29 (a)	0.809
Apparent tensile strength (MPa)	12.79 ± 0.60 (a)	12.96 ± 0.37 (a)	13.03 ± 0.37 (a)	0.809
Apparent elastic modulus (MPa)	391 ± 20 (a)	415 ± 7 (a)	382 ± 14 (a)	0.077

Property	M (Center)	K (Edge)	G (Graded)	ANOVA p
Displacement at failure (mm)	79.2 ± 13.5 (b)	136.9 ± 20.9 (a)	14.9 ± 16.0 (c)	< 0.001
Elongation at failure (%)	74.7 ± 12.8 (b)	129.2 ± 19.7 (a)	14.0 ± 15.1 (c)	< 0.001
Absorbed energy (J)	13.9 ± 0.5 (b)	22.5 ± 2.5 (a)	4.5 ± 3.0 (c)	< 0.001

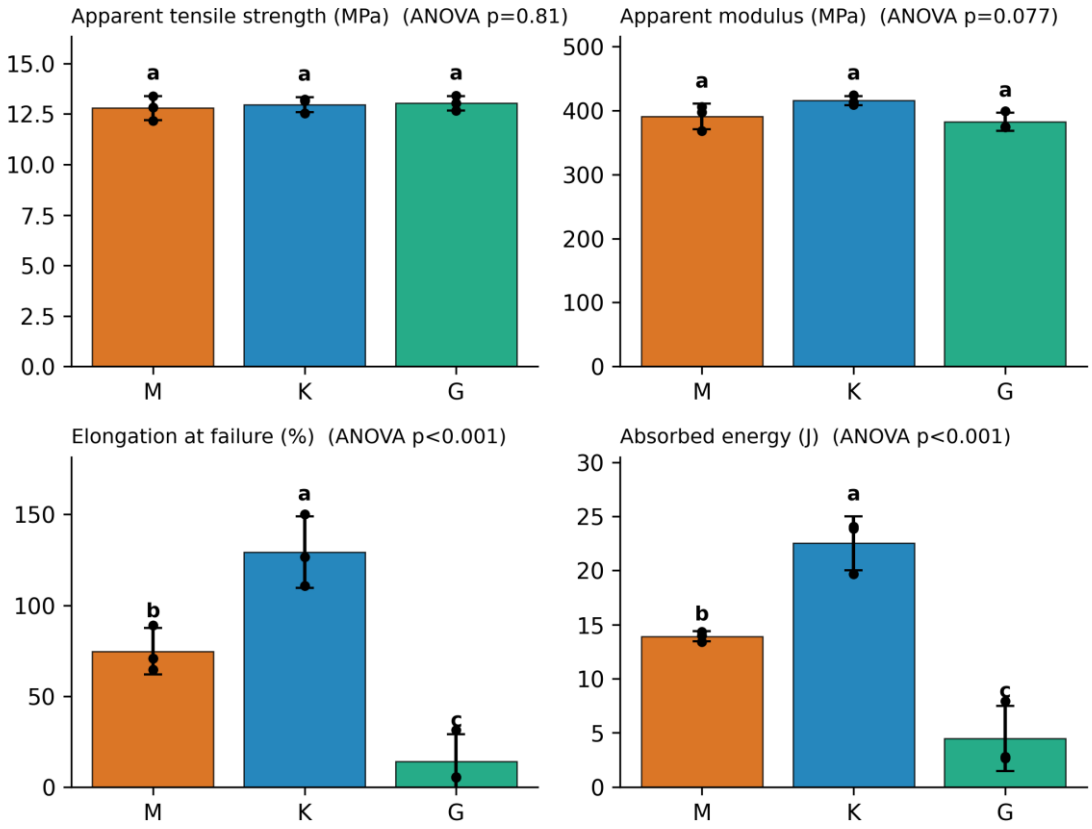
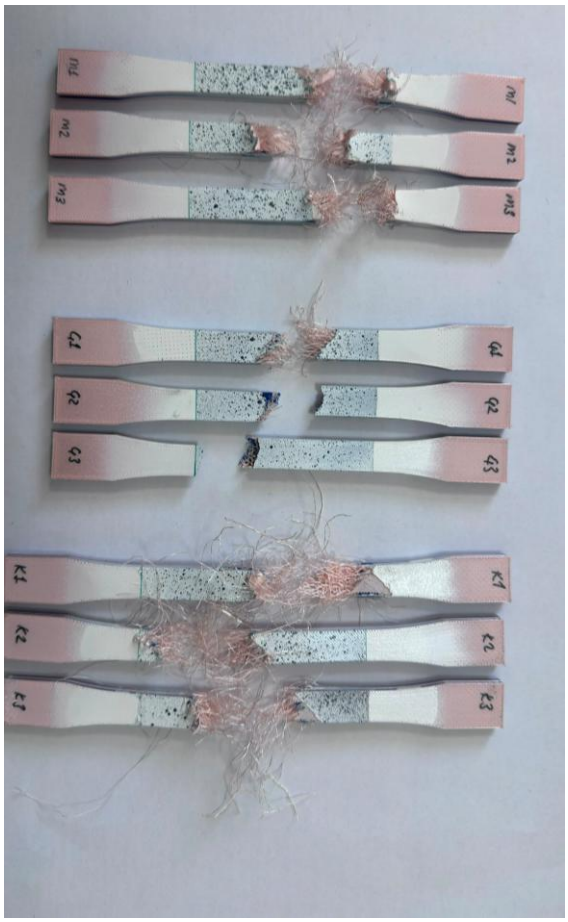


Figure 4. Variation of the mechanical properties with the architecture (bars: mean ± SD; points: individual specimens; letters: Tukey groups).

Failure Mechanisms and Discussion

Figures 5 and 6 present the post-test damage. In all architectures, the blue ABS bands exhibited flat, brittle fracture surfaces, whereas the silk PLA separated with intense fibrillation, in the form of thread-like bundles. In the M and K specimens, extensive clouds of pink fibrils formed around the fracture zone; in the K specimens, skin-interior delaminations and surface separations along the edges were additionally observed. In the G specimens, fibrillation remained limited and separation occurred on a relatively clean cross-section, indicating that stable post-peak drawing was largely suppressed in this architecture.



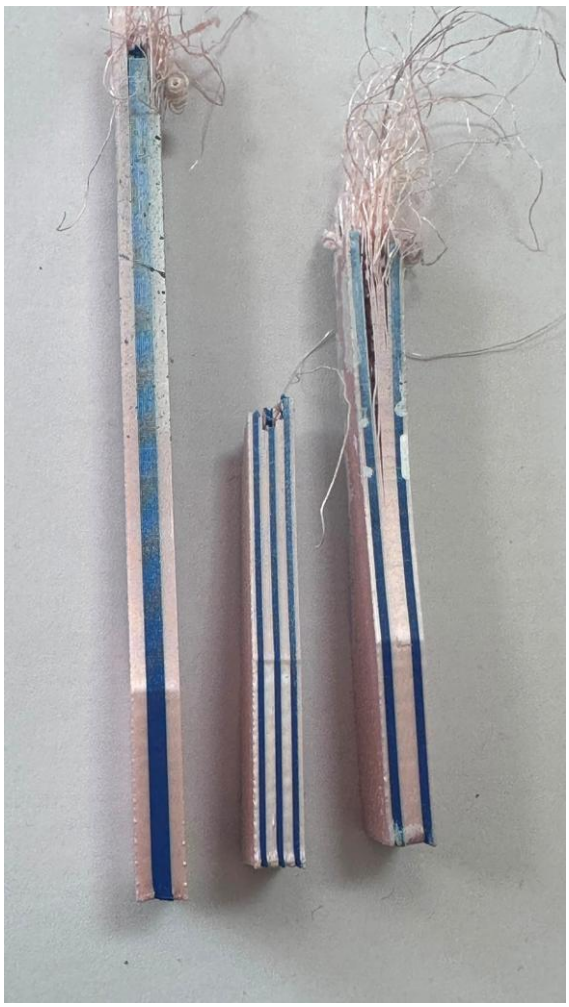


Figure 5. Overview of the specimens after tensile testing (top to bottom: M, G, and K groups); extensive silk PLA fibrillation in the M and K groups and a relatively clean separation in the G group.

Figure 6. Edge (through-thickness) views of the fractured specimens (left to right: M, G, K); brittle fracture of the ABS bands, silk PLA fibrillation, and skin delamination in the K specimen.

The observed ranking is consistent with a mechanism in which the post-peak behavior is controlled by the stable drawing capacity of the continuous PLA ligaments. After the ABS bands and the skins crack at the peak load, the remaining load is carried by the silk PLA bands that preserve their continuity across the section. The thickest continuous PLA block is found in the K architecture (a 2.4 mm central core), followed by M (1.8 mm blocks merged with the skins) and, in its thinnest form, G (1.2 mm bands); the ductility and energy ranking (K > M > G) matches this parameter exactly. On the other hand, the number of weak PLA/ABS interfaces is 2, 4, and 6 in M, K, and G, respectively; in G, the combination of the highest interface count and the thinnest PLA ligaments makes it easier for cracks initiated in the ABS bands to coalesce across the adjacent thin PLA bands, leading to early and sudden separation. The large scatter within the G group (elongations at failure of 5.5%, 5.5%, and 31.5%) is a signature of this unstable damage progression. The fact that the ductility ranking is not monotonic in the interface count (K is more ductile than M despite having more interfaces) indicates that the governing parameter is not the interface count alone but the thickness of the continuous ductile phase. These results show that graded placements are not automatically advantageous for polymer pairs with weak interfaces, and that subdividing the ductile phase can severely reduce toughness.

The limitations of the study should also be noted. Since the strain is derived from the crosshead displacement, it includes machine and gripping compliance; the apparent modulus values are therefore intended for comparison. As the stresses are computed on the gross cross-section, they are lower than

the true material-level stresses because of the 40% infill cellular interior. The number of replicates is three, and a single ABS fraction and a single test speed were examined. Future work will address flexural loading, different ABS fractions, interface characterization, and DIC measurements focused on the low-elongation regime.

CONCLUSIONS

1. At constant ABS content (2.4 mm in a 6 mm thickness), the through-thickness placement of ABS did not change the peak load or the apparent strength (about 1000 N and 13 MPa; $p = 0.809$). The differences in apparent modulus were also not significant ($p = 0.077$).

2. Placement governed the post-peak behavior: the displacement at failure ranked K (137 ± 21 mm) > M (79 ± 14 mm) > G (15 ± 16 mm) and the absorbed energy K (22.5 ± 2.5 J) > M (13.9 ± 0.5 J) > G (4.5 ± 3.0 J), with all pairwise differences significant (Tukey $p < 0.05$).

3. The damage consisted of brittle fracture of the ABS bands, extensive cold drawing and fibrillation of the silk PLA, and local skin delaminations. The ductility ranking matches the thickness of the thickest continuous PLA block (K: 2.4 > M: 1.8 > G: 1.2 mm) exactly.

4. The graded (G) placement, which multiplies the interfaces and thins the ductile phase, produced the most brittle and most scattered behavior; graded architectures are not automatically advantageous for polymer pairs with weak interfaces.

5. Layer placement is a practical design variable that allows the energy absorption to be tuned over roughly a five-fold range through the printing sequence alone, without changing the material quantity, the equipment, or the cost.

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DILEMMAS IN THE PROCESS OF CONCEPTUALIZING URBAN DESIGN

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ABSTRACT

Theoretical and practical debates on urban design—a field encompassing planning, architecture, and related disciplines—have continued from the Second World War to the present day. This concept, assumed to formally objectify urban space, entered the academic domain in the 1950s. After the 1960s and 1970s, it rapidly gained legal grounding in line with neoliberal policies, particularly in developed countries, and became the most effective instrument for intervening in urban areas. Beyond being characterized as an interdisciplinary and multidisciplinary field, dilemmas persist around the notion of "design" embedded within it. For urban design to develop an independent theoretical terminology, its content variables must be addressed together with social policy.

Sources analyzing the structural dilemmas arising from urban design's in-between identity were constructed through existing examples and documents. Using a literature review and critical discourse analysis, findings on urban design in the Scopus and Web of Science databases were qualitatively examined. A core assumption concerns the open-ended nature of the word "design" within the concept. Within both pre- and post-modernist relations of production, urban design has functioned as a fundamental policy instrument sustaining the continuity of the existing system through spatial production models at different urban scales; this is a defining feature that distinguishes urban design from the other supporting disciplines within the multidisciplinary process.

The findings show that after the 1960s and 1970s urban design turned into an instrument of economic repair grounded in neoliberal policies, while in practice it has been perceived either as a technical interpretation or as an element of aesthetics and image. Norms and regulatory instruments emerged as additional dilemmas alongside the central–local hierarchy. The study has produced a data set that contributes to the formal and administrative philosophy of spatial production. The findings underscore the need for a holistic, human-centered urban design philosophy that is use-value oriented and grounded in a philosophically based spatial production policy consistent with universal principles.

Keywords: Urban Design, Multidisciplinarity, Production of Space, Philosophy of Space.

INTRODUCTION

Although the word 'design' is embedded within the content of many scientific, artistic, and technical disciplines to which it belongs, it is not possible to say that it belongs exclusively to any one of them. For this reason, the word 'design' possesses a quality that meets the philosophical domain at a higher level. Consequently, the concept of 'Urban Design' also meets a philosophical domain. On the basis of its relationship with creativity, this philosophy emerges as an aesthetic philosophy across all artistic and scientific fields, while remaining distinct from philosophy in general. Every theory, in turn, is a design model (Tunalı, 2020, pp.11-30). According to this definition, the concept of 'urban design' cannot be associated with a single design model because of its multidisciplinary content. However, each of the different disciplines involved has its own theoretical domain. As a result, each discipline appears separately as its own design model. In Keleş's account, "Urban design is the process of forming and organizing urban space, building groups, and public open spaces not merely in aesthetic and formal terms but three-dimensionally, in their social, economic, ecological, and legal dimensions, bridging urban planning (the upper/macro scale) and architecture (the lower/micro scale)" (Keleş, 1998). Keleş further notes that the concept's mediating and complementary position among disciplines comes to the fore through its emphasis on public interest, public space, social and philosophical content, and administrative and legal dimensions (Keleş, 2021).

Beyond these definitions, although the historical emergence of the concept in an academic context can be traced back to the 1920s, significant developments occurred in both the academic and practical domains through the theoretical approaches that began to develop in opposition to modernism after the 1950s. In the 1960s, following the work of Donald Appleyard and Kevin Lynch on urban mental maps and perception, a virtually new era began. In the same years, the American Institute of Architecture also took the lead in bringing urban design discourse to the fore. This period also includes figures such as José Luis Sert, Lewis Mumford, Edmond Bacon, Jane Jacobs, and Cullen (Çubuk, 2016, p.3).

In the 1960s, urban design practices and legalization processes were observed, in differing forms, in Britain and France, following the lead taken by the United States and Britain. In the 1970s, following a new crisis of capitalism at the global scale, urban design practices appeared in many countries within the debates on urban competition, in a new period regarded as a repair of capital. Urban literature studies that began in Marxist writing on the spatial order of capitalist modernity reached a critical peak in the 1970s and afterward through analyses centered on labor-value theories. In the same period, however, neoliberal capitalism—along with economic and cultural policies centered on environment and sustainability—found broad ground, particularly in developed countries.

Following these developments, critical approaches at the philosophical level, rather than the technical content of urban design's disciplinary identity, came to the fore. Madanipour (1997) argued that the concept of urban design has a multilayered and ambiguous structure, but that this polysemy weakens the discipline (Madanipour, 1997, pp.363-364). Carmona and colleagues (2003) treated the process as an integrated whole of social, cultural, perceptual, visual, and spatial layers (Carmona et al., 2003, pp.61-208). Cuthbert (2007), meanwhile, stated that the discipline has failed to develop its own independent terminology and has been left to the initiative of capital groups rather than producing public policies, characterizing this development as the systematic dismantling of the understanding of public space (Cuthbert, 2007, pp.177-180). In this process, which served the interests of the capitalist class, urban design projects replaced comprehensive planning; urban areas took on a form that continuously changed meaning, was consumed through symbols and images, and became integrated with a populist free-market logic (Tekeli, 2009, pp.30-31). In the same period, the 'Postcolonial Urbanization' theory—held to be founded within the conceptual domain of Edward Said's (1980) 'Orientalism'—became, from the 2000s onward, a practice that radically questions urban design and urbanism. It has questioned the demolition of street vendors, informal settlements, and unregistered spaces by urban design projects on the grounds that they constitute a 'design flaw or visual pollution' (Roy, 2009, pp.79-81). 'Assemblage Theory,' meanwhile, is a post-structuralist approach in the field of urban design that treats cities as a constantly fluid and heterogeneous system. Colin McFarlane's 'Assemblage and Critical Urbanism' (2011) treats cities not as static structures but as a temporary assemblage of physical and non-physical elements, defining urban design as a set of processes in a state of 'becoming' (McFarlane, 2011, pp.207-221).

In this study, by constructing a data set addressing the structural dilemmas that arise from open-ended problems—both theoretical and conceptual, in relation to practice—an attempt will be made to derive a synthesis scheme concerning the philosophical domain to which the discipline is assumed to belong. Why has urban design been so widely used, and so easily instrumentalized, since the 1970s? What are the fundamental reasons behind the terminology problem and debates over modes of representation, as well as the emergence of features such as hierarchy, in-between disciplinary status, and multidisciplinarity? The debates over where, for whom, and how urban design is positioned need to be clarified.

CONCEPTUAL AND THEORETICAL FRAMEWORK

This section presents the definitions of the conceptual framework and the related theoretical domains within the content of the study. The word 'design' does not belong exclusively to a single scientific, technical, or artistic theory; rather, it resides within philosophy as a universal discipline that naturally carries a humanist character. Because this philosophy is grounded in creativity, it is aesthetic in origin at its core and distinct from philosophy in general. Every theory concerned with scientific or artistic systematization is a design model (Tunalı, 2020, pp.18-19). According to this definition, the concept of 'urban design' cannot be treated as a single design model because of its multidisciplinary content and

its in-between identity problems. Accordingly, in this study the word ‘design’ comes to the fore not as a theoretical domain but as a philosophical one. For this reason, the concept of urban design meets a philosophical domain.

In this study, multidisciplinarity is positioned as the core variable shaping the question of whether urban design is an independent discipline in its own right or an area of intersection among different disciplines (Carmona et al., 2003, pp.3-7). Urban design’s multidisciplinary and, correspondingly, in-between disciplinary character results in its remaining dominated by the epistemology and representational techniques of the design-model fields of planning, architecture, and landscape architecture, with which it is closely related. The discipline’s inability to develop an independent terminology also perpetuates the hegemony of this multidisciplinarity. The word ‘design’ that it carries brings it into contact not with a single design model but with the aesthetics-based philosophical domain to which design belongs.

In this study, the concept of the production of space occupies an important place in the urban literature in terms of obtaining a discipline-related data set and transforming it into a synthesis scheme. Within the multidisciplinary approach, this concept differentiates urban design from the other supporting disciplines outside its close disciplinary relations. Having entered the Marxist literature on urban space after the 1970s, this concept carried its theoretical grounding to a critical peak within capital and labor-value theories. Within this framework, the production of space provides an analytical basis explaining the economic-political and cultural conditions under which it takes shape for the social actors to whom urban design belongs. In this study, this analytical ground is carried beyond Lefebvre’s (1991) autonomous conceptualization of triadic space (perceived, conceived, and lived).

The concept of the dilemmas of design, also frequently used in this study, defines three distinct distributions concerning the theoretical and practical ground of urban design. The contradiction between normative values and regulatory controls, the contradiction between publicness and privatization, and the disagreements between central and local governance, as well as the domain of democratic initiative, give rise to significant conflicts. The functional outcomes of the increasingly differentiated spatial formation within the process of the production of space show that these dilemmas are increasingly intensifying on the social ground of social actors and their problems. In this study, a synthesis scheme will be derived that allows these tensions to be brought to light on behalf of the discipline of urban design.

The theoretical ground for the emergence and development of urban design was formed on the basis of opposition to the 1933 CIAM resolutions. The comprehensive and holistic planning approach indexed to the master plan began to give way to fields of urban design practice in which architectural applications would also come to the fore. The United States’ early applications, accompanied by Britain’s leadership and its parallel legalization process, marked the rise of urban design in the 1960s. While the earliest applications in the United States occurred through public–private partnerships, those in Britain emerged mostly as centrally and publicly weighted examples of practice. Having developed in opposition to modernism, the discipline of urban design found numerous opportunities for design implementation after the 1970s, following the economic crisis of that period, within urban competition policies at the global scale, alongside neoliberal capitalism and on the basis of the postmodern understanding that defined the era. Alongside these applications, theoretical developments emerged that, in contrast to the postmodern understanding, approached the process critically on the basis of socio-economic and cultural policies. Urban design applications, which continued worldwide until the 2008 global financial crisis, once again opened the way for state-supported capital repair, neoliberal policies, and public–private partnerships within the re-modeled economy. Throughout this entire process, the main reasons behind the instrumentalization of the field of urban design have been the mischaracterization of the discipline’s inability to become independent, and the persistent tendency to interpret it as a distinct design model despite its multidisciplinary field. Contrary to being treated as a discipline, it needs to be addressed on the basis of a design-philosophy framework.

METHOD

The method of this study is based on a qualitative literature review and critical discourse analysis. The study’s data set covers the 1970–2025 period. It consists of core literature examining theoretical developments and neoliberal transformations between 1970 and 2025, academic studies indexed in the

Scopus and Web of Science databases, and national/international examples of theory and practice. These reviews are supported by observations. The sources obtained were thematically coded to reveal the central points of tension in the process of conceptualizing urban design, and classified around the following main themes: the norm/regulation dilemma, the public–private dilemma, the central/local dilemma, the field problem arising from the discipline's definition through the concept of 'design,' and the interdisciplinary identity dilemma. Within the literature-related data set, these main themes were further separated into sections according to their thematic identities under the headings of historical dynamics, theorization, and the production of space and disciplinary development within capitalist modernity. The relationship among these themes is visualized through the conceptual scheme presented in the findings section of the study.

The claim of the findings lies not in statistical scope but in conceptual and theoretical depth. The causality behind them is situated within a framework that takes dialectical and historical determinism into account. The boundaries of the data set that will supply the study's theoretical tools are established here. The temporal boundaries cover the 1950–2025 period, although the post-1970 period is given the greater weight. Geographically, in order to compare the level of institutionalization of urban design practice and research guidelines, examples were selected from Britain and the United States—which have led the discipline of urban design—alongside Turkey; this selection stems from their capacity to represent three different planning-system traditions (integrated central–local, predominantly local, and dependent on the zoning/development plan). The study addresses urban design only through its core relationship with the disciplines of planning, architecture, and landscape architecture. Supporting technical disciplines such as transportation engineering and environmental engineering are left outside the scope of the study.

FINDINGS

The analyzed sources show that, following the 1960s and 1970s, urban design became intertwined with neoliberal policies and turned into an instrument of 'economic repair.' In this process of transformation, urban design is read in practice, at varying scales, in two different ways: on the one hand, as an accelerated technical instrument of intervention and regulation, and on the other, as an aesthetic instrument producing the marketable image of the city. This dual reading relates to urban design's structural problem of lacking an independent theoretical identity. Furthermore, findings on interdisciplinary identity ambiguity show that academic programs and professional chambers define urban design in different ways, and that this divergence delays the formation of a common professional language.

Analyses of the literature data and practice documents concentrate urban design's dilemmas in three main areas. The first is the dilemma between normative values and regulatory controls (flexibility versus standards). Findings on norms and regulatory instruments reveal that, in the large majority of the countries examined, urban design guidelines remain 'advisory' documents that lack binding enforcement power.

The second is the tension between publicness and privatization. A recurring finding in the sources examined is that urban design is largely legitimized by institutional actors through the discourse of 'enhancing urban quality,' yet in practice remains confined to projects aimed at increasing land value. This shows that the technical/aesthetic tension is not merely a theoretical debate but a concrete policy field within the public–private dilemma that directly affects the distribution of urban rent.

The third concerns the dilemmas over authority and practice between central and local governance systems. Findings on the central–local hierarchy show that decisions taken at the central level in large-scale urban projects significantly constrain local-level urban design processes. This finding concretizes the contradiction between the theoretical expectation that urban design should be sensitive to local context and the centralist tendency observed in practice. Debates over rationality and participation, meanwhile, have been an inseparable part of the process.

The examples of England (Essex–Harlow), the United States (Seattle), and Turkey (Galataport), examined to compare the level of institutionalization of urban design guidelines, are evaluated in detail in Table 1.

Comparison variables	UK	USA	Turkey
Historical period	1960s–1970s	1970s–1990s	Post-2000s
Institutional leadership	Central government + local authorities	Local authorities (West Coast cities)	Metropolitan municipalities, ministry
Position within the planning system	Integrated with national policy documents + local development plans	Integrated into the zoning and development control system	Supplementary / additional document to zoning plans
Core documents	Design guidelines, design briefs	Urban design guidelines, design standards	Urban design guidelines, urban design projects
Design approach	Process-based, holistic	Performance- and quality-oriented	Mostly product- and form-oriented
Neoliberal-era context	Indirect (visible through the 1998 Harlow update)	Direct (1990 Growth Management Act, inter-city investment competition)	Direct (global capital, brand-oriented masterplans)
Examples	Essex (1973), Harlow (1998)	Seattle (1993), San Francisco	Galataport (2022)

Table 1. Comparison of urban design instruments and guidelines

The English and American examples show that urban design guidelines become a powerful steering instrument within the planning system when supported by legal and institutional capacity. In Turkey, by contrast, urban design guidelines are mostly addressed at the project or site scale, remaining limited in their transformation into a process-based, multi-scalar planning instrument.

In line with the findings obtained, a scheme has been synthesized that categorizes the multidisciplinary character of urban design and offers a solution to the terminological problems experienced throughout the process (Figure 1). Rather than being a single disciplinary model, urban design is a scientific and philosophical superstructure framework that rises on the basis of the production of space. The main components of the scheme are as follows:

Upper Level (Philosophical/Theoretical Framework): A scientific-artistic philosophical position grounded in aesthetic philosophy, with a universal and humanistic character.

Intermediate Level (System of Disciplines and Instruments): Related design models, urban projects, guidelines, and governance instruments—principally in planning, architecture, and landscape architecture—together with spatial scales.

Lower Level (Spatial Practices and Production): The dialectical interaction of socioeconomic structure, cultural policies, and the processes of the production of space.

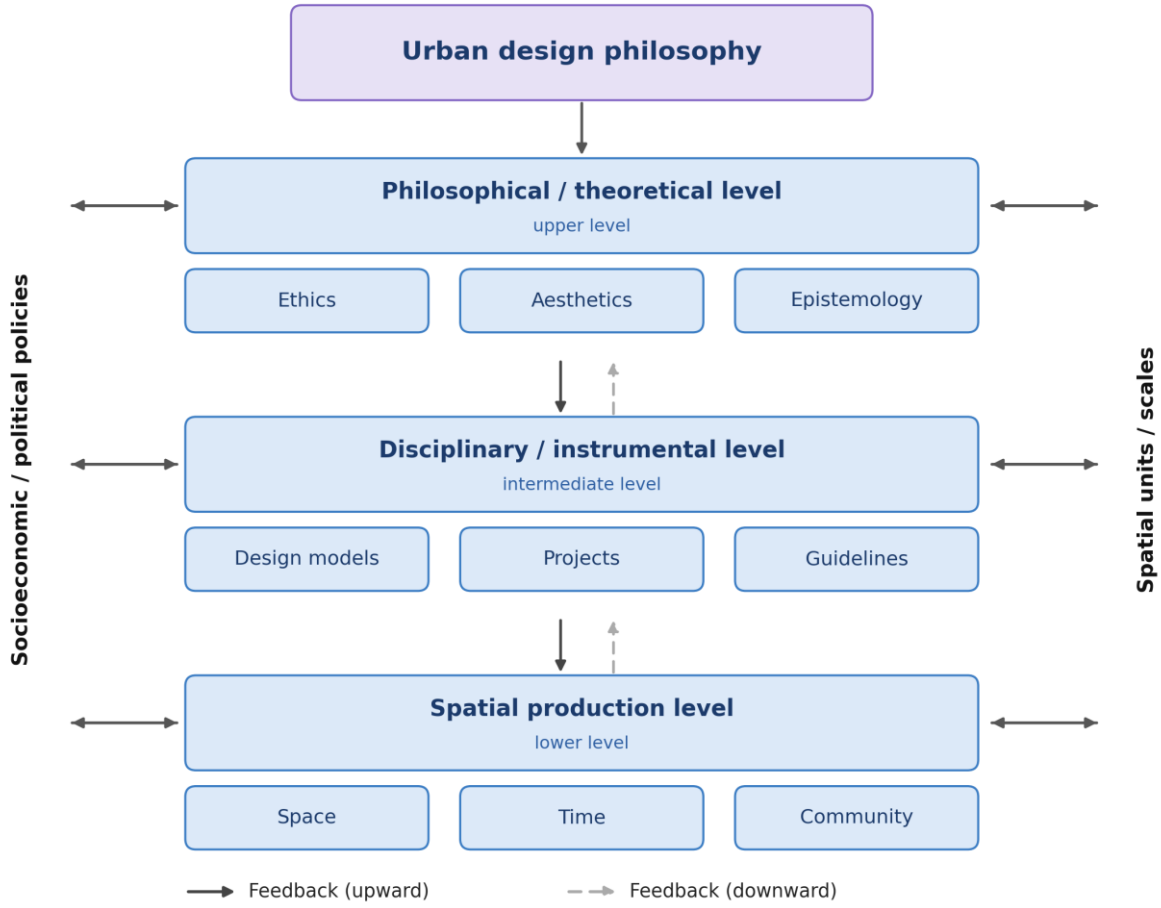

Figure 1. Formation scheme of the urban design philosophy

CONCLUSIONS

Through a literature review and critical discourse analysis, this study has revealed the fundamental dilemma in the process of conceptualizing urban design—within the technical/aesthetic tension: the inadequacy of norms and regulatory instruments, the public–private tension, the central–local hierarchy and rationality contradiction, and interdisciplinary identity ambiguity. The findings show that these dilemmas make it difficult to position urban design as an independent theoretical field, while at the same time defining the problem areas necessary for a proposed integrated scheme.

Rather than proposing a definitive scheme, the results presented by this study constitute the conceptual groundwork on which such a scheme could be built. In this context, the core conclusion reached by the study is the need for an integrated discipline of urban design philosophy based on a use-value-oriented, human-centered spatial production policy that is consistent with universal principles and grounded in aesthetics. For future studies, it is recommended that these dilemmas be tested through concrete case studies and that the applicability of the proposed scheme's components be examined.

The scheme presented in Figure 1 shows how reading these dilemmas together lays the groundwork for a proposed approach composed of three components: a use-value-oriented approach; a human-centered approach consistent with universal principles; and a philosophically grounded spatial production policy. These components are derived directly from the study's findings and are not independent of one another but form a mutually complementary whole.

The use-value-oriented approach emphasizes that urban design decisions should primarily serve the everyday life practices of city residents, while the human-centered approach consistent with universal

principles points to the need for urban design to remain sensitive to local context while also observing universally recognized spatial rights—accessibility, safety, and inclusiveness. The philosophically grounded spatial production policy, in turn, proposes that urban design decisions should be produced not as short-term project outputs but within the framework of a long-term philosophy of urban space.

The findings of this study show that addressing the three components mentioned above together will not entirely eliminate the dilemmas urban design faces at both the theoretical and applied levels, but will contribute to making these dilemmas more manageable and traceable. For this reason, the model proposed by the study represents not a prescriptive solution but the conceptual groundwork necessary for applied models to be developed in the future.

In conclusion, the conceptual ambiguity of urban design should be read not as a weakness of the field but as a consequence of the multiple functions it has assumed. The discipline of urban design is not a design model but a field of design philosophy. The findings of this study show that addressing this ambiguity in a systematic manner offers a ground that will strengthen urban design at the philosophical, theoretical, and applied levels alike.

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THE IMPACT OF DIFFERENTIATED INSTRUCTION ON THE ACADEMIC ACHIEVEMENT OF STUDENTS WITH SPECIAL EDUCATIONAL NEEDS IN INCLUSIVE CLASSROOMS

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ABSTRACT

Introduction and Purpose: Considering students' individual characteristics is one of the key factors that enhances the effectiveness of inclusive education. Differentiated instruction involves the use of teaching strategies tailored to diverse learning needs and abilities. The purpose of this study was to evaluate the impact of differentiated instructional methods on the academic achievement and classroom participation of students with special educational needs in inclusive educational settings.

Keywords: Inclusive education, differentiated instruction, special educational needs, pedagogical experiment, teacher questionnaire.

Introduction

Inclusive education is based on the principle that all students should have equal opportunities to participate in education and develop their potential. However, students who study in the same classroom may differ considerably in terms of their academic abilities, learning pace, interests, communication characteristics, prior knowledge, and educational needs. These differences become particularly evident in inclusive educational environments, where students with special educational needs study together with their peers in general education classrooms. Applying the same teaching method to all students may not always adequately address diverse learning needs. While some students may acquire new material quickly, others may require additional explanations, visual materials, repeated practice, or more time to complete a task.

Therefore, it is important for teachers working in inclusive classrooms to use flexible pedagogical approaches that can respond to individual differences. Differentiated instruction is one such approach that enables teachers to consider the diverse needs of students within the teaching process. Differentiated instruction refers to the purposeful adaptation of instruction according to students' readiness levels, interests, learning characteristics, and individual needs. Unlike the assumption that all students should learn in the same way and at the same pace, this approach allows teachers to modify the content, learning process, ways in which students demonstrate their learning, and the learning environment. For students with SEN, differentiated instruction can provide different ways of accessing the curriculum. For example, a student who experiences difficulties with reading may benefit from visual materials and oral explanations. For a student who learns more effectively through practical activities, working with real objects or completing hands-on tasks may be more effective.

The importance of differentiated instruction is not limited to academic achievement. When learning activities are adapted to students' abilities and needs, their willingness to participate in classroom activities may increase. Successful learning experiences can strengthen students' self-confidence and motivation, while an appropriate level of challenge can prevent both excessive cognitive load and loss of interest. At the same time, implementing differentiated instruction is not always easy. Limited planning time, insufficient teaching materials, large class sizes, and limited opportunities for professional development may create challenges for teachers. Therefore, the effectiveness of differentiated instruction depends not only on teachers' willingness to use this approach but also on the conditions in which the teaching process takes place.

The purpose of this study is to investigate the impact of differentiated instructional methods on the academic achievement and classroom participation of students with special educational needs in inclusive classrooms. Particular attention is given to students' engagement in learning activities, task completion, learning motivation, and teacher–student interaction.

Theoretical Foundations

One of the fundamental assumptions underlying differentiated instruction is that students do not learn in exactly the same way. Students enter classrooms with different levels of prior knowledge, language skills, motivation, learning experiences, and cognitive characteristics. They may also differ in the amount of time required to understand a new concept and complete a task. Traditional whole-class instruction often assumes that all students can understand the same explanation, complete similar tasks, and demonstrate their learning through the same assessment method. Although whole-class instruction can be effective in many situations, the use of a single teaching method may not be sufficient when significant differences exist among students.

This issue becomes particularly important in inclusive classrooms because students with SEN may require additional or alternative forms of support. Differentiated instruction responds to this diversity by providing a systematic approach through which teachers can adapt the teaching and learning process.

The Concept of Differentiated Instruction

Differentiated instruction does not mean preparing a completely different lesson for every student. Rather, it involves purposeful adaptations within the same learning environment. Differentiation can be implemented in several key areas: content, process, product, and learning environment. Content refers to what students are expected to learn. Teachers may present information in different formats or at different levels of complexity. Process refers to how students work with learning materials. Some students may work independently, while others may require guiding questions, visual prompts, peer support, or additional explanations. Product refers to how students demonstrate what they have learned. Depending on the learning objective, students may demonstrate their learning through written responses, oral presentations, practical activities, projects, or other forms.

The learning environment refers to the physical and social conditions in which learning takes place. Classroom organization, seating arrangements, group work, and opportunities for individual activities can be adapted according to students' needs. These elements enable teachers to maintain common learning objectives while creating different pathways for students to achieve those objectives.

Differentiated Instruction in Inclusive Classrooms

Inclusive classrooms are characterized by diversity. Students may differ in their abilities, language development, attention, communication, behavior, and learning pace. Providing students with SEN with access to the same curriculum does not necessarily mean that they should learn that curriculum in exactly the same way. A student may physically participate in the classroom but still experience various barriers to understanding learning materials and participating actively in lessons.

Differentiated instruction can help reduce these barriers. For example, visual schedules can help students understand the sequence of classroom activities. Pictures, diagrams, and graphic organizers can make ABSTRACT concepts easier to understand. Short and clearly structured tasks can be particularly useful for students who experience difficulties maintaining attention.

However, differentiation should not result in lowering expectations for students with SEN. The purpose is not simply to make learning easier but to create an appropriate pathway through which students can achieve the intended learning outcomes.

From this perspective, an inclusive teacher should not only ask, "Can this student complete this task?" but also, "What support does this student need to participate successfully in this task?"

Such an approach shifts the focus from students' limitations alone to the interaction between their needs and the educational environment.

Differentiated Instruction and Academic Achievement

Academic achievement is one of the main outcome indicators examined in research on differentiated instruction. When students receive tasks that correspond to their level of readiness, they may have greater opportunities to experience success. At the same time, differentiated instruction allows teachers to provide additional and more challenging tasks for students with higher levels of readiness.

For students with SEN, appropriate differentiation may reduce unnecessary barriers to learning. For example, a student who has difficulty processing lengthy written instructions may perform better when the same instructions are presented in shorter and clearly structured steps.

Similarly, flexible time arrangements may be provided for students who require additional time. Students who master a topic more quickly can be offered extension activities. The main purpose is not to simplify learning for every student but to make learning more accessible and meaningful. Differentiation can also support formative assessment. During lessons, teachers can observe students' responses and activities and modify instruction based on the information they obtain.

In this way, assessment becomes not only a means of measuring learning at the end of instruction but also an integral part of the teaching process.

Differentiated Instruction and Classroom Participation

Academic achievement is closely related to students' level of participation in the learning process. When students understand what they are expected to do and believe that they can successfully complete a task, they are more likely to participate actively in learning activities.

Some students with SEN may avoid participating in lessons because of previous unsuccessful learning experiences or fear of making mistakes in front of their peers. Differentiated instruction can create more opportunities for successful participation in this respect. When tasks are appropriately structured, students may be more likely to answer questions, participate in group activities, complete assignments, and contribute to classroom discussions.

Group work can also be differentiated. Teachers can create groups according to specific learning objectives and assign students particular roles. This allows students with different abilities to contribute to a common task.

Such activities can support not only academic learning but also social relationships and inclusion within the classroom.

The Role of the Teacher in Differentiated Instruction

The teacher plays a central role in implementing differentiated instruction. Effective differentiation begins with understanding students' individual needs. Teachers need to obtain information about students' current levels of knowledge, strengths, difficulties, interests, and learning patterns.

Assessment is therefore particularly important. Assessment should not be limited to formal examinations. Classroom observations, questions, short tasks, discussions, and students' written work can also provide valuable information. Based on this information, teachers can determine the level of support required by each student.

Professional knowledge is also essential. Teachers need to understand not only what students are expected to learn but also which forms of support are most appropriate for helping them achieve the intended outcomes.

However, teachers should not be expected to design complex differentiated lessons without adequate support. Professional development, methodological resources, collaboration with specialists, and school-level support are important conditions for effective implementation.

Research Methodology

The quantitative component of the study focused on identifying teachers' attitudes toward differentiated instruction and their level of use of differentiated instructional strategies. The qualitative component focused on classroom observations and practices observed during the pedagogical experiment. A short-

term pedagogical experiment was conducted in inclusive classrooms in which differentiated instructional strategies were purposefully implemented.

Combining these methods made it possible to examine both teachers' perspectives and the actual teaching and learning practices observed in the classroom.

Research Participants

The participants of the study included teachers working in inclusive classrooms and students with SEN studying in these classrooms. Students were observed during regular classroom activities and lessons in which differentiated instructional strategies were implemented.

Teacher Questionnaire

A structured questionnaire was used to identify teachers' attitudes toward differentiated instruction and their level of implementation of this approach in the teaching process.

The questionnaire covered the following areas:

1. teachers' understanding of differentiated instruction;
2. frequency of using differentiated strategies;
3. adaptation of learning tasks;
4. use of visual materials;
5. flexible assessment;
6. individualized support;
7. perceived benefits of the approach;
8. challenges encountered during implementation.

Teachers were also asked to provide their views on the impact of differentiated instruction on students' motivation and classroom participation.

Classroom Observations

Classroom observations were conducted to examine students' behavior and teacher–student interaction.

1. The observations focused on the following aspects:
2. students' engagement in the learning process;
3. participation in classroom activities;
4. task completion;
5. attention to learning;
6. interaction with the teacher;
7. interaction with peers;
8. use of instructional materials;
9. students' responses to differentiated tasks.

The observations made it possible to compare the approaches reported by teachers in the questionnaires with actual classroom practices.

Pedagogical Experiment

A short-term pedagogical experiment was conducted to investigate how differentiated instructional strategies could be implemented in inclusive classrooms.

The experiment included several main strategies.

Individualized Learning Tasks

Tasks were adapted according to students' existing knowledge levels and individual needs. Although students worked toward common learning objectives, different levels of support or task complexity were provided when necessary.

Visual Instructional Materials

Pictures, diagrams, graphic organizers, written instructions, and other visual materials were used.

Visual materials supported students who experienced difficulties processing oral explanations or ABSTRACT information and helped them understand the learning content more effectively.

Flexible Learning Activities

Students were provided with opportunities to work individually, in pairs, and in small groups. The format of the activity was determined according to the learning objective and students' needs.

Flexible Assessment

Students were provided with different opportunities to demonstrate their knowledge and skills. Depending on the nature of the task, assessment was conducted through written responses, oral explanations, practical activities, or teacher observation.

Additional Support

Students requiring greater support were provided with additional explanations, guiding questions, examples, guided practice, and additional time.

These strategies were implemented without requiring students to be separated from the general classroom environment.

Research Findings

The findings indicated that positive changes were observed in students' learning experiences following the implementation of differentiated instructional strategies.

One of the most noticeable changes was related to classroom participation. Students with SEN tended to become more involved in learning activities when tasks were adapted to their needs. Teachers reported that some students who had previously participated less actively in lessons became more engaged after differentiated tasks were introduced. Visual materials and clearly structured instructions were particularly useful. Positive changes were also observed in task completion. When tasks were presented at an appropriate level of difficulty and divided into smaller steps, students were more likely to begin and complete them.

The findings also indicated positive changes in learning motivation. When students successfully completed tasks, they demonstrated greater confidence in their learning abilities. This was particularly important for students who had experienced repeated difficulties in traditional learning environments. An increase in students' academic engagement was also observed. According to teachers, students paid greater attention to tasks and were more willing to answer questions and participate in discussions.

The implementation of differentiated activities also supported interaction among students. Pair and group work created opportunities for students with different abilities to contribute to common tasks. Teachers generally expressed positive attitudes toward differentiated instruction. According to their views, this approach enables teachers to respond more effectively to individual differences and increase students' opportunities to participate in the learning process.

At the same time, teachers identified several challenges related to implementation. These included the additional planning time required, a lack of appropriate instructional materials, and the difficulty of managing different activities simultaneously in large classrooms.

Discussion

The findings of the study indicate that differentiated instruction can make a positive contribution to the educational experiences of students with SEN in inclusive classrooms. One of the main findings was increased classroom participation. When students receive tasks that are appropriately structured and supported according to their needs, they may become more actively involved in the learning process.

This finding is particularly important because participation is an essential indicator of inclusion. Although a student may be physically present in the classroom, their inclusive educational experience may not be fully realized if they rarely participate in classroom activities. Differentiated instruction can help address this issue to some extent by creating multiple opportunities for participation. Positive changes in task completion may be associated with providing an appropriate level of challenge. When

a task is excessively difficult, students may become frustrated and attempt to avoid it. Conversely, when a task is too easy, their interest may decrease. Differentiation enables teachers to design tasks that are challenging but achievable for individual students.

The findings related to motivation are also important. Students who experience successful outcomes may develop greater confidence in their learning abilities. This can create a positive cycle in which increased self-confidence leads to more active participation, while active participation creates additional learning opportunities.

However, differentiated instruction should not be understood simply as making tasks easier for students with SEN. Effective differentiation maintains the essential learning objectives while modifying the pathways through which students can achieve them.

The findings also highlight the importance of teacher preparation. Differentiated instruction requires planning, observation, assessment, and continuous adaptation of instruction. Teachers need to understand not only what students should learn but also which forms of support are most effective in helping them achieve the intended outcomes. Therefore, professional development is an important condition for successful implementation of differentiated instruction.

Another important issue is the availability of educational resources. Even when teachers understand the importance of differentiated instruction, it may be difficult to implement this approach consistently without appropriate visual materials, adapted texts, technological tools, and specialist support. Therefore, responsibility for differentiated instruction should not be placed solely on individual teachers. Schools and educational authorities should provide the necessary conditions for implementing this approach.

Implications for Educational Practice

The findings of the study make it possible to identify several practical directions for inclusive classrooms.

1. Teachers should use regular formative assessment to identify students' strengths and areas in which they require additional support.
2. Learning tasks should be sufficiently flexible to accommodate differences in students' readiness levels and learning pace.
3. Visual and multisensory materials should be used purposefully, particularly for students who experience difficulties understanding verbal or ABSTRACT information.
4. Students should be provided with different opportunities to demonstrate what they have learned. Assessment should measure actual learning outcomes rather than simply students' ability to respond in a particular format.
5. Collaborative learning activities should be used purposefully. Pair and group work can create opportunities for peer learning and social interaction.
6. Schools should organize professional development programs focused on the practical implementation of differentiated instruction. Such programs should not be limited to theoretical information but should provide teachers with concrete strategies that can be used in real classroom situations.

Finally, teachers should have access to appropriate instructional resources and sufficient planning time to differentiate their lessons effectively.

Conclusion

Differentiated instruction is an important pedagogical approach for inclusive classrooms because it recognizes that students do not learn in exactly the same way or at the same pace.

The findings of the study indicate that differentiated instructional strategies can support classroom participation, task completion, learning motivation, and academic engagement among students with SEN. The main advantage of differentiated instruction is that it creates different pathways toward common learning objectives for diverse students. Rather than expecting all students to learn through the same methods, teachers can adapt instructional content, activities, materials, and assessment methods to

individual needs. For students with SEN, this flexibility can help reduce barriers to learning and increase opportunities for successful participation.

However, differentiated instruction should not be viewed as a simple technique that can be implemented without preparation. Effective differentiation requires teachers to know their students well, monitor their development, adapt instruction, and evaluate the outcomes of the strategies they use. Therefore, schools should provide continuous professional development, methodological support, appropriate instructional materials, and favorable working conditions. Expanding differentiated instructional practices can contribute to the creation of more equitable learning opportunities and improve the quality of inclusive education.

Ultimately, the purpose of differentiated instruction is not to create a completely different educational environment for every student. Its main purpose is to create realistic opportunities for all students to learn meaningfully, participate actively, and develop their potential within the same inclusive classroom.

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THE IMPACT OF PARENT–SCHOOL COLLABORATION ON THE DEVELOPMENT OF STUDENTS WITH SPECIAL EDUCATIONAL NEEDS IN INCLUSIVE EDUCATION

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ABSTRACT

Introduction and Purpose: The successful inclusion of students with special educational needs depends not only on schools but also on active parental involvement. Effective parent–school collaboration contributes significantly to students' academic, social, and emotional development. The aim of this study was to investigate the effectiveness of parent–school collaboration and its impact on the development of students with special educational needs in inclusive education.

Keywords: Inclusive education, parent–school collaboration, special educational needs, educational intervention, academic achievement.

Introduction

Inclusive education has become one of the fundamental principles of modern education systems. This approach assumes that all children should have opportunities to participate in education regardless of their individual abilities, disabilities, learning difficulties, or other characteristics. However, inclusion is not limited to placing students with special educational needs in mainstream classrooms. Genuine inclusion requires students to participate actively in the learning process, establish relationships with their peers, feel accepted, and receive the support necessary to realize their potential.

Students with special educational needs require educational approaches that take their individual characteristics into account. Some students may need additional academic support, while others may require assistance with communication, social interaction, emotional self-regulation, or adaptation to classroom routines and expectations. Meeting these diverse needs can create particular challenges for schools, especially when teachers do not have sufficient information about students' experiences outside the school environment.

In this context, collaboration between parents and schools is considered an important component of inclusive education. Parents know their children in ways that teachers may not always be able to observe. They possess extensive knowledge about their children's interests, strengths, communication patterns, daily routines, concerns, and responses to different situations. Teachers, in contrast, have professional knowledge of the curriculum, instructional processes, assessment, and classroom environments. When these two sources of knowledge are combined, educational support can become more individualized and consistent.

The quality of interaction between schools and families is therefore of considerable importance. This issue is particularly significant for students with SEN. Their educational development often depends on the coordination of support provided across different environments. When teachers and parents use similar approaches and regularly exchange information about the child's development, students can receive more consistent and stable support.

However, parent–school collaboration is not always established effectively. Communication may sometimes be limited to formal meetings or may occur primarily when a problem involving the student arises. Parents may feel that their perspectives are not sufficiently taken into account, while teachers may interpret limited parental participation as a lack of interest. Such misunderstandings can weaken mutual trust and limit opportunities for collaboration.

Therefore, the main purpose of this study is to examine the impact of parent–school collaboration on the development of students with SEN in inclusive education settings. Particular attention is given to academic engagement, learning motivation, school adjustment, and social participation.

Inclusive Education and Special Educational Needs

Inclusive education has evolved beyond simply placing students in mainstream educational settings and has increasingly focused on their participation in the educational process, equal opportunities, and sense of belonging.

The Salamanca Statement established an important international framework for inclusive education. It emphasizes that schools should respond to the diverse needs of students and create supportive educational environments for children with different characteristics (UNESCO, 1994).

The United Nations Convention on the Rights of Persons with Disabilities further strengthened the right to inclusive education. Article 24 of the Convention recognizes the right of persons with disabilities to education without discrimination and emphasizes the importance of individualized support that promotes their academic and social development (United Nations, 2006).

From this perspective, the success of inclusive education should not be measured solely by whether a student attends a mainstream school. Their participation in classroom activities, academic development, social relationships, independence, and sense of belonging to the school community should also be considered. Students with SEN constitute a heterogeneous group with diverse characteristics. Their needs may vary considerably depending on their developmental characteristics and educational environment. Some students may experience difficulties in reading, writing, or mathematics, while others may require support in communication, social interaction, attention, or behavior. This diversity necessitates the implementation of flexible pedagogical approaches in inclusive classrooms. Teachers may need to adapt instructional materials, teaching methods, assessment procedures, classroom activities, and communication strategies. Parents can make an important contribution to this process because they observe their children in a variety of situations outside school. Information provided by parents can help teachers develop a more comprehensive understanding of the student and design more appropriate support strategies.

Parent–School Collaboration in Inclusive Education

Parent–school collaboration refers to the process of continuous communication, information exchange, participation in decision-making, and joint activities between parents and education professionals aimed at supporting children's development. Mutual respect should form the foundation of effective collaboration. Parents should not be viewed merely as recipients of information, while teachers should not be expected to solve all educational problems independently. Both parties possess different forms of knowledge and experience, and these forms of knowledge should complement each other.

Communication is one of the key elements of collaboration. Regular communication enables parents and teachers to exchange information about children's development, difficulties, interests, and achievements. However, communication should not focus exclusively on problems. When parents receive positive information about their children's achievements, they may develop greater trust in the school. At the same time, when teachers learn about strategies used by parents at home that produce positive results, they can gain new perspectives on the student's behavior and learning. Another important element of collaboration is joint decision-making. Parents should have opportunities to participate in discussions concerning educational goals and support strategies. This is particularly important when individualized education plans are being developed.

However, collaboration does not mean that parents should replace teachers in making professional pedagogical decisions. Primary professional responsibility for educational planning and instruction remains with teachers. Collaboration means that parents' knowledge and observations are taken into consideration in the decision-making process.

This approach is particularly important for students with SEN. Effective collaboration combines parents' personal knowledge of their children with teachers' professional pedagogical knowledge.

Parent–School Collaboration and Student Development

Academic Development

Academic development is one of the main areas that can be influenced by parent–school collaboration. When parents are aware of the topics their children are learning at school, they can provide more appropriate support at home. Teachers can also provide parents with practical recommendations for supporting learning.

Individualized academic support is particularly important for students with SEN. A strategy that is effective for one student may not be appropriate for another. Therefore, information exchange between parents and teachers can help identify effective approaches.

However, parental support should not be understood as completing assignments on behalf of the child. The purpose of parental support should be to promote the child's independence, motivation, and self-confidence.

Learning Motivation

Motivation plays an important role in students' participation in the educational process. When students feel supported and their efforts are recognized, they may become more actively engaged in learning. Parents and teachers can contribute to this process by establishing realistic expectations and recognizing students' progress. For students with SEN, even small improvements can be highly significant. For example, a student who initially avoids classroom activities may gradually begin participating in group work. Recognizing such progress can contribute to increased motivation. Consistent messages from home and school can help students perceive the learning process as being based on support rather than pressure.

School Adjustment

School adjustment refers to students' ability to adapt to school rules and daily routines, participate in classroom activities, interact with teachers and peers, and feel comfortable within the school environment. Some students with SEN may require additional time and support to adapt to school routines. Parents and teachers can work together to identify challenging situations and develop consistent strategies. For example, if a student experiences anxiety in response to changes in the classroom, the teacher can inform the student about the change in advance, while the parent can prepare the child for the change at home. Such consistency can reduce uncertainty and facilitate adjustment.

Social Development

Social development is another important dimension of inclusive education.

Some students with SEN may experience difficulties initiating conversations, joining group activities, interpreting social cues, and maintaining relationships with peers. In some cases, these difficulties may lead to social isolation. Parent–school collaboration can contribute to the early identification of such difficulties. Teachers can create structured opportunities for interaction with peers, while parents can support communication and social skills in everyday life. The goal is not to force students to behave exactly like their peers. Rather, the primary objective is to increase their opportunities for meaningful social participation and interaction.

Research Methodology and Design

A mixed-methods research design was employed in the study. This approach was selected because it enabled the investigation of both measurable aspects of parent–school collaboration and the experiences of parents and teachers regarding this collaboration.

Research Participants

The participants in the study consisted of parents of students with SEN and teachers working in inclusive classrooms. Parents were included in the study because they can provide information about their children's learning behaviors, school adjustment, and development outside school. Teachers, in turn, have direct observations of students' classroom participation, academic engagement, social interaction,

and behavior. In the final version of the article, the exact number of participants and other demographic characteristics should be presented based on actual research data.

Data Collection

Surveys were used to identify different aspects of parent–school collaboration. The surveys focused on communication, parental involvement, information exchange, joint decision-making, and collaboration in addressing students' educational needs.

Participants were also asked to report their observations regarding students' school attendance, motivation, academic engagement, social participation, and school adjustment.

Observations were conducted during classroom activities and parent–teacher meetings. The observations focused on forms of communication, parental participation, teachers' responses, joint problem-solving, and discussions concerning students' strengths and areas of difficulty.

Eight-Week Educational Intervention

An eight-week intervention program was implemented to strengthen parent–school collaboration.

During the first week, discussions focused on the principles of inclusive education and the individual needs of students with SEN.

The second week focused on effective communication. Participants discussed how information concerning students' development and difficulties could be exchanged more regularly and constructively.

During the third week, attention was given to identifying students' individual strengths, interests, and learning needs.

The fourth week focused on supporting learning at home. Parents were provided with practical recommendations on how to support the learning process without placing excessive pressure on their children.

The fifth week was devoted to students' social and emotional development. Parents and teachers discussed ways of supporting peer interaction, self-confidence, and participation.

During the sixth week, attention was given to joint problem-solving. Common educational and behavioral difficulties were identified, and possible solutions were discussed collaboratively.

The seventh week focused on monitoring students' development. Participants reviewed observed changes in students' participation, motivation, and learning behaviors.

During the eighth week, the focus shifted to sustaining collaboration after the intervention. Possible strategies for maintaining continuous communication and cooperation between parents and schools throughout the academic year were identified.

Research Findings

The findings of the study indicated an overall positive association between systematic parent–school collaboration and student development. Following the intervention, teachers reported increased parental participation in the educational process. Communication with parents became more regular and focused not only on problems but also on students' development and achievements. Parents also reported gaining more information about their children's educational needs. They indicated that they had a better understanding of school expectations and felt more comfortable communicating with teachers.

One of the main changes observed was related to school adjustment. Parents reported that their children adapted more easily to school routines and showed greater willingness to participate in learning activities. Teachers also observed positive changes in learning motivation and classroom engagement. Some students were reported to show greater willingness to complete learning tasks and participate in classroom activities. Positive changes were also observed in social participation. Teachers noted that some students became more actively involved in group activities and interactions with peers.

Analysis of qualitative data indicated that the quality of communication was more important than its frequency alone. The most effective forms of communication involved reciprocal information exchange, joint problem-solving, and discussion of not only students' difficulties but also their strengths.

Conclusion

Parent–school collaboration is one of the important components of effective inclusive education. The findings of the study indicate that regular communication, joint planning, and coordinated support between parents and teachers can contribute to positive changes in the educational experiences of students with SEN. The primary value of collaboration lies not simply in the frequency of communication but in its quality. Parents should be recognized as partners who possess important knowledge about their children, while teachers should contribute their professional pedagogical knowledge and experience to the collaborative process.

For students with SEN, collaboration between families and schools can create a more consistent educational environment, facilitate school adjustment, strengthen learning motivation, and support social participation.

From this perspective, inclusive education should have a broader meaning than the physical placement of students with SEN in mainstream classrooms. The primary objective should be to ensure their meaningful participation, learning, development, and sense of belonging within the school environment. Schools should establish continuous communication systems, organize educational programs for parents, involve families in appropriate educational planning, and develop teachers' skills in effective family collaboration.

Ultimately, strong parent–school collaboration can be regarded as one of the important factors that not only enables students with SEN to be present in inclusive educational environments but also supports their learning, participation, and development within those environments.

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STABILITY ANALYSIS OF INSTANTON SOLUTIONS IN THE 4D GURSEY SPINOR MODEL

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ABSTRACT

Instanton solutions arising in nonlinear field theories play a fundamental role in understanding vacuum tunneling, topological transitions, and fermionic zero modes in quantum field theory. In conformally invariant spinor field models, instantons represent localized classical configurations with particle-like characteristics. The purpose of this study is to investigate the dynamical properties and stability of instanton solutions in the four-dimensional conformally invariant Gursey spinor model. The nonlinear field equations were transformed into a dimensionless autonomous dynamical system using the Heisenberg ansatz. The equilibrium points were obtained analytically, and the local dynamics around the instanton solutions were examined through linearization. The Jacobian matrix was constructed, and the eigenvalue spectrum was analyzed to determine the stability properties of the fixed points. The analytical findings were further supported by phase-space analysis to examine the qualitative behavior of the dynamical system. The stability analysis revealed that all equilibrium points possess purely complex eigenvalues, indicating elliptic fixed points. Accordingly, the instanton solutions exhibit stable closed trajectories around the equilibrium points. The corresponding phase-space structures confirmed these results by demonstrating regular, bounded, and non-divergent dynamical behavior. The present findings demonstrate that the instanton solutions of the four-dimensional conformally invariant Gursey spinor model are dynamically stable. The agreement between the analytical stability analysis and the phase-space structures provides a consistent geometric interpretation of the underlying dynamics. These results contribute to a deeper understanding of nonlinear spinor field models and offer further insight into the mathematical and physical properties of instanton configurations in conformally invariant field theories.

Keywords: Gursey model; instanton; spinor fields; stability analysis; phase space.

INTRODUCTION

Nonlinear field theories provide an important mathematical framework for describing physical systems in which interactions cannot be represented adequately by linear equations. Such theories may possess localized classical field configurations with properties that differ fundamentally from ordinary perturbative solutions. Among the most important examples of these configurations are solitons and instantons.

Solitons arise as localized solutions of nonlinear differential equations and can exhibit particle-like characteristics. In classical field theories described by Lagrangian equations, stable localized configurations displaying particle-like behavior are commonly classified as soliton-type solutions (Dunajski, 2010). Their mathematical and physical properties have consequently been investigated in several areas of nonlinear physics and mathematical physics.

Instantons constitute a particular class of nontrivial classical field configurations. They are associated with the vacuum structure of field theories and can provide connections between topologically distinct configurations. In the Euclidean formulation of a field theory, instantons are generally associated with localized finite-action solutions and play an important role in the description of nonperturbative phenomena (Dunajski, 2010; Rajaraman, 1987).

Although instantons are frequently discussed in the context of bosonic gauge fields, nontrivial classical configurations can also arise in nonlinear fermionic theories. Spinor-field models containing nonlinear self-interaction terms provide a particularly interesting framework in this respect because the field equations themselves may support localized classical configurations.

An important example of such a nonlinear fermionic theory is the four-dimensional spinor model proposed by Feza Gürsey in 1956. The model was introduced in the context of attempts to formulate fermionic particles through a nonlinear spinor wave equation and possesses a conformally invariant structure (Gürsey, 1956). Following the introduction of the model, different classes of classical solutions were investigated. Kortel (1956) studied solutions of Gürsey's conformally invariant spinor wave equation, while later studies examined classical solutions of the nonlinear model in greater detail (Akdeniz, 1982).

The nonlinear structure of the Gürsey model is particularly significant because it allows the existence of instanton-type configurations. In the formulation considered in the present study, the Gürsey instantons are obtained in connection with the spontaneous breaking of conformal symmetry. The resulting nonlinear equations can be reduced to a coupled system suitable for dynamical-systems analysis. The source study specifically identifies the Gürsey system as a four-dimensional fermionic model and presents the corresponding instanton solutions following the nonlinear reduction.

Determining the existence of an instanton configuration, however, does not completely characterize its dynamical properties. An important additional question is how the system behaves in the neighborhood of the equilibrium configurations associated with the instanton solution. This problem can be investigated using the methods of nonlinear dynamical systems.

Phase space provides a geometrical representation of the possible states of a dynamical system. Each state corresponds to a point in phase space, while the evolution of the system is represented by a trajectory. Fixed points are especially important because the behavior of trajectories in their neighborhood can be used to characterize the local dynamics of the system (Çambel, 1993; Morris et al., 2003; Rizaoglu & Sünel, 2011).

For a nonlinear autonomous system, local behavior around a fixed point can be investigated by linearizing the governing equations around that equilibrium configuration. The eigenvalues of the resulting linearized system provide information concerning the local character of the fixed point. Phase-space portraits can then be used as a complementary geometrical tool for visualizing the corresponding nonlinear trajectories.

In the present study, this approach is applied specifically to the four-dimensional Gürsey spinor model. The nonlinear field equation is reduced using the special Heisenberg ansatz and appropriate dimensionless transformations. The resulting autonomous system is analyzed by determining its fixed points and evaluating the corresponding eigenvalues.

The analysis is carried out for $\alpha = 1$ and the neighboring parameter values $\alpha = 1.2$ and $\alpha = 0.7$. In addition to the analytical stability analysis, phase-space portraits are examined for the same parameter values. The purpose is to determine whether the qualitative local behavior of the instanton configurations is preserved when the parameter is varied and to compare the analytical eigenvalue results with the geometrical structures observed in phase space.

THEORETICAL FRAMEWORK: THE FOUR-DIMENSIONAL GURSEY MODEL

The Gürsey model is a four-dimensional nonlinear spinor-field model originally proposed by Feza Gürsey in 1956 (Gürsey, 1956). The theory contains a nonlinear self-interaction term and was introduced as a conformally invariant spinor wave equation.

The Lagrangian density of the four-dimensional fermionic system is written as

$$L = \frac{i}{2}\overline{\psi}\gamma_\mu \partial_\mu \psi + g(\overline{\psi}\psi)^{\frac{4}{3}} \qquad (1)$$

where g is a dimensionless coupling constant and γ_μ represents the four-dimensional Dirac matrices (Gürsey, 1956). The form of the Lagrangian used in the source study is given explicitly in its Gürsey-model section.

Application of the Lagrangian formalism gives the corresponding nonlinear equation of motion,

$$(i\gamma_\mu \partial_\mu \psi) + g(\bar{\psi}\psi)^{1/3}\psi = 0 \tag{2}$$

The nonlinear term in this equation represents the self-interaction of the spinor field and is responsible for the nontrivial structure of the resulting classical configurations.

For the investigation of instanton-type solutions, the field equation is transformed into a form suitable for dynamical-systems analysis. In the present treatment, the special Heisenberg ansatz used in the original analysis is substituted into the equation of motion, followed by the required dimensionless transformations (Aydogmus, 2013).

The resulting equations are expressed in terms of the coupled functions F(z) and G(z):

$$\begin{aligned} 2\dot{F}(z) + \frac{3}{2}F(z) - g(AB)^{\frac{1}{3}}(\bar{c}c)^{\frac{1}{3}}G(z)(F^2(z)+G^2(z))^{\frac{1}{3}} = 0 \\ 2\dot{G}(z) - \frac{3}{2}G(z) + g(AB)^{\frac{1}{3}}(\bar{c}c)^{\frac{1}{3}}F(z)(F^2(z)+G^2(z))^{\frac{1}{3}} = 0 \end{aligned} \tag{3}$$

The original study gives this reduction together with the definitions ($A^2 = B^2$, $\sigma = \tau + \frac{1}{2}$ and $\tau = \frac{3}{4}$) used in obtaining the reduced system.

For the dynamical analysis, the variables are defined as

$$F = x,\ G = y,$$

and the effective parameter α is introduced through the dimensionless combination

and the nonlinear combination of the parameters is represented by the effective parameter α.

$$g(AB)^{\frac{1}{3}}(\bar{c}c)^{\frac{1}{3}} = \alpha$$

Using these definitions, the reduced Gürsey equations can be written as a two-dimensional autonomous dynamical system. This representation provides the basis for determining the equilibrium points and analyzing the local dynamical behavior of the instanton solutions.

RESULTS AND DISCUSSION

Equilibrium Points and Their Parameter Dependence

Using the dimensionless variables introduced above, the reduced Gürsey system is written as

$$\begin{aligned} \dot{x} &= -\frac{3}{4}x + \frac{1}{2}a\left(x^2+y^2\right)^{\frac{1}{3}}y \\ \dot{y} &= \frac{3}{4}y - \frac{1}{2}a\left(x^2+y^2\right)^{\frac{1}{3}}x \end{aligned} \tag{4}$$

The equilibrium points of the system are obtained by requiring both dynamical derivatives to vanish simultaneously:

$$\dot{x} = -\frac{3}{4}x + \frac{1}{2}a\left(x^2 + y^2\right)^{\frac{1}{3}}y = 0 \tag{5}$$

$$\dot{y} = \frac{3}{4}y - \frac{1}{2}a\left(x^2 + y^2\right)^{\frac{1}{3}}x = 0$$

The resulting equilibrium configurations depend on the parameter α. The reference instanton configuration is considered for $\alpha = 1$while $\alpha = 1.2$ and $\alpha = 0.7$ are examined as neighboring parameter values in order to investigate the behavior of the system around this case.

For $\alpha = 1$, the equilibrium points are obtained as (Gürsey, 1956; Akdeniz, 1982)

$$\{x \to 0, y \to 0\},\ \left\{x \to -\frac{3\sqrt{3}}{4}, y \to -\frac{3\sqrt{3}}{4}\right\},\ \left\{x \to \frac{3\sqrt{3}}{4}, y \to \frac{3\sqrt{3}}{4}\right\} \tag{6}$$

To investigate the neighboring configurations of the Gürsey instanton system, the equilibrium points were also calculated for $\alpha = 1.2$ and $\alpha = 0.7$.

For $\alpha = 1.2$ the equilibrium points are

$$\{x \to 0, y \to 0\},\ \left\{x \to -\frac{5\sqrt{\frac{5}{2}}}{8}, y \to -\frac{5\sqrt{\frac{5}{2}}}{8}\right\},\ \left\{x \to \frac{5\sqrt{\frac{5}{2}}}{8}, y \to \frac{5\sqrt{\frac{5}{2}}}{8}\right\} \tag{7}$$

whereas for $\alpha = 0.7$ they are

$$\{x \to 0, y \to 0\},\ \left\{x \to -\frac{15\sqrt{\frac{15}{14}}}{7}, y \to -\frac{15\sqrt{\frac{15}{14}}}{7}\right\},\ \left\{x \to \frac{15\sqrt{\frac{15}{14}}}{7}, y \to \frac{15\sqrt{\frac{15}{14}}}{7}\right\} \tag{8}$$

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Linearization and Eigenvalue Analysis

In order to investigate the local dynamical behavior around the equilibrium configurations, the Gürsey system is differentiated once. The resulting equations can be written as

$$x'' = -\frac{3}{4}x' + \frac{1}{2}\alpha\left[x^2 + y^2\right]^{\frac{1}{3}}y' + \frac{\alpha y\left[2xx' + 2yy'\right]}{6[x^2 + y^2]^{\frac{2}{3}}}$$
$$y'' = \frac{3}{4}y' - \frac{1}{2}\alpha\left[x^2 + y^2\right]^{\frac{1}{3}}x' + \frac{\alpha x\left[2xx' + 2yy'\right]}{6[x^2 + y^2]^{\frac{2}{3}}} \tag{9}$$

The corresponding linearized system can then be represented in matrix form as

$$\begin{pmatrix} x'' \\ y \end{pmatrix} = \begin{pmatrix} -\frac{3}{4} + \frac{\alpha xy}{3[x^2+y^2]^{\frac{2}{3}}} & \frac{\alpha y^2}{3[x^2+y^2]^{\frac{2}{3}}} + \frac{1}{2}\alpha(x^2+y^2)^{\frac{1}{3}} \\ -\frac{\alpha x^2}{3[x^2+y^2]^{\frac{2}{3}}} - \frac{1}{2}\alpha(x^2+y^2)^{\frac{1}{3}} & \frac{3}{4} - \frac{\alpha xy}{3[x^2+y^2]^{\frac{2}{3}}} \end{pmatrix} \begin{pmatrix} x' \\ y' \end{pmatrix}$$

(10)

The eigenvalues of the linearized system were evaluated at the nonzero equilibrium points obtained for each value of α. For $\alpha = 1$, the two symmetric nonzero equilibrium points yield

$$\lambda_{\pm}^{\left(-\frac{3\sqrt{3}}{4},-\frac{3\sqrt{3}}{4}\right)} = \pm\frac{i\sqrt{3}}{2} \quad \text{ve} \quad \lambda_{\pm}^{\left(\frac{3\sqrt{3}}{4},\frac{3\sqrt{3}}{4}\right)} = \pm\frac{i\sqrt{3}}{2} \tag{11}$$

For $\alpha = 1.2$, the corresponding eigenvalues are

$$\lambda_{\pm}^{\left(-\frac{5\sqrt{\frac{5}{2}}}{8},-\frac{5\sqrt{\frac{5}{2}}}{8}\right)} = \pm 0.872019i \quad \text{ve} \quad \lambda_{\pm}^{\left(\frac{5\sqrt{\frac{5}{2}}}{8},\frac{5\sqrt{\frac{5}{2}}}{8}\right)} = \pm 0.872019i \tag{12}$$

and for $\alpha = 0.7$, they are

$$\lambda_{\pm}^{\left(-\frac{15\sqrt{\frac{15}{4}}}{7},-\frac{15\sqrt{\frac{15}{4}}}{7}\right)} = \pm 0.85042i \quad \text{ve} \quad \lambda_{\pm}^{\left(\frac{15\sqrt{\frac{15}{4}}}{7},\frac{15\sqrt{\frac{15}{4}}}{7}\right)} = \pm 0.85042i \tag{13}$$

For all parameter values considered in the present analysis, the eigenvalues associated with the nonzero equilibrium points are purely imaginary, forming complex-conjugate pairs with vanishing real parts. Within the local linearized description, these equilibrium configurations therefore exhibit elliptic fixed-point behavior. The corresponding dynamics around the fixed points are characterized by bounded trajectories, consistent with the phase-space behavior of the system (Aydogmus, 2013).

In addition to the eigenvalue calculations performed at the individual equilibrium points, the characteristic behavior of the Gürsey system can be expressed in its general form as

$$\lambda = \pm\frac{1}{4}\sqrt{9 - \frac{16\alpha FG}{(F^2+G^2)^{\frac{2}{3}}} - \frac{80}{3}\alpha^2(F^2+G^2)^{\frac{2}{3}}} \tag{14}$$

Substituting the α-dependent equilibrium-point expressions into Eq. (14) and considering positive values of α, the expression under the square root takes a negative value for the Gürsey instanton configurations.

Phase-Space Analysis

The analytical results were further examined using phase-space portraits of the Gürsey instanton system.

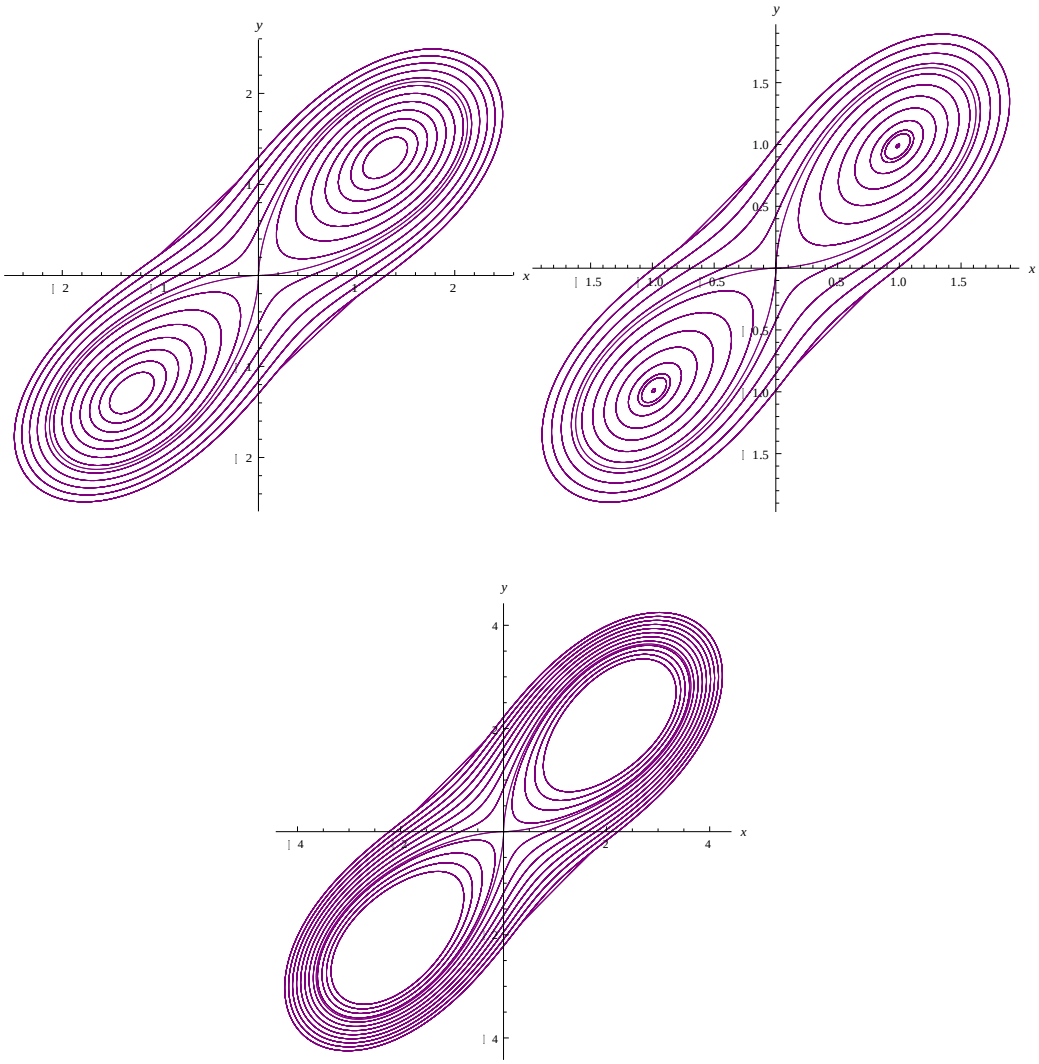

Figure 1. Phase-space portraits of the Gürsey instanton system for $\alpha = 1$, $\alpha = 1.2$ and$\alpha = 0.7$ respectively.

The three Gürsey phase-space portraits presented in the source study exhibit organized bounded trajectories around the corresponding nonzero equilibrium configurations. The phase portraits also preserve the symmetric two-center structure associated with the pair of nonzero fixed points. The actual three Gürsey plots are shown together in the original study before the corresponding Thirring plots.

For $\alpha = 1$, the trajectories form regular structures surrounding the two symmetric equilibrium configurations. When the parameter is changed to $\alpha = 1.2$, the positions and geometrical extent of the trajectories change, but the qualitative organization around the nonzero fixed points remains.

A similar behavior is observed for $\alpha = 0.7$. Although the quantitative phase-space geometry depends on the parameter value, the trajectories remain organized around the corresponding equilibrium configurations.

The phase-space structures are therefore consistent with the analytical eigenvalue results. The purely imaginary eigenvalues indicate elliptic fixed-point behavior in the local linearized system, while the corresponding phase portraits exhibit bounded trajectories around the equilibrium configurations.

The combined analytical and geometrical results show that the variation of α within the three investigated cases primarily modifies quantitative properties of the system, including the locations of

the fixed points and the magnitudes of the imaginary eigenvalues. It does not produce a qualitative change in the local dynamical character of the nonzero equilibrium configurations.

This observation is particularly relevant to the interpretation of the Gürsey instanton solutions. The classical solutions of the conformally invariant spinor model have previously been investigated within the original Gürsey framework and subsequent studies (Akdeniz, 1982; Gürsey, 1956; Kortel, 1956). The present dynamical-systems formulation provides a complementary description by characterizing the behavior of the reduced system in the neighborhood of the corresponding equilibrium configurations.

The stability interpretation should nevertheless be restricted to the scope of the adopted analysis. The eigenvalue calculation is based on the linearized system in the neighborhood of the fixed points and therefore provides a local characterization. The phase-space portraits provide complementary qualitative evidence by exhibiting regular bounded trajectories around the corresponding configurations. Within these limitations, the agreement between the eigenvalue analysis and the phase-space representations supports the interpretation that the investigated Gürsey instanton configurations exhibit elliptic local behavior for the parameter values considered.

CONCLUSION

In this study, the local dynamical behavior of instanton solutions in the four-dimensional Gürsey spinor model was investigated using nonlinear dynamical-systems methods. Starting from the nonlinear fermionic field equation, the special Heisenberg ansatz and appropriate dimensionless transformations were employed to reduce the original field problem to a coupled autonomous system.

The equilibrium configurations of the reduced system were determined for $\alpha = 1$, $\alpha = 1.2$ and $\alpha = 0.7$. For each parameter value, the system contains a pair of symmetric nonzero equilibrium points in addition to the origin. Although variations in α modify the quantitative locations of these equilibrium configurations, their qualitative symmetric structure is preserved.

The local behavior of the system was investigated by linearizing the equations around the nonzero equilibrium points. For all three parameter values considered, the resulting eigenvalues are purely imaginary and the corresponding fixed points exhibit elliptic behavior within the local linearized description. Furthermore, evaluation of the general characteristic expression at the α -dependent equilibrium points yields a negative quantity under the square root, consistently supporting the imaginary character of the eigenvalue spectrum.

The phase-space analysis provides a geometrical representation consistent with the analytical results. Regular and bounded trajectories are observed around the corresponding nonzero equilibrium configurations for all investigated parameter values. The preservation of this qualitative phase-space structure indicates that varying α within the considered range changes the quantitative properties of the system without altering the local dynamical character of the instanton configurations.

Overall, the agreement between the equilibrium-point analysis, the eigenvalue characteristics, and the phase-space structures provides a consistent description of the local dynamics of instanton solutions in the four-dimensional Gürsey spinor model. These results demonstrate the usefulness of nonlinear dynamical-systems methods for investigating the stability properties of instanton configurations in nonlinear fermionic field theories.

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INTERNATIONAL HUMANITARIAN LAW AND THE REGULATION OF ARMED CONFLICT

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ABSTRACT

International humanitarian law (IHL) constitutes a fundamental branch of public international law that regulates the conduct of armed conflict with the primary objective of limiting human suffering and protecting persons who are not or no longer participating in hostilities. It operates on the normative balance between military necessity and humanitarian considerations, ensuring that even in situations of armed violence, minimum standards of human dignity are maintained.

This chapter examines the legal and institutional framework governing armed conflict under international law. It analyzes the historical evolution of IHL from customary wartime practices to its codification in instruments such as the Geneva Conventions of 1949 and the Additional Protocols of 1977. The study further explores the core principles of IHL, including distinction, proportionality, necessity, precaution, and humanity, as foundational rules governing the conduct of hostilities.

In addition, the chapter evaluates the classification of armed conflicts into international and non-international categories and assesses their implications for legal protection regimes. It also examines the emergence of war crimes and individual criminal responsibility, with particular attention to the role of international judicial institutions such as the International Criminal Court (ICC), ad hoc tribunals, and the International Court of Justice (ICJ).

Finally, the chapter addresses contemporary challenges facing IHL, including asymmetric warfare, cyber operations, non-state armed groups, and technological developments such as autonomous weapons systems. It argues that while IHL remains a resilient normative framework, its effectiveness is increasingly dependent on state cooperation, enforcement mechanisms, and political will within the international system.

Keywords: International humanitarian law, armed conflict, Geneva Conventions, war crimes, proportionality, distinction, International Criminal Court, international law

Introduction

Armed conflict remains one of the most persistent and consequential phenomena in international relations. Despite the development of modern international institutions, legal frameworks, and diplomatic mechanisms, the use of force continues to shape global political order. As a result, international law has progressively developed normative systems aimed at regulating the conduct of hostilities and mitigating the humanitarian consequences of war.

International humanitarian law (IHL), as a specialized branch of public international law, governs the behavior of states and non-state actors during armed conflict. Its central purpose is not to prohibit war entirely—that function belongs primarily to the jus ad bellum framework—but rather to regulate how war is conducted under the principles of humanity and military necessity. In doing so, IHL seeks to protect individuals who are not or are no longer participating in hostilities, including civilians, prisoners of war, and the wounded.

The development of IHL reflects a broader transformation in the nature of the international legal order. Historically, warfare was largely governed by notions of sovereignty and strategic discretion, with limited legal constraints. However, the evolution of treaty law, customary international law, and

international judicial institutions has progressively restricted the discretion of belligerent actors and established binding legal obligations in times of armed conflict.

A central feature of contemporary international law is the attempt to balance two competing imperatives: military necessity and humanitarian protection. This balance is reflected in the core principles of IHL, which impose limitations on methods and means of warfare while recognizing the realities of armed conflict. These principles have become universally recognized standards governing state conduct, regardless of whether they arise from treaty obligations or customary international law.

In addition, the institutionalization of accountability mechanisms has significantly altered the legal landscape of armed conflict. The establishment of international criminal tribunals and the International Criminal Court (ICC) has reinforced the principle that individuals, including state officials and military commanders, may bear criminal responsibility for serious violations of IHL.

However, despite these normative and institutional developments, the application of IHL continues to face significant challenges. Contemporary forms of conflict, including asymmetric warfare, cyber operations, and the involvement of non-state armed groups, have complicated traditional legal classifications and enforcement mechanisms. Moreover, compliance with IHL remains heavily dependent on state cooperation and political will, limiting its uniform effectiveness.

Against this background, this chapter examines the legal framework governing armed conflict under international humanitarian law. It explores its historical development, core principles, legal classifications, enforcement mechanisms, and contemporary challenges. The analysis aims to demonstrate that while IHL represents one of the most developed areas of international law, its effectiveness is continuously tested by the evolving nature of warfare and the structural limitations of the international legal system.

Historical Development of International Humanitarian Law

The development of international humanitarian law (IHL) reflects a gradual and cumulative process shaped by changes in warfare, state practice, and humanitarian consciousness. Rather than emerging as a single unified system, IHL evolved through customary norms, fragmented treaty arrangements, and later comprehensive codification under modern international law.

Early Customary and Pre-Modern Rules of War

In early historical periods, the conduct of armed conflict was primarily regulated by customary practices, religious norms, and moral traditions rather than formal legal instruments. Ancient civilizations, including those in Greece, Rome, and various Asian legal traditions, recognized limited principles regarding the treatment of prisoners of war and non-combatants. However, these norms were inconsistent and lacked universal applicability or enforcement mechanisms.

During the medieval period, religious doctrines and chivalric codes introduced additional restraints on warfare. These included notions of honorable conduct in battle and protections for certain categories of individuals. Despite these developments, the absence of centralized authority in the international system meant that compliance remained largely voluntary and context-dependent.

Emergence of Modern State System and Early Legalization of War

The emergence of the modern state system in the seventeenth century transformed war into a structured instrument of state policy. Although sovereignty became the dominant organizing principle of international relations, it initially provided few legal constraints on the conduct of hostilities. Warfare was largely considered a legitimate extension of state power.

However, increasing industrialization of warfare and humanitarian concern gradually created pressure for legal regulation. This period laid the groundwork for the formal codification of rules governing armed conflict.

The Role of the International Committee of the Red Cross and the Geneva Tradition

A major turning point in the development of IHL occurred in the nineteenth century with the establishment of the International Committee of the Red Cross (ICRC) in 1863. The humanitarian initiative led to the adoption of the first Geneva Convention in 1864, which provided legal protection for wounded soldiers on the battlefield.

This marked the first instance of a binding multilateral treaty specifically dedicated to humanitarian concerns in armed conflict. It introduced the foundational idea that even in war, individuals retain certain legal protections.

The Hague Conventions and Regulation of Means and Methods of Warfare

The Hague Peace Conferences of 1899 and 1907 significantly expanded the legal regulation of armed conflict. Unlike the Geneva tradition, which focused on the protection of victims of war, the Hague Conventions emphasized the regulation of permissible means and methods of warfare.

These instruments introduced early prohibitions and restrictions on weapons, military tactics, and conduct during hostilities. Together, the Geneva and Hague systems formed the dual foundation of modern international humanitarian law.

The 1949 Geneva Conventions and Post–World War II Expansion

The Second World War marked a decisive moment in the evolution of IHL due to widespread atrocities and mass civilian suffering. In response, the international community adopted the four Geneva Conventions of 1949, which significantly expanded legal protections.

These conventions addressed:

Wounded and sick armed forces in the field

Wounded, sick, and shipwrecked members of armed forces at sea

Prisoners of war

Protection of civilians in times of war

The 1949 framework is widely recognized as the cornerstone of contemporary IHL and represents a comprehensive codification of humanitarian protections in armed conflict.

Additional Protocols and Expansion to Non-International Armed Conflicts

The adoption of the Additional Protocols of 1977 further strengthened and expanded the scope of IHL. These instruments were particularly significant because they extended legal regulation to non-international armed conflicts, which had previously been less comprehensively governed.

Additional Protocol I reinforced protections in international armed conflicts, while Additional Protocol II specifically addressed conflicts involving non-state armed groups. This development reflected the changing nature of warfare, particularly the rise of internal conflicts and civil wars.

Contemporary Evolution of IHL

In the contemporary period, IHL continues to evolve through customary international law, judicial interpretation, and state practice. International tribunals, including the International Criminal Tribunal for the former Yugoslavia (ICTY) and the International Criminal Court (ICC), have played a critical role in clarifying and expanding legal interpretations.

This evolutionary process demonstrates that IHL is not static but continuously adapts to new forms of warfare and emerging humanitarian concerns.

Sources of International Humanitarian Law

International humanitarian law (IHL) derives its authority from a structured set of legal sources that collectively define its binding norms, interpretive principles, and operational rules. These sources are

consistent with the general framework of international law as reflected in Article 38(1) of the Statute of the International Court of Justice (ICJ), which identifies treaties, customary international law, and general principles of law as primary sources, supplemented by judicial decisions and scholarly writings.

Treaty Law

Treaty law constitutes the primary and most explicit source of international humanitarian obligations. Treaties are formal written agreements between states that create legally binding obligations under international law upon ratification.

The most significant treaties in the field of IHL include the four Geneva Conventions of 1949 and their Additional Protocols of 1977. These instruments establish comprehensive rules governing the protection of persons who are not or are no longer participating in hostilities, including civilians, prisoners of war, and the wounded and sick.

Treaty law provides detailed and codified obligations regarding:

Protection of civilians in armed conflict

Treatment of detainees and prisoners of war

Regulation of means and methods of warfare

Obligations of occupying powers

The binding nature of treaties is grounded in the principle of pacta sunt servanda, which requires states to perform their treaty obligations in good faith.

Customary International Law

Customary international law is formed through consistent and general state practice accompanied by opinio juris, the belief that such practice is legally required. Unlike treaty law, customary law does not depend on formal ratification and is therefore binding on all states, including those that are not parties to specific treaties.

Customary IHL plays a critical role in filling gaps where treaty law is silent or incomplete. Many of the fundamental principles of IHL, including distinction, proportionality, necessity, and precaution, are widely recognized as customary norms.

The International Committee of the Red Cross (ICRC) has identified a large body of customary rules applicable to both international and non-international armed conflicts, reinforcing the universal applicability of core humanitarian protections.

General Principles of Law

General principles of law recognized by civilized nations constitute a supplementary source of international law. These principles are derived from domestic legal systems and are applied at the international level to ensure coherence and completeness of legal reasoning.

In the context of IHL, general principles include:

Good faith in the performance of obligations

Equality of belligerents under law

Due process in judicial proceedings

Human dignity as a foundational legal value

These principles assist in interpreting treaty provisions and customary rules, particularly in complex or ambiguous legal situations.

Judicial Decisions and International Jurisprudence

Judicial decisions are not primary sources of law but play a crucial interpretive role in the development of IHL. International courts and tribunals contribute to the clarification, application, and progressive development of humanitarian norms.

Key institutions include:

International Court of Justice (ICJ)

International Criminal Tribunal for the former Yugoslavia (ICTY)

International Criminal Tribunal for Rwanda (ICTR)

International Criminal Court (ICC)

Jurisprudence from these bodies has significantly shaped legal understanding of:

War crimes and crimes against humanity

Command responsibility

The classification of armed conflicts

Applicability of customary international law in internal conflicts

Judicial interpretation ensures consistency in the application of IHL and strengthens accountability mechanisms in cases of serious violations.

3.5 Soft Law and Institutional Contributions

In addition to binding legal sources, non-binding instruments and institutional outputs also influence the development of IHL. These include declarations, guidelines, and interpretive reports issued by international organizations, particularly the International Committee of the Red Cross.

Although not legally binding, such instruments contribute to:

Clarification of legal standards

Development of customary norms

Guidance for state practice and military manuals

Progressive development of humanitarian law

Soft law plays a significant role in adapting IHL to emerging challenges, especially in areas where formal treaty law has not yet fully developed, such as cyber warfare and autonomous weapons systems.

Core Principles of International Humanitarian Law

International humanitarian law (IHL) is structured around a set of fundamental principles that regulate the conduct of hostilities and ensure a minimum level of protection for persons affected by armed conflict. These principles operate as binding legal standards derived from treaty law, customary international law, and international jurisprudence. Collectively, they form the normative foundation of lawful warfare.

Principle of Distinction

The principle of distinction requires parties to an armed conflict to distinguish at all times between combatants and civilians, as well as between military objectives and civilian objects. Attacks may only be directed against lawful military targets.

Civilians are protected against direct attack unless and for such time as they take a direct part in hostilities. This principle is codified in Additional Protocol I of 1977 and is universally recognized as a cornerstone of customary international law.

The principle of distinction is essential to IHL because it establishes the legal boundary between permissible military action and unlawful violence. Violations of this principle are among the most serious breaches of international humanitarian law and often constitute war crimes.

Principle of Proportionality

The principle of proportionality prohibits attacks in which the expected incidental harm to civilians or civilian objects would be excessive in relation to the concrete and direct military advantage anticipated.

This principle does not prohibit collateral damage per se; rather, it requires a reasoned and context-specific balancing of military necessity against humanitarian impact. The assessment is inherently ex ante and must be based on information reasonably available at the time of the attack.

Proportionality is one of the most complex principles in operational practice, particularly in urban warfare and densely populated environments, where military objectives and civilian presence frequently overlap.

Principle of Military Necessity

Military necessity permits measures that are indispensable for achieving a legitimate military objective, provided they are not otherwise prohibited by international law.

This principle does not grant unlimited authority to use force. Instead, it operates as a restrictive doctrine that limits military action to what is necessary to achieve lawful objectives, such as the weakening of enemy armed forces.

Military necessity must always be interpreted in conjunction with other IHL principles, particularly humanity and proportionality, to prevent abuse or excessive force.

Principle of Humanity

The principle of humanity prohibits the infliction of unnecessary suffering and requires respect for human dignity in all circumstances of armed conflict.

It underpins the protection of persons who are hors de combat, including the wounded, prisoners of war, and civilians. This principle reflects the idea that even in war, individuals retain inherent legal and moral rights.

Humanity serves as a limiting principle that restricts means and methods of warfare that cause superfluous injury or unnecessary suffering.

Principle of Precaution

The principle of precaution requires all feasible measures to be taken to avoid or minimize incidental harm to civilians and civilian objects during military operations.

This includes obligations to:

Verify that targets are military objectives

Choose means and methods of attack that reduce civilian harm

Cancel or suspend attacks where civilian harm becomes excessive

Provide effective advance warnings where circumstances permit

Precaution operates as an operational safeguard that reinforces both distinction and proportionality in practice.

Interrelationship of Principles

These principles do not operate in isolation. Instead, they function as an integrated normative system governing the conduct of hostilities. Distinction defines lawful targets, proportionality limits acceptable harm, necessity justifies military action within legal bounds, humanity protects fundamental dignity, and precaution ensures preventive compliance.

Together, they form the core evaluative framework through which the legality of military conduct is assessed under international humanitarian law.

Classification of Armed Conflicts

International humanitarian law (IHL) applies differently depending on the legal classification of an armed conflict. The categorization of conflicts is therefore a foundational issue because it determines the scope of applicable legal protections, the obligations of parties, and the applicable enforcement mechanisms.

Under contemporary IHL, armed conflicts are primarily classified into two categories: international armed conflicts (IACs) and non-international armed conflicts (NIACs). This distinction, while doctrinally clear, has become increasingly complex in modern warfare due to the involvement of non-state actors, transnational operations, and hybrid conflict structures.

International Armed Conflicts (IACs)

An international armed conflict occurs whenever there is armed hostilities between two or more states, regardless of the intensity or duration of the conflict. This definition is reflected in Common Article 2 of the 1949 Geneva Conventions.

IACs trigger the full applicability of international humanitarian law, including:

All four Geneva Conventions of 1949

Additional Protocol I of 1977

Customary international humanitarian law

In IACs, legal protections are the most comprehensive. They include detailed rules governing:

Treatment of prisoners of war

Protection of civilians in occupied territories

Regulation of means and methods of warfare

Responsibilities of occupying powers

The legal regime for IACs reflects the traditional state-centric structure of international law, where states are the primary subjects of legal obligation.

Non-International Armed Conflicts (NIACs)

Non-international armed conflicts occur within the territory of a single state and involve either government armed forces and organized non-state armed groups, or armed groups engaged in hostilities among themselves.

The primary legal foundation for NIACs is Common Article 3 of the Geneva Conventions, supplemented by Additional Protocol II (where applicable) and customary international law.

Although the legal framework for NIACs is less detailed than for IACs, it still establishes binding obligations, including:

Humane treatment of all persons not taking active part in hostilities

Prohibition of torture, cruel treatment, and hostage-taking

Protection of civilians against violence and targeting

Minimum judicial guarantees for penal proceedings

NIACs reflect the increasing importance of internal conflicts in modern international relations and the growing role of non-state armed actors in global security dynamics.

Legal Challenges in Conflict Classification

The distinction between IACs and NIACs is increasingly difficult to apply in contemporary conflicts. Many modern wars involve mixed elements, including foreign intervention, proxy forces, and transnational armed groups operating across borders.

Key challenges include:

Determining when a NIAC becomes internationalized

Attributing responsibility to state or non-state actors

Identifying the threshold of intensity required for IHL applicability

Managing overlapping legal regimes in hybrid conflicts

International jurisprudence, particularly from the International Criminal Tribunal for the former Yugoslavia (ICTY), has expanded the understanding of armed conflict classification by emphasizing factual intensity and organization rather than formal declarations of war.

Hybrid and Transnational Armed Conflicts

Modern armed conflicts increasingly exhibit hybrid characteristics, combining conventional military operations with irregular warfare, cyber operations, and indirect proxy engagement. These conflicts blur traditional legal categories and create uncertainty in the application of IHL.

Transnational armed groups operating across multiple jurisdictions further complicate classification, particularly when they engage in sustained armed violence without clear territorial boundaries.

As a result, legal classification today often requires a functional rather than formal analysis, focusing on:

Intensity of hostilities

Level of organization of armed groups

Degree of state involvement

Legal Consequences of Classification

The classification of an armed conflict has direct legal consequences, as it determines:

Which treaty regime applies

The scope of civilian protection

The applicability of prisoner-of-war status

The jurisdiction of international criminal law mechanisms

Therefore, accurate classification is not merely theoretical but has significant implications for accountability, enforcement, and humanitarian protection.

War Crimes and Individual Criminal Responsibility

International humanitarian law (IHL) is not only a regulatory framework governing conduct during armed conflict, but also a system that establishes individual criminal responsibility for serious violations. These violations are classified as war crimes under international criminal law and are subject to prosecution before domestic and international tribunals.

The development of individual criminal responsibility represents a major transformation in international law, shifting accountability from states alone to natural persons, including military commanders, political leaders, and non-state actors.

Definition of War Crimes

War crimes refer to serious violations of international humanitarian law committed during armed conflict. These crimes are recognized under customary international law, the Geneva Conventions, and the Rome Statute of the International Criminal Court (ICC).

Common categories of war crimes include:

Intentional targeting of civilians

Attacks on civilian objects not justified by military necessity

Torture or inhuman treatment

Taking of hostages

Unlawful deportation or transfer of protected persons

Extensive destruction of property not justified by military necessity

Use of prohibited weapons or methods of warfare

War crimes are characterized by their serious nature and their direct connection to armed conflict.

Individual Criminal Responsibility

A core principle of international criminal law is that individuals are personally responsible for war crimes they commit, order, assist, or otherwise facilitate.

This principle applies regardless of official position. Holding a governmental or military rank does not exempt individuals from liability. This is reflected in the doctrine of individual accountability under the Rome Statute.

Key forms of liability include:

Direct perpetration

Ordering or instigating crimes

Aiding and abetting

Joint criminal enterprise (as developed in jurisprudence)

This framework ensures that legal responsibility is not limited to state structures but extends to individuals who make operational decisions in armed conflict.

6.3 Command Responsibility Doctrine

The doctrine of command responsibility holds military commanders and civilian superiors criminally liable for crimes committed by subordinates if they:

Knew or should have known about the crimes, and

Failed to prevent them or punish the perpetrators

This doctrine was significantly developed in the jurisprudence of the International Criminal Tribunal for the former Yugoslavia (ICTY), particularly in cases such as Prosecutor v. Čelebići and Prosecutor v. Tadić.

Command responsibility is essential in ensuring accountability in hierarchical military structures and preventing impunity through delegation of authority.

International Criminal Court (ICC)

The International Criminal Court (ICC), established under the Rome Statute of 1998, is the primary permanent judicial institution responsible for prosecuting individuals for war crimes, crimes against humanity, genocide, and the crime of aggression.

The ICC operates on the principle of complementarity, meaning it acts only when national jurisdictions are unwilling or unable to prosecute genuinely.

Despite its significance, the ICC faces structural limitations, including:

Dependence on state cooperation for arrests and enforcement

Limited jurisdiction over non-state parties to the Rome Statute

Political constraints affecting case referrals and execution

Nevertheless, the ICC remains a central institution in the enforcement of international humanitarian law.

Ad Hoc Tribunals and Jurisprudential Development

Ad hoc tribunals such as the ICTY and the International Criminal Tribunal for Rwanda (ICTR) played a crucial role in the development of international criminal law.

Their jurisprudence clarified key legal concepts, including:

The definition of armed conflict

The scope of crimes against humanity

The applicability of IHL in internal conflicts

The expansion of command responsibility

These tribunals significantly contributed to the evolution of accountability mechanisms under international law.

Immunity vs Accountability Debate

A persistent issue in international criminal law is the tension between state immunity and individual accountability. While customary international law recognizes immunities for certain state officials, international criminal tribunals have increasingly limited the scope of immunity in cases involving serious international crimes.

This tension reflects the broader conflict between sovereignty and universal accountability in international law. Contemporary legal practice increasingly prioritizes accountability for grave breaches of IHL over traditional doctrines of immunity, particularly in cases involving war crimes and crimes against humanity.

Significance of Criminalization in IHL

The criminalization of serious violations of IHL strengthens compliance by creating deterrence and reinforcing legal obligations. It transforms humanitarian norms from purely regulatory rules into enforceable standards backed by international criminal jurisdiction.

However, enforcement remains uneven due to political constraints, jurisdictional limitations, and dependence on state cooperation.

Role of International Institutions in Armed Conflict Regulation

International institutions play a central role in the development, interpretation, and partial enforcement of international humanitarian law (IHL). In the absence of a centralized global enforcement authority, these institutions collectively form a decentralized governance structure that regulates armed conflict through legal, political, and humanitarian mechanisms.

United Nations System

The United Nations (UN) is the principal international organization responsible for the maintenance of international peace and security. Its legal authority is grounded in the UN Charter of 1945, which establishes a collective security system designed to prevent and respond to threats to international stability.

The UN Security Council holds primary responsibility under Chapter VII of the Charter to determine the existence of threats to peace, breaches of peace, or acts of aggression. It may authorize:

Economic and diplomatic sanctions

Peacekeeping operations

Use of force by member states

Although the Security Council is a powerful enforcement mechanism, its effectiveness is often constrained by the political interests and veto power of its permanent members, which can limit consistent application of international legal norms.

International Court of Justice (ICJ)

The International Court of Justice (ICJ) serves as the principal judicial organ of the United Nations. It adjudicates disputes between states and provides advisory opinions on questions of international law referred by UN organs and specialized agencies.

The ICJ contributes to international humanitarian law through:

Interpretation of treaty obligations

Clarification of customary international law

Development of state responsibility principles

However, the ICJ's jurisdiction is based on state consent, which limits its compulsory authority and restricts its ability to address all armed conflicts.

International Committee of the Red Cross (ICRC)

The International Committee of the Red Cross (ICRC) is a unique humanitarian institution mandated to ensure protection and assistance for victims of armed conflict. Although it does not possess enforcement powers, it plays a critical operational and interpretive role in IHL.

Key functions include:

Monitoring compliance with IHL in conflict zones

Providing humanitarian assistance to civilians and detainees

Promoting dissemination and understanding of IHL

Acting as a neutral intermediary between parties to conflict

The ICRC's neutrality and independence allow it to operate in highly sensitive environments where other institutions may have limited access.

International Criminal Institutions

International criminal institutions, particularly the International Criminal Court (ICC), contribute to the enforcement dimension of IHL by prosecuting individuals responsible for serious violations.

These institutions reinforce accountability through:

Criminal prosecution of war crimes and genocide

Development of legal precedent through jurisprudence

Deterrence of future violations

However, their effectiveness remains dependent on state cooperation for arrest and enforcement of decisions.

Regional Organizations

Regional organizations complement global institutions by addressing conflicts within specific geographic contexts. Examples include the African Union (AU), European Union (EU), and NATO.

These organizations contribute through:

Peacekeeping and stabilization missions

Regional conflict mediation

Collective defense arrangements (e.g., NATO Article 5 framework)

Norm development aligned with regional security needs

Regional mechanisms often provide faster and more context-sensitive responses compared to global institutions.

Institutional Limitations

Despite their importance, international institutions face significant structural limitations:

Dependence on state consent and cooperation

Political influence of powerful states

Lack of centralized enforcement authority

Resource and operational constraints in conflict zones

These limitations create a gap between normative legal frameworks and actual enforcement capacity, particularly in high-intensity or politically sensitive conflicts.

Functional Interaction of Institutions

International institutions do not operate in isolation; rather, they function as an interconnected system. The UN provides political authority, the ICJ provides judicial interpretation, the ICC enforces individual accountability, and the ICRC ensures humanitarian implementation.

Together, they form a multi-layered governance structure that supports the operation of international humanitarian law in both legal and practical dimensions.

Section 9: Role of International Organizations in Global Security Governance (APA 7 Final Version)

Role of International Organizations in Global Security Governance

International organizations constitute the institutional backbone of contemporary international law and play a central role in maintaining global peace and security. In the absence of a centralized global authority, these institutions provide structured mechanisms for collective decision-making, conflict management, and legal coordination among states.

The United Nations is the most significant actor within this system. It performs multiple legal and political functions, including conflict prevention, peacekeeping operations, humanitarian coordination, and the promotion of international law. The United Nations Security Council holds primary responsibility for maintaining international peace and security under the UN Charter and is authorized to determine the existence of threats to peace, breaches of peace, or acts of aggression. In such cases, it may adopt binding resolutions, impose sanctions, or authorize the use of force under Chapter VII of the Charter.

The United Nations General Assembly contributes to global governance through normative development and diplomatic dialogue. Although its resolutions are generally non-binding, they play an important role in shaping international expectations, influencing state behavior, and contributing to the interpretation of international legal principles.

The International Court of Justice (ICJ), as the principal judicial organ of the United Nations, strengthens the legal dimension of the international system by resolving disputes between states and issuing advisory opinions on legal questions. While its jurisdiction depends on state consent, its jurisprudence significantly contributes to the clarification and development of international law.

Despite these institutional mechanisms, the effectiveness of international organizations is often constrained by political realities, particularly the veto power held by permanent members of the Security Council. This reflects the structural tension between legal equality and political hierarchy in global governance.

Regional Security Systems and Legal Cooperation

In addition to global institutions, regional organizations play a critical role in maintaining international peace and security within specific geographical contexts. These systems complement the global legal order by addressing conflicts that are often more localized, politically sensitive, and context-dependent.

Regional arrangements also enhance responsiveness, as they are typically closer to the political and security realities of affected states.

NATO and Collective Defense

The North Atlantic Treaty Organization (NATO) is one of the most developed collective security systems in international relations. It is founded on the principle of collective defense, as articulated in Article 5 of the North Atlantic Treaty, which provides that an armed attack against one member state shall be considered an attack against all members.

This legal commitment creates a deterrence framework designed to reduce the likelihood of external aggression against member states. Beyond collective defense, NATO also engages in crisis management operations, peace support missions, and cooperative security initiatives that extend beyond its traditional military mandate.

10.2 European Union Security Framework

The European Union (EU) has developed an integrated legal and institutional security architecture through its Common Security and Defence Policy (CSDP). This framework enables the EU to conduct civilian and military crisis management operations, peacekeeping missions, and capacity-building programs in third states.

A distinguishing feature of the EU system is its supranational legal structure, which binds member states through shared legal obligations and institutional decision-making procedures. This reduces unilateral security action and promotes coordinated responses to international crises.

African Union and Regional Peacekeeping

The African Union (AU) has progressively strengthened its role in regional peace and security through the Peace and Security Council, which is responsible for conflict prevention, management, and resolution across the continent.

A key normative innovation within the AU system is the principle of non-indifference, which permits intervention in member states in cases of grave circumstances such as genocide, war crimes, and crimes against humanity. This represents a significant evolution from traditional doctrines of absolute non-intervention toward a more humanitarian-oriented interpretation of sovereignty.

Legal Significance of Regional Security Systems

Regional security organizations contribute to international law by operationalizing collective security principles at a regional level. They provide mechanisms for early warning, mediation, peace enforcement, and post-conflict reconstruction.

However, their effectiveness varies depending on political cohesion among member states, resource availability, and alignment with broader international legal norms. In some cases, regional responses may be more efficient than global mechanisms due to proximity and shared political interests, while in other cases internal divisions may limit their effectiveness.

Limits of International Law Enforcement

Despite the existence of a comprehensive body of international legal norms and institutional mechanisms, the enforcement of international law remains structurally constrained. Unlike domestic legal systems, international law lacks a centralized enforcement authority capable of ensuring uniform compliance across all states and contexts. As a result, its effectiveness depends heavily on decentralized implementation through states, international organizations, and political cooperation.

Sovereignty and Consent

State sovereignty remains a foundational principle of international law. Under this principle, states are legally equal and cannot be bound without their consent. While this preserves independence and territorial integrity, it also limits the enforceability of international legal obligations.

Most international treaties and legal commitments operate on the basis of consent, meaning that states voluntarily assume obligations and may withdraw or limit compliance in practice. This consensual structure weakens enforcement capacity, particularly in politically sensitive disputes where compliance conflicts with national interests.

Power Asymmetry in Global Politics

International law operates within a structurally unequal global system. States differ significantly in military, economic, and political power, which affects their ability to influence the creation, interpretation, and enforcement of legal norms.

Power asymmetry is particularly visible in institutions such as the United Nations Security Council, where permanent members possess veto power. This structure embeds political hierarchy within legal decision-making processes, often limiting collective action in cases involving major powers or their allies.

Weak Compliance Mechanisms

Even where legal rules are clearly defined, enforcement mechanisms are often indirect. International courts and tribunals rely on state cooperation for implementation of judgments, while sanctions regimes depend on collective political will and sustained coordination among states.

In many cases, compliance is inconsistent, especially in high-stakes security disputes. The absence of coercive enforcement tools comparable to domestic policing systems means that legal outcomes may not always translate into practical compliance.

Political Selectivity and Inconsistent Application

The application of international law is frequently influenced by political considerations. States and international institutions may respond differently to similar legal violations depending on strategic interests, alliances, and geopolitical calculations.

This selective enforcement undermines perceptions of neutrality and universality within international law. It also contributes to a gap between formal legal equality and practical enforcement outcomes, particularly in conflicts involving strategically significant regions.

Structural Dependence on International Cooperation

International law enforcement ultimately depends on sustained cooperation among states. Where such cooperation exists, legal mechanisms can function effectively through diplomacy, sanctions, and judicial processes. However, where cooperation is absent or fragmented, enforcement capacity is significantly reduced.

This structural dependence highlights a fundamental characteristic of international law: it is not self-executing, but rather operates through a system of shared political responsibility and voluntary compliance supported by institutional pressure.

Fragmentation of the International Legal Order

A significant contemporary challenge in international law is the fragmentation of its normative and institutional structure. International law does not operate as a single unified system; instead, it consists of multiple specialized regimes that develop independently, including international humanitarian law, human rights law, international trade law, environmental law, and international criminal law. While these regimes are interconnected, they often evolve through separate treaties, institutions, and interpretive frameworks.

Overlapping Legal Regimes

The coexistence of multiple legal regimes frequently results in overlapping jurisdiction and normative tension. A single factual situation may engage several areas of international law simultaneously. For example, a military operation may be governed by international humanitarian law while also implicating international human rights law and environmental protection norms.

This overlap can create interpretive uncertainty regarding which legal regime takes precedence in cases of conflict between norms. Courts and international tribunals often rely on principles of treaty interpretation, lex specialis, and systemic integration to resolve such tensions.

Normative Conflicts Between Legal Domains

Fragmentation is particularly evident where different branches of international law impose competing obligations. Security-related actions may conflict with human rights protections, while economic sanctions may raise concerns under international humanitarian principles.

For instance, counterterrorism measures adopted under Security Council resolutions may restrict individual rights, raising questions about proportionality and legality under human rights law. Similarly, environmental harm caused during armed conflict may engage both humanitarian and environmental legal regimes, which do not always provide harmonized standards.

Institutional Fragmentation

In addition to normative fragmentation, international law is also institutionally divided. Different legal regimes are governed by distinct organizations and adjudicatory bodies, such as the International Court of Justice, the International Criminal Court, the World Trade Organization dispute settlement system, and various human rights treaty bodies.

This institutional separation can lead to inconsistent interpretations of similar legal principles, particularly when different tribunals address related issues from within their own specialized mandates.

Legal Interpretation and Systemic Integration

International law attempts to manage fragmentation through interpretive techniques that promote coherence across regimes. One key approach is systemic integration, which interprets legal rules in light of broader international law principles.

Another important principle is lex specialis derogat legi generali, which provides that more specific legal norms prevail over general ones in cases of conflict. These interpretive tools aim to reduce inconsistency and maintain the unity of international law as a functional system.

Implications for Global Governance

While fragmentation introduces complexity, it does not necessarily weaken international law. Instead, it reflects the expansion and specialization of legal regulation in response to increasingly complex global issues. However, it does require greater coordination among institutions and clearer interpretive frameworks to ensure legal coherence.

Ultimately, fragmentation highlights the evolving nature of international law as a decentralized but interconnected system that must continuously adapt to new political, technological, and environmental realities.

Conclusion

International law, particularly in its regulation of conflict and diplomacy, represents a central pillar of contemporary global governance. Its primary function is to structure relations between states in a manner that limits violence, promotes cooperation, and provides legal mechanisms for the peaceful settlement of disputes. Although the international system lacks a centralized authority, international legal norms and institutions collectively create a framework that regulates state behavior and contributes to global stability.

The analysis demonstrates that international law operates through a combination of treaty-based obligations, customary international norms, judicial interpretation, and institutional enforcement mechanisms. Together, these elements establish a normative system that governs both the use of force and the conduct of diplomatic relations. Instruments such as the United Nations Charter, multilateral treaties, and international jurisprudence reinforce the legal commitment of states to peaceful coexistence and regulated interaction.

At the same time, the effectiveness of international law is constrained by structural and political limitations. Issues such as state sovereignty, power asymmetries, selective enforcement, and weak compliance mechanisms continue to limit the uniform application of legal norms. International institutions, including the United Nations and international courts, play a critical role in maintaining legal order; however, their authority often depends on political cooperation among states, particularly major powers.

Despite these challenges, international law remains a resilient and evolving system. Its adaptability is evident in its response to emerging issues such as cyber warfare, counterterrorism, hybrid conflicts, and environmental security concerns. The continuous development of legal norms reflects the capacity of the international legal system to respond to changing patterns of conflict and global interdependence.

In conclusion, international law functions as both a normative and operational framework that shapes international relations, even in the absence of absolute enforcement authority. Its long-term effectiveness depends on the interaction between legal structures, institutional capacity, and political will. Strengthening compliance mechanisms, enhancing institutional coordination, and reinforcing commitment to legal norms are essential for improving the role of international law in maintaining global peace and security.

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ASSESSMENT OF PEDESTRIAN THERMAL COMFORT IN POCKET PARKS: A CASE STUDY OF ERZURUM, TÜRKIYE

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ABSTRACT

Rapid population growth and accelerating urbanization processes increase pressure on natural ecosystems, making cities more vulnerable to the impacts of global warming. Accordingly, the urban heat island effect intensifies, altering microclimatic conditions and reducing thermal comfort levels in outdoor spaces. In addition, biodiversity loss and the widespread use of impermeable surfaces disrupt the environmental balance within urban areas. These challenges necessitate reconsidering public open spaces not only as social environments but also as systems that regulate microclimate and support ecological balance. In this context, the ecological design approach aims to enhance urban environmental resilience and user comfort through the integration of green infrastructure systems, the use of sustainable materials, and nature-based solutions.This study examines a low-density urban area surrounding Erzurum Garı in the Yakutiye district of Erzurum. The main objective is to develop ecological-based pedestrian pathway and pocket park design scenarios by considering the city's harsh continental climate conditions and projected climate risks. The study area covers approximately 773.81 m², and microclimatic data—including air temperature, relative humidity, and wind speed—were analyzed. Based on these data, Physiological Equivalent Temperature (PET) values were calculated to assess thermal comfort levels.The research was conducted in two stages: fieldwork and office-based analysis. Following site observations, Sky View Factor (SVF), Computational Fluid Dynamics (CFD), and ENVI-met 5.7.2 microclimate simulations were employed to evaluate the existing conditions and test alternative design scenarios. Based on the findings, solutions were developed to address key issues such as the urban heat island effect, insufficient shading, excessive impermeable surfaces, and limited green infrastructure.As a result, increasing vegetation density, enhancing shading capacity, and integrating water surfaces and water elements into the design are proposed to improve microclimatic conditions. The study is expected to contribute to sustainable and resilient urban design practices not only for Erzurum but also for other cities with similar climatic characteristics.

Keywords: Pocket Park, Microclimate, Ecological Design, Thermal Comfort, Green Infrastructure

INTRODUCTION

The global population has undergone a rapid urbanization trend, with over fifty percent of people today living in urban environments (Henderson & Turner, 2020; Sun et al., 2020).Urbanization and rapid industrialization processes have exerted pressure on natural ecosystems, making cities more vulnerable to environmental degradation (Bocquier, 2005). According to new estimates by the United Nations, the global population will continue to grow until 2084. The world population, currently exceeding 8 billion, is projected to reach 10.3 billion within 60 years. This biennial United Nations estimate is based on 2022 data (UN, 2024).

Rapid urbanization and the intensifying global climate crisis exacerbate the problem of overheating in urban areas, threatening the thermal safety and comfort of urban residents (Nazarian et al., 2022). Urban overheating has become a widespread environmental stress factor in densely built environments, where alterations to buildings and infrastructure modify airflow, temperature, and humidity distribution,

thereby reducing thermal comfort and negatively impacting the quality of life of urban dwellers (Yang et al., 2023).

The Urban Heat Island (UHI) effect is recognized as one of the most critical environmental phenomena reinforced by climate change in recent years and has been extensively researched (Arnfield, 2003; Bowler et al., 2010; Oke et al., 2017). Heatwaves, characterized by prolonged extreme temperatures at the regional scale, have become a major global concern due to global warming. Concurrently, urbanization leads to local climatic events such as the urban heat island effect, causing urban areas to experience higher temperatures compared to rural areas (Oke et al., 2017). The urban microclimate is a complex system resulting from the interaction between the natural environment, human activities, and man-made structures (Moonen et al., 2012). Urbanization directly affects regional microclimatic conditions by inducing significant changes in land use and energy balance (Oke et al., 2017; Wang et al., 2023). In recent years, the increasing interaction between heatwaves and the urban heat island effect has further degraded the urban thermal environment (He et al., 2021).

City parks are considered essential components of urban infrastructure (Zhou et al., 2022). Pocket parks, in particular, stand out due to their small scale, low cost, flexible design features, and high accessibility, contributing to addressing green space inequality in dense urban environments (Geng et al., 2024; Zeng et al., 2024). In this regard, pocket parks are recognized as an important tool for providing green space in high-density urban fabrics (Zhou vd., 2024).

Simulation tools used in urban microclimate analysis play a significant role in the design process. ENVI-met is a widely used tool focusing on urban microclimate simulations, particularly for evaluating the role of green spaces and high-albedo materials in mitigating the urban heat island effect (Crank et al., 2018). However, ENVI-met has limitations, such as high computational requirements and long processing times during iterative design processes. Furthermore, model accuracy depends on grid resolution, which may lead to a loss of precision in complex urban environments (Crank et al., 2018). Microclimate studies have seen a marked increase, especially in recent years. According to a comprehensive review by Roy et al. (2025), the number of high-resolution simulation and modeling studies focused on microclimate has increased nearly tenfold since 2010. Within these studies, Computational Fluid Dynamics (CFD) emerges as the dominant research approach, while the Urban Heat Island (UHI) effect and outdoor thermal comfort are among the most frequently investigated topics (Arnfield, 2003; Bowler et al., 2010; Oke et al., 2017; Roy et al., 2025).

METHODOLOGY

This study addresses the low-density urban area surrounding the Erzurum Train Station, located in the Yakutiye district of Erzurum Province (Figure 1). The main objective of the study is to develop ecology-based pedestrian walkway and pocket park design scenarios, taking into account Erzurum's harsh continental climate conditions and future climate risks. In the center of Erzurum, particularly around the Train Station, microclimatic conditions are degraded due to heavy vehicular traffic, extensive impervious surfaces, insufficient shading, and limited green cover. This situation reduces pedestrian comfort and exacerbates cold thermal stress, especially during winter months. By using microclimate-based design principles, this study aims to develop pedestrian-friendly sidewalk and pocket park designs around the Erzurum Train Station, evaluate the impact of these designs on thermal comfort using the ENVI-met 5.7.2 model and SVF (Sky View Factor) analyses, and present site-specific, applicable improvement strategies.

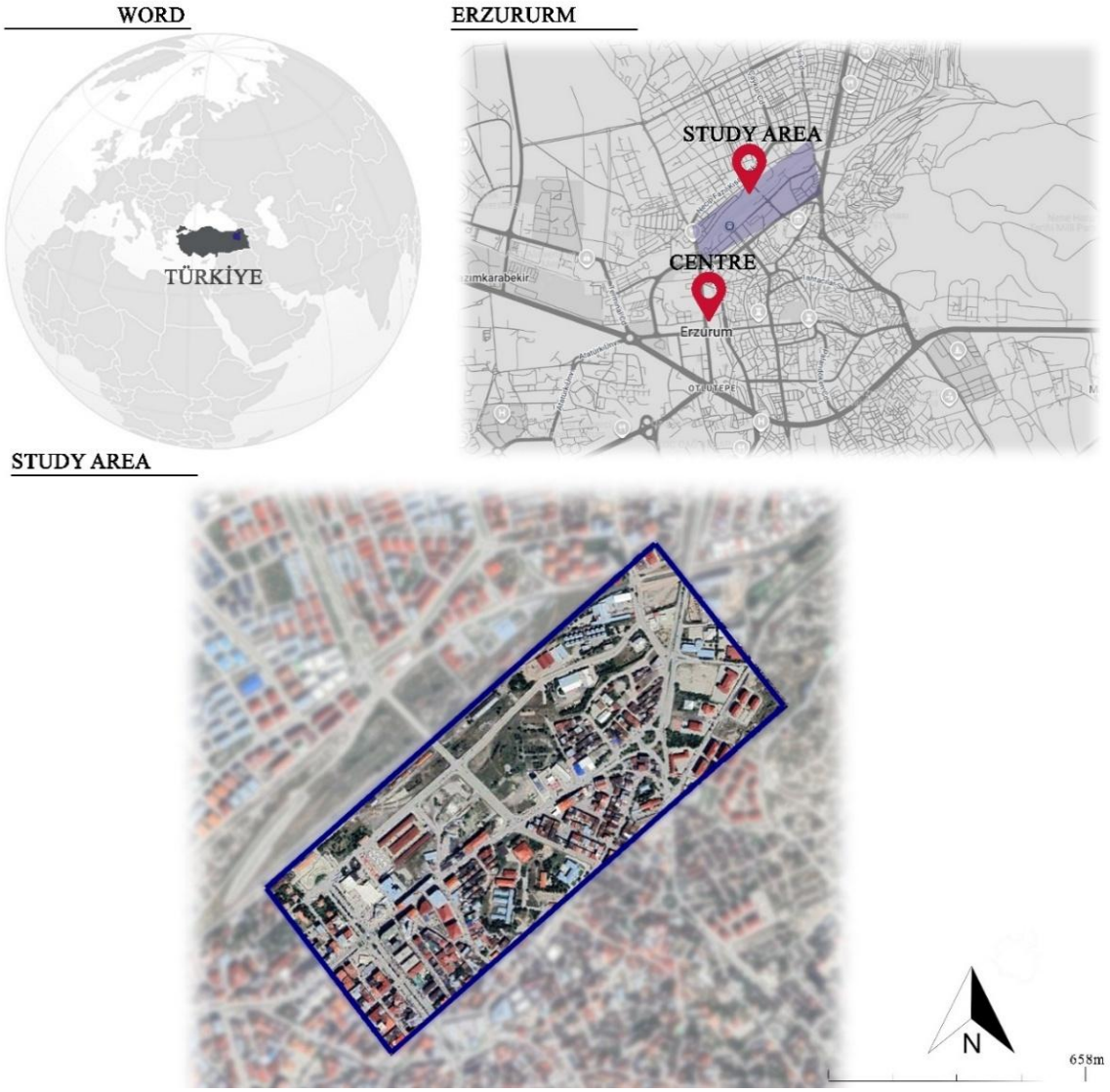


Figure 1. Location map of the study area: Erzurum Train Station

METHODOLOGY

The street passing in front of the Train Station building, located in the north of Erzurum city center, was selected as the study area. The Erzurum Train Station is situated on İstasyon Avenue in the Ömer Nasuhi Bilmen Neighborhood, Yakutiye District, Erzurum Province, Türkiye. The geographical coordinates of the station are approximately 39°54′56″ N and 41°16′07″ E. The study area covers an area of approximately 773.81 m² with a perimeter measuring roughly 3,889 m. The location of the study area is shown in Figure 2. Microclimate data for the study area were obtained from daily temperature, humidity, and wind measurements recorded at the meteorological station located in the garden of Erzurum Güneş High School, and were subsequently used to calculate Physiological Equivalent Temperature (PET) values.



Figure 2. Visuals of the study area

Field analyses of the study area, comprising the Erzurum Train Station and its immediate surroundings, are presented in Figure 3.

Heavy vehicular traffic originating from the primary axis, combined with extensive impervious surfaces (asphalt/concrete), insufficient shading, and limited green coverage, leads to microclimatic degradation in the area. Under the influence of severe continental climate conditions, the Erzurum Train Station and its immediate surroundings are exposed to hot thermal stress in summer and cold thermal stress in winter in terms of pedestrian use. By virtue of its location and environmental structure, the site holds strategic potential for enhancing thermal comfort through pedestrian-friendly sidewalk designs and pocket park interventions.

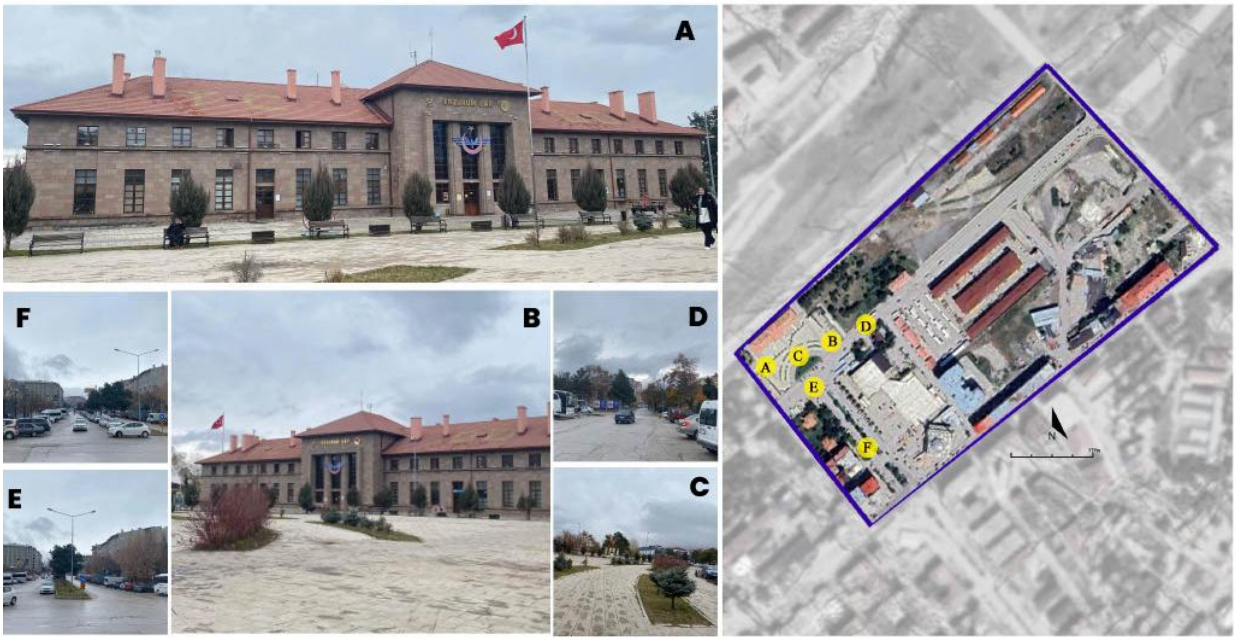


Figure 3. The main building of the Erzurum Train Station

(Figure a), the transportation axis located to the left of the station (Figure b), the landscape design and open space utilization within the station complex (Figure c), and the primary transportation artery situated opposite the station building (Figure d)

Pocket Park Planting Design Scenarios

A pocket park model incorporating a planting design scenario was developed to transform the road in front of the Erzurum Train Station into a pedestrian-friendly street. In the pocket parks designed along this street, tree density was increased by 10%, 20%, and 50%. The selected tree species primarily consist of species well-adapted to the urban environment and commonly grown in the city. The species used in the scenario analyses include *Ulmus glabra* (Wych Elm), Adi ny (*Betula pendula*), sarıçam (*Pinus sylvestris*), küçük yapraklı ıhlamur (*Tilia cordata*) ve akçaağaç (*Acer platanoides*) which are naturally occurring in Erzurum, exhibit high adaptation to the urban environment, and are compatible with the structural and ecological characteristics of the area (Yılmaz & Irmak, 2004). Indeed, literature indicates that different tree species reveal distinct variations in surface temperatures and that the Sky View Factor (SVF) plays a critical role in tree surface temperatures (Irmak et al., 2018).

In this study, ecology-based design scenarios were developed to improve microclimatic conditions and pedestrian thermal comfort in open public spaces around the Erzurum Train Station. The research is based on a multi-stage, quantitative methodology encompassing field observations, *in-situ* meteorological measurements, sky view factor (SVF) analysis, and integrated microclimate (ENVI-met) simulations to compute thermal comfort indices (PET). The software packages utilized in the analysis are detailed below, respectively.

Sky View Factor (SVF)

The Sky View Factor (SVF) value ranges between 0 and 1. An SVF of 1 indicates that the sky is fully unobstructed and there are no limitations to sky visibility from the camera location. However, as the SVF value approaches 0, the density of the surrounding cover that restricts visibility increases. SVF allows for understanding whether a specific point is influenced by solar energy and enables comparisons across different locations. Values vary between 0 and 1, where an SVF value of 1 signifies that the sky is completely visible from that given point (de Souza, 2007).

ENVI-met

ENVI-met is a modeling tool specifically designed to simulate and analyze urban microclimate dynamics, widely preferred in scientific studies globally (Bruse & Fleer, 1998; Banerjee et al., 2024; Yılmaz et al., 2025; Migliari et al., 2025; Roy et al., 2025). It sees extensive use in urban climate research for assessing local climate conditions and testing strategies to mitigate urban heat islands. Offering low computational costs along with a user-friendly and efficient structure, the software caters to users of varying expertise levels thanks to its intuitive graphical user interface and integrated pollutant dispersion module (Crank et al., 2018). Originally developed by Michael Bruse in 1998, ENVI-met is a fully integrated three-dimensional microclimate model (Bruse & Fleer, 1998). Its capacity to simulate complex surface-vegetation-atmosphere interactions within urban ecosystems brings it to the forefront of urban climate studies. One of the model's standout features is its comprehensive vegetation modeling capability (Simon, 2016). Within ENVI-met, vegetation is not merely treated as a passive, porous medium for wind flow and solar radiation; it actively interacts with the environment through evapotranspiration processes, directly shaping temperature, humidity, and airflow patterns (Morakinyo et al., 2017). The model excels in simulating critical microclimatic variables—such as airflow, temperature, and humidity—with high precision. Consequently, it provides a significant advantage in analyzing complex urban structures where buildings, green cover, and the heat island effect coexist (Ouyang et al., 2020).

ArcGIS

ArcGIS spatial analysis is a computational technique grounded in the geographical positions and morphological properties of spatial features. At its core, it involves processing, examining, and visualizing spatial data through digital tools and geospatial technologies. The foundation of spatial

analysis relies on geospatial databases that store, structure, and enable a range of operations, including geometric logic, statistical modeling, and algebraic computation. The primary objective is to extract, interpret, and convey spatial information—especially hidden spatial patterns—to support decision-making processes (Scott & Janikas, 2009; ESRI, 1996). Within the ArcGIS platform, spatial analysis can be applied to compute geometric attributes such as feature-to-feature distances, surface areas, and orientations. Additionally, it facilitates the evaluation of spatial relationships across various zones or features using techniques like overlay analysis, buffer analysis, and proximity modeling (ESRI, 1996).

RayMan

While RayMan permits the configuration of site location, building geometry, surface temperature, and sky view factor, it lacks options for integrating potential shading devices. This inability to account for the canopy's shading effect substantially diminishes the accuracy of the simulation outputs. To address this limitation, an empirical method was implemented wherein each material is treated as 'cloud cover.' In other words, any structural application designed for shading is considered equivalent to a sky with varying degrees of cloudiness, depending on the properties of the chosen shading material. This correlation hinges on an empirical framework developed in this study, which assumes that clouds reduce sky brightness as outlined by Suárez-García et al. (2020). Indeed, they established a metric represented by the Okta indicator to quantify this phenomenon, spanning from 0 Octas for a completely clear sky to 8 Octas for a fully overcast sky.

RESULTS AND DISCUSSION

Conducted around the Erzurum Train Station, this study highlights the transformative impact of microclimate regulations and ecological pocket park interventions on pedestrian thermal comfort in cities with severe continental climates. The high accessibility and flexible design features of small-scale open spaces and pocket parks (Geng et al., 2024; Zeng et al., 2024) create a microclimatic oasis effect within dense and impervious urban fabrics. The fact that even interventions made within a limited area provide cooling in the surrounding microclimate supports the view of "high climatic efficiency of small-scale interventions" advocated by Zhou et al. (2024).The temporal variation values of these parameters between 10:00 and 18:00 are presented in the table above (Table 1).In the study, the microclimatic characteristics and thermal comfort conditions of a 50x50 pocket park located around the Train Station were analyzed based on August, the hottest summer month of 2025. Within the scope of the research, the microclimate parameters and comfort indicators of the pocket park were structured under six different scenarios:

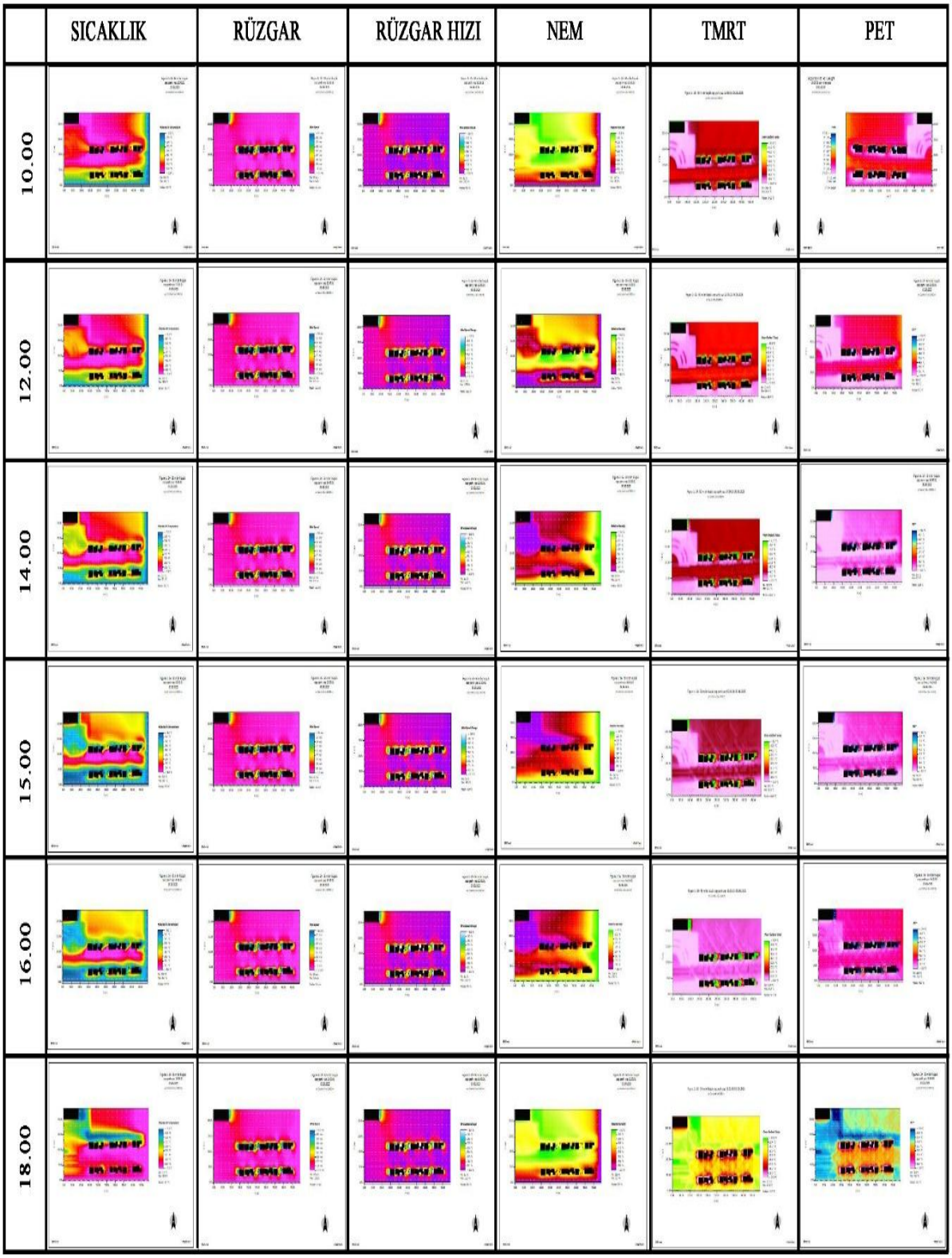
- Air Temperature (Ta= °C)
- Wind Speed Change (%)
- Wind Speed (V=m/s)
- Relative Humidity (RH=%)
- Mean Radiant Temperature (Tmrt)
- Physiological Equivalent Temperature (PET)

Air Temperature and Relative Humidity

Air temperature exhibited an upward trend throughout the day, reaching its highest average values at 14:00 and 15:00 (35.0 °C and 35.2 °C, respectively). The maximum air temperature was recorded as 37.1 °C at 14:00. In line with the increase in temperature, a pronounced decrease in relative humidity levels was observed; the average relative humidity, which was 33.5% at 10:00, declined during the hours of peak temperatures, dropping to its lowest level of 19.1% by 16:00.

Table 1. Microclimate analysis results for the pocket parks

Wind Speed



Wind speed values across the site remained remarkably low and stable throughout the day. Mean wind speeds varied between 1.0 and 1.1 m/s, while the maximum wind speed reached a peak of only 1.5 m/s during the day. Minimum values of 0.0 m/s indicate the presence of stagnant air pockets in certain parts of the area where air circulation ceased entirely.

Mean Radiant Temperature and Physiological Equivalent Temperature

Mean Radiant Temperature values, representing the load of direct and reflected radiation from surfaces, reached critical levels during hours when the solar elevation angle was steepest. Physiological Equivalent Temperature values, which define the perceived temperature and human thermal stress in the area, exhibited a trend parallel to. The highest average value of the day was recorded at 14:00 as 52.0 °C, with a maximum value reaching 60.2 °C. At 18:00, as the solar radiation angle declined, average dropped to 24.7 °C and average decreased to 31.8 °C.

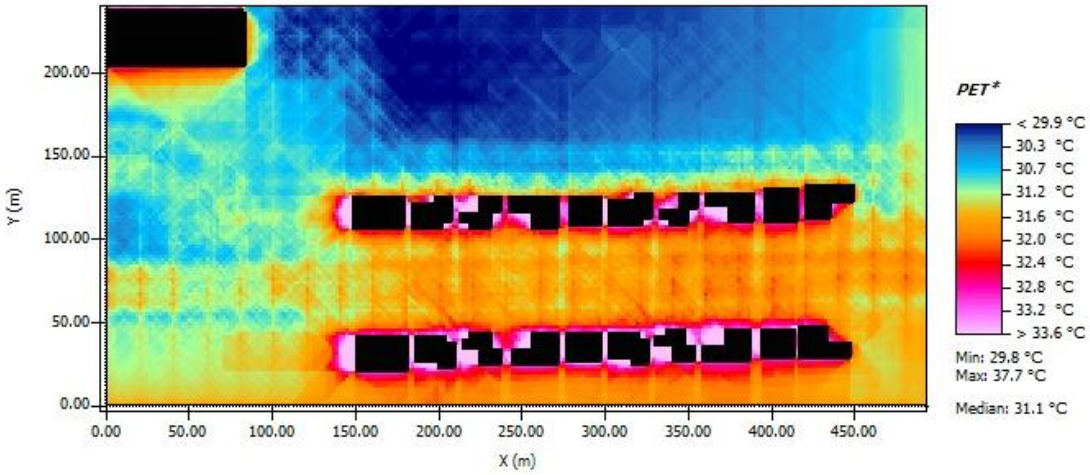


Figure 4. Medium-density tree analysis

Particularly during hot periods, the stabilizing and regulatory effect of green spaces on microclimate is remarkable (Table 2). Coupled with ecological functions such as shading, solar radiation reflectance, and moisture generation through evapotranspiration, this effect yields highly positive outcomes for outdoor thermal comfort during summer (Irmak et al., 2020). Indeed, the results obtained from Figure 4, which presents the Medium Tree Density data, clearly demonstrate that nature-based solutions—such as strategically positioned dense greenery and supporting green roofs—serve as potent strategies for alleviating urban heat island intensity and enhancing outdoor thermal comfort (measured through PET values) in semi-arid urban environments (Yuca et al., 2025).

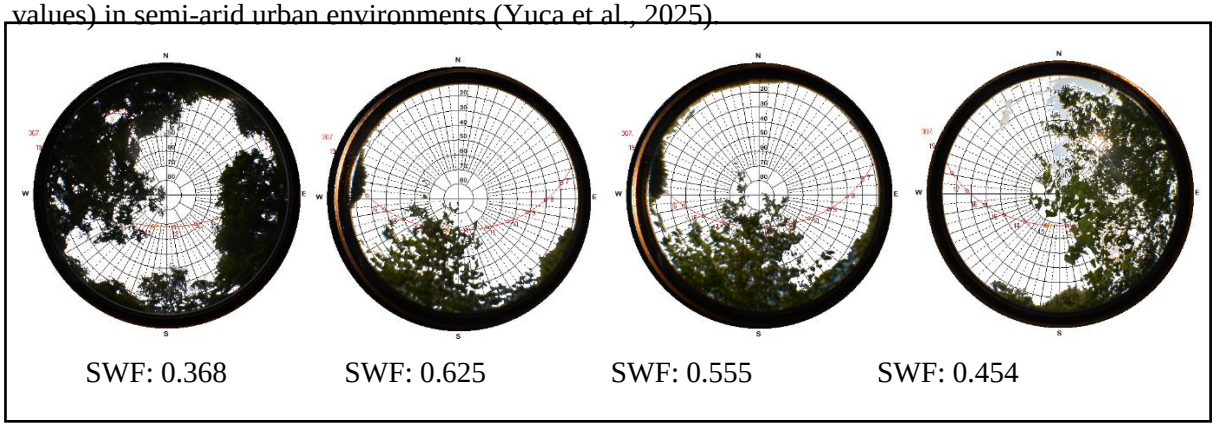


Figure 5. SVF images captured from the field

Table 2. Microclimate analysis of 50 x 50 m pocket park design scenarios for the summer season

		Air Temperature C º			Wind Speed m/s			Wind Speed Change %			Relative Humidity %			PET C º			Tmrt C º		
	Time	Min.	Max.	Mean	Min.	Max.	Mean	Min.	Max.	Mean	Min.	Max.	Mean	Min.	Max.	Mean	Min.	Max.	Mean
KÜÇÜK CEP PARK-YAZ	10.00	27.3	34.0	31.3	0.0	1.4	1.0	0.1	126.3	91.6	28.7	44.3	33.5	31.7	58.9	47.7	28.4	82.4	64.2
	12.00	30.3	35.9	33.4	0.0	1.5	1.1	0.1	117.8	85.1	26.0	37.7	29.9	35.8	59.5	50.2	33.6	84.4	66.5
	14.00	33.1	37.1	35.0	0.0	1.4	1.1	0.1	116.5	85.2	21.9	27.2	24.6	36.1	60.2	52.0	32.8	92.3	68.5
	15.00	33.6	36.8	35.2	0.0	1.4	1.1	0.1	116.1	85.3	17.3	22.2	20.3	35.8	60.0	50.8	32.1	92.8	66.4
	16.00	33.5	36.0	34.7	0.0	1.4	1.1	0.1	116.1	85.4	16.9	20.8	19.1	35.4	59.3	48.3	31.6	85.3	61.9
	18.00	31.2	32.9	32.3	0.0	1.5	1.1	0.1	115.9	84.7	16.7	22.1	20.0	30.4	40.2	31.8	22.3	40.8	24.7

The temporal variation of microclimatic parameters (Air Temperature, Wind Speed, Relative Humidity) and thermal comfort indicators in the study area between 10:00 and 18:00 is presented in Table 2.

Air Temperature and Relative Humidity :Air temperature exhibited an upward trend throughout the day, reaching its highest average values at 14:00 and 15:00 (35.0 °C and 35.2 °C, respectively). The maximum air temperature was recorded as 37.1 °C at 14:00. In line with the increase in temperature, a pronounced decrease in relative humidity levels was observed; the average relative humidity, which was 33.5% at 10:00, declined during the hours of peak temperatures, dropping to its lowest level of 19.1% by 16:00.

Wind Speed :Wind speed values across the site remained remarkably low and stable throughout the day. Mean wind speeds varied between 1.0 and 1.1 m/s, while the maximum wind speed reached a peak of only 1.5 m/s during the day. Minimum values of 0.0 m/s indicate the presence of stagnant air pockets in certain parts of the area where air circulation ceased entirely.

Mean Radiant Temperature and Physiological Equivalent Temperature :Mean Radiant Temperature values, representing the load of direct and reflected radiation from surfaces, reached critical levels during hours when the solar elevation angle was steepest. At 14:00 and 15:00, average values were calculated as 68.5 °C and 66.4 °C, respectively, while maximum peaked at 92.8 °C at both 14:00 and 15:00. Physiological Equivalent Temperature values, which define the perceived temperature and human thermal stress in the area, exhibited a trend parallel to. The highest average value of the day was recorded at 14:00 as 52.0 °C, with a maximum value reaching 60.2 °C. At 18:00, as the solar radiation angle declined, average dropped to 24.7 °C and average decreased to 31.8 °C.

CONCLUSION

The ENVI-met analyses revealed that increasing tree density in pocket parks along pedestrian-oriented street designs with ongoing vehicular traffic significantly affects microclimatic conditions. A comparison of scenarios with 10%, 20%, and 50% tree densities demonstrated that the 20% tree density

scenario yielded positive results in terms of temperature reduction and enhanced shading capacity. Furthermore, while an increase in tree quantity enhanced shading capacity, overly dense vegetation restricted wind movement, thereby reducing air circulation. Particularly under high tree density, the blockage of wind led to heat accumulation within the site and a subsequent increase in air temperature. This finding highlights that improving thermal comfort relies not merely on increasing tree quantity, but also on the balanced planning of plant density and spatial distribution within the area. Consequently, incorporating trees into pocket parks is evaluated as an appropriate design strategy for providing adequate shading, reducing direct solar radiation on surfaces, and improving pedestrian-level thermal conditions during the summer season. The study offers a data- and simulation-based approach for developing climate-responsive, sustainable, and thermal comfort-enhancing designs in urban streets that accommodate both vehicular and pedestrian usage.

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ICT TOOLS AND E-COMMERCE AS AGENTS OF NIGERIA'S ECONOMIC DEVELOPMENT

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ABSTRACT

Role of ICT in E-Commerce Business developing are inseparable terms as the e-commerce industry is absolutely dependent on ICT and e-commerce for its operations and intensification. E-commerce is referred to as application of ICT in business and E- commerce. ICT is term which involves usage of computers, including hardware, software, application and networks used to communicate, store and cover the requisite information. The concept of e–Business has been evolving since a number of years and is causative to the economic growth of several developing economies. The approaching for the growth of e-commerce in the developing countries is very high but ICT being the precondition, lack of ICT infrastructure hampers the rate of its growth. The growth of e- commerce is primarily dependent upon the boost in ICT infrastructure. The Smart mobile phone market and Internet diffusion has proved to be a catalyst for growth of ecommerce industry. This paper focus to discuss the role of ICT and e-commerce its services in driving ecommerce industry in developing countries like India and the shift from e-commerce to commerce in large scale in the near future.

Keywords: ICT; e-commerce; m-commerce, E- Business

Introduction

The invention of computers gave birth to Information and Communication Technology (ICT) which in turn has immensely altered the mode of human interaction by providing portable and faster means of communication in recent times. The applications of ICT in business transactions today have changed the world into a global marketplace via the use of e-commerce technologies. The rapid increase in the growth and applications of ICT in businesses today have caused a lot of enterprises in Nigeria to adopt e-commerce in their business operations so as to meet their customers' urgent need for modern technologies and innovations.

Agwu, M. E., & Murray, J. P. (2014), disclosed that Nigeria has experienced considerable level of progress and development in the ICT sector within the first decade of the 21st century; this is mainly due to the large number of ICT-related infrastructural development recorded in the country between the years 2000 and 2009. Despite the perceived level of progress in Nigeria's ICT sector, Nigeria is still lagging behind in terms of digital development when compared to its competing economy emerging countries of the world. Ahmed, L., & Richard, C. O. (2015). revealed that Information and communication technologies (ICTs) proved to be one of the factors that necessitated the speedy growth of e-Commerce transactions in today's global economy; it has influenced organizations, businesses and purchasers otherwise known as e-consumers positively in our society. Electronic commerce or e-Commerce is highly favored due to its global market accessibility as well as its compatible application in all types of businesses. The increasing global rate of online business transactions with the associated

innovative attitude of the customers has forced organizations to adopt e-Commerce to become a vital component of their businesses.

Alain, D., & Jean-Marc, K. (2015), have shown that the history of electronic commerce dates back to the late twentieth century. According to e-commerce was successfully employed for selling and buying products online for the first time in the year 1994, with the on-line sale of Ten Summoner's Tales, Sting's fourth album. After a period of twenty years from the time, it was first introduced, e-commerce has spread all over the world, and it has an estimated global value of $1500 billion in the year 2014. Despite all the contributions of e-commerce to the global economic development, the Middle East and African regions were reported to be in the marginal position of e-commerce development compared to other regions of the world.

Alireza, G., Ebrahim, F., & Lachin, H. (2011), defined e-commerce as the exchange of goods and services, usually conducted over computer networks by different methods and processes that were designed purposely for placing and accepting orders from customers. The products and services must be ordered online by those methods, but the options for payment and delivery of the goods and services are not necessarily conducted online. in their research defines e-commerce as the buying and selling of goods and services over the Internet; based on their research, those who engage in the transaction of buying and selling of goods and services over the Internet are called "electronic consumers" or e-consumers for short.

Chris, A. (2012), argued that e-commerce encompasses the collections of online business transactions which has to do with the exchange of products and services between producers and consumers of such products and services mainly over Internet. It also involves the sharing of business information electronically and the digital processing of such business information by using the modern technology in order to enhance the satisfaction of both parties involved in the transaction; in e-commerce, the parties involved in the business transaction interact electronically in a virtual market place rather than by direct physical contact.

The use of Internet to conduct online business transactions today has now been established as a strong marketing strategy that drives e-commerce which has been recognized worldwide as a mechanism that empower business organization to compete in the global markets based on the facts that marketers use the Internet to gather data for marketing survey and planning.

Danish, M. K., Farmeena, K., & Ehmer, M. K. (2014), exposed that Nigeria has the highest rate of Internet connectivity in Africa, recording over 56 million Internet users in the year 2013. This high rate of Internet penetration in Nigeria has motivated a reasonable number of business organizations to compete with other businesses from different regions of the world within the virtual market place and the online business environment with much support from the over 56 million Internet subscribers in the country.

Literature Review

The e-commerce remains the most prominent application of information technology (IT) that has revolutionized the global economies in recent years; it is clearly associated with all the processes that directly or indirectly involves the buying, selling and exchange of goods and services by means of computer networks and the Internet. Electronic commerce has found much application in the banking industry most especially in the area of e- banking in recent times.

According to Stephen, A.O. and Ailemen O.I (2012), disclosed that e-banking denote the process of carrying out banking transactions such as payment of bills, fund transfer and withdrawal of cash using Automated Teller Machine (ATM) as some of the prominent contribution of e-commerce in the global economy most especially in Nigeria.

Mohammed, M. R (2009), emphasized that e-banking encompasses the different types of banking operations, transactions and activities conducted over the Internet through the help of electronic network of computers; it stands as the major delivery platform of all the banking services that is widely applied in both the Business-to Business and Business-to-Consumer e-commerce transactions in recent times.

Morufu, O. and Taibat (2012), suggested that bankers in Nigeria regard electronic banking as a necessary mechanism that helps to reduce the level of inconveniences encountered during banking transactions; it also minimizes transaction costs as well as enhancing customers banking experience by reducing the amount of time needed for customers to carry out transaction in Nigerian banks.

Ayo C.K, Adewoya J.O, and Oni, A.A (2011), seen e-commerce as another opportunity for economic growth and development offered by the adoption of e-commerce in the banking industry in Nigeria; because the quality of financial service delivery in Nigerian banking sector was very poor before the introduction of electronic banking in the country in the 1990s which was primarily driven by the new generation. This was a deliberate attempt to address the challenges associated with the manual processing of transactions that forced customers to spend many hours queuing up in the banking hall before they can carry out transactions either to deposit money into their accounts, withdraw money from their accounts or pay their bills.

According to Gabriel, J.M.O etal (2011), improvement in information and communication technologies and Internet services have completely changed the way and manner of conducting business transactions through the introduction of new and smatter ways of conducting business operations known as online shopping. The concept of online shopping is another aspect of e-commerce that has experienced a rapid growth in Nigeria recently; it is simply the type of shopping in which consumers visit an online store, portal or website solely to order for or buy a product online.

Ahmed, L and Richard, C.O (2015), in their studies posited that the adoption, practice and proper utilization of e-commerce and Internet in businesses can led to an appreciated level of economic growth and development, one notable feature of the Internet is its vast ability of bringing different people from different parts of the world together into a global electronic market place known with other names such as online stores or virtual market place. The timely delivery and processing of consumers' order for products from an online store is consider to have a positive influence on the economies of developing countries like Nigeria.

Ai – somali, S.A (2011), In his research opined that Internet and the World Wide Web (WWW) or web for short are the two products of technological innovations that propelled many organizations to conduct transactions, exchange information, and to work jointly with others across the different geographical territories of the world and across computing platforms that are connected in a network of computers. The Internet and its accompanying technology is a vital tool that ensures continuity, growth and success of businesses in today's competitive business environment. The importance of e-commerce cannot be overemphasized because it has affected the ways and manners through which business transactions were carry out today.

Anthony, I etal (2014), revealed that after many years of investigation on electronic commerce, it was found to have affected virtually every business in a positive way for example, the online booksellers and music stores and other online businesses like Amazon, Barnes and Noble, Borders, and e-Bay just to mention few were connected to a significant consumer segment due to their online presence in an e-commerce market place.

CONCEPTUAL FRAMEWORK

Types of E-Commerce

There are four major types of e-commerce to be discuss in this paper and all its associated e-commerce models were adapted from. The following are the four types of e-commerce discuss in this paper:

Business-to-Business (B2B): This type of e-commerce has to do with the use of Internet to bring about modern supply-chain operations such as electronic data interchange and electronic funds transfer between two or more business organizations; it also involves companies that engage on a business deal with each other such as producers and manufacturers selling to distributors, and wholesalers selling in bulk to unit retailers. The Business –to- Business model of e-commerce is shown in Figure 1 below.

Business-to-Consumer (B2C): This type of e-Commerce involves transactions between a business organization and its target consumer thereby creating an electronic medium that allows instant transfer

of messages and information. It also enables the sharing of goods and services between business organizations and final consumers in a retailing transaction; it can be regarded as an e-commerce model that involves the selling and buying of goods and services between businesses and consumers over the Internet. It also involves direct selling of products from businesses to their substantive consumers. A typical example of Business-to-Consumer e-commerce model in Nigeria is Jumia. The Business to Consumer model of e-commerce is show in Figure 2 below.

Consumer-to-Business (C2B): This model of e-commerce is characterized by consumers of products and services advertising online what price they are ready to pay for a given service, product or loan while the business organizations involved in such business responds accordingly, this type of e-commerce enables both business owners and consumers of products and services to have a neutral meeting ground where prices of goods and services are negotiated and also the provision of platforms for such commercial transactions to take place. The Consumer to Business model of e-commerce is show in Figure 3 below.

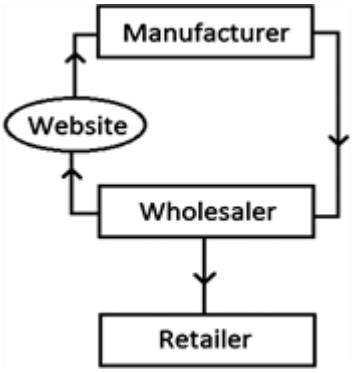

Figure 1. The e-commerce Business to Business model (Source: https://www.csetutor.com).

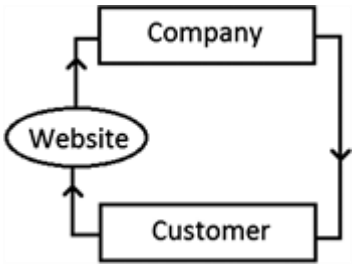

Figure 2. The e-commerce Business to Consumer model (Source: https://www.csetutor.com).

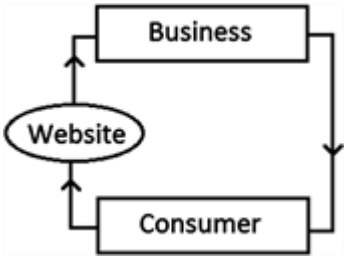

Figure 3. The e-commerce Consumer to Business model (Source: https://www.csetutor.com).

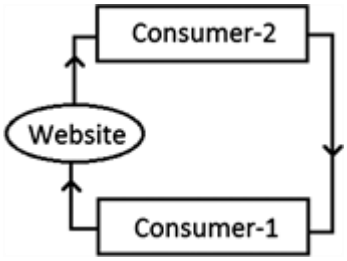

Figure 4. The e-commerce Consumer-to-Consumer model (Source: https://www.csetutor.com).

Consumer-to-Consumer (C2C): this refers to the type of e-commerce in which consumers interact and carry out a direct business transaction with other consumers in a virtual market place known as cyberspace. Agwu,M.E and Murrary, J.P. (2014), the Consumer to Consumer model of e-commerce is shown in Figure 4.

Contributions of e-Commerce in Nigeria's Economic Growth.

The inclusion and adoption of ICT services and Internet Technology for e-commerce in business organizations in Nigeria presents the following as major contributions of e-commerce to Nigeria's economic growth and development:

1. Improvement in the current channels of payment in the Nigeria's Banking industry: The Nigerian Banking sector has shown a remarkable level of improvement in the quality of their service delivery most especially in terms of making payments to customers today. The e-commerce technology has brought about the emergence of various E-Payment systems which make use of other alternatives to cash like debit cards, credit cards, electronic funds transfer, Internet banking and e-payment systems. Presently, buyers and sellers can pay and receive money from other means apart from raw cash; such monetary payments can be achieved using e-payment systems, the Automated Teller Machine (ATM), Internet or online transaction, Point of Sale terminals (POS), Mobile money solutions are good examples of the e-payment systems that have helped to improve the quality of payments in the Nigerian banking sector.

2. **It Serves as a link that Connects Customers, Workers, Suppliers, Distributors and Competitors in a Business Environment:** A.I and Mohammed, A. (2015), stressed that the adoption of e-Commerce helps in networking the various business organizations together there by enabling small business organizations to depend on other business organizations otherwise known as "partners" for supplies, product distribution and to meet customer demands for products and services more effectively through the implementation of a very functional e-commerce supply chain management solution.

3. Facilitates 24/7 Operation of Businesses: Business organizations that adopt E-commerce in their business set up can sell their products either in the night or during the day time, business transactions can be carried out for 365 days a year. Even while business owners have closed for the day to rest, their potential customers can visit the business online store or web site to search for goods and services and to place their orders.

4. Promotes the Development of Local Online stores in Nigeria: Many Nigerian companies and business ventures were engaged in active global market competition through the development of universal business portals and online store that they use to advertise their products and services to their target consumers and buyers. Typical examples of indigenous Nigerian business organizations that have achieved a remarkable success in online business transactions include Jumia, Konga and Jiji; these Nigerian owned business ventures were engaged in active global economic competition through their universal accessibility and online presence.

5. Creation of jobs and Employment opportunities: According to Kazeem, O.O. and Kate, D. (2015), in their study on "Roles of E-Service in Nigeria's Economic Development" The creation of jobs through ICT driven platforms which is the backbone of e-commerce in Nigeria has experienced a significant improvement whose Capacity building in recent times has generated huge revenue for the government each year.

6. Help in the Removal of Fraudulent Payees from the Government Payroll: Reports by e-transform Africa in the year 2012 on ICT Competitiveness reveals that in the year 2008, the Federal government of Nigerian in collaboration with the World Bank had successfully implemented an Integrated Personnel and Payroll Information System (IPPIS) which was aimed at reducing fraud and increasing the level of accountability in payroll administration and human resource management records in the country. It was reported that an estimated 12 billion naira (US$120 Million) were saved by the technological implementation solely in the pilot phase; this is achieved through the elimination of "ghost workers or fraudulent payees on the payroll" It can be seen that the adoption of modern technology like the

Integrated Personnel and Payroll Information System (IPPIS) helps a lot in removing fraudulent payees from the Government payroll in Nigeria.

E-Commerce Development in Nigeria

The use of Internet to operate business transactions has gain more impetus in the country and it is practice widely within the more commercially concentrated states of the nation. A lot of new business ventures also known as "business startups" have been observed springing up within the virtual market place and cyber space where the primary target of each one of them is the over 40 million Internet subscribers in the country.

Jumia and Konga were report as the "Beasts" or the leaders of e-Commerce in Nigeria as both of the business organizations have shown commitment towards the use of e-commerce technology in their business transactions. Ayo, C.K, Adewoye, J.O and Oni, A.A (2011) in their research, examined the series of changes that reflect the growth rate of Internet subscribers in Nigeria from year 2000 to 2010.

The result of their studies revealed that the total number of Internet users in Nigeria as at 2000 were 200,000 representing less than 1% of Nigeria's national population; precisely 0.1% of the country's population have access to Internet, this figure rose sharply to over 40 million precisely 43,982,200 in June 2010 which represent 29.5% of the country's population.

The continuous growth of the number of Internet users in Nigeria from 0.1% in 2000 to 29.5% of its population in June 2010 is a strong determinant for Nigeria's engagement in e-commerce.

Table 1 below presents the total number of internet subscribers in Nigeria over the past twenty years and according to Ayo, C.K, Adewoye, J.O and Oni, A.A (2011), the total number of internet users in Nigeria rises from 200,000 in the year 2000 to 1.7 million in 2004 which increases to 30.8 million in 2009; it also jumps to 76.4 million in 2014 and stood at over 126 million subscribers as at 31st December 2019 all these figures are shown in Table 1 below.

According to the 2018 report on business to consumer (B2C) e-commerce index by Javier, E, etal (2012), about 151 countries were rank globally, including 44 African nations by measuring their readiness for online shopping. The index is based on four key indicators:

1. Bank or mobile money account penetration;

2. Internet usage;

3. Availability of internet servers and

4. The reliability of postal services.

Out of the 44 African countries, Mauritius occupies the first position being the highest ranked while Nigeria the Africa's largest e-commerce market by number of shoppers and revenue is the second ranked African nation closely followed by South Africa. Table 2 below presents the top ten African countries based on their e-commerce readiness index with their associated global e-commerce ranking.

Factors Challenging the Growth of e-Commerce in Nigeria

There are numerous factors that challenge the growth of e-commerce in Nigeria thereby adversely affecting Nigeria's economic growth; these barriers include:

High Cost of Acquiring Relevant ICT Facilities and Skills: Recent research by some scholars has found that the high cost of acquiring the computer systems, ICT equipment, Internet access cost, cost of personnel training, network installation and maintenance cost and the cost of implementing new technologies such as e-commerce site and its security have thwarted the growth of e-commerce in Nigeria's economy. The low level of broadband penetration and lack of Internet access among the rural dwellers in Nigeria as a result.

Year	Number of internet users	sources of data
2000	200.000	https://www.csetutor.com
2004	1,749,576	
2009	30,897,614	
2014	76,492,866	
2019	126,078,999	

Table 1. Total number of internet users in Nigeria within the distance of five years over the past twenty years from 2000-2019.

Rank in Africa	Country	Global Ranks
1	Mauritius	55
2	Nigeria	75
3	South Africa	77
4	Tunisia	79
5	Morocco	81
6	Ghana	85
7	Kenya	89
8	Uganda	99
9	Botswanna	100
10	Cameroon	101

Table 2. Top ten African countries ranked by e-commerce readiness index as at December 2018 (Source:https://www.csetutor.com) of the high cost involved in acquiring such facilities has impeded the growth of e-commerce in Nigeria. Additionally, Internet access is not readily accessible to most users in the developing countries because of its high cost.

2. Socio-cultural barriers: The situation of socio-cultural barriers to e-commerce in the developing countries enunciated by McKinsey posit Al Somali, S.A (2011) holds true in Nigeria that the preference for personal face-to-face communications rather than the electronic versions of communication like e-mails followed by a strong affinity for established physical business relationships instead of the inter-personal Internet enabled business relationship proves to be a strong enemy of the growth and development of e-commerce in the economies of third world countries. Obi, C.A. (20215) opined that it may not be acceptable to deliver physical goods to women when they are alone at home in some parts of the country particularly Northern Nigeria; even if such goods were ordered from an e-commerce online store, the e-commerce delivery agent must have to wait for the presence of another person before such delivery can be made and this factor is believed to have crippled the growth of e-commerce in Nigeria.

3. Security and legal Issues: The low level of ICT and computer literacy as well as general lack of understanding regarding the operations of the Internet was clearly spelt out by Lawal, M.M and Khadija, A. (2012) as another factor that exposes consumers in e-commerce to different risks; this factor tends to deter e-consumers from active participation in e-commerce transactions thereby crippling the growth of e-commerce in Nigeria. According to Leonard, C.O (2014) despite the good intentions of the Central Bank of Nigeria by introducing the cash-less economy policy which is aimed at promoting the economic growth of the country through financial inclusion, revenue leakage minimization, reduction in the level of robbery and also reduction in the amount of cash payment in favor of electronic payments. The emergence of security challenges such as cybercrime and related electronic fraudulent practices in financial institutions that operates within the country renders the effort of the Central Bank of Nigeria, CBN's cashless transformation project useless. Researches by Al Somali, S.A (2011) suggested that the lack of a functional legal framework and proper policies that can address the problems of the validity of electronic transactions in an online business is a strong factor that inhibits the growth of electronic commerce in the economies of the developing countries.

4. Cognitive Barriers: Recent researches have shown that business owners and enterprises were restricted from making use of the Internet technologies to carry out business transactions in the

developing countries due to the way in which their customers behaves by demonstrating a very strong unwillingness to use the Internet for online business transactions and also because of the lack of commitment of the top management in using the technology. Additionally, there is a perceived lack of trust on the part of prospective customers in an e-commerce market space due to fear of cyber-crime; these issues mentioned above constitute the strongest hindrance to the adoption of Business-to-Consumer (B2C) e-commerce in Nigeria today.

5. Logistic and Delivery Barriers: The concept of logistic and delivery in e-commerce involves the transportation and delivery of the ordered goods to their consumers. The authors Franco, C.E and Bulomine, R.S (2016) argued that logistics and courier services needed a lot of improvement in India, owing to the fact that an effective logistic service is ideal for the success of all online retailers. India was reported to be lagging behind in this sector; this problem of lack of effective logistic and delivery services is also peculiar to Nigeria, other problems of logistic and delivery that negatively affect e-commerce in Nigeria are the delay in delivering the products, loss of product during delivery and delivery of products to wrong individuals.

6. Poor electricity supply: Poor electricity supply is also one of the factors that inhibit the growth of electronic commerce in Nigeria. According to Kuliva, M. (2015), indicated that 97% of Nigerian firms and business organizations experience power outages of one form or the other.

Andrew, A.U and Erezi, B.U (2014), in their research opined that the nature of electricity supply in Nigeria is very epileptic and it proves to be one of the greatest challenges that confronts the Nigeria's business sector; E-marketing, E-commerce or E-business can never be practice effectively without regular power supply therefore many business set ups were forced out of the E-commerce market place as a result of poor electricity supply.

Recommendations

In order to harness the power of the innovations in ICT and implement an effective, reliable and responsive e-commerce system in Nigeria, this paper wish to recommend the following measures which Nigerian government and business organizations should adopt as follows:

1. Nigerian government should in addition to the ICT policy formulations such as the introduction of computer studies in Nigerian education sector introduce e-commerce into the national curriculums. This will discourage the cognitive factor as a barrier that Challenges the Growth of e-commerce in Nigeria and will promote the e-commerce readiness in the country.

2. Nigerian government should ensure that ICT services and electricity supplies are available, accessible and affordable to all Ministries, Departments and Agencies (MDAs), business organizations and her citizens

3. The Federal government of Nigeria through the ministry of communications and digital economy should ensure that secured Internet data connectivity should be made available to Nigerian citizens residing in the urban and rural areas at a lower cost as it stands to address the security challenges affecting the progress of e-commerce in Nigeria.

4. One of the hindrances to the successful implementation of e-commerce project in Nigeria is the low rate of ICT literacy or Skills which can be addressed by embarking on formal and informal ICT training for all Nigerian citizens.

Conclusion and Discussion

Today, e-commerce has affected the global economy in numerous ways primarily due to its vast possibility for strengthening economic growth and business expansion worldwide. It can be concluded that both the existing business set ups and start-up entrepreneurs in Nigeria can only be engaged in a healthy business competition with their contemporaries in other countries of the world if they would integrate e-commerce technologies into their business transactions. For a developing country like Nigeria to exploit the benefits of e-commerce in her economy, the factors challenging the growth of e-

commerce such as the high cost of acquiring relevant ICT facilities and skills, socio-cultural barriers, security and legal issues etc. discussed in this paper need to be addressed by the Nigerian Government.

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IDENTIFYING ADMINISTRATIVE PROBLEMS USING PROBLEM-SOLVING TECHNIQUES AND THEIR ROLE IN DECISION-MAKING FOR CONTINUOUS IMPROVEMENT AND DEVELOPMENT: ANAPPLIED STUDY ON THE PROPERTY INVESTMENT DEPARTMENT OF GREATER AMMAN MUNICIPALITY

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ABSTRACT

This study aims to highlight the role of modern administrative problem-solving techniques—such as the Cause-and-Effect Diagram, the 5 Whys methodology, and Pareto Analysis—in identifying and diagnosing operational and administrative challenges within the organizational environment. It further examines how this diagnostic clarity enhances leadership capacity to make sound decisions oriented toward continuous improvement and institutional development. Focusing on the Property Investment Department at the Greater Amman Municipality, the paper investigates practical mechanisms for diagnosing challenges related to real estate valuation, investment contract management, and the optimization of municipal assets to protect public funds. Utilizing a descriptive-analytical approach, the study analyzes field data and procedural decision-making workflows. The findings demonstrate that relying on structured problem-solving methodologies directly supports evidence-based decision-making, mitigates financial and legal risks, and streamlines administrative processes, thereby driving organizational performance and maximizing investment returns. The study concludes with an applied framework linking systematic problem diagnosis to sustainable, decision-driven development

Keywords: Problem Identification, Problem-Solving Techniques, Decision-Making, Continuous Improvement, Property Investment, Greater Amman Municipality.

HOUSEHOLD EXPENDITURE AND REGIONAL ECONOMIC WELFARE: EVIDENCE FROM WEST JAVA, INDONESIA

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ABSTRACT

This study examines differences in household expenditure across cities and regencies in West Java, Indonesia, to provide evidence on regional economic welfare. Household expenditure is employed as a proxy for welfare because it reflects purchasing power and living standards more comprehensively than income alone. The study uses secondary data from 27 cities and regencies in West Java covering the period 2019–2024, resulting in 162 observations. Descriptive statistical analysis is conducted to compare household expenditure by gender and regional classification, focusing on average expenditure, variability, and distributional characteristics. The results indicate consistent disparities in household expenditure between cities and regencies. Average expenditure is higher in cities for both men and women, with the difference being substantially larger among women. In addition, expenditure variability is greater in cities, suggesting wider differences in household purchasing power and economic conditions. These findings indicate that household welfare remains uneven across regional classifications despite sustained economic development. This study contributes to the regional economics literature by demonstrating how household expenditure can be used as an empirical indicator of regional economic welfare. The findings also provide evidence that can support fiscal planning, targeted social assistance, and resource allocation aimed at reducing regional welfare disparities.

Keywords: household expenditure; economic welfare; regional inequality; gender; regional development; Indonesia

Introduction

Household expenditure is widely recognized as one of the most reliable indicators of economic welfare and living standards. Household expenditure is an explicit indicator of individual and community-wide social welfare levels (Paulus Luciany et al., 2024). Consumption expenditure serves as a foundational index for assessing household welfare because it smooths out the severe temporal and seasonal fluctuations typical of raw income reporting (Robert Alex, 2023). Household consumption also

constitutes the largest component of aggregate demand in many developing economies, making it an important driver of economic growth and macroeconomic stability. Private household spending represents the single largest component of aggregate demand, routinely eclipsing government spending, exports, and investments (Karimah et al., 2025). The highest structural share of aggregate demand, making up between 55% to 70% of gross domestic product (GDP) globally. It explicitly tracks how rising consumption in developing regions acts as a primary macroeconomic driver, incentivizing private investment and expanding formal market operations (Enenmoh & Iortyer, 2026). Understanding how household expenditure differs across regions therefore provides valuable insights into variations in purchasing power, economic opportunities, and welfare outcomes.

Regional economic disparities remain a persistent challenge in many developing countries, particularly those characterized by uneven patterns of urbanization and economic development. while disparities in advanced nations are tied to de-industrialization, regional gaps in developing countries are driven by highly uneven economic take-offs (Floerkemeier et al., 2021). Differences in infrastructure availability, industrial concentration, labor market opportunities, educational attainment, and public service provision often generate unequal economic conditions across regions. These structural differences influence household income generation and consumption behavior, ultimately creating disparities in household welfare. Although economic growth may increase aggregate prosperity, its benefits are not necessarily distributed equally across geographic areas. Examining regional differences in household expenditure provides important evidence regarding the inclusiveness of economic development and the effectiveness of regional development policies.

Indonesia presents an important context for studying regional household expenditure because of its substantial socioeconomic diversity and decentralized system of regional governance. Since the implementation of fiscal decentralization, local governments have been granted greater responsibility for managing regional development and delivering public services. Despite considerable progress in national economic growth, significant disparities remain between provinces and among districts and municipalities within provinces. Indonesia geographical disparities in basic infrastructure directly lead to unequal employment pathways, manifested by high vocational graduate unemployment and a persistent rural-urban gender gap in informal work (Hanri et al., 2026). West Java represents a particularly interesting case for examining regional household expenditure. West Java is highly dependent on localized consumption and wage metrics (Khaerunnisa & Puspitasari, 2024).

Household expenditure has long been employed in development economics as an empirical measure of household welfare. According to the institutional framework of national living standards, official parameters affirm that consumption expenditure functions as the primary proxy for household welfare, adjusted appropriately for family scale and demographics to evaluate relative baseline poverty (Pakistan Bureau of Statistics, 2025). Utilizing household expenditure diversification patterns to accurately quantify improvements in rural and urban welfare (Chakrabarty & Mukherjee, 2022).

This study provides a comprehensive descriptive assessment of household expenditure across cities and regencies in West Java. Rather than estimating causal relationships, the study seeks to document regional expenditure patterns and evaluate differences in household welfare using official expenditure statistics. The analysis compares average expenditure, expenditure variability, and distributional characteristics between regional classifications while distinguishing expenditure patterns for males and females. Such evidence contributes to a clearer understanding of regional welfare differences and provides an empirical basis for evaluating the inclusiveness of regional economic development.

The findings are expected to contribute to the literature in three ways. First, the study extends the discussion of household welfare by demonstrating how regional expenditure statistics can be used to evaluate differences in living standards across local governments. Second, it provides updated empirical evidence on regional household expenditure patterns in West Java using recent official statistics, thereby enriching the limited literature on subnational expenditure disparities in Indonesia. Third, the findings offer practical implications for regional governments and policymakers responsible for fiscal planning, social protection, and regional development. By identifying differences in household expenditure across cities and regencies, policymakers may better target development programs, allocate public resources more effectively, and design interventions aimed at reducing regional welfare disparities.

The object of this study is to examine household expenditure patterns across cities and regencies in West Java and to evaluate the extent to which regional differences in expenditure reflect variations in household economic welfare. Through a comprehensive descriptive analysis of household expenditure statistics, this study provides evidence that may support regional development planning and contribute to a better understanding of economic welfare disparities within one of Indonesia's most economically significant provinces.

Method

This study employs a quantitative descriptive research design to examine household expenditure patterns across cities and regencies in West Java, Indonesia. The descriptive approach is appropriate because the objective of the study is to compare expenditure characteristics between regional classifications and evaluate their implications for regional economic welfare rather than to establish causal relationships. By summarizing expenditure levels and their distribution, the study provides empirical evidence regarding differences in household welfare across local governments.

The study uses secondary data obtained from the West Java Provincial Statistics Office (Badan Pusat Statistik/BPS). The dataset covers all 27 administrative regions in West Java, consisting of 18 regencies and 9 cities, over the 2019–2024 period. The balanced panel comprises 162 region-year observations. The dataset includes annual average household expenditure for males and females, which are reported by BPS as indicators of household consumption and welfare. These official statistics are widely used in Indonesia for monitoring living standards and evaluating regional socioeconomic conditions.Because the dataset covers the entire population of cities and regencies in West Java during the study period, no sampling procedure was required.

The analysis focuses on two expenditure variables and one regional classification variable. Household expenditure is used as an indicator of economic welfare because it reflects realized consumption and purchasing power. Higher expenditure generally indicates greater household capacity to meet consumption needs and maintain living standards. Variable definition is shows in Table 1.

Table 1. Variable Definitions

Variable	*Measurement*	*Description*
Male household expenditure	Average annual expenditure	Average household expenditure for the male population reported by BPS
Female household expenditure	Average annual expenditure	Average household expenditure for the female population reported by BPS
Regional classification	Dummy variable	City = 1; Regency = 0

The study employs descriptive statistical techniques to compare household expenditure across cities and regencies. Specifically, the analysis includes measures of central tendency, variability, and distribution to provide a comprehensive overview of regional expenditure patterns. These statistics provide complementary information regarding expenditure levels and variability across regional classifications. While the mean summarizes average expenditure, measures of dispersion indicate the degree of heterogeneity in household consumption among local governments. Distributional statistics, including skewness and kurtosis, are used to assess the symmetry and concentration of expenditure observations. To complement the numerical analysis, boxplots are employed to visualize expenditure distributions and identify potential differences in variability between cities and regencies. The graphical presentation facilitates comparison of expenditure patterns across regional classifications and assists in identifying the presence of extreme observations. All statistical analyses were conducted using IBM SPSS Statistics version 27.

The research was conducted in four stages. First, household expenditure data for all cities and regencies in West Java during the 2019–2024 period were collected from BPS. Second, the dataset was organized according to regional classification and gender. Third, descriptive statistical analyses and graphical visualizations were performed to summarize expenditure patterns. Finally, the findings were interpreted within the context of regional economic welfare and regional development in West Java.

This methodological approach is suitable because the study aims to provide a comprehensive descriptive assessment of household expenditure rather than estimate causal relationships. Descriptive statistics offer a straightforward yet informative means of identifying regional differences in household welfare and provide policymakers with evidence that can support regional planning and resource allocation. By using official regional expenditure statistics, the study contributes to the understanding of economic welfare disparities across cities and regencies in West Java.

Results

Descriptive Statitics of Household Expenditure

Table 2 presents the descriptive statistics of household expenditure for cities and regencies in West Java during the 2019–2024 period. The descriptive evidence indicates notable differences in expenditure levels between the two regional classifications for both male and female populations.

Table 2. Descriptive Statistics of Household Expenditure by Regional Classification

Variable	Region	Mean	SD	Minimum	Maximum
Male expenditure	City	18,451.89	3,402.04	13,430	25,068
	Regency	14,597.81	1,848.32	11,221	19,800
Female expenditure	City	11,638.35	2,977.38	7,295	17,615
	Regency	7,228.29	1,751.07	3,904	11,011

Source: Authors' calculations based on BPS West Java data (2026)

The results demonstrate that household expenditure is consistently higher in cities than in regencies. Average male expenditure in cities reached 18,451.89, compared with 14,597.81 in regencies, representing an absolute difference of 3,854.08. A similar pattern is observed for female expenditure, where average expenditure in cities amounted to 11,638.35, substantially exceeding the regency average of 7,228.29, with a difference of 4,410.06. These findings suggest that households residing in cities generally possess greater purchasing power and higher levels of economic welfare than households in regencies.

The descriptive statistics also reveal that expenditure variability is greater in cities. Male expenditure exhibits a standard deviation of 3,402.04 in cities compared with 1,848.32 in regencies, while female expenditure records standard deviations of 2,977.38 and 1,751.07, respectively. Greater variability indicates that household expenditure in urban areas is more heterogeneous, reflecting wider differences in income opportunities, occupational structures, and consumption behavior.

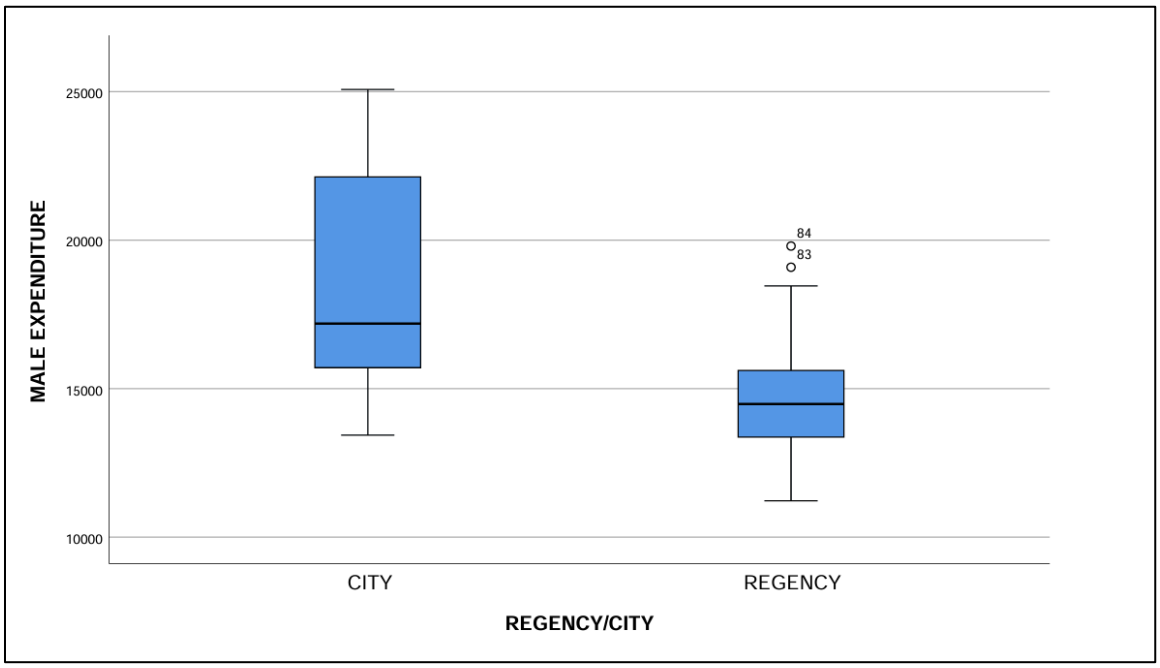
Regional Differences in Household Expenditure

To further illustrate the magnitude of regional differences, Table 3 reports the expenditure gap between cities and regencies. The expenditure gap is evident for both genders, although its magnitude differs considerably. Male expenditure in cities is approximately 26.4% higher than in regencies. In contrast, female expenditure in cities exceeds that of regencies by approximately 61.0%, indicating a considerably larger regional disparity. This suggests that regional differences in household welfare may affect female expenditure more strongly than male expenditure, possibly because women are more sensitive to differences in employment opportunities, household income allocation, or access to economic resources.these findings indicate that regional classification remains closely associated with household expenditure, with cities consistently recording higher consumption levels than regencies.

Distribution of Household Expenditure

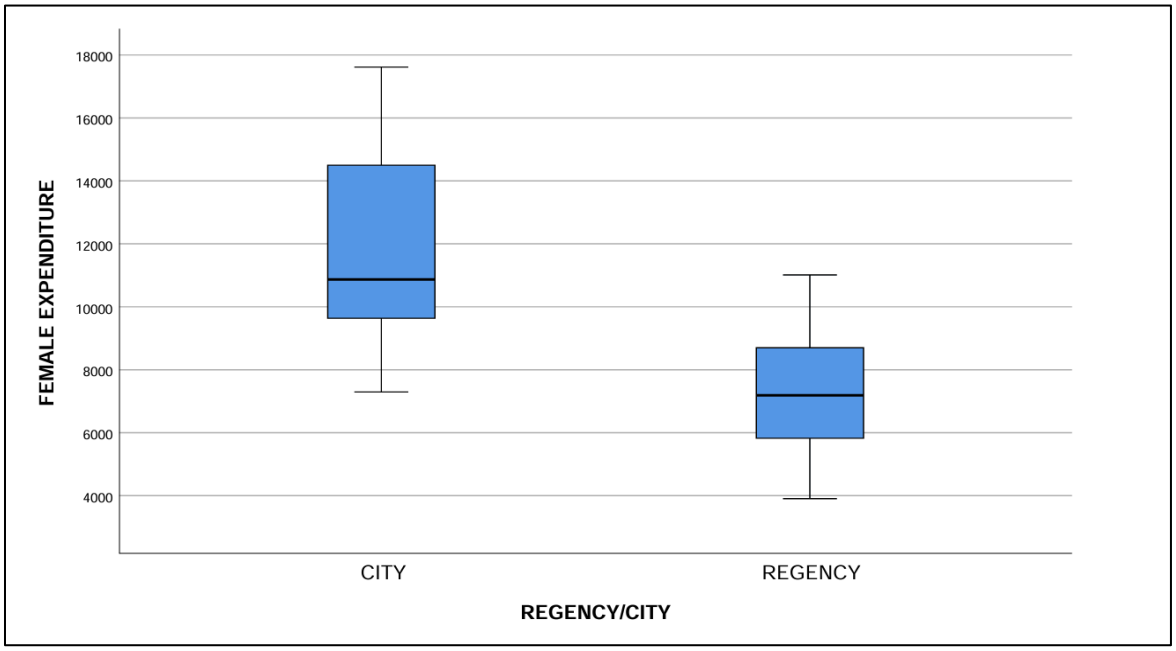
Beyond differences in average expenditure, the distributional characteristics provide additional insights into regional household welfare. Figure 1 presents boxplots of male household expenditure for cities and regencies and Figure 2 presents boxplots of female household expenditure for cities and regencies.

Figure 1. Male Household Expenditure for Cities and Regencies



Source: Authors' elaboration based on BPS West Java (2026).

Figure 2. Female Household Expenditure for Cities and Regencies



Source: Authors' elaboration based on BPS West Java (2026)

The boxplots reveal that expenditure distributions in cities are generally positioned at higher values than those in regencies for both male and female populations. In addition, the interquartile ranges of cities appear wider, indicating greater dispersion of expenditure observations. Several observations also approach the upper whiskers, suggesting that some cities experience substantially higher expenditure than others.

The descriptive statistics support these graphical observations. Male expenditure in cities ranges from 13,430 to 25,068, while regency expenditure ranges between 11,221 and 19,800. Similarly, female expenditure ranges from 7,295 to 17,615 in cities and from 3,904 to 11,011 in regencies. The broader

expenditure ranges observed in cities suggest greater diversity in household economic conditions, consistent with the coexistence of high-income and middle-income households within urban economies.

Discussion

The findings demonstrate persistent differences in household expenditure between cities and regencies in West Java, with urban areas consistently exhibiting higher average expenditure than rural areas for both men and women. Since household expenditure is widely accepted as a proxy for economic welfare, these results indicate that economic well-being remains unevenly distributed across regional classifications. The higher expenditure observed in cities suggests that households benefit from stronger purchasing power, reflecting more favorable economic conditions and greater access to employment opportunities, markets, infrastructure, and public services. These findings support the view that household expenditure provides a meaningful indicator for evaluating regional welfare because it captures realized consumption rather than potential income.

The observed differences are consistent with theories of regional economic development, which argue that economic activities tend to concentrate in areas with greater industrialization, higher labor productivity, and more diversified economic structures. Cities generally attract investment, business activities, and skilled labor, creating higher-value employment opportunities and increasing household purchasing power. Higher expenditure levels in cities are expected because households possess greater financial capacity to consume goods and services. Regencies often rely more heavily on agriculture and resource-based activities, sectors that typically generate lower and more volatile household incomes. These structural differences contribute to disparities in consumption and living standards across regional classifications. Infrastructure deficits are a main cause of Indonesia's regional income gaps. It models how government capital spending on logistics, digital readiness, and public facilities directly dictates the geographic distribution of quality education and productive employment options (Nurdina, 2021).

An important contribution of this study is the finding that the regional expenditure gap is proportionally larger among women than among men. Female household expenditure in cities exceeds that of regencies by a substantially greater percentage than the corresponding difference observed for male expenditure. The descriptive evidence suggests that regional economic development may influence women's consumption opportunities differently from men's. Compared directly to men, when women gain control over disposable income, they prioritize structural investments in human capital. Women channel household budgets heavily toward education, health care, and nutrient-dense foods, while systematically reducing expenditures on "vices" like alcohol and tobacco (Eissler & Bryan, 2025).

Improvement in regional economic development may generate relatively larger gains in female household expenditure.

The analysis also reveals greater expenditure variability in cities than in regencies. While cities exhibit higher average household expenditure, they also display larger standard deviations and wider expenditure ranges. This finding indicates that urban economies are characterized by greater socioeconomic diversity. a city's economic performance depends heavily on having a wide mix of labor market skills, knowledge, and experiences. While major global centers attract highly skilled flows to drive innovation, this dynamic inherently relies on a diverse base of support services, widening the socioeconomic spectrum (Syrett & Sepulveda, 2025). As urban populations grow, the efficiency gains of economic specialization create a vast ecosystem of interdependent job sectors (Youn et al., 2016). Therefore, although urban economies generally provide higher living standards, the benefits of economic development are not distributed uniformly across households. This result highlights the importance of considering not only average welfare but also the distribution of household expenditure when evaluating regional economic performance.

These findings have important policy implications. Higher household expenditure in cities indicates stronger economic capacity, whereas lower expenditure in regencies suggests persistent regional welfare disparities. This highlights the need for policies that strengthen economic opportunities in regencies through infrastructure development, improved education, productive sector support, and expanded labor market access. Moreover, the larger expenditure gap among women underscores the importance of gender-sensitive policies that promote women's economic participation and financial inclusion. Finally, household expenditure statistics provide a valuable evidence base for regional fiscal planning by

enabling policymakers to identify areas with relatively weak purchasing power and design more targeted development and social protection programs. As such, expenditure indicators should complement conventional measures, such as Gross Regional Domestic Product (GRDP), in evaluating regional development outcomes.

The results also contribute to the broader literature on household welfare by emphasizing the usefulness of expenditure-based indicators for evaluating regional inequality. Much of the existing literature measures regional disparities using income, poverty rates, or economic output. While these indicators remain important, household expenditure provides a direct measure of realized welfare because it reflects households' actual ability to consume goods and services. The present study demonstrates that descriptive analysis of official expenditure statistics can provide valuable insights into regional economic conditions without requiring complex econometric techniques. Such evidence is particularly useful for policymakers seeking to monitor welfare conditions and evaluate the inclusiveness of regional development strategies.

This study indicate that household expenditure remains an informative indicator of regional economic welfare in West Java. The consistently higher expenditure observed in cities, together with greater expenditure variability and a larger regional gap in female expenditure, suggests that regional development has not translated into uniformly distributed welfare gains. Addressing these disparities requires development strategies that not only promote economic growth but also strengthen the capacity of households across all regions to achieve sustainable improvements in living standards.

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MASS EVOLUTION OF A SCHWARZSCHILD BLACK HOLE UNDER DARK ENERGY ACCRETION IN THE BISWAS-ROY-BISWAS EOS PARAMETERIZATION CONSTRAINED BY DIFFERENTIAL AGE DATA

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ABSTRACT

The Schwarzschild black hole is an exact vacuum solution of Einstein's field equations in general relativity, describing the exterior spacetime of a static, spherically symmetric, uncharged mass in the absence of a cosmological constant. Although dark energy drives the accelerated expansion of the Universe on cosmological scales, the Schwarzschild geometry provides a useful local approximation for investigating the accretion of cosmological fluids onto black holes. To describe the late-time evolution of dark energy, we adopt the Biswas-Roy-Biswas (BRB) parameterization of the dark energy equation of state, which is designed to capture the low-redshift dynamics while remaining flexible enough to accommodate observational constraints from Type Ia supernovae (SNe Ia), baryon acoustic oscillations (BAO), and cosmic microwave background (CMB) measurements. Using eighty five cosmic chronometer (differential age) measurements, we obtain the best-fit model parameters together with their confidence contours and marginalized posterior distributions. We then investigate the steady, spherically symmetric accretion of BRB dark energy onto a Schwarzschild black hole within the Bondi-Michel framework. The critical point analysis identifies the sonic point, where the infall velocity equals the local sound speed, thereby determining the corresponding accretion rate. Our analysis indicates that, over the redshift interval 0<redshift<3, the black hole mass increases by approximately 55.331% due to the accretion of BRB dark energy.

Keywords : Black Hole, Accretion, Dark Energy.

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BORIC ACID ATTENUATES GLYPHOSATE-INDUCED NEPHROTOXICITY IN RATS BY MODULATING OXIDATIVE STRESS, PRO-INFLAMMATORY CYTOKİNES, AND THE RENAL INJURY MARKERS KIM-1 AND NGAL

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ABSTRACT

Introduction and Purpose: Glyphosate (GLP), the active ingredient of the most widely used broad-spectrum herbicides, persists in the environment and accumulates in the food chain. Following exposure, it reaches the kidney, an organ particularly susceptible to xenobiotic-induced injury. Boric acid (BA), a naturally occurring boron compound, has been reported to possess antioxidant and anti-inflammatory properties. However, its potential protective effect against glyphosate-induced nephrotoxicity remains unclear. This study investigated whether boric acid attenuates glyphosate-induced renal oxidative stress and alters the expression of genes associated with tubular injury, fibrosis, and inflammation in rats.

Materials and Methods: Male Sprague–Dawley rats (220–250 g, 8 weeks old) were randomly allocated to four groups (n = 6) and treated via oral gavage once daily for 7 consecutive days: Healthy control (physiological saline), BA100 (boric acid, 100 mg/kg), GLP (glyphosate, 150 mg/kg), and GLP+BA100 (glyphosate followed by boric acid). On Day 8, kidneys were collected. Oxidative stress markers, Malondialdehyde (MDA), superoxide dismutase (SOD), reduced glutathione (GSH), glutathione peroxidase (GPx), and catalase (CAT) were measured by ELISA. Relative mRNA expression of the tubular injury markers KIM-1 and NGAL, the profibrotic mediator TGF-β1, and the pro-inflammatory cytokines TNF-α, IL-1β, and IL-6 was determined by qRT-PCR ($2^{-\Delta\Delta Ct}$, normalized to β-actin). Data were analysed by one-way ANOVA with Tukey's HSD post-hoc test and are presented as mean ± SEM.

Results: Compared with healthy controls, GLP significantly increased renal MDA (98.13 ± 3.22 vs. 35.73 ± 1.09 nmol/g tissue; $p < 0.001$) while reducing SOD, GSH, GPx, and CAT levels (all $p < 0.001$). GLP also markedly upregulated KIM-1 (3.81-fold), NGAL (3.54-fold), TGF-β1 (5.24-fold), TNF-α (3.21-fold), IL-1β (3.64-fold), and IL-6 (2.05-fold) expression (all $p < 0.001$). In the GLP+BA100 group, MDA was lower (66.20 ± 2.65 nmol/g tissue) and SOD, GSH, GPx, and CAT were higher than in the GLP group, while all six transcripts were expressed at lower levels than in the GLP group. Although most parameters remained different from controls, IL-6 expression was restored to a level comparable with healthy animals ($p = 0.222$).

Discussion and Conclusion: In this short-term model, co-administration of boric acid appears to attenuate the oxidative, inflammatory, and tubular-injury changes associated with glyphosate exposure in rat kidney tissue. The concurrent reduction of KIM-1 and NGAL expression may suggest that the proximal tubule is involved in this protective pattern. These findings may support further evaluation of boric acid as a candidate protective agent against glyphosate-associated nephrotoxicity.

Key Words: boric acid; glyphosate; inflammation; KIM-1; nephrotoxicity; NGAL; oxidative stress

IMPACT OF TECHNOLOGY-INTEGRATED INSTRUCTION ON ENVIRONMENTAL RESPONSIBILITY AND ACADEMIC ACHIEVEMENT AMONG SENIOR SECONDARY GEOGRAPHY STUDENTS IN KATSINA STATE, NIGERIA

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ABSTRACT

This study investigated the impact of technology-integrated instruction on environmental responsibility and academic achievement among senior secondary Geography students in Katsina State, Nigeria. A quasi-experimental, pre-test/post-test control group design was adopted. From a total population of 4,211 students across sixteen senior secondary schools within the Dutsin-ma Zonal Education Quality Assurance, a sample of 109 Senior Secondary II (SSII) Geography students was selected from intact classes using random sampling. The participants were divided into an experimental group exposed to technology-integrated instruction for six weeks and a control group taught via the traditional lecture method. Data collection instruments included the Geography Achievement Test (GAT), adapted from the West African Senior School Certificate Examination (WASSCE) physical geography syllabus, and a 20-item Environmental Responsibility Scale (ERS) structured on a 4-point Likert scale. Reliability was established using the test-retest method and analyzed via Pearson Product Moment Correlation (PPMC) for the GAT, while Cronbach's alpha was applied to the pilot test data for internal consistency. Data analysis was performed using Statistical Package for the Social Sciences (SPSS) software. Mean and standard deviation were used to answer the research questions, while Analysis of Covariance (ANCOVA) was used to test the hypotheses at a 0.05 level of significance. The results revealed that students taught using technology-integrated instruction achieved significantly higher academic performance scores and demonstrated a greater level of environmental responsibility regarding landform concepts compared to those in the control group. The study concludes that integrating digital technology into Geography pedagogy enhances cognitive learning outcomes and fosters positive environmental behaviors. It recommends that the Ministry of Education provide sustainable technological infrastructure and continuous professional development for Geography teachers to effectively implement ICT-driven instructional strategies.

Keywords: Technology-Integrated Instruction, Academic Achievement, Environmental Responsibility, Geography Education.

Introduction

Education has continued to evolve in response to rapid technological advancement and the changing demands of the twenty-first century. The emergence of digital technologies has transformed the methods through which knowledge is created, accessed, shared, and applied across different educational settings (Mena-Guacas, López-Catalán, Bernal-Bravo & Ballesteros-Regaña, 2025). Consequently, educational

systems worldwide are increasingly shifting from conventional teacher-centred approaches to learner-centred instructional practices that integrate digital technologies to enhance teaching effectiveness and students' learning outcomes. This transformation is particularly important in developing countries such as Nigeria, where educational reforms emphasize the development of digital competencies, critical thinking, creativity, problem-solving skills, and environmental consciousness among learners (Akintoye & Oluwaferanmi, 2026). Technology-integrated instruction has therefore become an essential pedagogical approach capable of improving students' academic achievement while preparing them to become responsible citizens in an increasingly technology-driven society (Bhattacharya, 2025).

Technology-integrated instruction refers to the purposeful incorporation of digital technologies into classroom teaching and learning processes to improve instructional delivery, students' engagement, collaboration, knowledge construction, and assessment (Sain, Thelma & Sain, 2025). Unlike the traditional use of chalkboards and textbooks as the primary instructional resources, technology-integrated instruction employs various digital tools such as multimedia presentations, interactive whiteboards, educational software, mobile applications, Geographic Information Systems (GIS), remote sensing technologies, virtual field trips, online simulations, digital maps, Google Earth, learning management systems, and internet-based learning resources (Rahman, 2025). These technologies provide students with opportunities to visualize complex geographical phenomena, participate actively in classroom activities, collaborate with peers, and develop higher-order thinking skills required for addressing contemporary environmental challenges (Zbereanu & Zbereanu, 2024).

The integration of technology into classroom instruction has attracted considerable attention among educational researchers because of its potential to improve learning outcomes across different disciplines (Almufarreh, & Arshad, 2023). Studies have consistently shown that students exposed to technology-supported instruction demonstrate higher levels of academic achievement, increased motivation, stronger critical thinking abilities, and improved retention of learned concepts than those taught through conventional teaching methods (Demir, & Önal, 2021).

Geography is one of the core subjects offered at the senior secondary school level in Nigeria. The discipline focuses on the study of the Earth's physical features, human activities, environmental interactions, spatial relationships, and sustainable resource management (Ekpoto, Nkanu, Offiong, Ugah & Egbulefu, 2022). Geography equips students with the knowledge, skills, values, and attitudes required to understand the complex interactions between humans and their environment (Meadows, 2020). Through Geography education, learners develop competencies in map interpretation, spatial analysis, environmental management, disaster risk reduction, climate change adaptation, and sustainable development (Li, Xia, Qin, Fu, Guo, Li & Zhao, 2022). These competencies are essential for preparing young people to make informed decisions concerning environmental conservation and responsible utilization of natural resources (Hart, 2013).

Despite the strategic importance of Geography, the teaching and learning of the subject in many Nigerian secondary schools continue to rely heavily on conventional instructional methods characterized by teacher-centred lectures, rote memorization, and limited practical engagement (Ekpoto & Adie, 2025). Such approaches often fail to stimulate students' curiosity, critical thinking, and active participation in the learning process (Agustini, Meilanie & Pujiastuti, 2024). Through technology-integrated instruction, students can observe environmental changes over time, analyse spatial data, interpret satellite images, simulate natural processes, and investigate real-life environmental problems (Verma, 2025). These experiences promote active learning and improve students' conceptual understanding of geographical phenomena while enhancing their ability to apply theoretical knowledge to practical situations (Hassan, Puteh & Buhari, 2015).

One of the major educational goals of Geography is the development of environmental responsibility among learners. Environmental responsibility refers to the willingness, commitment, and ability of individuals to protect, conserve, and sustainably manage environmental resources through responsible attitudes, behaviours, and decision-making. It encompasses environmental awareness, environmental ethics, conservation practices, sustainable resource utilization, waste management, climate change mitigation, biodiversity conservation, and active participation in environmental protection initiatives (Foster, Muhammad, Yusliza, Faezah, Johansyah, Yong & Fawehinmi, 2022). Students who possess

strong environmental responsibility are more likely to engage in environmentally friendly behaviours such as tree planting, proper waste disposal, water conservation, energy efficiency, pollution prevention, and community environmental sanitation (Yusliza, Amirudin, Rahadi, Nik Sarah Athirah, Ramayah, Muhammad & Mokhlis, 2020).

In recent years, environmental issues such as climate change, deforestation, desertification, flooding, soil erosion, biodiversity loss, and indiscriminate waste disposal have become increasingly significant global concerns (Singh & Singh, 2016). Nigeria is not exempt from these challenges, particularly in the northern region, where desert encroachment, declining vegetation cover, irregular rainfall patterns, and land degradation continue to threaten agricultural productivity, livelihoods, and ecological sustainability (Olagunju, 2015). Katsina State, located within the Sudan Savannah ecological zone, experiences several environmental challenges, including desertification, drought, wind erosion, deforestation, and increasing pressure on natural resources due to population growth and human activities (Yahaya, Wang, Zhang, Inuwa, Zhao, You & Shoukat, 2024). These environmental problems underscore the need for effective Geography education that not only improves students' academic achievement but also develops environmentally responsible citizens capable of contributing to sustainable development (Aada, 2024).

Technology-integrated instruction has considerable potential to promote environmental responsibility by exposing students to authentic environmental data, real-time satellite imagery, interactive simulations, and problem-based learning activities centred on local and global environmental issues (Tiwari & Fahrudin, 2024). Digital platforms enable students to explore the causes and consequences of climate change, analyse patterns of land-use change, monitor environmental degradation, and propose evidence-based solutions to environmental problems. Such learning experiences encourage environmental awareness, critical reflection, responsible decision-making, and active participation in environmental conservation activities (Callejas, Huang, Cira, Croze, Lee, Cason & Jay, 2023). By connecting classroom learning with real-world environmental challenges, technology-integrated instruction fosters deeper understanding and lasting behavioural change among students.

Academic achievement remains one of the most widely used indicators for evaluating the effectiveness of instructional practices in schools. Accordint to Tian and Sun (2018) It refers to the extent to which learners attain the intended learning outcomes measured through classroom assessments, standardized examinations, assignments, and other academic evaluations. In Geography education, academic achievement reflects students' understanding of geographical concepts, spatial reasoning abilities, environmental knowledge, map-reading skills, and problem-solving competencies (Sonrum, & Worapun, 2023). Improving students' academic achievement is a major objective of curriculum implementation and instructional innovation because it contributes to educational quality, national development, and students' future career opportunities (Serdyukov, 2017). Consequently, investigating how technology-integrated instruction influences both environmental responsibility and academic achievement among senior secondary Geography students is essential for informing educational policy and improving classroom practice in Katsina State, Nigeria.

Statement of the Problem

Geography is one of the core subjects in the Nigerian senior secondary school curriculum because it equips learners with knowledge, skills, values, and attitudes required to understand the interactions between humans and their environment. The subject contributes significantly to the achievement of national educational goals by promoting environmental awareness, spatial thinking, sustainable resource management, disaster risk reduction, and informed decision-making. As environmental challenges such as climate change, desertification, flooding, deforestation, biodiversity loss, and environmental pollution continue to intensify globally and within Nigeria, Geography education is expected to produce environmentally responsible citizens who can contribute meaningfully to environmental conservation and sustainable development. However, the realization of these objectives depends largely on the effectiveness of instructional approaches adopted in the classroom.

Despite the recognized importance of Geography, the academic achievement of many senior secondary school students in the subject has remained a matter of concern among educators, parents, school administrators, and examination bodies. Reports from external examinations such as the West African

Senior School Certificate Examination (WASSCE) and the National Examination Council (NECO) have consistently indicated that many candidates experience difficulties in map reading, interpretation of geographical data, practical geography, environmental analysis, and the application of geographical concepts to real-life situations. These persistent challenges suggest that many students are not acquiring the expected conceptual understanding and practical competencies required by the Geography curriculum.

One factor that may contribute to this situation is the continued reliance on conventional teacher-centred instructional methods in many public secondary schools. Traditional lecture methods often emphasize memorization of facts rather than active learning, critical thinking, inquiry, and practical problem-solving. Consequently, students may become passive recipients of information instead of active participants in the learning process. Since Geography involves the study of spatial relationships, environmental systems, physical processes, and human-environment interactions, instructional approaches that fail to provide visual, interactive, and experiential learning opportunities may limit students' understanding of complex geographical concepts. This instructional gap has generated increasing concern regarding the need to adopt innovative teaching strategies capable of improving students' academic performance.

In Katsina State, these challenges are particularly evident in many public secondary schools where Geography teachers continue to depend largely on conventional teaching methods. Although government and educational stakeholders have introduced various initiatives aimed at promoting Information and Communication Technology (ICT) in schools, effective classroom integration remains relatively low. Many schools lack adequately equipped computer laboratories, reliable internet services, digital instructional materials, and continuous professional development opportunities for teachers.

Beyond poor academic performance, another major concern is the relatively low level of environmental responsibility demonstrated by many secondary school students. Environmental responsibility involves the willingness and commitment to protect the environment through sustainable behaviours such as proper waste disposal, tree planting, water conservation, pollution prevention, and responsible utilization of natural resources. Although environmental education forms an integral component of the Geography curriculum, evidence from many communities indicates that environmentally unfriendly practices such as indiscriminate refuse disposal, bush burning, deforestation, and poor sanitation continue to persist. This situation raises questions regarding the effectiveness of existing instructional approaches in developing positive environmental attitudes and responsible environmental behaviour among students. Consequently, students may not benefit from technology-supported learning experiences that could improve their academic achievement and deepen their understanding of environmental issues.

Research Objectives

1. Determine the effect of technology-integrated instruction on the academic achievement of senior secondary Geography students in Katsina State.

2. Examine the effect of technology-integrated instruction on the environmental responsibility of senior secondary Geography students in Katsina State.

3. Compare the academic achievement of students taught Geography using technology-integrated instruction with those taught using the conventional teaching method.

Research Questions

1. What is the effect of technology-integrated instruction on the academic achievement of senior secondary Geography students in Katsina State?

2. What is the effect of technology-integrated instruction on the environmental responsibility of senior secondary Geography students in Katsina State?

3. What difference exists in the academic achievement of students taught Geography using technology-integrated instruction and those taught using the conventional teaching method?

Research Hypotheses

H_{01}: There is no significant difference in the academic achievement of senior secondary Geography students taught using technology-integrated instruction and those taught using the conventional teaching method.

H_{02}: There is no significant difference in the environmental responsibility of senior secondary Geography students taught using technology-integrated instruction and those taught using the conventional teaching method.

H_{03}: There is no significant difference in the academic achievement of male and female students exposed to technology-integrated instruction.

Methodology

This study employed a quasi-experimental, pre-test/post-test control group design. The setup involved two groups: an experimental group (EG) and a control group (CG). Prior to the treatment, both groups were pre-tested (O_1) to ensure the selection of schools with comparative abilities. The experimental group was exposed to technology-integrated instruction (X_1) as a treatment for a period of six weeks, while the control group (X_0) was taught using the traditional lecture method.

The study area, Dutsin-ma Zonal Education Quality Assurance, comprises sixteen (16) senior secondary schools, with nine (9) located in the Dutsin-ma Local Government Area and seven (7) in the Kurfi Local Government Area. All sixteen schools offer Geography and have a combined total population of 4,211 students. The sample for this study consisted of 168 Senior Secondary II (SSII) students selected from three public senior secondary schools offering Geography in the study area, which included GDSS Tamawa and GDSS Dabawa. Initially, these schools were selected using random sampling, and an intact SSII class was utilized from each school. The choice of 109 students aligns with the Central Limit Theorem developed by Turing (1934), which prescribes that a minimum of 30 participants is adequate to form a sample in an experimental study of this nature.

The study utilized two research instruments: the Geography Achievement Test (GAT) and the Environmental Responsibility Scale (ERS). The GAT instrument consists of a 40-item test adapted from the West African Senior School Certificate Examination (WASSCE) conducted by the West African Examinations Council (WAEC) between 2019 and 2023. All 40 questions adapted for this instrument are objective, multiple-choice items focusing on Physical Geography. Each item features four options (A–D), with only one correct answer. To test the reliability of the GAT, a test-retest method was used, and the resulting scores were analyzed using the Pearson Product Moment Correlation (PPMC). For the Geography Student Questionnaire (GSQ), a split-half method utilizing odd and even-numbered items was employed, and the students' scores from the pilot test were analyzed using Cronbach's alpha. The items were based on landform concepts selected from the SSII Geography syllabus.

The ERS consisted of a 20-item scale adapted from Abao, Kapuya, and Prado (2021) to determine the environmental responsibility of students before and after the treatment on landform concepts. The questionnaire items were structured using Likert's (1970) 4-point rating scale, consisting of Strongly Agree (SA), Agree (A), Disagree (D), and Strongly Disagree (SD). Each option was weighted in order of priority from four (4) to one (1) for positive responses, and from one (1) to four (4) for negative responses regarding landform concepts. Participants completed the scale by ticking the option that best suited their perspective.

Results

Research Question One

What is the effect of technology-integrated instruction on the academic achievement of senior secondary Geography students in Katsina State?

Table 1 Mean and Standard Deviation of Students' Academic Achievement Scores Before and After Exposure to Technology-Integrated Instruction

Test	N	Mean	SD	Mean
Pre-test	45	43.51	7.18	35.11
Post-test	45	78.62	6.41	

Table 1 the students exposed to technology-integrated instruction obtained a pre-test mean score of **43.51 (SD = 7.18)**. Following the intervention, the post-test mean increased substantially to **78.62 (SD = 6.41)**, producing a **mean gain of 35.11**. The lower post-test standard deviation also indicates that students' performance became more consistent after the treatment. This suggests that technology-integrated instruction had a positive effect on students' academic achievement.

Research Question Two

What is the effect of technology-integrated instruction on the environmental responsibility of senior secondary Geography students in Katsina State?

Table 2 Mean and Standard Deviation of Students' Environmental Responsibility Scores

Test	N	Mean	SD	Mean Df
Pre-test	45	50.42	6.82	33.05
Post-test	45	83.47	5.73	

Table 2 the students recorded a pre-test mean environmental responsibility score of **50.42 (SD = 6.82)**. After receiving technology-integrated instruction, the mean increased to **83.47 (SD = 5.73)**, yielding a **mean gain of 33.05**. The findings indicate that the instructional approach considerably improved students' environmental responsibility.

Research Question Three

What difference exists in the academic achievement of students taught Geography using technology-integrated instruction and those taught using the conventional teaching method?

Table 3 Mean and Standard Deviation of Academic Achievement Scores by Instructional Method

Group	N	Mean	SD	Mean Difference
Experimental	45	78.62	6.41	20.38
Control	64	58.24	8.15	

Table 3 The Students taught using technology-integrated instruction obtained a higher mean academic achievement score **(78.62)** than those taught using the conventional teaching method **(58.24)**. The mean difference of **20.38** points indicates a substantial advantage for the experimental group.

Test of Hypothesis One

H_{01}: There is no significant difference in the academic achievement of senior secondary Geography students taught using technology-integrated instruction and those taught using the conventional teaching method.

Table 4 Independent Samples t-test on Academic Achievement

Variable	Group	N	Mean	SD	t	df	Sig. (2-tailed)	Decision
Academic Achievement	Experimental	45	78.62	6.41	12.84	107	0.000	Reject H_{01}
	Control	64	58.24	8.15				

Table 4 Independent Samples t-test produced **t(107) = 12.84, p = .000**, which is less than the 0.05 significance level. Therefore, the null hypothesis is rejected. This indicates a statistically significant difference in academic achievement between students taught using technology-integrated instruction and those taught using the conventional teaching method.

Test of Hypothesis Two

H_{02}: There is no significant difference in the environmental responsibility of senior secondary Geography students taught using technology-integrated instruction and those taught using the conventional teaching method.

Table 5 Independent Samples t-test on Environmental Responsibility

Variable	Group	N	Mean	SD	t	df	Sig.	Decision
Environmental Responsibility	Experimental	45	83.47	5.73	15.02	107	0.000	Reject H_{02}
	Control	64	61.84	7.63				

Table 5 the calculated **t-value of 15.02** with **p = .000** is statistically significant. Consequently, the null hypothesis is rejected. Students exposed to technology-integrated instruction demonstrated significantly higher environmental responsibility than those taught using the conventional method.

Test of Hypothesis Three

H_{03}: There is no significant difference in the academic achievement of male and female students exposed to technology-integrated instruction.

Table 6 Independent Samples t-test Comparing Male and Female Students in the Experimental

Gender	N	Mean	SD	t	df	Sig.	Decision
Male	26	79.31	6.22	0.74	43	0.463	Fail to Reject H_{03}
Female	19	77.68	6.71				

Table 6 the calculated **t-value of 0.74** with a significance level of **0.463** exceeds the 0.05 threshold. Therefore, the null hypothesis is not rejected. This indicates that there is no statistically significant difference in the academic achievement of male and female students who received technology-integrated instruction.

Discussion of Findings

The primary purpose of this study was to investigate the effect of technology-integrated instruction on the academic achievement and environmental responsibility of senior secondary Geography students in Katsina State, Nigeria. It also examined whether the effects of this instructional approach were influenced by gender. The findings from the empirical analysis are discussed comprehensively across the following thematic sub-sections.

The results from Research Question One (Table 1) and Hypothesis One (Table 4) demonstrate that technology-integrated instruction exerts a powerful positive effect on students' academic performance.

Students exposed to digital integration showed a remarkable mean gain of 35.11 points from pre-test to post-test. Crucially, the independent samples t-test ($t(107) = 12.84$, $p < 0.05$) confirmed that the experimental group ($M = 78.62$, $SD = 6.41$) significantly outperformed the control group ($M = 58.24$, $SD = 8.15$) who were taught using conventional methods.

This finding indicates that moving away from ABSTRACT, teacher-centred lectures toward visually rich, interactive digital mediums substantially enhances conceptual clarity. Geography is inherently spatial and ABSTRACT, making features like plate tectonics, weather patterns, or landform evolution difficult to grasp through chalkboards alone. By utilizing tools like Google Earth, online simulations, and virtual field trips, complex geographical phenomena become tangible. These tools allow students to visualize data dynamically, bridging the gap between theoretical definitions and spatial realities.

This outcome strongly aligns with the assertions of Bhattacharya (2025) and Rahman (2025), who noted that digital tools expand opportunities for active knowledge construction. Furthermore, the empirical evidence mirrors earlier findings by Demir and Önal (2021) and Almufarreh and Arshad (2023), who consistently observed superior academic retention and motivation among students exposed to technology-supported environments compared to traditional lecture-driven classrooms.

The analysis of Research Question Two (Table 2) and Hypothesis Two (Table 5) revealed that technology-integrated instruction significantly cultivates environmental responsibility among senior secondary school learners. The experimental group experienced a substantial mean increase from 50.42 to 83.47 after the intervention. The inferential analysis yielded a highly significant difference ($t(107) = 15.02$, $p < 0.05$), rejecting the null hypothesis and proving that students taught via technology-integrated methods possessed a much deeper commitment to environmental stewardship than their traditionally taught peers ($M = 61.84$, $SD = 7.63$).

This finding is particularly critical given the ecological vulnerabilities of Katsina State, which sits within the fragile Sudan Savannah zone. Traditional instructional methods often relegate localized crises such as desertification, irregular rainfall, and wind erosion to mere facts in a textbook. Conversely, technology integration allows students to interact directly with temporal satellite imagery, geographic information systems (GIS), and remote sensing data to track real-time vegetation loss and desert encroachment in their immediate regions.

By grounding international crises in local contexts, digital learning environments foster empathy, awareness, and proactive ethics. As observed by Tiwari and Fahrudin (2024), authentic environmental data changes student attitudes. These findings corroborate the work of Callejas et al. (2023), which demonstrated that digital platforms catalyze evidence-based problem-solving, converting passive learners into active proponents of sustainability practices like tree planting, conservation, and proper waste management.

The independent samples t-test showed no statistically significant difference between the post-test scores of male students ($M = 79.31$, $SD = 6.22$) and female students ($M = 77.68$, $SD = 6.71$) within the experimental group ($t(43) = 0.74$, $p = 0.463$). Because the p-value safely exceeds the 0.05 threshold, the null hypothesis failed to be rejected.

This finding is highly encouraging as it indicates that technology-integrated instruction is an equitable pedagogical approach that benefits male and female students equally. Digital learning interfaces, interactive software, and cooperative multimedia projects provide an objective, engaging framework that cuts across gender lines. This equalizing effect is vital for educational reform in Northern Nigeria, where closing the gender gap in science and humanities subjects remains a priority.

The result reinforces the findings of Akintoye and Oluwaferanmi (2026), who argued that well-structured, learner-centred digital environments neutralize historical gender performance gaps by providing uniform access to interactive learning stimuli. When technology is meaningfully integrated, it accommodates diverse learning styles, ensuring that both male and female students develop the critical thinking, spatial reasoning, and problem-solving competencies necessary for twenty-first-century success.

Conclusion

Based on the empirical findings of this study, it is concluded that technology-integrated instruction is a highly effective, transformative, and equitable pedagogical approach for teaching Geography at the senior secondary school level in Katsina State. The integration of digital tools such as online simulations, interactive media, and spatial visualization software substantially improves students' academic achievement compared to traditional, teacher-centred lecturing methods.

Furthermore, this instructional paradigm plays a vital role in fostering environmental responsibility. By bringing real-world ecological challenges into the classroom through visual and interactive data, technology-integrated instruction successfully translates ABSTRACT geographical concepts into actionable environmental ethics. This is particularly crucial for students in the Sudan Savannah region, who must navigate localized crises like desertification and land degradation. Finally, because the academic gains were uniform across both male and female students, technology-integrated instruction serves as a gender-equitable educational tool capable of closing performance gaps and providing uniform opportunities for all learners.

Recommendations

The following recommendations are put forward to improve instructional practices and educational policy includes but not limited to:

Mandatory Integration of Digital Tools in Geography Classrooms

The Ministry of Education, Katsina State, in collaboration with secondary school administrators, should formally integrate digital resources such as Google Earth, Geographic Information Systems (GIS) software, and interactive environmental simulations into the senior secondary school Geography curriculum. Traditional lecturing should be systematically replaced with these learner-centred approaches to enhance academic performance.

Targeted Continuous Professional Development for Teachers

The Katsina State Ministry of Education and the State Teachers' Service Board should organize regular, hands-on training workshops and seminars for Geography teachers. These programs should focus specifically on developing digital competencies, helping teachers effectively manipulate spatial software and embed local environmental data into their daily lesson deliveries.

Equitable Distribution of ICT Infrastructure and Digital Facilities

The government and relevant educational stakeholders should prioritize equipping secondary schools across Katsina State with reliable ICT infrastructure, including functional computer laboratories, steady internet access, interactive whiteboards, and power backup solutions. This infrastructure is essential to ensure that both rural and urban schools can successfully implement technology-integrated teaching.

Curriculum Reorientation Toward Localized Environmental Action

Curriculum planners, such as the Nigerian Educational Research and Development Council (NERDC), should revise the secondary school Geography curriculum to feature technology-supported, problem-based learning tasks. These tasks should directly engage students in monitoring and proposing evidence-based solutions to Northern Nigeria’s pressing environmental challenges, such as desert encroachment and soil erosion, thereby strengthening civic responsibility.

Promotion of Gender-Inclusive Digital Learning Strategies

School administrators and teachers should actively encourage gender-neutral collaboration during technology-integrated lessons. By ensuring equal access to digital devices and multimedia projects for both male and female students, schools can capitalize on technology's capacity to act as an academic equalizer.

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THE ROLE OF LEGAL PROFESSIONALS IN TRANSITIONAL JUSTICE

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ABSTRACT

The term 'transitional justice' refers to a field of practice and research focused on enabling societies to come to terms with past human rights violations, large-scale massacres or other forms of severe social trauma, with the aim of building a more democratic, just and peaceful future. This concept is generally understood as a framework for coming to terms with the past as part of major political transformations. It encompasses a range of complementary judicial and non-judicial measures; for example, the prosecution of perpetrators, the payment of compensation to victims, the establishment of truth commissions and various methods for examining the past.

In the transitional justice process, if the aim is to redress the past, some authors do not insist that those involved in the process must be legal professionals; according to these authors, non-professionals play key roles in the transitional justice process. In the Rwandan process, which is regarded as a good example of coming to terms with the past, the role played by non-professionals as arbitrators and decision-makers in the Gacaca Courts has served as a guiding example in this regard. Similarly, members of civil society have played a role in shaping transitional justice mechanisms in East Timor, Peru, Sierra Leone and Ghana. Following the acts of violence committed by the Lord's Resistance Army in Uganda, community elders led the 'mato oput' rituals.

The involvement of non-professionals in defence, claiming and decision-making roles throughout the process—listening to and compiling the victims' stories, establishing the truth, and conducting comprehensive historical research—can contribute to the establishment of justice. However, without conducting judicial investigations into those responsible for human rights violations, without establishing compensation schemes, and without identifying the true perpetrators of mass and systematic crimes, the transitional period will not only be ineffective in terms of accountability but the process cannot succeed in achieving its own objectives either.

Keywords: Transitional Justice, Legal Professional, Accountability for Past Abuses, Reconciling the Past, Peace Process

HYPER-LOCAL JOURNALISM: AN EXAMPLE OF JOURNALISM TYPES IN THE NEW MEDIA WHERE BOUNDARIES ARE BECOMING BROAD

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ABSTRACT

The new media age has caused transformations in many fields, including journalism. The technologies of this era have led to a major change that necessitates a reassessment of all stages of the news production process. One of the clearest indicators of this change is the emergence of new types of journalism. Some of these types have emerged with new media technologies, while others existed before these technologies but require re-evaluation. There are even types that offer alternatives to the advancements of the new media age. However, debates about these new genres are still ongoing. Whether they are genres or journalistic practices, or where the genres begin and end, are at the forefront of these discussions. This is because the boundaries of these genres are more blurred than those of previous genres.

However, debates about these new genres are still ongoing. Whether they are genres or journalistic practices, or where the genres begin and end, are at the forefront of these discussions. This is because the boundaries of these genres are more blurred than those of previous genres. Some even argue that it is a genre reproduced through social media. As seen in these definitions, which feature news concerning a local area or community that cannot be found in any area of conventional media, it is often associated with genres such as local journalism, citizen journalism, and social media journalism. However, considering the areas where it finds fertile ground, the genre can be associated with internet journalism, mobile journalism or video journalism when evaluating the tools used for the genre, innovation journalism due to its innovative approaches, and alternative journalism with the alternative perspective it creates. So, what is the answer to the question of where the boundaries of this genre begin and end? It is difficult to answer this question in a process where even the debate about whether it is a genre is still ongoing. However, journalism is ultimately being practiced in this way, which offers an alternative path for journalism, is thought to increase trust in journalism, is sustainable, increases interaction with the target audience, and can be the voice of those who cannot be heard. In other words, even if the news process changes to the point of needing to be re-evaluated, the fundamental principles of journalism remain the same. When viewed from a more holistic perspective without deviating from this foundation, it will be seen that things will fall into place over time. Because the new media age is still an ongoing process; just as the new media of the past transformed into the conventional media of today, these technologies will give way to new ones, and media will move into a new era.

Keywords: New Media; New Media Technologies; Journalism; Hyperlocal Journalism.

INSTITUTIONAL INDICATORS IN MEDIA DISCOURSE (ON THE EXAMPLE OF ECOLOGY MACRODISCOURSE)

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ABSTRACT

Introduction and Purpose: Institutional discourse is the type of communication in which communicators establish with each other according to their status-role positions, which takes place within the generally accepted standard requirements of a certain institution. There are five indicators of any field's relevance to institutional discours: participants, chronotope, goals, values, subject. Based on these indicators, political, religious, scientific, economic, sports and many other fields are attributed to the institutional discourse. We can also say that media and ecology discourses belong to institutional discourse. The main goal of our research work is to determine the indicators that prove that these two institutional discourses belong to the institutional discourse in unity.

Methods. To achieve this goal, we examined the institutional indicators of media discourse, then identified indicators that prove that the ecological discourse belongs to institutional discourse, and in the final stage, we tried to prove that it is a component of institutional discourses by identifying which institutional indicators these two discourses have in common.

Results: Thus, ecological media discourse, which is a complex type of discourse, has all the institutional indicators. Although the indicators of this complex discourse consist of a combination of the indicators of the discourses of which it is composed, they are not the same. In some indicators, the indicators of the media discourse are in the priority position, while in others, the indicators of the environmental discourse are.

Conclusions. In general, these two discourses, due to their compatible indicators, are able to easily synthesize and create a perfect institutional discourse, as well as create a unity with other discourses and form a more complex discourse unity.

Keywords: discourse, institutional discourse, ecological discourse, media discourse, ecological media discourse

INTELLIGENT VIRTUAL ARCHITECTURAL ENVIRONMENTS: ADVANCING SPATIAL PERCEPTION AND HUMAN EXPERIENCE THROUGH IMMERSIVE COMPUTING IN LAGOS STATE, NIGERIA

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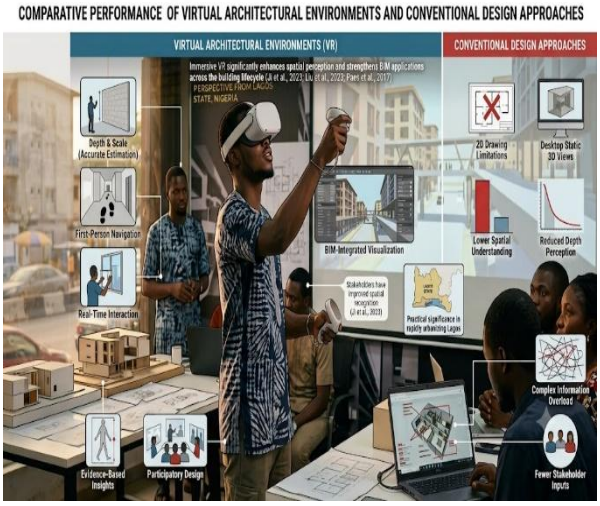
ABSTRACT

The rapid advancement of immersive digital technologies has transformed architectural visualization from static two-dimensional representations into interactive virtual environments that simulate real-world spatial experiences. This study aims to examine the influence of virtual architectural environments on human spatial perception and user experience within the built environment of Lagos State, Nigeria. The study adopts a qualitative review and conceptual synthesis methodology based on recent peer-reviewed literature, architectural reports, and empirical studies on virtual reality (VR), Building Information Modelling (BIM), spatial cognition, environmental psychology, and digital architecture. Relevant studies published between 2020 and 2026 were systematically reviewed to identify emerging trends, applications, challenges, and opportunities associated with immersive architectural technologies. The findings indicate that immersive virtual environments significantly improve spatial understanding, design communication, stakeholder engagement, navigation, decision-making, and user satisfaction throughout architectural design and project delivery. The review further demonstrates that integrating VR with BIM and human-centred design principles enhances collaboration while reducing design errors and construction uncertainties. The major strength of this study lies in its integration of global evidence with the unique socio-economic and urban development realities of Lagos State, thereby providing context-specific implications for developing economies. The principal research gap identified is the limited empirical investigation of human experience and spatial cognition within immersive architectural environments in Nigeria despite increasing adoption of digital construction technologies. The study concludes that virtual architectural environments represent an important pathway towards sustainable, inclusive, and user-centred architectural practice capable of improving design quality, urban planning, and stakeholder participation across rapidly urbanising cities such as Lagos. Recent research also shows that immersive VR improves spatial decision-making and design evaluation, supporting its increasing use in architecture and construction.

Keywords: Built Environment; Human Experience; Spatial Perception; Virtual Architectural Environments

INTRODUCTION



The Architecture, Engineering, and Construction (AEC) industry has undergone a remarkable digital transformation through the adoption of immersive technologies that enhance architectural visualization, simulation, and decision-making before physical construction. Technologies such as Virtual Reality (VR), Augmented Reality (AR), Mixed Reality (MR), Building Information Modelling (BIM), and Digital Twins have revolutionized architectural practice by enabling architects, engineers, and stakeholders to experience and evaluate building designs within interactive virtual environments rather than relying solely on conventional two-dimensional drawings or static three-dimensional models. These innovations facilitate realistic spatial visualization, real-time interaction, and human-scale navigation, allowing users to assess spatial dimensions, circulation patterns, lighting conditions, accessibility, environmental comfort, and design quality more accurately during the conceptual design stage. Consequently, immersive technologies support evidence-based architectural decision-making, improve stakeholder communication, strengthen interdisciplinary collaboration, and reduce costly design modifications before project implementation. Furthermore, integrating BIM with immersive visualization aligns with the principles of Industry 4.0 and Construction 4.0 by promoting digital collaboration, intelligent project delivery, and lifecycle building management. From a human-centred perspective, virtual architectural environments enhance spatial perception by enabling users to cognitively interpret depth, scale, orientation, enclosure, and environmental relationships while simultaneously evaluating emotional responses, usability, and behavioural interactions. These capabilities contribute to more inclusive, sustainable, and user-oriented architectural solutions that accommodate diverse stakeholder needs. Despite growing global adoption, the practical implementation of immersive architectural technologies in Nigeria remains relatively limited due to infrastructural constraints, high implementation costs, inadequate technical expertise, and insufficient institutional support. Nevertheless, Lagos State—Nigeria's largest metropolitan region and one of Africa's fastest-growing megacities—offers a compelling context for investigating these technologies because of its rapid urbanization, increasing infrastructure demands, and complex development challenges. Against this background, this study synthesizes contemporary evidence on virtual architectural environments to examine their influence on spatial perception and human experience, identify implementation opportunities and barriers, and discuss their implications for sustainable architectural practice, digital transformation, and evidence-based urban development within the built environment of Lagos State, Nigeria.

LITERATURE REVIEW

The emergence of virtual architectural environments has transformed architectural design from a predominantly representational process into an immersive, user-centred practice where stakeholders can experience proposed buildings before construction. The convergence of Virtual Reality (VR), Building Information Modelling (BIM), Digital Twins, Augmented Reality (AR), Mixed Reality (MR), and extended reality (XR) has significantly expanded opportunities for evaluating human experience, spatial cognition, environmental behaviour, and collaborative decision-making throughout the building lifecycle. Recent scholarship demonstrates that immersive architectural technologies not only improve design communication but also facilitate evidence-based architectural practice by allowing users to perceive, navigate, and assess spatial qualities in realistic virtual settings. Spatial perception represents one of the most fundamental aspects of architectural experience because human interaction with buildings depends largely on how occupants interpret dimensions, scale, enclosure, visibility, circulation, lighting, orientation, and environmental comfort. According to environmental psychology,

spatial cognition involves the mental processes through which individuals perceive, interpret, remember, and navigate physical environments. Traditional architectural drawings and computer-generated renderings often fail to communicate these experiential qualities effectively, particularly to non-technical stakeholders. Consequently, immersive VR environments have become valuable tools for bridging communication gaps between architects, engineers, clients, and future occupants by providing realistic first-person experiences of proposed spaces. Studies consistently demonstrate that immersive visualization significantly enhances users' ability to estimate room sizes, circulation efficiency, spatial relationships, and environmental quality compared with conventional visualization techniques. The theoretical foundation underpinning virtual architectural environments is strongly influenced by Gibson's ecological theory of perception, environmental psychology, and human-centred design principles. These perspectives emphasize that architectural space acquires meaning through human interaction rather than merely through physical geometry. Immersive virtual environments support this perspective by enabling users to engage actively with architectural spaces using natural movement, stereoscopic vision, and spatial audio, and real-time interaction. Rather than observing architecture from fixed viewpoints, users experience buildings dynamically, thereby generating more accurate judgments regarding accessibility, functionality, comfort, aesthetics, and usability. Such experiential evaluation has become increasingly important within contemporary architectural practice, where user satisfaction is recognized as a critical indicator of design quality. Recent literature further demonstrates that Building Information Modelling has become the technological backbone supporting immersive architectural visualization. BIM provides comprehensive digital representations containing geometric, structural, mechanical, environmental, and operational information throughout a building's lifecycle. When integrated with VR technologies, BIM models are transformed into interactive environments where users can perform virtual walkthroughs, inspect building components, evaluate construction sequencing, identify design conflicts, and simulate occupant behaviour before physical implementation. Liu et al. (2023) observe that BIM-integrated immersive technologies significantly improve project collaboration, visualization, information sharing, and lifecycle management while supporting emerging concepts associated with Digital Twins and the metaverse. Similarly, systematic reviews indicate that VR-BIM integration has become increasingly important across design review, construction management, quality assurance, facility management, and stakeholder engagement. Human experience within virtual architectural environments has attracted increasing scholarly attention because immersive technologies provide opportunities to evaluate emotional, cognitive, behavioural, and physiological responses during the design process. Unlike conventional design evaluation methods, VR enables researchers to observe users' movement patterns, navigation behaviour, visual attention, decision-making processes, and perceived environmental quality under controlled experimental conditions. Such capabilities enable architects to optimise spatial layouts, circulation networks, accessibility provisions, lighting conditions, and interior configurations before construction commences. Numerous empirical investigations demonstrate that immersive VR environments increase user confidence in design evaluation while improving communication between technical professionals and non-specialist stakeholders. Another significant development concerns collaborative architectural design. Contemporary construction projects involve multidisciplinary teams comprising architects, engineers, planners, contractors, quantity surveyors, clients, regulators, and facility managers. Effective communication among these participants remains one of the greatest challenges affecting project performance. Immersive virtual environments address this challenge by providing shared digital workspaces where project stakeholders simultaneously interact with three-dimensional building models regardless of geographical location. Such collaborative environments improve decision-making, reduce design errors, minimise conflicts, and accelerate project delivery. Reviews of immersive collaboration conclude that although interoperability and workflow standardisation remain challenges, BIM-enabled immersive environments have become central to Construction 4.0 initiatives. The literature also identifies growing interest in immersive technologies for inclusive and universal architectural design. Buildings are increasingly expected to accommodate users with diverse physical, cognitive, sensory, and cultural needs. Virtual environments facilitate early evaluation of accessibility features, circulation routes, emergency evacuation procedures, wayfinding systems, and ergonomic performance without requiring expensive physical prototypes. Inclusive architectural design therefore benefits substantially from immersive simulations because designers receive direct feedback from representative user groups before construction. Recent reviews further highlight VR's contribution to socially inclusive and culturally

responsive architecture through participatory design approaches. Sustainability constitutes another recurring theme within recent scholarship. Researchers increasingly recognise that immersive architectural technologies contribute to sustainable construction by reducing design revisions, minimizing material waste, improving stakeholder communication, and enhancing building performance evaluation. Virtual prototypes enable architects to compare multiple design alternatives efficiently while integrating environmental simulation tools that evaluate daylighting, thermal comfort, energy performance, ventilation, and occupant wellbeing. Consequently, immersive technologies support evidence-based sustainable design while reducing project risks and lifecycle costs. Experimental BIM-based immersive environments have further demonstrated improved daylight analysis and performance-driven design decisions, strengthening the integration between environmental simulation and architectural visualization. Within developing countries, however, adoption of immersive architectural technologies remains uneven. Existing African literature indicates that technological infrastructure, hardware costs, limited institutional investment, inadequate professional training, interoperability challenges, and low digital literacy continue to restrict implementation. Nevertheless, growing awareness of BIM, VR, and digital construction is gradually transforming architectural education and professional practice across several African countries, including Nigeria. Emerging Nigerian studies report increasing experimentation with AR and VR for working drawings, design communication, and educational applications, although empirical investigations focusing specifically on users' spatial perception and experiential responses remain scarce. This suggests that while technological adoption is progressing, research concerning human-centred evaluation of immersive architecture remains relatively underdeveloped within the Nigerian built environment. Lagos State represents an especially important setting for extending this body of knowledge. As Nigeria's commercial capital and one of Africa's fastest-growing megacities, Lagos faces complex urban development challenges involving rapid population growth, transportation infrastructure, housing demand, environmental sustainability, and smart city development. These challenges require architectural solutions that prioritise functionality, user satisfaction, resilience, and stakeholder participation. Immersive virtual architectural environments offer significant opportunities for evaluating large-scale residential, commercial, institutional, and transportation projects before implementation while improving public engagement and reducing planning uncertainties. Although international scholarship strongly supports immersive technologies for enhancing spatial perception and design communication, relatively few studies have examined these applications within the socio-cultural and institutional realities of Lagos State. Overall, the reviewed literature demonstrates broad consensus that virtual architectural environments have become indispensable tools for improving spatial perception, human experience, collaborative design, sustainable construction, and digital transformation within the Architecture, Engineering, and Construction (AEC) industry. The integration of BIM, VR, AR, Digital Twins, and immersive visualization continues to redefine architectural practice by enabling user-centred evaluation before construction, thereby improving design quality and project outcomes. Nevertheless, the literature also reveals an important research gap concerning empirical assessment of how Nigerian users perceive and experience immersive architectural environments within rapidly urbanising contexts such as Lagos State. Addressing this gap is essential for developing context-sensitive architectural frameworks capable of supporting digital transformation, evidence-based design, and sustainable urban development in Nigeria.

MATERIALS AND METHODS

This study employed a Systematic Literature Review (SLR) guided by the PRISMA 2020 framework to investigate the relationship between spatial perception and human experience in virtual architectural environments from a built environment perspective, focusing on Lagos State, Nigeria. The SLR approach was adopted because it provides a transparent, rigorous, and reproducible method for identifying, evaluating, and synthesizing evidence while minimizing selection bias through predefined search protocols and eligibility criteria. A comprehensive search was conducted across major scholarly databases, including Scopus, Web of Science, ScienceDirect, SpringerLink, IEEE Xplore, Wiley Online Library, Taylor & Francis Online, SAGE Journals, Emerald Insight, MDPI, and Google Scholar, with bibliographic details verified through CrossRef and publishers' websites. Boolean search operators

("AND", "OR") were used to combine keywords such as *Virtual Reality*, *Spatial Perception*, *Human Experience*, *Building Information Modelling (BIM)*, *Digital Twin*, *Construction 4.0*, *Architecture*, and *Nigeria*. Eligible studies published between 2020 and 2026, together with selected seminal works, were screened using predefined inclusion and exclusion criteria before undergoing full-text review. Relevant data, including study characteristics, methodologies, immersive technologies, principal findings, limitations, and recommendations, were extracted and synthesized using thematic content analysis. The findings were organized into four themes addressing virtual architectural environments, human experience, immersive technology applications, and sustainable architectural practice. Bibliographic information and DOIs were independently verified to enhance the credibility, accuracy, and reliability of the synthesized evidence.

RESULTS AND DISCUSSION

Influence of Virtual Architectural Environments on Spatial Perception

The reviewed literature demonstrates that virtual architectural environments have fundamentally transformed the way individuals perceive, interpret, and evaluate architectural spaces before physical construction. Unlike conventional two-dimensional drawings and static three-dimensional visualizations, immersive Virtual Reality (VR) environments provide users with realistic, full-scale representations that significantly enhance spatial cognition and environmental awareness. Through stereoscopic visualization, real-time interaction, and first-person navigation, users develop a stronger understanding of spatial dimensions, circulation routes, room proportions, visibility, and environmental relationships. Consequently, architects are able to identify potential design deficiencies during the conceptual design stage, thereby reducing costly modifications after construction. Recent studies indicate that BIM-integrated VR enhances stakeholders' visual comprehension and supports more effective architectural communication. The findings further indicate that immersive architectural technologies significantly improve users' ability to perceive depth, scale, enclosure, orientation, and spatial connectivity. According to Ji et al. (2023), stakeholders interacting with BIM-based virtual environments exhibit improved spatial recognition, while gaming experience further enhances users' ability to interpret virtual architectural spaces accurately. Likewise, Paes, Arantes, and Irizarry (2017) established that immersive VR systems outperform conventional desktop-based virtual environments in improving users' spatial perception of architectural models, enabling participants to estimate room dimensions and spatial relationships with greater accuracy. These findings reinforce environmental psychology theories that spatial perception is influenced not only by physical dimensions but also by cognitive engagement and experiential interaction within an environment. Another important observation emerging from the reviewed studies is the integration of Building Information Modelling (BIM) with immersive visualization technologies. Liu et al. (2023) observed that immersive technologies, including VR, Augmented Reality (AR), Mixed Reality (MR), and Digital Twins have substantially strengthened BIM applications across the building lifecycle by improving visualization, interdisciplinary collaboration, remote communication, and design evaluation. Their bibliometric review further demonstrates that immersive BIM technologies are increasingly integrated with Artificial Intelligence (AI), blockchain, and digital twins to support the digital transformation of the Architecture, Engineering, and Construction (AEC) industry. Similarly, Khan et al. (2021) concluded that integrating BIM with immersive technologies enhances project coordination, stakeholder participation, and decision-making while facilitating more effective communication among multidisciplinary project teams. Within the context of Lagos State, these technological capabilities possess considerable practical significance. Lagos continues to experience rapid urbanisation characterised by increasing population density, housing demand, transportation congestion, and expanding commercial infrastructure. Such urban complexity requires architectural solutions capable of communicating spatial information effectively to government agencies, developers, investors, professional consultants, and future occupants. Immersive virtual environments therefore provide an efficient platform for evaluating residential developments, high-rise buildings, transportation facilities, educational campuses, healthcare infrastructure, and mixed-use developments before construction begins. Although empirical studies focusing specifically on Lagos remain limited, international evidence strongly suggests that immersive visualization can improve planning decisions within rapidly urbanising metropolitan environments. The

literature also reveals that immersive visualization contributes significantly to participatory architectural design by enabling individuals without technical architectural expertise to understand complex building proposals. Yu et al. (2022) reported that immersive virtual environments strengthen collaborative architectural design by facilitating interactive communication among architects, engineers, clients, and end users, particularly within multidisciplinary project environments. Similarly, Abdelsalam et al. (2023) demonstrated that VR integrated with BIM and game-engine technologies enhances public participation during architectural and urban planning projects by enabling stakeholders to experience and evaluate proposed developments more intuitively than through conventional drawings. This participatory capability is particularly valuable in Lagos State, where major infrastructure and urban regeneration projects increasingly require meaningful stakeholder engagement. Furthermore, immersive virtual environments support evidence-based architectural design by providing measurable insights into user movement, spatial behaviour, visibility patterns, accessibility, and environmental preferences. Paes et al. (2023) established a significant relationship between three-dimensional perception and users' sense of presence within reconstructed virtual architectural environments, suggesting that enhanced immersion directly improves the quality of architectural evaluation and decision-making. More recently, research on smartphone-based BIM-VR applications has shown that immersive visualization substantially improves non-expert users' understanding of residential designs, reduces design revisions, and facilitates user-centred decision-making during the early stages of architectural development. Overall, the reviewed evidence consistently demonstrates that virtual architectural environments significantly enhance spatial perception by combining immersive visualization with human-centred design principles. As argued by Ji et al. (2023), Liu et al. (2023), Khan et al. (2021), Yu et al. (2022), and Paes et al. (2017; 2023), these technologies improve architectural communication, strengthen stakeholder collaboration, support evidence-based design, and reduce project uncertainty. Their adoption within the built environment of Lagos State therefore presents considerable opportunities for improving design quality, user satisfaction, and sustainable urban development while advancing the digital transformation of Nigeria's architectural profession.

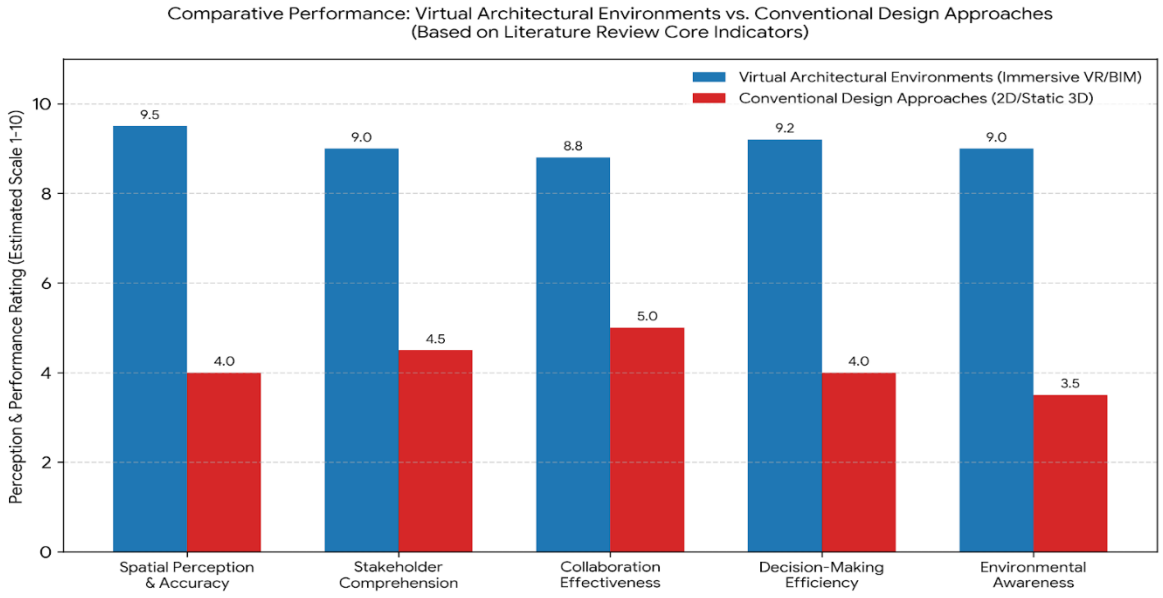


Fig.1: Chart illustrating the Comparative Performance of Virtual Architectural Environments vs. Conventional Design Approaches.

Human Experience and User Behaviour in Immersive Architectural Spaces

Human experience has become a central consideration in contemporary architectural design, as buildings are increasingly evaluated not only by their structural integrity and aesthetic appeal but also by their ability to support occupants' psychological well-being, functional efficiency, and social interaction. The emergence of immersive Virtual Reality (VR) technologies has enabled architects to

assess these experiential dimensions before construction by simulating realistic architectural environments that replicate users' sensory and behavioural interactions. The reviewed literature consistently demonstrates that immersive virtual architectural environments enhance users' cognitive engagement, emotional responses, spatial orientation, and overall satisfaction compared with conventional visualization techniques. By enabling occupants to navigate and interact with digital buildings at full scale, VR provides architects with valuable insights into how design decisions influence user experience, thereby facilitating evidence-based and human-centred architectural practice. The literature indicates that the sense of presence, the psychological feeling of "being there" within a virtual environment, is one of the most influential factors affecting human experience in immersive architectural spaces. According to Paes et al. (2023), immersive reconstructed virtual environments significantly improve users' perception of architectural spaces by strengthening spatial presence and increasing confidence in evaluating design alternatives. Their findings demonstrate that users who experience higher levels of immersion develop more accurate judgments regarding room dimensions, circulation patterns, interior layouts, and environmental quality. This enhanced sense of presence enables architects to obtain realistic user feedback before construction, reducing uncertainty during design development and improving the overall quality of architectural outcomes. Similarly, Azarby and Rice (2023) observed that users' visual exploration strategies within VR environments significantly influence spatial interpretation and architectural decision-making, highlighting the importance of immersive interaction in supporting design evaluation. Another recurring finding concerns the influence of immersive technologies on human behaviour and navigation within architectural environments. Traditional architectural drawings often require users to mentally interpret spatial relationships, a process that can be difficult for non-professionals. In contrast, immersive VR allows users to move naturally through architectural spaces, improving their understanding of wayfinding, accessibility, visual connectivity, and functional organization. Ji et al. (2023) reported that immersive BIM-enabled virtual environments significantly improve users' spatial recognition and navigation performance by enabling realistic interaction with building layouts. Their study further revealed that individuals with greater familiarity with digital environments demonstrated enhanced spatial cognition, suggesting that immersive technologies may also contribute to developing users' environmental awareness and decision-making capabilities. These findings reinforce the argument that architectural quality should be evaluated based on users' experiential responses rather than solely on technical or aesthetic considerations. The reviewed studies also emphasize the role of immersive technologies in enhancing stakeholder communication and collaborative design. Architectural projects typically involve diverse participants, including architects, engineers, clients, contractors, facility managers, government agencies, and future occupants, each possessing different levels of technical expertise. Effective communication among these stakeholders remains essential for successful project delivery. Yu et al. (2022) found that immersive virtual environments significantly improve collaborative architectural design by enabling participants to experience and discuss design alternatives in real time. Rather than relying on ABSTRACT technical drawings, stakeholders can directly explore virtual buildings, identify functional concerns, and recommend modifications based on their lived experiences. This collaborative process promotes shared understanding, minimizes design conflicts, and improves decision-making throughout the project lifecycle. Likewise, Abdelsalam et al. (2023) demonstrated that BIM integrated with VR and game-engine technologies strengthens public participation by enabling community members and clients to engage meaningfully in architectural planning processes. Human experience within immersive environments is also closely associated with emotional comfort, environmental satisfaction, and psychological well-being. Environmental psychology suggests that architectural elements such as lighting, colour, openness, enclosure, ceiling height, texture, and spatial sequence influence occupants' emotional responses and behavioural patterns. Immersive VR enables architects to evaluate these environmental characteristics under realistic conditions before physical construction. According to Paes et al. (2017), immersive VR environments provide more accurate assessments of users' emotional and cognitive responses than desktop visualization systems because participants experience buildings from a first-person perspective. Consequently, designers can identify environmental features that may generate discomfort, confusion, or anxiety while optimizing architectural layouts to promote comfort, safety, and well-being. This capability has become particularly valuable in the design of hospitals, educational institutions, workplaces, residential developments, and public buildings, where user experience directly affects operational performance and occupant satisfaction. From the perspective of

Lagos State, the application of immersive architectural technologies presents substantial opportunities for improving human-centred urban development. As one of Africa's fastest-growing megacities, Lagos faces increasing challenges associated with housing shortages, transportation infrastructure, healthcare facilities, educational buildings, and mixed-use developments. Immersive virtual environments enable architects, planners, government agencies, investors, and local communities to evaluate proposed projects collectively before implementation, thereby ensuring that buildings respond more effectively to users' functional, cultural, and social needs. Although empirical investigations focusing specifically on user experience within virtual architectural environments in Lagos remain limited, international evidence suggests that immersive technologies can significantly improve stakeholder engagement, participatory planning, and evidence-based architectural decision-making within rapidly urbanising metropolitan contexts. Furthermore, immersive technologies contribute to inclusive and universal architectural design by enabling architects to simulate the experiences of diverse user groups, including older adults, children, and persons with disabilities. Virtual environments facilitate the assessment of accessibility features, circulation routes, emergency evacuation procedures, and ergonomic performance without requiring expensive physical prototypes. Such evaluations support compliance with universal design principles while promoting equitable access to the built environment. As digital transformation accelerates across Nigeria's construction industry, these capabilities provide significant opportunities for creating more inclusive, resilient, and user-centred architectural solutions. Overall, the reviewed evidence consistently demonstrates that immersive virtual architectural environments substantially improve human experience by enhancing spatial presence, navigation, collaboration, emotional engagement, and stakeholder participation. Studies by Paes et al. (2017; 2023), Ji et al. (2023), Azarby and Rice (2023), Yu et al. (2022), and Abdelsalam et al. (2023) collectively affirm that immersive technologies enable architects to evaluate human behaviour more accurately, optimize design performance, and promote evidence-based decision-making throughout the architectural design process. Consequently, the adoption of virtual architectural environments within Lagos State has considerable potential to improve user satisfaction, design quality, and sustainable built environment development while advancing the broader digital transformation of the Architecture, Engineering, and Construction (AEC) industry.

Implications for Sustainable Architecture, Smart Cities, and Future Architectural Practice

The synthesis of the reviewed literature demonstrates that virtual architectural environments have become a critical component of sustainable architecture and smart city development by enabling evidence-based design, enhancing stakeholder collaboration, and improving decision-making throughout the building lifecycle. The integration of immersive technologies such as Virtual Reality (VR), Building Information Modelling (BIM), Digital Twins, Artificial Intelligence (AI), and Augmented Reality (AR) has transformed conventional architectural practice into a data-driven and user-centred process. These digital innovations enable architects to evaluate building performance, human behaviour, environmental quality, and spatial functionality before construction, thereby minimizing design errors, reducing material waste, and promoting sustainable resource utilization. Liu et al. (2023) observed that the convergence of BIM, immersive technologies, and Digital Twins represents a significant advancement in Construction 4.0, facilitating intelligent building management, lifecycle optimization, and digital transformation across the Architecture, Engineering, and Construction (AEC) sector. These findings indicate that immersive technologies are no longer supplementary visualization tools but essential components of modern architectural practice. A major implication identified in the reviewed studies is the contribution of virtual architectural environments to sustainable design and environmental performance. Sustainable architecture requires careful consideration of energy efficiency, daylight utilization, thermal comfort, ventilation, indoor environmental quality, and lifecycle performance during the early stages of project development. Immersive technologies enable architects to simulate these environmental parameters within realistic virtual settings, allowing multiple design alternatives to be evaluated before physical implementation. Khan et al. (2021) reported that BIM-integrated VR improves project planning, interdisciplinary collaboration, and environmental analysis while reducing construction waste and design conflicts. Similarly, Stabryła and Grudzińska (2025) demonstrated that smartphone-enabled BIM-VR applications improve client understanding of

architectural proposals, reduce design revisions, and support more efficient decision-making, thereby contributing to resource conservation and sustainable project delivery. Such findings reinforce the role of immersive technologies in advancing environmentally responsible architectural practice. The reviewed literature further highlights the importance of virtual architectural environments in supporting smart city development. Smart cities rely on digital technologies to optimize infrastructure, transportation systems, public services, environmental management, and citizen engagement. Immersive architectural platforms provide urban planners and policymakers with powerful tools for evaluating land-use alternatives, transportation networks, public spaces, housing developments, and infrastructure projects within interactive virtual environments. According to Fan et al. (2026), immersive visualization technologies, including head-mounted displays and CAVE systems, enhance collaborative urban planning by enabling multidisciplinary stakeholders to evaluate complex urban environments collectively. For rapidly urbanizing cities such as Lagos, these technologies facilitate informed planning decisions while strengthening public participation and improving urban resilience. Their integration into smart city initiatives can therefore enhance the quality, efficiency, and sustainability of future urban development projects. Another important implication concerns the transformation of architectural education and professional practice. Digital transformation within the global AEC industry increasingly requires architects to possess competencies in BIM, VR, AR, Digital Twins, computational design, and AI-assisted architectural workflows. Immersive technologies have consequently become valuable educational tools that enable architecture students and professionals to develop spatial reasoning, design evaluation skills, and collaborative problem-solving capabilities through experiential learning. Yu et al. (2022) emphasized that immersive virtual environments improve multidisciplinary collaboration by creating shared digital workspaces where architects, engineers, contractors, and clients can evaluate design alternatives simultaneously. Likewise, Paes et al. (2023) demonstrated that increased spatial presence within immersive virtual environments enhances users' confidence in architectural evaluation and supports more informed design decisions. These developments suggest that future architectural education in Nigeria should incorporate immersive technologies into curricula to prepare graduates for the digital demands of contemporary professional practice.

Within the specific context of Lagos State, the adoption of virtual architectural environments presents considerable opportunities for addressing persistent urban development challenges. Lagos continues to experience rapid population growth, increasing housing demand, transportation congestion, environmental degradation, and expanding infrastructure requirements. Immersive technologies provide government agencies, architects, urban planners, developers, and local communities with opportunities to evaluate proposed developments collaboratively before construction. Such participatory planning processes improve transparency, reduce project risks, strengthen stakeholder confidence, and ensure that architectural solutions respond effectively to users' functional, cultural, and environmental needs. Furthermore, Digital Twin technologies integrated with BIM can support infrastructure monitoring, predictive maintenance, disaster preparedness, and facility management, thereby improving the long-term resilience of public infrastructure throughout the state. Despite these opportunities, the literature identifies several challenges that must be addressed to achieve widespread implementation. Liu et al. (2023) and Khan et al. (2021) observed that barriers including high technology costs, inadequate digital infrastructure, limited interoperability, insufficient professional training, and institutional resistance continue to constrain adoption, particularly within developing countries. In Nigeria, additional challenges include inconsistent electricity supply, limited investment in research and innovation, inadequate government policies supporting digital construction, and shortages of skilled professionals capable of implementing immersive technologies effectively. Addressing these constraints requires coordinated investment in digital infrastructure, professional education, research funding, institutional capacity building, and policy frameworks that encourage technological innovation within the construction industry. The findings also reveal a significant research gap concerning empirical investigations of human spatial perception within immersive architectural environments in Nigeria. While international scholarship has extensively examined VR applications in architecture, relatively few studies have explored how Nigerian users perceive, navigate, and evaluate virtual architectural spaces within culturally and socially diverse urban environments such as Lagos. Future research should therefore employ quantitative, qualitative, and mixed-method approaches to investigate user behaviour across different demographic groups, building typologies, and immersive technologies. Such empirical

evidence would provide architects and policymakers with context-specific insights capable of improving user-centred design strategies and supporting sustainable urban development. Overall, the reviewed evidence indicates that virtual architectural environments represent a transformative innovation capable of reshaping architectural practice, urban planning, and infrastructure development in Lagos State and across Nigeria. Studies by Liu et al. (2023), Khan et al. (2021), Yu et al. (2022), Paes et al. (2023), Stabryła and Grudzińska (2025), and Fan et al. (2026) consistently demonstrate that immersive technologies enhance sustainability, stakeholder engagement, collaborative decision-making, and evidence-based architectural design. Consequently, their integration into architectural practice offers a strategic pathway toward achieving resilient built environments, smart city development, and human-centred design while strengthening the global competitiveness of Nigeria's Architecture, Engineering, and Construction industry.

CONCLUSION

The rapid advancement of immersive digital technologies has fundamentally transformed architectural design, planning, and project delivery by enabling architects and other built environment professionals to evaluate buildings from a human-centred perspective before physical construction. This study examined the role of virtual architectural environments in enhancing spatial perception and human experience within the built environment, with particular emphasis on the rapidly urbanising context of Lagos State, Nigeria. Drawing upon contemporary literature on Virtual Reality (VR), Building Information Modelling (BIM), Augmented Reality (AR), Digital Twins, and environmental psychology, the study demonstrated that immersive technologies provide substantial opportunities for improving architectural visualization, design communication, stakeholder engagement, and evidence-based decision-making throughout the building lifecycle. The review established that virtual architectural environments significantly enhance users' spatial perception by providing realistic, interactive, and full-scale simulations of proposed architectural spaces. Unlike conventional two-dimensional drawings and static three-dimensional renderings, immersive virtual environments enable users to experience architectural spaces through natural navigation, real-time interaction, and stereoscopic visualization. Consequently, architects, clients, engineers, planners, and end users develop more accurate understanding of spatial dimensions, circulation systems, environmental quality, accessibility, and functional relationships. As reported by Paes et al. (2017; 2023) and Ji et al. (2023), immersive visualization improves spatial cognition, user confidence, and design evaluation while facilitating more informed architectural decision-making. The study further demonstrated that human experience has become an essential indicator of architectural quality. Buildings should no longer be assessed solely according to structural performance or visual aesthetics but also according to how occupants perceive, navigate, and emotionally respond to architectural environments. The integration of immersive VR with BIM enables architects to evaluate user behaviour, spatial presence, environmental comfort, wayfinding, and accessibility during the design stage. Studies by Yu et al. (2022) and Abdelsalam et al. (2023) further indicate that immersive collaborative environments strengthen communication among multidisciplinary stakeholders, thereby reducing misunderstandings, improving design quality, and encouraging participatory planning. From the perspective of Lagos State, the findings reveal considerable opportunities for integrating virtual architectural environments into urban development initiatives. As one of Africa's fastest-growing megacities, Lagos continues to experience rapid population growth, infrastructure expansion, housing shortages, transportation challenges, and increasing environmental pressures. The application of immersive technologies provides architects, planners, government agencies, developers, and local communities with practical tools for evaluating design alternatives, improving public participation, and supporting sustainable infrastructure development. Furthermore, the integration of Digital Twins, BIM, and immersive visualization can improve facility management, infrastructure monitoring, predictive maintenance, and long-term urban resilience. Despite these significant opportunities, the review also identified important implementation challenges that continue to affect the adoption of immersive architectural technologies in Nigeria. High hardware and software costs, inadequate digital infrastructure, inconsistent electricity supply, limited institutional support, insufficient professional training, and the absence of comprehensive national digital construction policies remain major constraints. Addressing these barriers requires coordinated efforts among

government agencies, professional bodies, higher education institutions, software developers, and private-sector stakeholders to strengthen technological infrastructure, research capacity, digital literacy, and policy implementation. Such interventions will accelerate the digital transformation of Nigeria's Architecture, Engineering, and Construction (AEC) industry while improving international competitiveness. A notable contribution of this study is its contextualization of global advancements in immersive architectural technologies within the socio-economic and urban development realities of Lagos State. While existing international literature provides substantial evidence regarding the effectiveness of VR and BIM in enhancing spatial perception and human experience, empirical investigations focusing specifically on Nigerian users and architectural projects remain limited. This study therefore highlights an important research gap concerning the influence of cultural, behavioural, institutional, and technological factors on users' experiences within virtual architectural environments in developing countries. Future studies should employ quantitative, qualitative, and mixed-method research designs involving architects, planners, construction professionals, policymakers, and building users across Lagos State to validate the conceptual relationships identified in this review. Conclusively, virtual architectural environments represent a transformative innovation capable of reshaping architectural practice, urban planning, and sustainable infrastructure development within Nigeria. Their integration into professional practice supports human-centred design, improves stakeholder collaboration, enhances spatial perception, reduces design uncertainties, and facilitates evidence-based decision-making. As emphasized by Liu et al. (2023), Khan et al. (2021), Ji et al. (2023), Yu et al. (2022), Paes et al. (2023), and Fan et al. (2026), immersive technologies are becoming indispensable components of Construction 4.0 and smart city development. Therefore, wider adoption of these technologies in Lagos State will not only improve architectural quality and user satisfaction but also contribute significantly to sustainable urban development, resilient infrastructure, and the realization of Nigeria's digital transformation agenda within the built environment.

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INTERSECTIONS OF RELIGION AND CULTURE IN CONTEMPORARY SOCIAL LIFE

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ABSTRACT

This study explores how religion and culture interact as dynamic forces shaping identity, social behaviour, and collective meaning-making in diverse communities. The aim is to examine how religious practices influence cultural norms and how cultural contexts reinterpret religious traditions over time. The objectives are to analyze patterns of continuity and change, identify points of tension or negotiation, and highlight how individuals use religious and cultural resources to construct a sense of belonging. The study's summary shows that religion and culture cannot be separated; rather, they operate as mutually reinforcing systems. The literature review draws on classical and contemporary scholarship in anthropology, sociology of religion, and cultural studies, noting that scholars such as Clifford Geertz and Talal Asad emphasize the symbolic, interpretive, and power-laden dimensions of religious life. Recent studies also highlight migration, digital communication, and globalization as factors accelerating cultural transformation. The method used is qualitative documentary analysis, examining texts, community narratives, and cultural artifacts to trace how religious meanings are expressed, adapted, or contested. The results indicate that religious rituals often serve as cultural anchors, while cultural change encourages reinterpretation of religious norms. Findings show that communities negotiate identity through hybrid practices that blend tradition with modernity. The outcome demonstrates that religion remains a vital cultural resource, offering moral frameworks, emotional support, and social cohesion. Its relevance lies in helping educators, policymakers, and community leaders understand how cultural diversity and religious pluralism shape contemporary societies. The conclusion affirms that studying religion and culture together provides deeper insight into human behaviour and social transformation. It also suggests that future research should examine digital religious expression and intercultural dialogue as emerging sites of cultural negotiation.

Keywords: religion, culture, identity.

INVESTIGATING THE ASSOCIATION BETWEEN C-REACTIVE PROTEIN AND CHRONIC KIDNEY DISEASE IN PATIENTS WITH TYPE TWO DIABETES MELLITUS: A cross sectional study

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ABSTRACT

Background: Type 2 Diabetes Mellitus (T2DM) is a leading cause of chronic kidney disease (CKD) worldwide. Chronic inflammation has been implicated in the development and progression of diabetic kidney disease, with C-reactive protein (CRP) serving as an important inflammatory biomarker. However, evidence on the relationship between CRP and CKD among patients with T2DM in Cameroon remains limited.

Objectives: This study aimed at investigating the association between CRP and CKD among patients with T2DM attending the Buea Regional Hospital.

Methods: A hospital-based cross-sectional study was conducted among 125 patients with T2DM. Socio-demographic and clinical data were collected using structured questionnaires. Blood samples were analyzed for fasting blood glucose, glycated hemoglobin, CRP, urea, and creatinine, while eGFR was calculated using a standard equation. Data was analyzed using descriptive statistics and Pearson's correlation, with significance set at $p < 0.05$.

Results: Majority of participants were females (86.4%) and aged 60–83 years (48.0%). Poor glycemic control was common, with a mean fasting blood glucose of 167.50 mg/dL and mean HbA1c of 7.52%. Positive CRP was observed in 35.2% of participants. The mean urea, creatinine, and eGFR values were 37.0 mg/dL, 0.98 mg/dL, and 77.96 mL/min/1.73 m², respectively. Correlation analysis showed weak, non-significant associations between CRP and urea ($r = 0.049$), creatinine ($r = -0.041$), and eGFR ($r = -0.098$) (all $p > 0.05$).

Conclusion: Approximately one-third of patients with T2DM had elevated CRP levels, while renal function was generally preserved. No significant association was found between CRP and CKD biomarkers, suggesting that CRP alone may not be a useful predictor of renal impairment in this study population. Further longitudinal studies with larger sample sizes are recommended.

Key words: Type 2 Diabetes Mellitus, C-reactive protein, Chronic kidney disease, Creatinine, Urea, eGFR.

INVESTIGATION OF THE EFFECT OF UV CURING ON TEMPARARY DENTAL RESINS PRODUCED VIA PHOTOPOLYMERIZATION BASED STEREOLITHOGRAPHIC ADDITIVE MANUFACTURING IN DENTISTRY

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GİRİŞ

Giriş ve Amaç: Eklemeli imalat teknolojisi, malzemelerin katman katman eklenmesiyle nihai ürünün oluşturulduğu modern bir üretim yöntemidir. Otomotiv, tıp, havacılık ve diş hekimliği gibi birçok sektörde kullanımı giderek artmaktadır. Hızlı üretim, karmaşık geometrilerin üretilebilmesi, düşük malzeme atığı ve yüksek mekanik özellikler sağlaması gibi avantajları sayesinde önemli bir üretim teknolojisi haline gelmiştir. Üretim sonrasında uygulanan UV kürleme işlemi, polimerizasyonun tamamlanmasını sağlayarak malzemenin mekanik özelliklerinin iyileşmesine katkı sağlamakta, ancak reçinede meydana gelen hacimsel büzülme nedeniyle nihai boyutlarda değişikliklere neden olmaktadır. Bu çalışmanın amacı, SLA yöntemiyle üretilen geçici dental reçine numunelerine üretim sonrası uygulanan UV kürleme işleminin boyutsal doğruluk üzerindeki etkisini değerlendirmektir.

Materyal ve Yöntem: Çalışmada, 10 mm çap ve 20 mm yükseklik ölçülerine sahip geçici dental reçine numuneleri SLA teknolojisi kullanılarak aynı üretim parametreleri ve dikey baskı yönünde üretilmiştir. Boyutsal doğruluk, numunelerin çap ve boy ölçülerinin dijital kumpas ile belirlenmesi ve elde edilen değerlerin tasarım ölçüleriyle karşılaştırılması yoluyla değerlendirilmiştir.

Bulgular: Her iki grupta da tasarım ölçülerine göre boyutsal sapmalar tespit edilmiştir. UV kürleme işlemi sonrası çapta büzülme meydana gelmiştir. Buna karşılık, ortalama numune boyu kürlenmemiş grupta 18,78 mm iken UV kürleme sonrasında 19,17 mm'ye ulaşarak tasarım ölçüsüne daha yakın sonuçlar elde edilmiştir.

Tartışma ve Sonuç: Elde edilen bulgular, UV son kürleme işleminin SLA yöntemiyle üretilen dental reçinelerin boyutsal davranışı üzerinde önemli bir etkiye sahip olduğunu göstermektedir. Kürleme işlemi çap yönünde ilave büzülmeye neden olurken, boy yönünde boyutsal kararlılığı artırmış ve yüzey bütünlüğünü olumsuz etkilememiştir.

Anahtar Kelimeler: Eklemeli imalat, Fotopolimerizasyon, Dental reçine, Boyutsal doğruluk

ABSTRACT

Introduction and Purpose: Additive manufacturing is a modern manufacturing method in which materials are deposited layer by layer to produce a final product. It has been increasingly adopted in various fields, including the automotive, medical, aerospace, and dental industries. Owing to its advantages such as rapid production, the ability to fabricate complex geometries, reduced material waste, and improved mechanical properties, it has become an important manufacturing technology. Post-processing UV curing enhances the completion of polymerization, thereby improving the mechanical properties of the material. However, volumetric shrinkage occurring during curing may lead to dimensional changes in the final product. The aim of this study was to evaluate the effect of post-processing UV curing on the dimensional accuracy of temporary dental resin specimens fabricated using stereolithography (SLA).

Materials and Methods: Temporary dental resin specimens with dimensions of 10 mm in diameter and 20 mm in height were fabricated using SLA technology under identical printing parameters and in a

vertical build orientation. Dimensional accuracy was evaluated by measuring the diameter and height of the specimens with a digital caliper and comparing the obtained values with the original design dimensions.

Results: Dimensional deviations from the design dimensions were observed in both groups. Following UV curing, shrinkage occurred in the specimen diameter. In contrast, the mean specimen height increased from 18.78 mm in the uncured group to 19.17 mm after UV curing, resulting in dimensions that were closer to the intended design values.

Discussion and Conclusion: The findings demonstrate that post-processing UV curing has a significant effect on the dimensional behavior of SLA-fabricated dental resin specimens. While the curing process caused additional shrinkage in the diameter, it improved dimensional stability in the height direction and did not adversely affect surface integrity.

Keywords: Additive manufacturing; Photopolymerization; Dental resin; Dimensional accuracy

GİRİŞ

Sanayi devrimi ile başlayan teknolojik gelişmelere her geçen gün yenileri eklenmeye başlamıştır. Günümüzde, torna, frezeleme, döküm, kaynak gibi geleneksel üretim yöntemlerinin yerini eklemeli imalat teknolojisi almaktadır. Bu değişimin en önemli nedeni, üreticiye sunmuş olduğu avantajlardır. Amerikan Test ve Malzeme Derneği (ASTM International) AM'yi geleneksel talaş kaldırmalı imalat yöntemlerinin aksine, 3B tasarlanan model verilerinden nesneler oluşturmak için genellikle katman katman malzeme birleştirme işlemi olarak tanımlamaktadır (ASTM International, 2012)

Eklemeli imalat yönteminin (Eİ) sağladığı avantajlar şu şekilde sıralanabilir (Özer, G., 2020);

- Parçaların kişiye özgü üretimini sağlar
- Üretim süresini kısaltır
- Tasarım sürelerini kısaltır
- Kalıp ihtiyacını ortadan kaldırır
- Atık malzeme miktarını azaltır
- Karmaşık yapıda ki malzemelerin üretimini kolaylaştırır

Fotopolimerizasyon tabanlı eklemeli imalat yöntemlerinde temel üretim malzemesi olarak ultraviyole (UV) ışığa duyarlı sıvı reçineler ve fotopolimerler kullanılmaktadır. Bu malzemeler, belirli dalga boyundaki UV ışınlarına maruz kaldıklarında fotokimyasal bir reaksiyon başlatarak katılaşmaktadır. Reaksiyon sırasında reçine içerisinde bulunan fotobaşlatıcılar UV enerjisini absorbe eder ve polimer zincirlerinin oluşumunu sağlayan çapraz bağlanma mekanizmasını tetikler. Bu kimyasal sertleşme mekanizması literatürde **fotopolimerizasyon** olarak adlandırılmaktadır. (Gıbson vd., 2015). Fotopolimerizasyon yöntemi, stereolitografi (SLA), direk ışık işleme (DLP) ve sürekli ışık işleme (CDLP) olmak üzere üç ana başlık altında incelenmektedir.

Stereolitografi (SLA), sıvı halde bulunan fotopolimer reçinenin ultraviyole (UV) lazer ışını kullanılarak seçici biçimde katılaştırılması esasına dayanan eklemeli imalat yöntemlerinden biridir. Bu yöntemde katmanlar ardışık olarak oluşturularak üç boyutlu parçalar elde edilir. Yüksek boyutsal hassasiyet sağlaması, karmaşık geometrilere sahip parçaların üretimine olanak tanıması ve geleneksel üretim yöntemlerine kıyasla kısa üretim süreleri sunması nedeniyle birçok endüstriyel alanda yaygın olarak tercih edilmektedir. Ayrıca geniş fotopolimer malzeme seçeneğine sahip olması ve prototip ile fonksiyonel parçaların düşük maliyetle üretilebilmesi, SLA teknolojisinin önemli avantajları arasında yer almaktadır (Ngo vd., 2018).SLA teknolojisinde, sıvı fotopolimer reçine ile doldurulmuş bir hazne ve bu hazne içerisinde dikey eksende hareket eden bir üretim platformu yer almaktadır. Üretim platformu, polimerize edilecek reçinenin yüzeyinin hemen altında konumlanır. Bilgisayar kontrollü lazer ışını, dijital modelin kesit geometrisine uygun olarak sıvı reçineyi seçici biçimde polimerize eder. Bir katmanın tamamlanmasının ardından üretim platformu, önceden belirlenen katman kalınlığı kadar aşağı hareket eder ve yeni katmanın oluşmasını sağlar. Bu işlem, model tamamen üretilinceye kadar tekrarlanır. (Çelik vd., 2013).

Eklemeli İmalat Kullanım Alanları

Eklemeli imalat teknolojileri, son yıllarda gösterdiği hızlı gelişim sayesinde birçok endüstriyel ve bilimsel alanda yaygın olarak kullanılmaya başlanmıştır. Bu teknoloji; tıp, diş hekimliği, otomotiv, havacılık ve uzay, kalıpçılık, askeri uygulamalar, mimarlık, kuyumculuk, eğitim, heykelcilik, kişisel ürün tasarımı ve gıda sektörü gibi farklı alanlarda üretim süreçlerine önemli katkılar sağlamaktadır (Özsoy ve Duman, 2017).

Havacılık endüstrisinde eklemeli imalat teknolojilerinin tercih edilmesinin başlıca nedenleri; üretim süresini azaltması, üretim maliyetlerini düşürmesi ve hava araçlarında kullanılan parçaların ağırlığını azaltarak performansa katkı sağlamasıdır (Huang ve diğ., 2016).

Mimarlık ve inşaat sektöründe ise karmaşık geometrilere sahip yapı elemanlarının üretilebilmesi, eklemeli imalat yöntemlerinin kullanım alanının artmasını sağlamıştır. Yapı inşasında kullanılan kalıpların üretimi de bu yöntemlerle gerçekleştirilebilmektedir (Özer, 2020). Ayrıca farklı geometrik yapılara sahip yapıların üretilebilmesi amacıyla birçok firma araştırma ve geliştirme faaliyetleri yürütmektedir. Bu çalışmalar sonucunda üç boyutlu üretime uygun farklı malzemeler, kompozit karışımlar, çeşitli üretim sistemleri ve farklı nozul tasarımları geliştirilmiştir (Çalışkan vd., 2020).

Eklemeli imalat teknolojileri eğitim alanında da önemli bir yere sahiptir. Bu teknoloji, tasarım ve üretim eğitiminde öğrencilerin temel tasarım derslerinden başlayarak ileri düzey bitirme projelerine kadar uzanan süreçte kullanılan öğretim araçlarından biri haline gelmiştir (Stamper ve ark., 2000; Lantada ve ark., 2010).

Biyomedikal uygulamalarda eklemeli imalat teknolojileri; tıbbi görüntüleme, cerrahi planlama, doku mühendisliği ve tıbbi cihaz üretimi gibi birçok farklı alanda kullanılmaktadır. Özellikle polimer esaslı malzemelerin tercih edildiği kardiyovasküler uygulamalarda kullanımının giderek arttığı görülmektedir. Ayrıca doğumsal kalp hastalıklarının tedavisinde kullanılan hasta özel implantların ve tedaviye yönelik cihazların tasarlanması ile üretilmesinde de bu teknolojiden yararlanılmaktadır (Saito, 2005). Biyouyumlu malzemeler kullanılarak gerçekleştirilen canlı doku üretimi, kan damarı oluşturulması, diş implantları ve kişiye özel medikal protezlerin geliştirilmesi de eklemeli imalat teknolojilerinin biyomedikal alandaki önemli uygulamaları arasında yer almaktadır (Jammalamadaka ve Tappa, 2018).

Günümüzde diş hekimliğinde kullanılan eklemeli imalat yöntemleri temel olarak fotopolimerizasyon tabanlı sistemler ile toz bazlı üretim teknolojileri olmak üzere iki ana grupta değerlendirilmektedir. Fotopolimerizasyon esaslı SLA, DLP ve MJM yöntemlerinde ışığa duyarlı reçineler ile metal veya seramik dolgu malzemeleri içeren fotopolimerler kullanılmaktadır. Bu teknolojiler sayesinde kuron, köprü, kaplama, sabit protez altyapıları, dental modeller, cerrahi kılavuzlar ve ortodontik apareyler gibi birçok dental ürün yüksek hassasiyetle üretilebilmektedir (Liaw ve Guvendiren, 2017).

MATERYAL YÖNTEM

Dental reçinelerin üretiminde diş protezi uygulamaları için özel olarak geliştirilen Alias Dental Denture model ürün kullanılmıştır. Bu çalışmada kullanılan reçine, diş protezleri uygulamalarında geniş bir kullanım alanına sahip olması, biyo-uyumlu olması ve iyi mekanik özelliklere sahip olması nedeniyle tercih edilmiştir. Üretici firmanın geliştirmiş olduğu dental reçinenin mekanik ve fiziksel özellikleri Tablo 1'de verilmiştir.

Tablo 1. Dental reçinenin fiziksel ve mekanik özellikleri

Fiziksel Özellikler	**İlgili Standart**	**Değer**
Maksimum Gerilme (MPa)	ISO 178	60
Elastsite Modülü (GPa)	ISO 178	2,49
Kopma Uzaması (%)	ISO 178	5
Shore D	ISO 7619-1	92
HDT (°C)	ISO 75-1	110

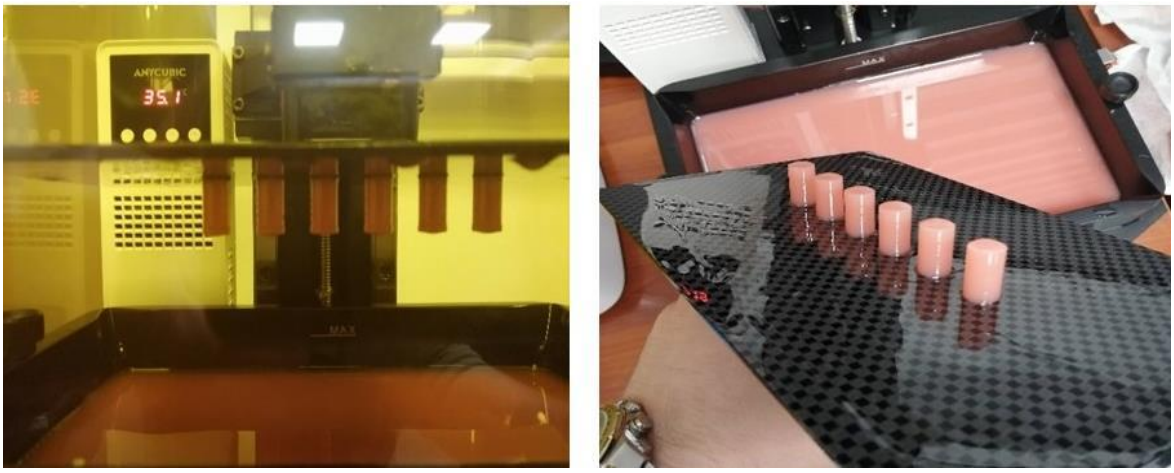
3B Baskı Çalışması

Planlanan çalışma için ilk olarak, üretimi yapılacak olan test numunelerinin boyutlarının 10 mm çapında ve 20 mm yüksekliğe sahip olması gerektiği belirlenmiştir. Bu değerler belirlenirken, mevcut literatüre uyumluluk esas alınmıştır. Diş numuneleri Anycubic Photon Mono M5S model yazıcı kullanılarak üretilmiştir. Yazıcıya ait görsel Şekil 1' de paylaşılmıştır.



Şekil 3. Numune üretiminde kullanılan yazıcının görüntüsü

Ardından, bilgisayar destekli katı model tasarım yazılımı olan Siemens NX programı ile ilgili katı modeller oluşturulmuştur. Akabinde, ilgili yazıcı marka ve modeline uygun olarak Anycubic Photon Workshop yazılımına aktarılarak Slicer yazılımı ile G kodları oluşturulmuştur. Oluşturulan dosya, katmanlı üretimin başlaması için SLA tip üretim yapabilen 3B yazıcı makinesine aktarılmıştır. Dental diş numunelerinin üretimine ait görsel Şekil 2'de paylaşılmıştır.



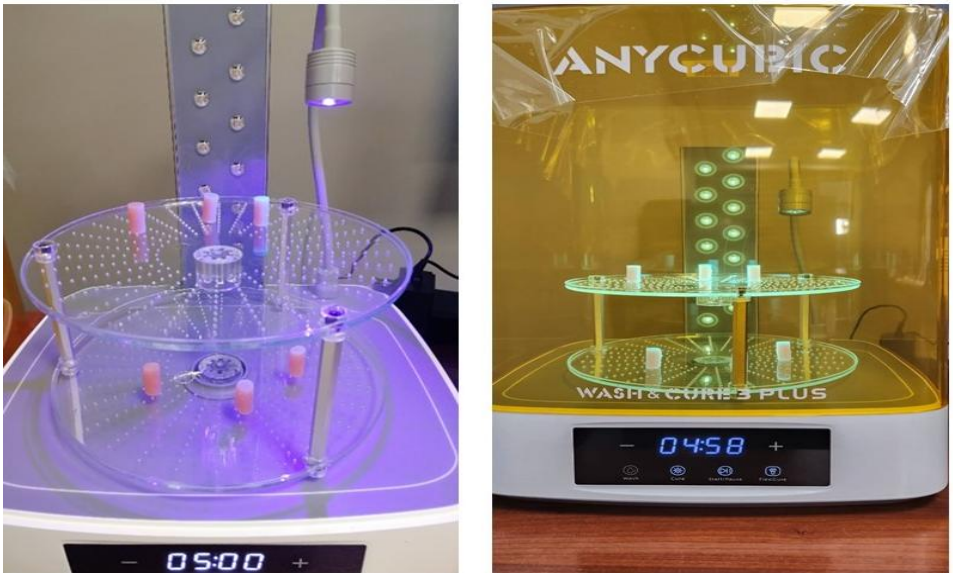
Şekil 4. SLA yazıcıda üretilen dental diş numuneleri

Şekil 3'de gösterildiği gibi üretimi tamamlanan test numunelerine kürleme işlemi uygulanacağından, baskı sonrası yüzeyde kalan reçine kalıntılarının giderilmesi, yüzey kalitesinin arttırılması ve kürleme işleminin tam sağlıklı olması için numuneler izopropil alkol (%99) ile yıkanmıştır. Her bir numune grubu yıkama makinesinde yaklaşık 5 dakika yıkanmış ve sonrasında hava ile kurutulmuştur.



Şekil 5. Üretim sonrası numunelerin izopropil alkol ile yıkanma prosesi

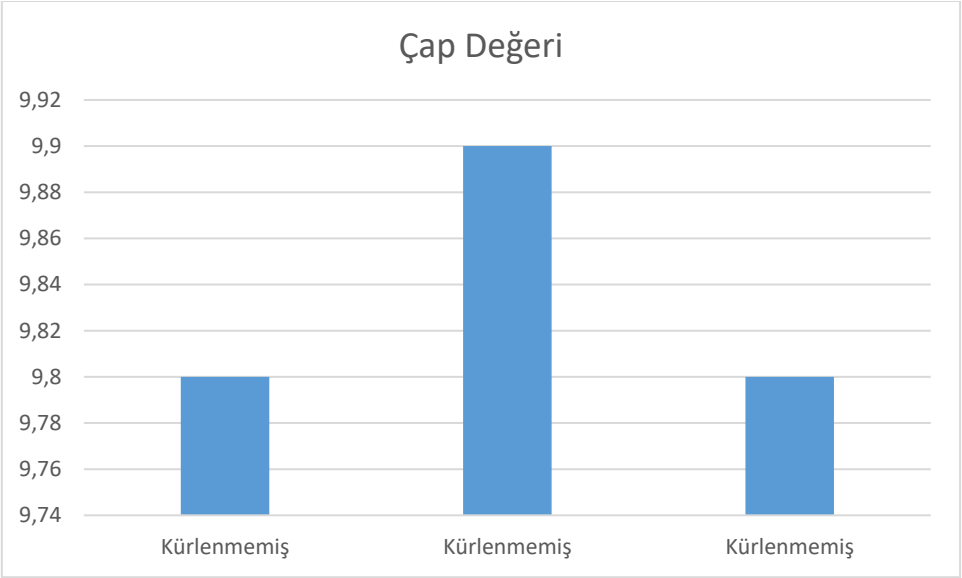
Yıkaması tamamlanan test numuneleri Anycubic Wash ve Cure 3 Plus kürleme makinesinde işleme alınmış, üretilen her altılı kombinasyon ki numunelerin üç tanesine ilave UV kürleme işlemi uygulanmıştır. UV kabinin içerisinde tüm numuneler, kabin tabanına dik olacak şekilde yerleştirilmiş ve ortalama 5 dakika boyunca ikincil kürleme işlemi yapılmıştır. Kürleme işlemine ait görsel Şekil 4'de verilmiştir.



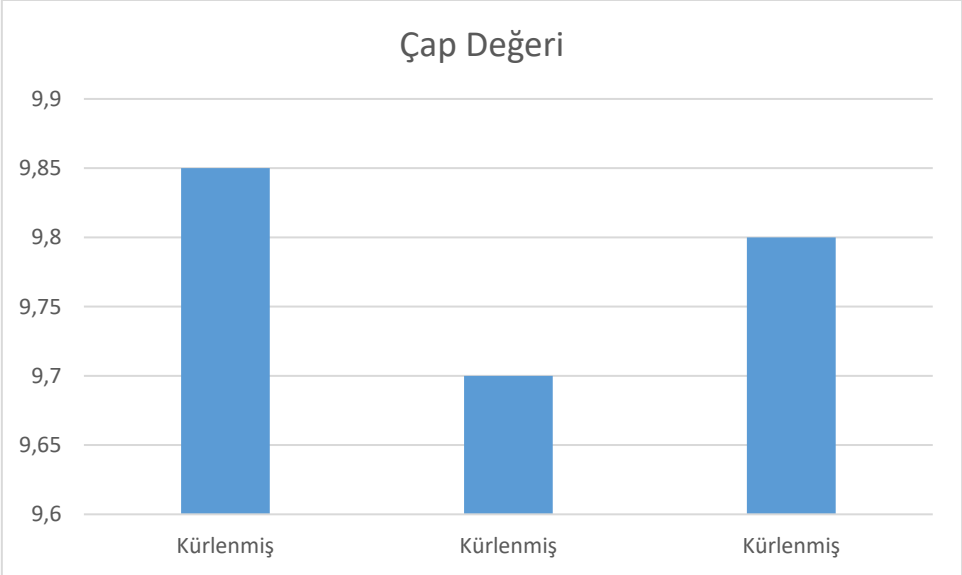
Şekil 6. Dental numunelerin ilave UV kürleme işlemi

BULGULAR

Üretimi yapılan 10x20 mm boyutlarında ki dental numuneler, taban platformundan ayrıldıktan sonra fiziksel yapı ve boyutsal açıdan görsel olarak incelenmiştir. Yapılan bu kontrollerde, üretim sonrasında ve kürleme işlemi sonunda numunelerin yüzey bütünlüklerinin sağlandığı görülmüştür. Numunelerin dış yüzeylerinde üretim hatasına işaret edebilecek belirgin bir delik, boşluk, çatlak veya yüzey süreksizliği tespit edilmemiştir. Yapısal kontrolleri sağlanan numuneler daha sonrasında, boyutsal doğruluk açısından değerlendirilmiştir. Boyutsal doğruluk çıktı değişkenleri olarak numune çapı ve numune yüksekliği parametreleri seçilmiştir. Şekil 5' de üretimi yapılan numunelere ait üretim sonrası ve Şekil 6'da UV kürleme işlemi sonrası çap değerleri ve Şekil 7'de numunelerin üretim sonrası ve Şekil 8'de uygulanan UV kürleme sonrası değişen boy değerleri verilmiştir.



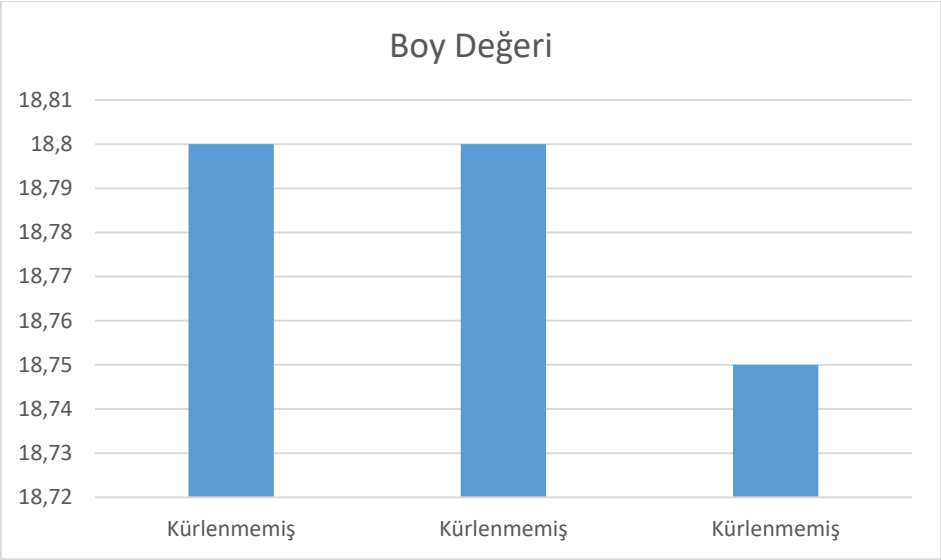
Şekil 7. Üretim sonrası ölçülen çap değerleri



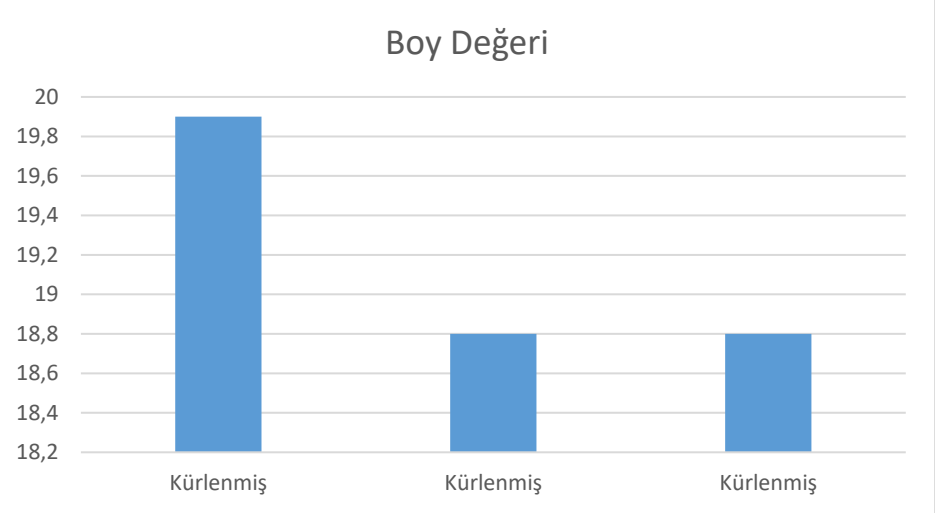
Şekil 8.Test numunelerinin ilave UV kürleme sonrası çap değerleri

Şekil 3'de verilen ölçüm sonuçları incelendiğinde, tasarım ölçüleri 10 mm çap ve 20 mm boy olarak belirlenen SLA yöntemiyle üretilmiş dental reçine numunelerinde hem kürlenmiş hem de kürlenmemiş gruplarda boyutsal sapmalar meydana geldiği görülmektedir. Kürlenmiş numunelerde ortalama çap değeri 9,78 mm olarak ölçülmüştür. Kürlenmemiş numunelerde ise ortalama çap değeri 9,83 mm olarak belirlenmiştir.

Elde edilen sonuçlar, UV kürleme işleminin numunelerin boyutsal özellikleri üzerinde etkili olduğunu göstermektedir. Çap ölçümleri açısından değerlendirildiğinde, kürlenmiş numunelerde nominal değere göre ortalama 0,22 mm (%2,17) küçülme meydana gelirken, kürlenmemiş numunelerde bu sapma ortalama 0,17 mm (%1,67) olarak gerçekleşmiştir. Bu durum, UV kürleme sonrasında fotopolimer reçinenin polimerizasyon reaksiyonunun devam etmesi ve buna bağlı olarak hacimsel büzülme oluşması ile açıklanabilir.



Şekil 9. Üretim sonrası ölçülen boy değerleri



Şekil 10.Test numunelerinin ilave UV kürleme sonrası boy değerleri

Boy ölçümleri incelendiğinde ise kürlenmiş numunelerin ortalama boyunun 19,17 mm, kürlenmemiş numunelerin ise 18,78 mm olduğu görülmektedir. Tasarım boyu olan 20 mm'ye göre değerlendirildiğinde, kürlenmiş numunelerde ortalama 0,83 mm (%4,17) kısalma meydana gelirken, kürlenmemiş numunelerde bu değer 1,22 mm (%6,08) olarak hesaplanmıştır. Bu sonuçlar, UV kürleme işleminin çap yönünde ilave büzülmeye neden olmasına rağmen, boy yönünde ölçülerin daha kararlı hale gelmesini sağladığını göstermektedir.

Numuneler arasındaki değişkenlik incelendiğinde, kürlenmiş grupta çap ölçümlerinin 9,70–9,85 mm arasında, boy ölçümlerinin ise 18,80–19,90 mm arasında değiştiği görülmektedir. Kürlenmemiş grupta ise çap ölçümleri 9,80–9,90 mm, boy ölçümleri 18,75–18,80 mm aralığında gerçekleşmiştir. Özellikle kürlenmiş numunelerde boy ölçülerindeki farklılıkların daha yüksek olması, ikincil UV kürleme sırasında numunelerin konumlanması, ışık yoğunluğunun dağılımı ve reçinenin iç yapısında meydana gelen ilave çapraz bağlanma reaksiyonlarından kaynaklanabilir.

SONUÇ VE ÖNERİLER

Bu çalışmada, SLA (Stereolitografi) yöntemi kullanılarak üretilen dental reçine numunelerinde UV kürleme işleminin boyutsal doğruluk üzerindeki etkisi araştırılmıştır. Tasarım ölçüleri 10 mm çap ve 20 mm boy olarak belirlenen numuneler, kürlenmiş ve kürlenmemiş olmak üzere iki grup halinde

değerlendirilmiştir. Yapılan ölçümler sonucunda, her iki gruptaki numunelerin de tasarım ölçülerinden belirli oranlarda sapma gösterdiği tespit edilmiştir. Kürlenmiş numunelerde ortalama çap değeri 9,78 mm, kürlenmemiş numunelerde ise 9,83 mm olarak ölçülmüştür. Buna göre UV kürleme işlemi sonrasında çap yönünde yaklaşık 0,05 mm ilave küçülme meydana gelmiştir. Boy ölçümleri incelendiğinde ise kürlenmiş numunelerde ortalama boy değeri 19,17 mm, kürlenmemiş numunelerde ise 18,78 mm olarak belirlenmiştir. Sonuçlar, UV kürleme işleminin çap ölçülerinde ek büzülmeye neden olmasına rağmen boy ölçülerinde daha kararlı sonuçlar elde edilmesini sağladığını göstermektedir. Numunelerin tamamında yüzey bütünlüğünün korunduğu, üretim sonrasında veya kürleme işlemi sonrasında herhangi bir çatlak, boşluk veya belirgin yüzey kusuru oluşmadığı gözlemlenmiştir. Bu durum, kullanılan reçine malzemesinin ve belirlenen üretim parametrelerinin başarılı bir üretim süreci sağladığını göstermektedir.

Genel olarak değerlendirildiğinde, SLA yöntemi ile üretilen tüm numunelerin tasarım ölçülerine oldukça yakın sonuçlar verdiği, ancak üretim sonrası uygulanan UV kürleme işleminin boyutsal doğruluk üzerinde belirgin bir etkisinin bulunduğu belirlenmiştir. Elde edilen bulgular, fotopolimer esaslı reçinelerde kürleme sürecinin yalnızca mekanik özellikleri değil, aynı zamanda nihai ürünün boyutsal hassasiyetini de etkileyen kritik bir işlem basamağı olduğunu göstermektedir. Bu nedenle hassas ölçü toleranslarının gerekli olduğu dental uygulamalarda, kürleme sonrası oluşabilecek boyutsal değişimlerin tasarım aşamasında dikkate alınması önerilmektedir.

Gelecekte yapılacak çalışmalarda farklı kürleme sürelerinin, farklı UV ışık şiddetlerinin ve farklı reçine türlerinin boyutsal doğruluk üzerindeki etkilerinin araştırılması önerilmektedir. Ayrıca farklı baskı yönleri, katman kalınlıkları ve geometrilere sahip numuneler kullanılarak boyutsal değişimlerin daha kapsamlı şekilde incelenmesi, SLA teknolojisinin hassas üretim uygulamalarındaki performansının daha iyi anlaşılmasına katkı sağlayacaktır. Özellikle dental uygulamalar gibi yüksek boyutsal hassasiyet gerektiren alanlarda, kürleme sonrası meydana gelen ölçü değişimlerinin tasarım aşamasında dikkate alınması ve gerekli toleransların belirlenmesi tavsiye edilmektedir.

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AN ANALYSIS OF BIRD STRIKES AT JOHN F. KENNEDY INTERNATIONAL AIRPORT

JOHN F. KENNEDY ULUSLARARASI HAVALİMANININ KUŞ ÇARPMALARI AÇISINDAN İNCELENMESİ

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ÖZET

Havacılık endüstrisinde uçuş emniyetini doğrudan tehdit eden yaban hayatı karşılaşmaları, özellikle sulak ve otluk alanlara komşu olan havalimanlarında ciddi operasyonel riskler barındırmaktadır. Bu araştırmada, Jamaika Körfezi'nin sunduğu zengin habitat nedeniyle yoğun bir kuş popülasyonuna ev sahipliği yapan John F. Kennedy (JFK) Uluslararası Havalimanı'ndaki çarpışma vakaları incelenmiş ve uçuş parametrelerinin bu olaylar üzerindeki etkisi ekonometrik olarak değerlendirilmiştir. Çalışma kapsamında Amerikan Federal Havacılık Dairesi (FAA) veri tabanından 1990-2025 dönemine ait 6.456 bildirim taranmış; eksik kayıtlar ile kara hayvanları dışlanarak analize elverişli 1.044 adet sayma verisi üzerinden modelleme yapılmıştır. Veri setinde varyansın ortalamadan yüksek çıkması (aşırı yayılım) sebebiyle geleneksel Poisson modeli yerine Negatif Binom regresyon analizi tercih edilmiştir. Elde edilen bulgular, irtifa ile kuş çarpmaları arasında istatistiksel açıdan anlamlı ($p < 0,01$) ve negatif yönlü bir ilişki bulunduğunu; irtifada yaşanacak her 1.000 feet'lik (304,8 m) artışın çarpma riskini logaritmik olarak yaklaşık %20,5 oranında düşürdüğünü kanıtlamaktadır. Ayrıca vakaların büyük çoğunluğunun gece saatlerinde, son yaklaşma safhasında ve 120-180 knot hız aralığında kümelendiği görülmüştür. Bu doğrultuda, havalimanı çevresindeki biyolojik riskleri en aza indirmek adına Standart Terminal Varış Rotası (STAR) prosedürlerinin gözden geçirilmesi; uçakların alçak irtifada uzun süre süzülmek yerine yüksek irtifayı son ana kadar koruyup dik ve kademeli bir alçalışla piste yaklaşmalarını sağlayacak operasyonel düzenlemelerin hayata geçirilmesi politika önerisi olarak sunulmaktadır.

Anahtar Kelimeler: Kuş Çarpması, Havacılık Güvenliği, JFK Havalimanı, Negatif Binom Regresyonu, STAR Prosedürleri

JEL Kodları: L93, R41, C25

ABSTRACT

Wildlife encounters pose a persistent and critical threat to aviation safety, particularly at airports situated in close proximity to wetlands and natural habitats. This study investigates bird strike incidents at John F. Kennedy (JFK) International Airport—a location highly exposed to avian hazards due to the surrounding Jamaica Bay Wildlife Refuge—and econometrically evaluates how specific flight parameters influence collision rates. Drawing from the Federal Aviation Administration (FAA) Wildlife Strike Database for the 1990–2025 period, a total of 6,456 incident reports were screened. After excluding incomplete entries and terrestrial animal strikes, 1,044 valid count data observations were utilized for empirical modeling. Because the dataset exhibited overdispersion, where the variance significantly exceeded the mean, a Negative Binomial regression model was adopted over standard Poisson regression to evaluate speed and altitude variables. The analytical results confirm a statistically

significant ($p < 0.01$) negative relationship between altitude and bird strikes, demonstrating that every 1,000-foot (304.8 m) increase in altitude logarithmically reduces collision frequency by approximately 20.5%. Furthermore, the data reveals that collisions are heavily clustered during the final approach phase, at night, and within the 120–180 knot speed bracket. Based on these findings, it is recommended to revise Standard Terminal Arrival Route (STAR) procedures; implementing steeper descent profiles that allow aircraft to maintain higher altitudes until the final stages of landing—rather than gliding at low altitudes and speeds for extended periods—offers a strategic operational policy to mitigate wildlife hazards.

Keywords: Bird Strike, Aviation Safety, JFK Airport, Negative Binomial Regression, STAR Procedures

JEL Codes: L93, R41, C25

GİRİŞ

Havacılık endüstrisi artan globalleşme, zaman yönetimi ve ekonomiklik gibi faktörlere bağlı olarak büyümektedir. İnsanların ulaşım tercihlerinin havayolu taşımacılığı yönünde değişmesi, havayolu ile kargo, yük taşımacılığının yaygınlaşması ve maliyetlerinin düşmesi ile birlikte sektör hızlı büyüme trendi göstermiştir. Global ticari hava taşımacılığı uçak filosu 30,9 bin uçak ile faaliyet göstermektedir. Önümüzdeki on yıllık süreçte filo uçak sayılarında %38'lik büyüme ile 42,8 bin uçak sayısına ulaşılması beklenmektedir (IATA MCC Conference Hanoi 2023).

Dolayısıyla havacılık endüstrisi öngörüldüğü üzere büyüme yönelimine hız kaybetmeden devam edeceği gerçeği sarsılmaz niteliktedir. Bu gelişmeler ışığında askeri ve sivil hava faaliyetlerinin ve trafiğinin artması uçuş emniyet ve güvenliğinin daha titiz ve örgütlü bir biçimde yönetilmesi ihtiyacını beraberinde getirmektedir. Uçuş güvenliğini doğrudan etkileyen ve giderek büyüyen etki faktörlerden biri de gökyüzündeki artan yaban yaşam karşılaşmalarıdır.

Literatüre "bird strike", "bird ingestion" gibi tanımlamalarla giren kuş çarpmaları, yüksek hızla ilerleyen bir hava aracının kuş veya kuş sürüleri ile ani gerçekleşen, uçak gövde ve komponentlerine hasar veren havacılık ve uçuş olaylarıdır (Çoban 2017).

Kuş çarpmaları sivil havacılık endüstrisine yıllık 1,2 milyar doları aşan maliyetlere sebep olmakta[1] ve bu hadiseler uçuş ekibinden yolculara ve yer ekipmanlarına kadar zarar verebilmektedir.[2]

Hava taşımacılığının tarihsel gelişimine bakıldığında jet motorlu uçak teknolojisine geçiş ile birlikte kuş çarpması vakalarının kayda değer bir şekilde arttığı ve ele alınması gereken bir güvenlik unsuru olarak ortaya çıktığı bilinmektedir. Pervaneli motorlara sahip uçak tiplerinde üretilen yüksek titreşim ve ses sebebiyle bu uçaklar hava sahalarında ve göç yollarındaki kuşlar tarafından daha kolay fark edilebilmekte ve jet motorlu uçaklara kıyasla düşük süratle seyretmesi bakımından hayvanlar tarafından kaçınma manevraları ile çarpışmadan kurtulma imkânı tanımaktaydı.

Ancak bahse konu sektörel büyüme, hava araçlarının değişen endüstri dinamikleri ve taleplerine göre yeniden tasarlanmasına ve bununla beraber daha yüksek emiş, sıkıştırma, itiş güçlü ve geniş hava alıklı motorların, yakıt, uçuş verimliliği ve aerodinamiğinin iyileştirilmesi için ise kompozit gövde yüzeylerinin daha yaygın halde kullanılmasına sebep olmuştur.

Bu bağlamda hayata geçen ve yeniden şekillenen hava araçları kendileri ile aynı hava sahasını paylaşan canlılar ile daha fazla çarpışma yaşamakta, gelişmiş malzeme teknolojisi ile üretilen yeni satıhların çarpmalar vasıtasıyla aldıkları hasarlar ile yüksek maliyetlere sebep olmaktadır.

Kuş çarpmalarına hava aracı etki faktörlerinde olduğu üzere mevsimsel, meteorolojik, topoğrafik ve konumsal etmenleri gibi etki edici diğer faktörler de bulunmaktadır.

Dünya nüfusu her geçen gün artmaktadır. Bununla beraber şehirler büyümekte, yaşam alanları kırsal alanlara doğru genişlemektedir. Dünya nüfusunun 2026 yılı itibari ile 8,3 milyar olduğu, yıllık %0,84 oranında büyüdüğü ve %58,5'nun kentsel yaşamı tercih ettiği düşünüldüğünde şehirlerdeki kırsala doğru büyümenin devam edeceği, yaban yaşamın sahip olduğu alanları işgal edeceği ve bir anlamda o yaşama komşu olacağı öngörülen ve gerçekleşen bir gerçektir.

Şehir merkezine nispeten yakın olmayan ancak kırsal alanlar üzerine kurulan havalimanları sulak, otluk alanlar gibi yaban yaşama komşu alanlarda hizmet vermekte ve halihazırda kuş çarpmaları gibi hadiselere sebep olmaktadırlar.

Bahse konu büyüyen şehirler artan nüfus ile bu havalimanlarına zaman içerisinde yaklaşmakta ve şehrin tam ortasında yer alacak şekilde şehir ile bütünleşmektedirler.
Böylelikle nüfusa bağlı artan şehir atıkları, sürekli gıdaya ulaşım gibi sebepler bu alanları cephe göçü yapan veya üreme döneminde olan kuşlar için cazibe merkezi olmakta ve bazı türler için bulunmaz habitat özellikler barındırmaktadır.
Bu sebeplerden ötürü havacılık endüstri için havalimanı yerleşkeleri hayati önem arz etmekte ve her geçen gün kuş çarpmalarını önlenmesi bakımından artan yönetimsel faaliyetlere ihtiyaç duyulmaktadır.
Yoğun uçuş faaliyetleri gerçekleştirmesi, şehir merkezinde bulunması ve yaban yaşam alanlarına komşu olması gibi benzer özellikler barındırması bakımından irdelendiğinde Amerika Birleşik Devletleri'nin New York eyaletinde bulunan ve ülkenin en yoğun havalimanlarından biri olan John F. Kennedy Uluslararası Havalimanı kuş çarpmalarının incelenmesi, analiz edilmesi ve önlenmesi gibi faaliyetler bakımından ele alınması ve üzerinde durulması gereken havalimanlarından biri olarak öne çıkmaktadır.
John F. Kennedy Uluslararası Havalimanı bu bağlamda pek çok akademik araştırmaya konu olmuş ve halihazırda konu olmaya ve dikkat çekmeye devam etmektedir.
Araştırma John F. Kennedy Uluslararası Havalimanını kuş çarpmaları açısından dikkat çekici ve örnek teşkil eden özellikleri bakımından incelemeye tabi tutmayı, gerçekleşen çarpışmalar üzerinden ise de istatistiksel ve matematiksel bulgular ile soruna ışık tutmayı amaçlamaktadır.

LİTERATÜR TARAMASI

1963 yılına kadar Idlewild Havalimanı olarak anılan ve ABD'nin 35. Başkanı John F. Kennedy'in öldürülmesi sonrası bugünkü ismini alan ve New York'un üç büyük havalimanından biri olan John F. Kennedy Uluslararası Havalimanı spesifik konumu, hava trafik yoğunluğu ve kuş çarpmalarının incelenmesi bakımından literatürde makalelere konu olmaktadır.
Havalimanı Jamaika körfezinin hemen bitişiğinde konumlanmaktadır. Jamaika Körfezi, New York eyaleti Long Island'ın batı ucunun güney kısmında konumlanmaktadır. Körfez 51,80 km² büyüklü ile 325'den fazla kuş türüne ev sahipliği yaptığı, tuzlu bataklıklar, yüksek rakımlı tarlalar ve ormanlar, tatlı su göletleri ve acı su göletleri dahil olmak üzere habitat çeşitliliğiyle bilinmektedir.[3]
Yapılan çalışmalarda havalimanının 1970 yılından itibaren JFKIA kodu ve 14CFR139 numaralı Amerikan havacılık dairesi regülasyonu ile aktif bir şekilde kuşların yeme, içme ve havalimanında vakit geçirilme yönelimleri bakımından uzun otların korunması ve su toplanma alanların bertaraf edilmesi, araçlı kuş devriyelerinin gezdirilmesi gibi cesaret kırıcı önlemler alan kuş mücadele programına dahil olduğunu, ancak tüm bu çabalara rağmen martı türleri için havalimanı üzerinden uçuşun önüne geçilemediği, martı türleri tarafından beslenme ve zaman geçirme alanları olarak kullanılmaya devam edildiği 1979 yılında 15 olan yuva sayısının 1990 yılında 7.629 yuvaya çıktığı ifade edilmektedir.
Çalışmada 1991-1998 yılları arası dönemde mayıs ağustos ayları boyunca havalimanı üzerinden uçuş gerçekleştiren martıları 2-5 kişilik bir ekip tarafından vurulmasını içeren bir program yürütüldüğü, program dahilinde 55.452 martının vurulduğunu ve 1991-1995 dönemi için yıllık çarpma sayılarının ortalama 68,4'e düştüğü 1988-1990 döneminde gerçekleşen yıllık ortalama 259,7 sayısına oranla ise %74'lük düşüşün sağlandığını ortaya koymaktadır. Ancak deneysel süreç boyunca martı türleri azalırken diğer türlere bağlı çarpışma sayılarının arttığına değinilmekte, şahincilik ve tüfekle vurma faaliyetleri ile birlikte uygulandığında ise anlamlı düzeyde bir değişimin yaşanmadığı, martı yuvalarının havalimanından koloni olarak taşınması içeren fiziki önlemlerin alınmasına ihtiyaç duyulduğu vurgulanmaktadır.[4]
Çalışmalar John F. Kennedy Uluslararası Havalimanını etrafında bulunan çöp toplama ve geri dönüşüm tesislerinin kuşlar için cazibe merkezi haline gelmesi kuş çarpmalarının sıklığını ve etkisini arttırdığını, 13 kilometre karelik bir alanın uçuş emniyeti açısından kritik olduğunu ve çalışmaların John F. Kennedy Uluslararası Havalimanını etrafında bulunan 20 yapının kuş çarpmalarının artmasında rol oynadığını ortaya koymaktadır.[5]
Yapılan bir diğer çalışmada havalimanı çevresindeki yaban yaşam cazibesini azaltmak için çeşitli analizler gerçekleştirilmiş, mum defnesi olarak anılan çalılık türü bitki meyvesinin ağaç kırlangıçları için mevsimsel besin kaynağı olduğu, pistlerin 800 metre yakınındaki bu çalılıkların bertaraf edilmesiyle tekil ağaç kırlangıcı kuş çarpması sayılarında %75, çoklu çarpmalarda ise %92 oranlarında azalmanın meydana geldiği ortaya konmuştur.[6]

Kuş çarpmalarının incelenmesi ve önlenmesi için alınan tedbirler, geliştirilen teknolojiler ve uygulamaya sokulan regülasyonlar ne kadar sıkı ve zorunlu olsa da kuş çarpmaları hızla artmaya devam etmektedir. Çarpışmaların daha iyi analiz edilebilmesi olayların doğru, zamanında ve tam olarak raporlanması vasıtasıyla mümkün olmaktadır yapılan çalışmalar Amerika Birleşik Devletleri (ABD) genelinde kuş çarpması vakalarının yalnızca %75'nin raporlandığını, John F. Kennedy Uluslararası Havalimanını gerçekleşen inceleme faaliyetlerinde ise raporlanmamış kuş çarpması olaylarının %86,8 gibi yüksek oranlarda seyrettiğini gözler önüne sermektedir.[7]

Jamaika körfezinin bitişiğinde konumlanması bakımından John F. Kennedy Uluslararası Havalimanı çok sayıda kuş türüne ev sahipliği yaptığı bilinmektedir. Martı popülasyonun azaltma ve kuş çarpmalarını önleme amaçlı gerçekleştirilen tüfekle vurma ve şahincilik gibi aktif önlemlerin sorunu tamamen ortadan kaldırmadığı, kuş yuvalarının da bertaraf edilmesi gerektiğine daha önce vurgu yapılmıştı, yapılan başka bir çalışmada ise 300 adet Kanada kazına boyun halkası takılıp iki yıl boyunca izlemeye alındığı, kazların %78'nin John F. Kennedy Uluslararası Havalimanının 8 km'lik yakın çevresinde yer aldığını, kuş çarpması sebepli kazaların önlenebilmesi, azaltılması için söz konusu kuş türlerine ait yuvaların ve embriyoların yok edilmesi gerektiği ortaya konmaktadır.[8]
John F. Kennedy Uluslararası Havalimanında 1986 yılından beri uygulanan çimleri biçmeme ve uzun bırakma stratejisinin başarılı sonuçlar vermediği, uzun çimli alanlarda yapılan gözlemlerde biçilmiş alanlara nispeten 5 dakikalık periyotlarda daha fazla kuş görüldüğü, biçilmeyen uzun çimli alanların, kuşlar ve küçük memeliler için daha fazla koruma ve besin kaynağı sağladığı, bu durumun da yaban hayatı popülasyonunu mevsimsel olarak artırdığı başka bir araştırma sonucu ortaya konmaktadır.[9] John F. Kennedy uluslararası havalimanında kullanılan ve çimlik alanları habitat haline getiren kuş türleri için kullanılan otların biçilmediği demode tekniğin halihazırda olumlu etki yaratması beklenirken uzun bırakılan otlar sayesinde yaban yaşamı cezbedecek canlı türlerini barındırabileceği ve acilen bu eski sistemin bırakması gerektiği, havalimanı yerleşkesindeki çim ve otluk alanların 15 ila 25 cm yükseklikte sürekli biçilmiş halde tutmasının stratejik olarak otlak alanlardaki kuş ve küçük memeli yoğunluğunu azaltacağı sonuçlarına varılmaktadır.[9]

VERİ SETİ

1990-2025 yıllarını kapsayan dönem incelendiğinde John F. Kennedy uluslararası havalimanında gerçekleşen 6.456 adet çarpma incelenmiştir. Bu süreçte 204 farklı kuş türünün raporlarda yer aldığı görülmektedir.

Tablo 1 Raporlanan Kuş Türleri

TÜR	**SAYI**
Herring gull	678
Unknown bird	575
Laughing gull	574
Unknown bird - medium	456
Unknown bird - small	344
American kestrel	259
Barn swallow	203
Horned lark	183
American barn owl	169
Mourning dove	155
American robin	130
European starling	125
Osprey	119
Rock pigeon	118
Peregrine falcon	103
Gulls	96

Great black-backed gull	90
Ring-billed gull	78
Snow bunting	69
Brown-headed cowbird	65
Killdeer	63
Mallard	62
Brant	53
Canada goose	51
Snowy owl	51
Tree swallow	51
Yellow-rumped warbler	51
American oystercatcher	46
Double-crested cormorant	45
Gray catbird	44
Northern harrier	44
Black-crowned night heron	39

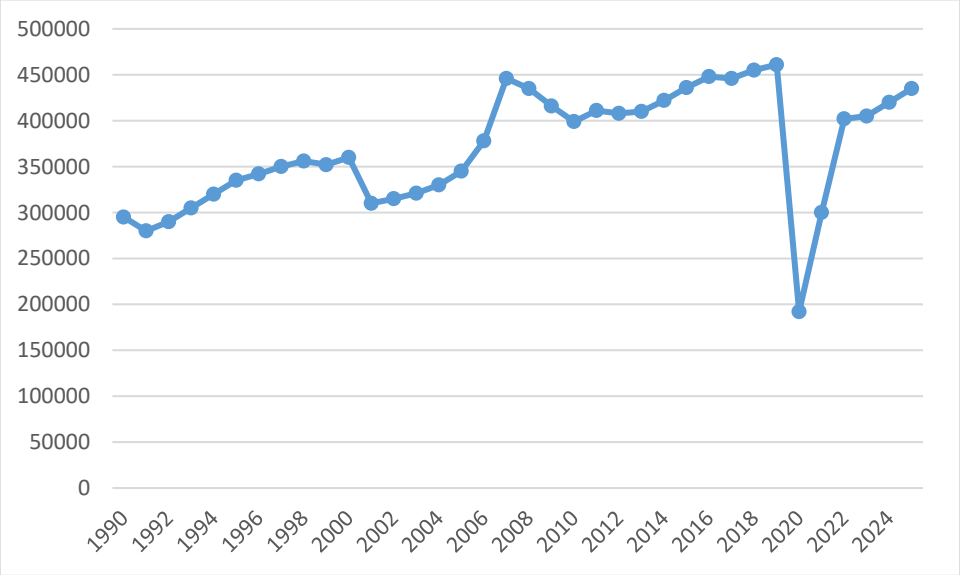
35 yıllık periyot içerisinde raporlanan kuş çarpmalarından tekrarlanma sıklığı bakımından incelendiğinde John F. Kennedy uluslararası havalimanında gerçekleşen tüm çarpmaların %80'nini oluşturan ve sıralandığında oluşan liste tablo 1'de verilmiştir.

Verilerden hareketle en sıklıkla raporlarla konu olan kuş türünün kuzey gümüş martısı olarak bilinen Kuzey Amerika, Avrupa ve Asya kıyılarında görülen iri gövdeli bir martı türü olan Herring gull martısı olduğu sonucuna ulaşılmaktadır. 678 çarpma ile tüm çarpmalara %10,5 oranlık dilimde yer aldığı dolayısıyla her on çarpmadan birinin bu tür hayvan ile gerçekleştiği anlaşılmaktadır. Ancak tüm martı türleri tek tür olarak ele alındığında 6.456 adet olan toplam çarpma arasında 1.542 ile %23,88'i gibi kayda değer bir orana sahip olduğu martı türlerinin John F. Kennedy Uluslararası Havalimanı özelinde ciddi ölçüde uçuş ve yer emniyet riski oluşturduğu anlaşılmaktadır.

Bilinmeyen "Unknown" etiketi ile raporlanan çarpmaların ise toplamda 1.413 raporda yer aldığı genele oranla %21,88 oranına sahip olduğu görülmektedir. Kuş çarpmalarının önlenmesi ve havalimanı çevresindeki yaban yaşam ile mücadele edilebilmesi, türlerin popülasyonun azaltılması gibi eylemlerin verimliliğinin artırılması ancak kuş türlerinin tam olarak bilinmesi yoluyla mümkün olmaktadır. Dolayısıyla bilinmeyen adıyla yaşanan çarpma verilenin istatistiksel olarak bilgi ihtiva ettiği ancak kuş çarpmalarının önlenmesine yönelik yapılan çalışmalara yeterli katkıyı sağlamayacağı değerlendirilmektedir. Pek çok raporda adı geçen bir diğer tür ise kırlangıçlardır "swallow" tür ismiyle incelendiğinde ise toplamda 262 adetle %4,05'lik payı temsil ettiği görülmektedir. Küçük gövdeli yapıları gereği herhangi bir pilot tarafında kuş çarpmalarında raporlanmadığı durumlarda bile pistte onlarca ölü kırlangıcın bulunduğu, 3 Ekim 1997 tarihinde 163 adet ağaç kırlangıcının pistte ölü halde bulunduğu ancak o gün herhangi bir kuş çarpması hadisesinin raporlanmadığı, 30 Eylül 1995 Boeing 737 uçağına 100 adet kırlangıcın çarptığı raporlandığı, geleneksel kuş çarpması önleme yöntemlerinin kırlangıç türü özelinde yetersiz kaldığı bilinmektedir.[6]

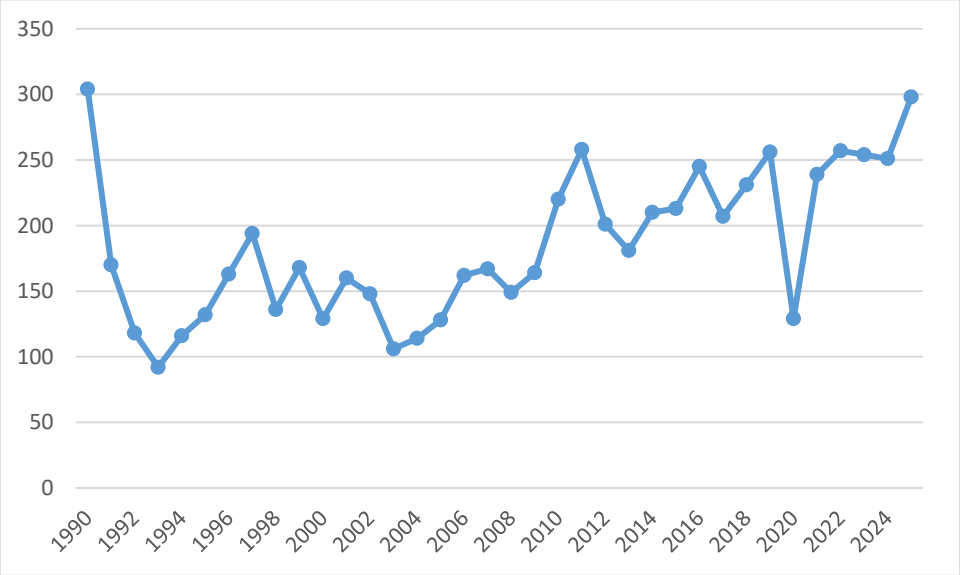
Bu bağlamda çarpışma sayılarına bakılmaksızın kırlangıç türlerinin kuş çarpması risk analizi kapsamında önemli risk çarpanı olduğu ve titizlikle ele alınması gerektiği değerlendirilmektedir.

Grafik 1 1990-2025 Dönemi Taşınan Yolcu Sayıları



Grafik 1 John F. Kennedy uluslararası havalimanında 35 yıllık dönem içerisinde taşınan yolcu sayılarını göstermektedir. Verilerden hareketle yolcu sayılarında dönemsel kırılmalara rağmen istikrarlı bir yükseliş devam etmektedir. Havacılık sektörünü durma noktasına getiren 2020 yılı pandemi verileri sektörün uzun yıllar araştırma ve tartışma konusu olmaya devam edecektir. Pandemi öncesi yolcu sayılarına halihazırda yetişilmemesine rağmen artış eğilimi devam ettiği görülmektedir. 2025 yılı itibariyle havalimanına 435.000 yolcu uçuşu gerçekleştirilmiştir. 35 yıl içerisinde ise 13.331.000 adet yolcunun taşındığı görülmektedir. Bu dönem içerisinde ortalama yıllık 370.305 yolcu sayısına ulaşılmıştır. Sayıların büyüklüğüne bakıldığında yüzbinlerce yolcunun taşınması beraberinde binlerce uçuş ve yer operasyonunu getirmektedir. Havadaki uçak sayısının artması kuş çarpmalarının artması ile doğru orantılı olduğundan sektördeki büyüme çarpmaları doğrudan etkilemektedir. Dolayısıyla hava trafiğinin artışı ile beraber kuş çarpmalarının önlenmesine yönelik organizasyonlarında aynı ağırlıkta devam etmesi gerekmektedir.

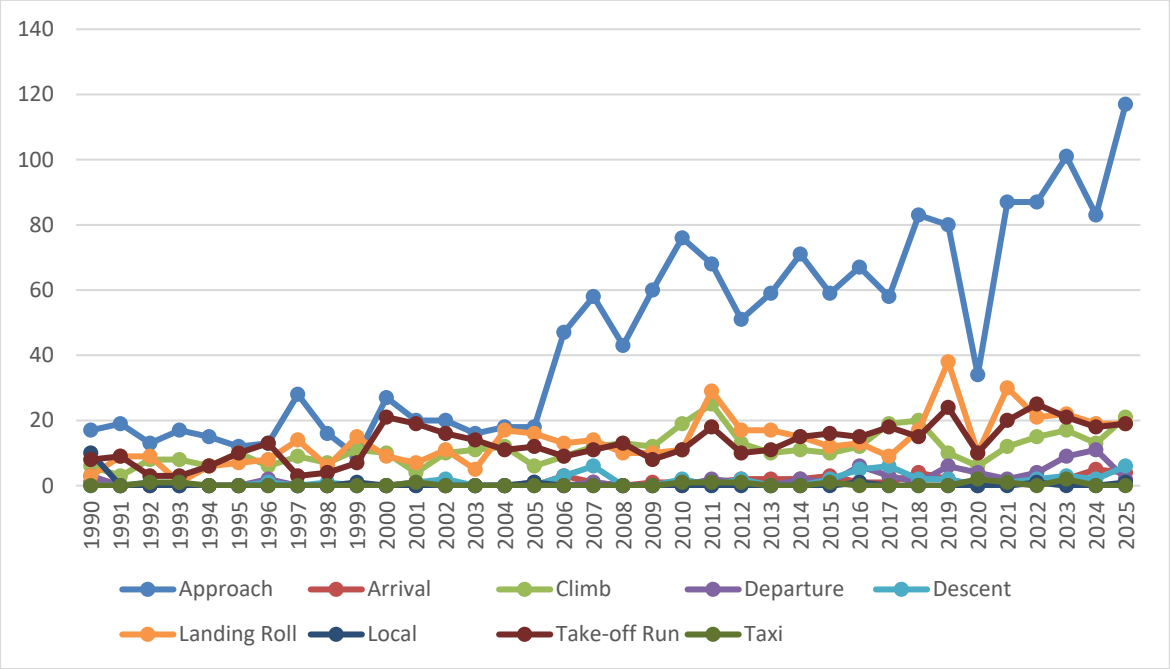
Grafik 2 1990-2025 Dönemi Taşınan Yolcu Sayıları



Grafik 2'de havalimanında yaşanan yıllara göre kuş çarpması dağılımı verilmektedir. Grafik incelendiğinde 1990 yılında rapor edilen 304 adet çarpma ile son 35 yılın en yüksek değerinin taşınan yolcu sayısı 1990 yılına kıyasla %67,8 oranında artmasına rağmen geçilmemiştir. Bu dikkat çekici değişiklik yukarıda detaylı açıklanan ve 1991-1995 dönemi başlatılan tüfekle mücadele ve şahincilik faaliyetleri ile anlamlı hale gelmektedir.

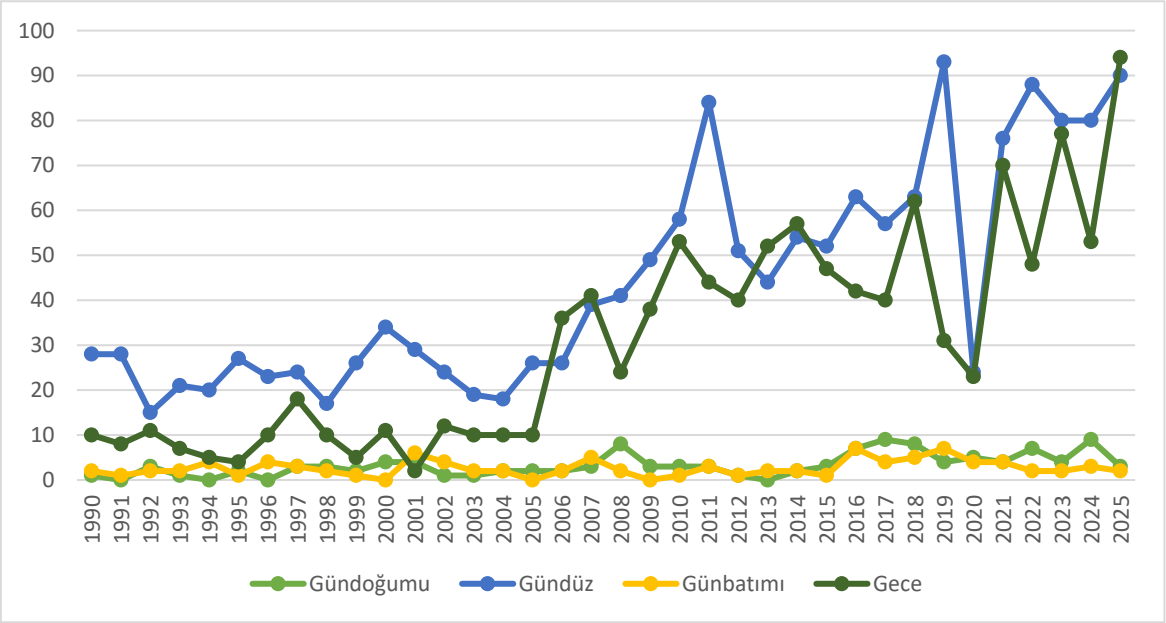
Programın sonlanması ile sayıların 2025 yılı itibariyle 298 çarpma ile yeniden 1990 yılı seviyelerine geldiği ve ilerleyen süreçlerde artarak devam edeceği düşünülmektedir.

Grafik 3: John F. Kennedy Uluslararası havalimanı uçuş safhalarına göre çarpma grafiği



John F. Kennedy Uluslararası havalimanının çarpmalar tasnif edildiğinde uçuş safhaları arasında en çok çarpışmanın yaklaşma esnasında gerçekleştiği görülmektedir, grafik 2'de verilen taşınan yolcu verilerine bakıldığında yaklaşma grafiği ve yolcu grafiğindeki benzerlik dikkat çekmektedir. Uçakların iniş öncesi uyguladıkları son yaklaşma profili belli bir hız, irtifa ve belirli mesafeden pist başının karşılanması ile icra edilmektedir. Söz konuşu pistin karşılanması ve merdiven diyagramı gibi irtifa azaltmalı iniş prosedürleri uçağın tehlikeli irtifalarda daha çok seyretmesine sebep olmakta ve bu sebeple yaklaşma safhası çarpışmalarında yaşanan hadiselerin yüksek olduğu değerlendirilmektedir. Safha verileri incelendiğinde 2025 yılı itibariyle 2005 yılında gerçekleşen çarpma sayısı toplamının yaklaşık 6,5 katına ulaşıldığı görülmektedir. Dolayısıyla John F. Kennedy Uluslararası Havalimanının 2005 yılı sonrası kuş çarpmaları açısından özel olarak ele alınmalı ve havalimanı ve çevresi, kuşların göç ve habitat alanları gibi hususlar tekrar araştırılmalıdır. Grafikte okunan 2005 yılı ve sonrası gibi ani kırılım dönemleri, havalimanı yönetimi ve kuş çarpmalarını önleme çalışmaları için büyük önem arz etmekte ve ilerleyen süreçlerde sektöre bu bağlamda ışık tutabilmektedir.

Grafik 4: John F. Kennedy Uluslararası havalimanı vakaların zaman dilim grafiği



Grafik 4'de sunulan grafik incelendiğinde John F. Kennedy Uluslararası Havalimanı için gece ve gündüz çarpma vakalarının birbirine benzer özellikler gösterdiği her iki zaman dilimi için de pandemi öncesi çarpma sayılarına ulaşıldığı anlaşılmaktadır. Gündüz yaşanan çarpmalarda 2004 – 2011 yılları arasında belirgin bir artış görülürken gece yaşanan çarpmalarda yıllar içerisinde inişli çıkışlı bir grafik izlese de artan bir yönelimin istikrarlı bir şekilde devam ettiği, 2005 yılı itibari ile ise de anlamlı bir biçimde artış yöneliminde olduğu, anlaşılmaktadır. Artan gece çarpmalarının diğer zaman dilimlerine göre yüksek risk taşıdığı, gelişmiş radar sistemleri dışında pist ve meydan aydınlatmaların yetersiz kalmaları durumunda çarpma risklerinde önemli ölçüde artışların yaşanabileceği dolayısıyla Havaalanı yönetimi ve federal havacılık dairesince gerekli emniyet tedbirlerinin, caydırıcı ve önleyici tedbirlerin alınması ve uygulanması önem arz etmektedir.

METODOLOJİ

John F. Kennedy Uluslararası Havalimanı özelinde analize konu tüm veriler FAA yaban hayatı çarpışma veri tabanlarından çekilmiştir. Çarpışma hız ve irtifa bilgileri barındırmayan çarpışma bilgileri ve kara hayvanları ile gerçekleşen çarpışmalar dışlandığında 1044 adet çarpma verisi elde edilmektedir. Bu veriler kuş çarpmalarının önüne geçilebilmesi ve literatüre bakış açısı kazandırabilmek için kullanılacaktır.

Veri tabanından elde edilen bilgiler içerisinde hız, irtifa, koordinat, günün dilimi, uçuş safhaları, saat, tarih, uçak tipi, rapor numarası vb gibi verilere yer verilmektedir. Bu verilerden hareketle istatistik olarak günün dilimi, mevsimsel çarpma, çarpışmaların uçuşun hangi safhalarında en çok yaşandığı gibi sorulara cevap verilebilmektedir. Matematiksel olarak ele alınabilecek tek veri hız, irtifa ve bunlar ile birlikte çarpma sayıları olacaktır.

Regresyon analizi

Tanımlı bir süreç dahilinde yürütülen gözlemler sonucunda bir olayın meydana gelme adedi sayma verisi özelliği taşımaktadır ve bunlara sayma verileri denmektedir.[10]

Sayıma dayalı yapılacak regresyon analizlerinde ise Poisson regresyon analiz modeli yaygın olarak tercih edilen bir yöntemdir. Gözlemlenen değişkenler arasında var olan ilişkilerin istatistiksel olarak test edilmesini ve yapısal olarak modellenmesini sağlayan analiz yöntemine regresyon analizi denmektedir.

Negatif bir değer almayan ve ondalık bir değere sahip olmayan doğal sayma sayıları için poisson

regresyonu en uygun model olarak öne çıkmaktadır. Modelin üstel olması ve veri setindeki olayların ortalaması ile varyansı birbirine eşit olması zorunluluğu modelin kısıtları arasında yer almaktadır.[11]

Varyansın ortalamadan büyük olma durumuna aşırı yayılım (overdispersion) olarak tanımlanmaktadır.[12] varyansın ortalamadan küçük olması durumu ise (underdispersion) az yayılım olarak ifade edilmektedir.[13] Aşırı yayılım gösterir özellikte verilerin analizinde Negatif binom regresyon analizi tercih edilmektedir.[14]

Negatif binom regresyonu

Veri tabanlarından alınan ve poisson regresyon analizi için gruplanan veriler analiz edilmiştir varyans aşırı yayılım özellikleri göstermektedir bu sebeple negatif binom regresyon modeli analiz metodu olarak seçilmiştir.

Çalışmada kullanılacak veri setinde aşırı yayılım (overdispersion) olup olmadığını tespit etmek amacıyla Eviews programı vasıtasıyla önce Genelleştirilmiş Doğrusal Model (GLM) üzerinden bir tablo 2'de detayları verilen Poisson regresyon modeli kurulmuştur.

Tablo 2 Poisson Regresyonu (irtifa)

Variable	Coefficient	Std. Error	z-Statistic	Prob.
C	3,131424	0,03867	80,97887	0,0000
IRTIFA	-0,000276	0,0000214	-12,88824	0,0000
Mean dependent var	14,91429	S.D. dependent var		30,42489
Sum squared resid	59989,87	Log likelihood		-1046,098
Akaike info criterion	29,94567	Schwarz criterion		30,00991
Hannan-Quinn criter.	29,97119	Deviance		1847,866
Deviance statistic	27,17449	Restr. deviance		2136,517
LR statistic	288,6513	Prob(LR statistic)		0,000000
Pearson SSR	3034,654	Pearson statistic		44,62726
Dispersion	1,000000			

Elde edilen bulgulara göre Pearson Ki-Kare istatistiği (Value/df) 44.62 ve Sapma (Deviance/df) istatistiği 27.17 olarak hesaplanmıştır. Bu istatistiklerin referans değeri olan 1.0'dan büyük çıkması, bağımlı değişkenin varyansının beklenen ortalamasından daha yüksek olduğunu ve aşırı yayılımın mevcudiyetini kanıtlar niteliktedir. Tespit edilen bu durum nedeniyle, analizde standart Poisson varsayımı reddedilmiş ve aşırı yayılımı bastıran Negatif Binom regresyon modeli tercih edilmiştir.

Negatif binom modeli için varyans eşitlik 1'de verilmiştir.

$$Var(y_i|x_i) = \mu_i + \alpha\mu_i^2 \qquad (1)$$

$Var(y_i|x_i)$: Modele sunulan bağımsız değişken (x_i) bilindiği koşulda, tahmin edilen olayın (y_i) ne kadar sapma veya değişkenlik (varyans) göstereceğini ifade eder.

μ_i: i'inci gözlem için gerçekleşmesi öngörülen ortalama olay sayısıdır.

α: Gerçek verideki varyansın, ortalamadan daha büyük olmasına sebep olan dalgalanmayı ölçen katsayıdır.

μ_i^2: Aşırı yayılım parametresinin α etki düzeyini belirlemek için beklenen ortalamanın karesi alınarak modele hata payı olarak eklenir.

Negatif binom modeli için beklenen değer denklemi 2'de verilmiştir.

$$\ln(\mu_i) = \beta_0 + \beta_1 x_i \qquad (2)$$

$\ln(\mu_i)$: Modelin fiziksel olarak imkansız, negatif sonuçlar üretmesini engellemek için beklenen ortalama olay sayısının (μ_i) doğal logaritma (ln) ile dönüştürülmüş halidir.

β_0 Modeldeki bağımsız değişkenin (x_i) değeri sıfır olduğunda, olay sayısının alacağı temel başlangıç değerinin logaritmasıdır.

β_1 Analize dahil edilen bağımsız değişkendeki (x_i) bir birimlik değişimin, beklenen olayın logaritması ($\ln(\mu_i)$): üzerinde yaratacağı istatistiksel etkiyi veya eğimi gösterir.

x_i: i'inci gözlem sırasındaki tahminin yapılmasını sağlayan veridir.

Tablo 3 Negatif Binom Regresyonu (İrtifa)

Variable	**Coefficient**	**Std. Error**	**z-Statistic**	**Prob.**
C	3,05995	0,187187	16,34704	0,0000
IRTIFA	-0,00023	0,0000536	-4,285176	0,0000
		Mixture Parameter		
SHAPE:C (3)	0,416875	0,156636	2,661425	0,0078

R-squared	0,057718	Mean dependent var	14,91429
Adjusted R-squared	0,043861	S.D. dependent var	30,42489
S.E. of regression	29,75018	Akaike info criterion	7,109042
Sum squared resid	60184,96	Schwarz criterion	7,205406
Log likelihood	-245,8165	Hannan-Quinn criter.	7,147319
Restr. log likelihood	-1190,424	LR statistic	1889,215
Avg. log likelihood	-3,511664	Prob(LR statistic)	0,000000

Analizde hız ve irtifa verileri yakın korelasyon göstermeleri sebebiyle ayrı ayrı regresyon analizine tabi tutulmuştur. Tablo 3'de verilen negatif binom regresyon sonuçlarına göre Shape:C(3) aşırı yayılım paremetresi probe değeri 0,0078 ile 0,05 değerinden küçük olduğu ve dolayısıyla istatistiksel olarak anlamlı olduğu görülmektedir. Varyansın aşırı yayılım gösterdiği ve poisson modelinin analize uygun olmadığı anlaşılmaktadır.

İrtifa katsayısına (Coefficient) bakıldığında-0.000230 değerini görülmektedir. Katsayının negatif ve Prob değerinin 0.0000 olması istatistiksel olarak anlamlıdır ve bulgular irtifa arttıkça çarpma olaylarının azaldığını göstermektedir.

Tablo 4 Poisson Regresyonu (Hız)

Variable	**Coefficient**	**Std. Error**	**z-Statistic**	**Prob.**
C	2,249537	0,08688	25,89254	0,0000
HIZ	0,002084	0,000516	4,03859	0,0001

Mean dependent var	13,05	S.D. dependent var	25,29467
Sum squared resid	50446,15	Log likelihood	-1256,335
Akaike info criterion	31,45838	Schwarz criterion	31,51793
Hannan-Quinn criter.	31,48225	Deviance	2251,214
Deviance statistic	28,86172	Restr. deviance	2267,9
LR statistic	16,68548	Prob(LR statistic)	0,000044
Pearson SSR	3862,888	Pearson statistic	49,52421
Dispersion	1,000000		

Hız verilerinin aşırı yayılıma sahip olup olmadığı da Genelleştirilmiş Doğrusal Model (GLM) üzerinden bir Poisson regresyonu kurularak test edilmiştir. Bulgulara göre Pearson Ki-Kare istatistiği (Value/df) 49.52 ve Sapma (Deviance/df) istatistiği 28.86 olarak hesaplanmıştır. 1.0 olan referans değerinden büyük çıkması, bağımlı değişkenin varyansının ortalamadan çok daha yüksek olduğunu hız verileri için de aşırı yayılıma sahip olduğunu göstermektedir.

Tablo 5 Negatif Binom Regresyonu (Hız)

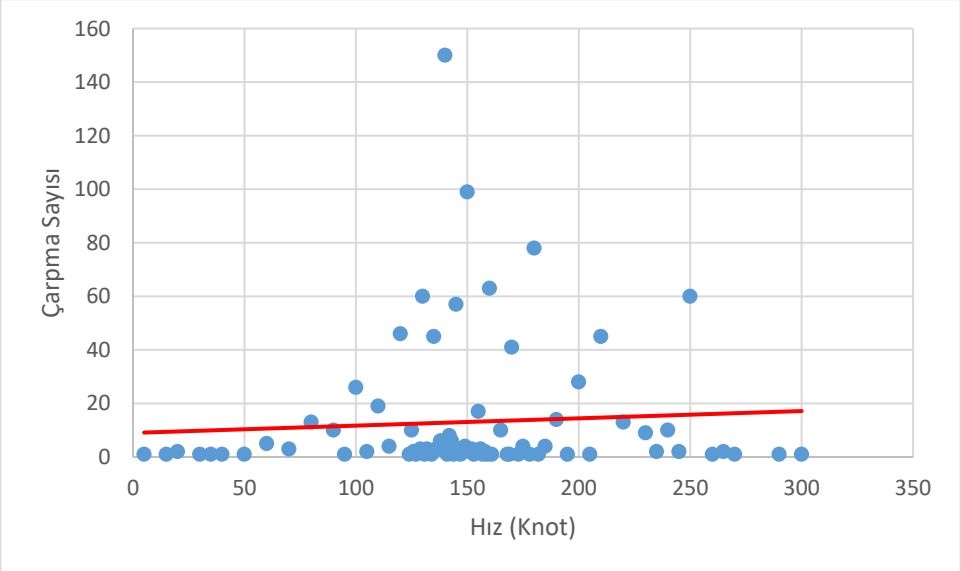
Variable	Coefficient	Std. Error	z-Statistic	Prob.
C	1,873021	0,607472	3,083306	0,0020
HIZ	0,004542	0,003918	1,159367	0,2463
		Mixture Parameter		
SHAPE:C(3)	0,658411	0,141528	4,652162	0,0000

R-squared	-0,014603	Mean dependent var	13,05000
Adjusted R-squared	-0,027611	S.D. dependent var	25,29467
S.E. of regression	25,64150	Akaike info criterion	6,953848
Sum squared resid	51283,94	Schwarz criterion	7,043174
Log likelihood	-275,1539	Hannan-Quinn criter.	6,989661
Restr. log likelihood	-1264,678	LR statistic	1979,048
Avg. log likelihood	-3,439424	Prob(LR statistic)	0,000000

Tablo 5'de verilen negatif binom regresyon sonuçlarına göre Shape:C(3) aşırı yayılım paremetresi probe değeri 0,0000 ile 0,05 değerinden küçük olduğu ve dolayısıyla istatistiksel olarak anlamlı olduğu buna bağlı olarak varyansın aşırı yayılım gösterdiği ve poisson modelinin analize uygun olmadığı anlaşılmaktadır.

Hız katsayısına (Coefficient) bakıldığında 0,004542 değerini görülmektedir. Katsayının Prob değerinin 0,2463 ile 0,05 değerinden yüksek olması nedeniyle istatistiksel olarak anlamlı olmadığı sonucuna ulaşılmıştır.

Grafik 5: Uçuş Hızı ve Çarpma Sıklığı Dağılım İlişkisi



Aşırı yayılım olması sebebiyle hız parametresine uygulanan negatif binom regresyon modeli istatistiksel olarak anlamlı çıkmaması bazı temellere dayanmaktadır. Grafik 5'de John F. Kennedy Uluslararası havalimanında raporlanan ve hangi hız değerinde kaç adet çarpmanın gerçekleştiği verilmektedir.

Grafikte belirtilen mavi noktaların her biri gerçek çarpma vakalarına ait dağılımları ifade ederken kırmızı hat trend yönünü ifade etmektedir. Trend yönünden hareket edilecek olursa hız artarsa çarpmaların da artacağı yönlü bir çıkarım yapılması mümkündür ancak yukarıda açıklandığı üzere çarpmaların büyük bir çoğunluğu son yaklaşma safhasında gerçekleşmektedir.

Son yaklaşma safhasında ve iniş esnasında uçak hızlarının 130-160 Knot arasında seyretmesi grafikte resmedilen mavi noktaların yoğunlaştığı bölgeyi açıklar niteliktedir. Her ne kadar trend yönü nispeten

yukarı yönlü olsa da yoğunlaşılan hız bölgesi negatif binom regresyonu analizi ile istatistik olarak anlamsız bulunmaktadır.

SONUÇ

Kuş çarpmalarını önleme ve kuş davranışlarını anlama havacılık endüstrisinin giderek artan çarpışma riskleri sebebiyle inceleme alanı olmakta ve ilgi duyulan bir akademik araştırma konusu olmaya devam etmektedir.

Jamaika Körfezi'ne komşu ve tartışmalı konumu ile John F. Kennedy Uluslararası Havalimanı 1990 - 2025 yılları arasında 6.456 adet kuş çarpmasına maruz kalmıştır. Yıllar içerisinde bahse konu havalimanı çeşitli kuş çarpması önleme çalışmalarına konu olmuş ve kuş çarpmalarının önlemesine yönelik deneysel çalışmalar gerçekleştirilmiştir. 1990 yılında gerçekleştirilen çalışmaların çarpma grafikleri incelendiğinde başarı sonuçlar verdiği ancak tüm örgütlü çabalara rağmen martı türlerinin yuvalanma sayılarında artış gözlemlendiği, martılara yönelik başarılı önleme çabaları esnasında diğer türlere yönelik kuş çarpma sayılarında artışların yaşandığı sonuç olarak martı türleri için kalıcı çözümün kuş yuvalarının havalimanı yerleşkelerinden taşınmasıyla mümkün olacağı belirtilmiştir. Diğer bir dikkat çeken husus olarak çarpışmaların ezici bir çoğunluğunun yaklaşma safhasında gerçekleştiği, günün zaman dilimlerine yorumlandığında ise en fazla çarpışmanın gece saatlerinde yaşandığı dolayısıyla en riskli çarpışma grubunun gece yaklaşmaları esnasında yaşanacağı değerlendirilmesi yapılmaktadır. Elde edilen çarpışma verilerinin makalenin metodoloji bölümünde belirtildiği üzere sayma sayısı özelliği barındırması ve kategorik bir durum teşkil etmemesi sebepleriyle en uygun analiz yöntemi poisson regresyon modeli olduğuna karar verilmiştir. Poisson regresyon analizi koşullarından biri olan varyans ortalamasına eşit ortalamaya sahip olunması hız ve irtifa verileri için sağlanamadığından aşırı yayılım parametrelerinin bastırılması sebebiyle negatif binom regresyon modeline geçiş yapılmıştır. İrtifa katsayısına (Coefficient) değeri incelendiğinde katsayının-0.000230 değerini aldığı görülmektedir. Katsayının negatif ve Prob değerinin 0.0000 olması istatistiksel olarak anlamlıdır ve irtifa arttıkça çarpma olaylarının bilimsel olarak negatif yönlü bir ilişki olduğunu ortaya koymaktadır. Verilerden hareketle ve diğer bir ifade ile irtifada yaşanacak 1000 feetlik (304,8m) artışın kuş çarpması sayılarını logaritmik olarak %20,5 oranında azalttığı sonuçlarına ulaşılmıştır. Hız verilerinin ise poisson ve negatif binom regresyonlarının her ikisinde de anlamlı sonuçlar vermediği ancak 120-180 knot arasında gerçekleşen çarpmaların kümelendiği dolayısıyla bu hız aralığının en yüksek risk grubunu oluşturduğu değerlendirilmektedir.

Her havalimanın kendisine ait SID (Standard Instrument Departure - Standart Aletli Kalkış) ve STAR (Standard Terminal Arrival Route - Standart Terminal Varış Rotası) prosedürleri bulunmaktadır. Bu prosedürlerden SID Uçakların kalkıştan hemen sonra engellerden dağlar, yüksek yapılar vb. güvenli bir şekilde kaçınmasını sağlarken, STAR varış yapacak bir uçağın, havayolu rotasından çıkıp iniş yapacağı havalimanının yaklaşma noktasına kadar izlemesi gereken standart rotayı tanımlamaktadır.

Çalışma sonuçlarına göre 1000 feetlik irtifanın çarpışmaları %20,5 azaltması, son yaklaşma ve gece yapılan uçuşların en riskli grubu oluşturması gibi etmenlerden yola çıkıldığında, John F. Kennedy Uluslararası Havalimanı standart yaklaşma prosedürlerinin tekrar gözden geçirilmesi gerektiği, özellikle 120-180 knot arası ve gece yapılan son yaklaşma prosedürlerinde riski azaltacak çarpmaları en aza indirgeyecek önlemlerin alınması gerektiği, piste uzak mesafelerde alçak irtifada ve düşük hızda uzun süre süzülmek yerine yüksek irtifayı son ana kadar koruyup, pistin yakınlarında kontrollü ve dik bir alçalışla hızla iniş hızına düşerek teker koymak suretiyle inişin tamamlanmasının riskleri en aza indirgeyeceği, bu sayede hem kuş tehlikesi olan katmanda daha az kalınacağı hem de en riskli hız dilimi minimum sürede atlatılmış olunacağı değerlendirilmiştir.

Sonuç olarak John F. Kennedy Uluslararası Havalimanı STAR (Standard Terminal Arrival Route - Standart Terminal Varış Rotası) prosedürünün bu bağlamda ele alınması, sivil havacılık regülasyonları kapsamında uygulanıp uygulanmayacağının otoriteler tarafından değerlendirilmesi, çalışmanın politika önerileri olarak öne çıkmaktadır.

Bu çalışma, Erciyes Üniversitesi Sosyal Bilimler Enstitüsü Havacılık Yönetimi Anabilim Dalı bünyesinde hazırlanan " Regresyon Analizi Tabanlı Kuş Çarpmalarını Önleme ve Rota Optimizasyonu" başlıklı yüksek lisans tezinden üretilmiştir.

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AN ATYPICAL CYSTIC-POLYPOID INTRACAVITARY UTERINE LESION WITH BENIGN HISTOPATHOLOGY: A CASE REPORT

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ABSTRACT

Introduction and Purpose: Atypical cystic or polypoid intracavitary uterine lesions may be difficult to interpret in perimenopausal women with abnormal uterine bleeding, because benign structural lesions and suspicious endometrial or myometrial pathologies may overlap on ultrasonography. This case presents an unusual cystic-polypoid intracavitary uterine lesion that appeared atypical on transvaginal ultrasonography but was ultimately confirmed as benign histopathology.

Case Presentation: A 46-year-old gravida 2, para 2 woman with two previous cesarean deliveries and a history of cholecystectomy was evaluated for dysmenorrhea and menometrorrhagia. Her hemoglobin level was 9.2 g/dL, and tumor markers were within normal limits. Preoperative endometrial sampling revealed disordered proliferative endometrium. Transvaginal ultrasonography demonstrated a 35 × 17 mm atypical lesion in the endometrial cavity, mainly toward the left cornual region, with a 28 × 13 mm central cystic component. Degenerated myoma and intracavitary coagulum were considered in the differential diagnosis, and pelvic magnetic resonance imaging was recommended. The patient underwent definitive surgical treatment. Intraoperatively, no abnormal adnexal or intra-abdominal finding was observed. Gross pathological examination revealed an approximately 4 cm polypoid intracavitary lesion, with hemorrhagic fluid draining from cystic areas on sectioning. Final histopathology showed chronic cervicitis, late secretory endometrium, leiomyoma, adenomyoma, and adenomyosis. No endometrial hyperplasia, atypia, or malignancy was detected.

Discussion and Conclusion: This case underlines that benign uterine pathologies may occasionally present with a striking cystic-polypoid intracavitary appearance. Careful correlation of clinical, sonographic, gross pathological, and histopathological findings is essential to distinguish benign mimics from suspicious uterine lesions.

Key Words: Atypical uterine lesion; Intracavitary lesion; Abnormal uterine bleeding; Adenomyoma; Benign histopathology.

THE AKHISM ORGANIZATION AND WELFARE THOUGHT: A CONCEPTUAL ANALYSIS THROUGH TITMUSS, MARSHALL, AND ESPING-ANDERSEN

AHİLİK TEŞKİLATI VE REFAH DÜŞÜNCESİ: TİTMUSS, MARSHALL VE ESPİNG-ANDERSEN ÇERÇEVESİNDE KAVRAMSAL BİR ANALİZ

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ÖZET

Giriş ve Amaç: Ahilik teşkilatı, 13. yüzyılda Anadolu'da kurumsallaşmış, mesleki eğitim, üretim ahlakı, dayanışma, yoksullukla mücadele ve sosyal içerme işlevleriyle dikkat çeken özgün bir sosyal örgütlenme modelidir. Bu çalışmanın amacı, Ahiliğin modern Batı sosyal politika literatüründe 20. yüzyılda sistematikleşen refah, sosyal vatandaşlık ve sosyal güvence yaklaşımlarını tarihsel olarak önceleyen yönlerini ortaya koymaktır.

Gereç ve Yöntem: Çalışmada nitel ve kavramsal analiz yöntemi benimsenmiştir. Ahiliğin sosyal politika işlevleri, Richard Titmuss'un refah modelleri tipolojisi, T. H. Marshall'ın sosyal vatandaşlık teorisi ve Gøsta Esping-Andersen'in refah rejimleri sınıflandırması çerçevesinde karşılaştırmalı olarak değerlendirilmiştir.

Bulgular: Elde edilen değerlendirmeler, Ahiliğin söz konusu kuramsal yaklaşımlarla yalnızca işlevsel benzerlik taşımadığını, dayanışma, sosyal hak, mesleki örgütlenme, koruyucu güvence ve toplumsal bütünleşme ilkelerini bu teorilerden yüzyıllar önce kurumsal pratiğe dönüştürdüğünü göstermektedir.

Tartışma ve Sonuç: Ahilik geleneği, günümüz Türkiye'sinde aktif istihdam politikaları, yoksullukla mücadele, mesleki eğitim, sosyal içerme ve yerel dayanışma mekanizmaları açısından özgün tarihsel bir referans sunmaktadır. Bu bağlamda çalışma, Ahiliğin modern sosyal politika tasarımına katkı sağlayabilecek yerli ve tarihsel bir model olarak yeniden değerlendirilmesi gerektiğini savunmaktadır.

Anahtar Kelimeler: Ahilik; Sosyal Politika; Refah Devleti; Sosyal Vatandaşlık; Sosyal Dayanışma

ABSTRACT

Introduction and Purpose: The Akhism organization, institutionalized in thirteenth-century Anatolia, represents an original model of social organization through its functions in vocational training, production ethics, solidarity, poverty alleviation, and social inclusion. The purpose of this study is to reveal the historical aspects of Akhism that preceded the welfare, social citizenship, and social security approaches systematized in twentieth-century Western social policy literature.

Materials and Methods: This study employs a qualitative and conceptual analysis method. The social policy functions of Akhism are comparatively evaluated within the framework of Richard Titmuss's typology of welfare models, T. H. Marshall's theory of social citizenship, and Gøsta Esping-Andersen's classification of welfare regimes.

Results: The findings indicate that Akhism does not merely display functional similarities with these theoretical approaches. Rather, it transformed the principles of solidarity, social rights, vocational organization, protective security, and social integration into institutional practice centuries before these theories were developed.

Discussion and Conclusion: The Akhism tradition offers an original historical reference for contemporary social policy design in Türkiye, particularly in active employment policies, poverty

reduction, vocational education, social inclusion, and local solidarity mechanisms. In this context, the study argues that Akhism should be reconsidered as an indigenous and historical model capable of contributing to modern social policy.

Key Words: Akhism; Social Policy; Welfare State; Social Citizenship; Social Solidarity

SAFE DEEP REINFORCEMENT LEARNING–BASED VOLTAGE MANAGEMENT IN LV DISTRIBUTION NETWORKS

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ABSTRACT

Voltage rise is an increasingly critical challenge in low-voltage (LV) distribution networks, mainly driven by the accelerating penetration of photovoltaic (PV) systems. As PV adoption continues to grow, reverse power flows result in voltage rises that violate statutory voltage limits. Although various voltage regulation methods have been proposed in the literature, including rule-based approaches and optimisation-based techniques, these methods often struggle to adapt to dynamic nature of modern LV networks (e.g.,connection of new technologies). LV networks are becoming significantly more and more dynamic due to the rapid adoption of new technologies, hence calling for more adaptive and intelligent control algorithms. In order to adequately address this dynamic environment, reinforcement learning (RL) stands out as a promising approach, owing to its ability to learn optimal control policies through interaction with the environment without needing an explicit system model. To this end, this study proposes a safe deep reinforcement learning-based voltage control algorithm, employing Soft Actor-Critic (SAC), for the coordinated control of battery energy storage systems (BESS). Operational limits are explicitly included as safety constraints to prevent unsafe exploration during training, hence rendering the algorithm suitable for real-world deployment. The proposed method is validated on an LV distribution network, reflecting practical operating conditions. The results demonstrate that the proposed safe DRL-based controller effectively reduces maximum voltages along the distribution feeders, hence improving network operational safety. The findings highlight the potential of safe RL-based approaches as scalable and adaptive solutions for voltage management in future LV networks.

Keywords: BESS control; Distribution automation; Low-voltage distribution network; Reinforcement learning; Voltage control.

STRESS FRACTURES AND VITAMIN D DEFICIENCY IN THE MILITARY POPULATION: DIAGNOSIS, IMAGING AND PREVENTION STRATEGIES

ASKERÎ POPÜLASYONDA STRES KIRIKLARI VE D VİTAMİNİ EKSİKLİĞİ: TANI, GÖRÜNTÜLEME VE ÖNLEME STRATEJİLERİ

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ÖZET

Amaç: Stres kırıkları, askerî personelde iş gücü kaybının ve erken terhisin önlenebilir nedenleri arasında yer almaktadır. Temel eğitim döneminde yüklenmenin ani ve yoğun biçimde artması, yetersiz dinlenme ve düşük D vitamini düzeyi bu yaralanmaların başlıca risk faktörleridir. Bu çalışmanın amacı, askerî popülasyonda stres kırıklarının epidemiyolojisini, D vitamini eksikliğinin patogenezdeki rolünü, tanısal görüntüleme yaklaşımlarını ve önleme stratejilerine ilişkin güncel kanıtları bir arada değerlendirmektir.

Materyal ve Yöntem: PubMed, Web of Science ve Scopus veri tabanlarında "stress fracture", "military", "recruit", "vitamin D" ve "bone stress injury" anahtar kelimeleriyle yapılan tarama sonucunda ulaşılan klinik çalışmalar, randomize kontrollü çalışmalar ve derlemeler; epidemiyoloji, risk faktörleri, tanı ve önleme başlıkları altında anlatısal (narrative) yöntemle sentezlenmiştir.

Bulgular: Literatürde stres kırıklarının askerî acemi erlerde en sık tibiada görüldüğü, kadın personelde insidansın belirgin biçimde daha yüksek olduğu bildirilmektedir. Düz radyografinin erken dönemdeki duyarlılığı sınırlı olduğundan, kesin tanıda ve evrelemede manyetik rezonans görüntüleme öne çıkmakta; Fredericson sınıflaması tedavi kararını ve eğitime dönüş süresini yönlendirmektedir. Düşük 25-OH D vitamini düzeyi hem yetersiz mineralizasyona hem de kırık iyileşmesinin gecikmesine katkıda bulunmakta; kalsiyum ve D vitamini takviyesinin insidansı azalttığını gösteren randomize kontrollü çalışma verileri bulunmaktadır. Ayrıca eğitim yükünün kademelendirilmesi ve asgari uyku süresinin güvence altına alınması, ekipman temelli müdahalelere kıyasla daha etkili görünmektedir.

Sonuç: Askerî popülasyonda stres kırıklarının azaltılmasında en güçlü kanıt, eğitim programının kademelendirilmesi, yeterli dinlenme ve D vitamini durumunun düzeltilmesi üzerinedir. Eğitim öncesi D vitamini taraması ve kademeli yüklenme protokollerinin ülkemiz koşullarında etkinliğini araştıran prospektif çalışmalara ihtiyaç vardır.

Anahtar Kelimeler: stres kırığı; askerî personel; D vitamini eksikliği; manyetik rezonans görüntüleme; önleme

ABSTRACT

Aim: Stress fractures are among the preventable causes of lost duty time and early medical discharge in military personnel. A sudden and intense increase in loading during basic training, insufficient rest and low vitamin D levels are the principal risk factors for these injuries. The aim of this study is to evaluate together the epidemiology of stress fractures in the military population, the role of vitamin D deficiency in their pathogenesis, diagnostic imaging approaches and the current evidence on prevention strategies.

Material and Method: Clinical studies, randomised controlled trials and reviews identified through a search of the PubMed, Web of Science and Scopus databases using the keywords "stress fracture", "military", "recruit", "vitamin D" and "bone stress injury" were synthesised narratively under the headings of epidemiology, risk factors, diagnosis and prevention.

Results: The literature reports that stress fractures in military recruits occur most frequently in the tibia and that the incidence is markedly higher among female personnel. Because the early sensitivity of plain radiography is limited, magnetic resonance imaging is central to definitive diagnosis and grading, and the Fredericson classification guides treatment decisions and the timing of return to training. Low 25-OH vitamin D levels contribute both to defective mineralisation and to delayed fracture healing, and randomised controlled trial data indicate that calcium and vitamin D supplementation reduces incidence. Furthermore, graduated training loads and guaranteed minimum sleep duration appear more effective than equipment-based interventions.

Conclusion: The strongest evidence for reducing stress fractures in the military population concerns graduated training programmes, adequate rest and correction of vitamin D status. Prospective studies are needed to investigate the effectiveness of pre-training vitamin D screening and graduated loading protocols under the conditions of our own country.

Keywords: stress fracture; military personnel; vitamin D deficiency; magnetic resonance imaging; prevention

THE IMPACT OF ENVIRONMENTAL POLLUTION CAUSED BY INDUSTRIAL PLANTS ON ECO-GEOGRAPHICAL CONDITIONS.

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ABSTRACT

Anthropogenic activity, including the utilization of natural resources, disrupts the geological and biological cycling of matter in nature. Consequently, humans strive to prevent potential negative impacts on the environment by implementing various protective measures aimed at preserving, improving, and restoring the natural state of environmental components. A disruption of ecological balance is being observed on the Absheron Peninsula due to the proliferation of anthropogenic impacts; indeed, these effects have reached dangerous levels and have come to encompass the ways of life of human society itself.

The extraction of widespread mineral resources is leading to the replacement of the soil and vegetation cover with technogenic formations. It is possible to mitigate the resulting environmental impact by analyzing the composition of raw materials, finished products, and waste associated with the production of construction materials and quarrying operations in the area.

Mineral extraction and processing have caused a reduction in grassland and forest areas, which play a key role in regulating the atmospheric balance of oxygen and carbon dioxide. Observations indicate that the environment has undergone significant alteration due to mining activities; specifically, previously undisturbed areas have become contaminated and polluted with waste materials.

Keywords: Degradation; Pollution; Quarry; Mineral resources; Dust emissions.

INTRODUCTION

On one hand, scientific and technological progress reduces human dependence on nature and facilitates the use of natural resources; on the other, it leaves a negative mark on the ecosystem: air, seas, and freshwater bodies become polluted; soil cover and forest resources are degraded; mineral resources are depleted; the number of plant species declines; and other problems arise (Hakimova N.F. 2005).

Human society has become a powerful force that impacts the biosphere and alters the environment. The Republic of Azerbaijan faces significant technogenic hazards, which are considered the primary sources of various types of emergencies. Pollutants disrupt the functional system of soil fertility and, in many cases, impair the soil's water and air regimes; by adversely affecting the nutritional conditions of living organisms, they negatively alter their normal life processes. (Yagubov G.Sh., Ahmadov V.A. 1999).

Azerbaijan holds a leading position in the South Caucasus and the Middle East due to its rich mineral resources. The country's most significant mineral resources include oil, gas, and gas condensate; ferrous, non-ferrous, and precious metals; as well as non-metallic raw materials, construction materials, and mineral waters. The development of these abundant metallic and non-metallic mineral resources is of great importance for the socio-economic progress of the independent Republic of Azerbaijan, as these minerals form the foundation of both heavy and light industries. Mineral raw materials account for 70% of the natural resources utilized in the industrial sector (Afandiyeva Z.J. 2023).

It is well known that work is carried out annually across various geological structures of the republic to increase mineral raw material reserves through systematic geological studies. Mineral resources occur in the Earth's crust as various types of accumulations; such accumulations form deposits. Based on their intended use, mineral resources are classified into two types: metallic and non-metallic. Non-metallic mineral resources are widespread throughout the republic and are considered economically valuable. These resources are categorized into several groups, including construction materials, gemstones, and building stones. All lands that have undergone degradation due to the extraction of mineral and organic

resources, mining operations, geological exploration, or other excavation activities—and which require soil fertility restoration to become usable again—are classified as technogenically disturbed lands. Particular attention is paid to geo-ecological studies aimed at assessing and forecasting changes in the geo-ecological environment resulting from geological exploration and extraction activities within the republic.

Research has shown that the extraction and processing of mineral resources from deposits, as well as the construction of surface and underground infrastructure, have resulted in the degradation of the fertile topsoil layer on agricultural lands, effectively removing them from productive use. Such lands are found across all of the republic's natural-economic and natural landscape zones. Lands with degraded fertility due to the extraction of construction materials (stone) are particularly common on the Absheron Peninsula, a consequence of the intensive exploitation of limestone deposits that began in the early 20th century (Amanov V.K. 2016). On the Absheron Peninsula, lands have become contaminated with construction materials (stone, sand, gravel, clay) and waste of various compositions. This waste renders productive land unusable and litters the environment; soil erosion is spreading, and some quarries and depressions have even been filled with various types of waste. Removing this waste from the sites entails additional transportation costs.

DISCUSSION AND CONCLUSION

Areas of the peninsula most heavily subjected to technogenic impacts are found in its eastern section (Turkan-Shuvalan) and the Garadagh massif. Figuratively speaking, the resources extracted from these deposits have brought economic efficiency and prosperity to the national economy on the one hand, while causing environmental misfortune on the other. Mineral resource deposits—yielding limestone, gravel, bentonite clay, and quartz sand—have developed at locations across the peninsula such as Gizildash, Korgoz, Guzdak, Turkan, Shuvalan, and Khidirli. The productive reserves of these deposits total 59.79 million cubic meters (Fataliyev S.A., Imanov A.M., Bayramov F.H. 2020).

As is known, quarrying operations have resulted in the accumulation of vast quantities of limestone dust and debris within the quarry sites and along their margins. These deposits are not only substantial in volume but, being primarily in powder form, are highly susceptible to wind erosion (deflation). Observations indicate that on windy days, the accumulated limestone dust is easily lifted into the air and subsequently settles on surrounding areas, thereby disrupting the natural environmental balance and exerting a negative impact on the ecosystem. Consequently, the limestone deposits accumulated around stone quarries are considered a source of atmospheric pollution. Before quarrying operations commenced, the topsoil layer was typically stripped away during the warm season; due to the soil's natural moisture content-ranging between 16.5% and 22.0%-this process generated dust that dispersed into the surrounding environment, particularly within the layer of air immediately above the ground. As a result, a dual source of environmental pollution is created (Mammadov Q.Sh., Khalilov M.Y.2005).

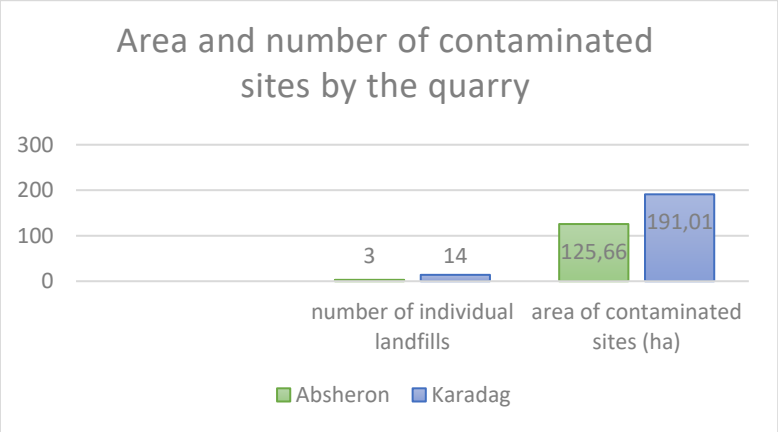
RESULTS

Dust emissions from quarries are a primary source of air pollution, though the severity depends on factors such as local microclimatic conditions, ambient dust particle concentrations, particle size, and chemical composition—for instance, limestone quarries generate highly alkaline (and reactive) dust, whereas coal mines produce acidic dust. Air pollution not only causes environmental nuisance and poses potential health risks—particularly for individuals with respiratory issues—but the dust can also physically affect surrounding vegetation; it can damage internal structures, cause abrasion to leaves and cuticles, and exert chemical effects that may impact long-term viability.

Stone and gravel quarry operations create two sources of environmental pollution. Before extraction begins—typically during the warm season—the topsoil (humus layer) is removed; as the natural moisture content of the soil mass ranges between 16.5% and 22.0% during this process, dust is generated and disperses into the environment, particularly into the layer of air close to the ground. It should be noted that, due to the disturbance of the soil cover—and specifically ongoing soil degradation—the total

area of contaminated soil amounts to 191.01 hectares in the Garadagh district and 125.66 hectares in the Absheron district.

Diagram 1



Calculations indicate that up to 10–15% of the soil mass displaced during overburden removal operations is released into the environment as airborne dust emissions. In addition to dust-related air pollution, quarries also generate carbon emissions through the use of heavy machinery, material transport, and energy-intensive stone processing. These activities contribute to climate change by releasing greenhouse gases (Chris 2024).

Quarry Waste

As with many other industrial activities, quarrying generates significant amounts of waste. While some types of quarries—such as sand and gravel pits—do not produce large quantities of permanent waste, others generate substantial amounts of waste material, such as clay and silt.

Waste generated from stone cutting and processing can range from a minimum of 35% to a maximum of 75% of the stone product. Thus, from an input of 100 kg of stone (block), only 25 kg of finished product is obtained, while the remaining 75 kg constitutes waste (Albina S. & Graziella B. & İppolita M. & Fabio F. 2024).

The good news is that, unlike waste from many other processes, these materials are generally inert and non-hazardous. However, the potential for environmental harm—particularly through water pollution—still exists.

For instance, suspended particles—even if chemically inert—can disrupt the balance of freshwater ecosystems. Large quantities of solid material deposited on floodplains can also exacerbate flooding. Finally, accumulated waste by-products must be stored and managed in a way that avoids negative environmental impacts. Furthermore, the processing and disposal of waste can itself have significant adverse environmental effects.

While quarries can have a substantial environmental impact, proper planning and management can minimize or control many negative effects; indeed, there are often significant opportunities to protect and improve the environment—such as by relocating existing habitats or creating new ones.

In addition to physical waste, water management at quarry sites is also a critical factor. Effective control of discharges and the responsible disposal of wastewater are essential to prevent the contamination of groundwater and surface water sources (Chris 2024).

Fine dust generated during the quarrying and processing of decorative stone is potentially suitable for reuse as an inert component in new green materials designed to reduce the volume of waste sent to landfills (Albina S. & Graziella B. & İppolita M. & Fabio F. 2024).

Quarries are created by clearing the topsoil, followed by drilling and blasting operations to extract minerals and sedimentary rock. Roads and other infrastructure are also constructed to support mining

operations, including transportation. Every stage of a quarry's lifecycle entails significant environmental costs: the loss of natural carbon sinks, the destruction of biodiversity, noise and air pollution, and the disruption of natural watercourses and springs. Moreover, these losses are irreversible, even after the quarries are inevitably abandoned.

These harmful effects are felt not only by local flora and fauna but also by human populations; in some instances, local communities have even been permanently displaced. Once extraction is complete or no longer profitable, quarries often fill with rainwater—creating hazardous lakes filled with jagged rocks—or, worse, are used as dumping grounds.

Quarry restoration represents just one small step toward ecological recovery. There are numerous examples of completed or ongoing restoration projects, ranging from rewilding quarries to transforming them into parks and safe lakes (Thea Lyngseth & Katarzyna Krok 2023).

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ANALYSIS OF THE REPATRIATION PROCESS USING THE METHOD OF INFORMATIVE-SOCIOLOGICAL ANALYSIS

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ABSTRACT

Introduction and Purpose: Informative-sociological analysis of the repatriation process involves the identification and interpretation of the directions of public opinion formation regarding the problem. Thus, the method of informative-sociological analysis is considered a systematic approach aimed at the study of social trends directly related to any problem, the identification of the sources from which the formed public opinion is derived, as well as the study of institutional behaviors influenced by public opinion. Using the method of informative-sociological analysis, the researcher analyzes empirical data related to the object of study (statistical indicators, results of sociological surveys) at various levels based on both quantitative and qualitative indicators, analyzes the directions of reflection of the obtained data in social norms, the possibilities of changing existing values and the features of making changes in the structure of the existing social reality, and systematizes concepts related to the problem under study.
Materials and Methods: The directions of informative-sociological analysis of the repatriation process were investigated based on the methods of content analysis, statistical comparative analysis, and text interpretation.
Results: Experiences in solving social problems faced by states in the process of returning people who have been subjected to repatriation to their homeland have served as the basis for the creation of projects, laws, programs and strategies related to repatriation.
The informative-sociological or analytical analysis of the repatriation process is aimed at identifying the possibilities of adapting and applying the international political experience applied in connection with the return of people who have forcibly left their original places of residence. The informative-sociological analysis of international policy related to repatriation directly involves the application of the directions of ensuring international legal security and protection in relation to repatriates, as well as the methods of statistical-comparative and historical-comparative analysis of the current situation in the world regarding this issue in the modern era.
Key Words: Informative-sociological analysis, repatriation process, social reality,

Introduction

Informative-sociological analysis of the repatriation process involves the identification and interpretation of the directions of public opinion formation regarding the problem. Thus, the method of informative-sociological analysis is considered a systematic approach aimed at the study of social trends directly related to any problem, the identification of the sources from which the formed public opinion is derived, as well as the study of institutional behaviors influenced by public opinion. Using the method of informative-sociological analysis, the researcher analyzes empirical data related to the object of study (statistical indicators, results of sociological surveys) at various levels based on both quantitative and qualitative indicators, analyzes the directions of reflection of the obtained data in social norms, the possibilities of changing existing values and the features of making changes in the structure of the existing social reality, and systematizes concepts related to the problem under study.

The application of the method of informative-sociological analysis for the problem of repatriation

The application of the method of informative-sociological analysis for the purpose of studying the problem of repatriation involves the collection, evaluation and interpretation of social data on the subject. The analysis of decisions made in this direction, the identification of social trends caused by the

social policies being formed, the features of the application of the obtained results in real life and the analysis of the results are the main points of informative-sociological analysis.

Another point of the application of the method of informative-sociological analysis to the repatriation process is related to the conduct of surveys, interviews and thus quantitative and qualitative research in order to assess the socio-cultural, psychological and professional reintegration of internally displaced persons returning to their former places of residence.

Based on the above, it is intended to conduct an informative-sociological analysis of the repatriation process in the following directions:

International policy related to repatriation;

Projects implemented related to the socio-psychological adaptation of repatriates.

The experiences of states in solving social problems encountered in the process of returning people subjected to repatriation to their homelands have served as the basis for the creation of projects, laws, programs and strategies related to repatriation.

The informative-sociological or analytical analysis of the repatriation process is aimed at identifying the possibilities of adapting and applying the international political experience applied in connection with the return of people who have forcibly left their original places of residence. The informative-sociological analysis of international policy on repatriation directly involves the application of the directions of ensuring international legal security and protection in relation to repatriates, as well as the methods of statistical-comparative and historical-comparative analysis of the current situation in the world on this issue in the modern era.

It should be noted that the Universal Declaration of Human Rights, adopted in 1948, as well as the 1951 Convention on the Status of Refugees and Internally Displaced Persons, were the first documents to protect the rights of refugees and internally displaced persons. The 1951 Convention was the first to grant legal status to internally displaced persons and to define the status of “refugee” and “forced displacement”. On this basis, the United Nations High Commissioner for Refugees (UNHCR) established a mandate to protect refugees and a framework for assisting them. The general provisions of International Humanitarian Law protect civilian refugees in States involved in armed conflict, but they also receive special protection under the Fourth Geneva Convention and Additional Protocol I.

International law protects refugees and internally displaced persons through various levels of legal bodies:

- In this regard, through domestic legislative bodies based on international human rights law;

- In situations of armed conflict, through IHL (International Humanitarian Law) bodies.

Under IHL, persons not taking part in hostilities are protected from displacement as civilians, unless they are involved. International human rights law plays a crucial role in preventing displacement, first of all, by prohibiting the displacement of people except in cases of necessity. A widespread or systematic policy of displacement of civilians without such a basis constitutes a crime against humanity.

International humanitarian law provides for the access of humanitarian organizations and assistance to refugees and internally displaced persons in situations of armed conflict. Parties to the conflict facilitate the delivery of relief materials such as medicine, food, blankets and tents. Unfortunately, these rules have been ignored in many recent conflicts, putting both refugee populations and internally displaced persons at risk. Respect for the rules of armed conflict can prevent refugee flows and internal displacement, and if people have to flee their homes, they can only be protected if IHL is respected.[1]

[1] Refugees and displaced persons protected under international humanitarian law.//URL:

https://www.icrc.org/en/document/protected-persons/refugees-displaced-persons

The Geneva Convention "Regarding the Protection of Civilian Persons in Time of War", adopted on August 12, 1949, was amended in 1877 and 2005, granting people who were forced to leave their areas of residence due to war and conflict the right to return - repatriation.[2]

It is on the basis of these legal documents that it is possible to conduct a statistical analysis of the return - repatriation - of people who have left their countries due to war and armed conflicts in various countries.

The statistical analysis of the repatriation problem does not only cover the numerical indicators of refugees returning to their homeland, but also includes figures related to many areas, from financial activities to cultural movements related to repatriation.

The issue of managing the mass migration process resulting from wars, which have become a global problem in modern times, the cessation of conflicts and wars, and the return of refugees and internally displaced persons to their homelands remains an important problem for UNHCR to solve.

UNHCR distinguishes between the concepts of “forcibly displaced persons” and “refugees.” UNHCR’s presentation states that “Forcibly displaced persons are people who have been forced to flee their homes because of conflict, violence, persecution or disaster, but who remain within the borders of their own country.” In this context, “forcibly displaced persons” are also referred to as “internally displaced persons.”

The United Nations Guiding Principles on Internal Displacement define internally displaced persons as “individuals or groups of persons who have been forced to flee their homes or places of habitual residence, or who have not crossed an internationally recognized state border, in particular as a result of or in order to avoid the consequences of armed conflict, human rights violations or natural disasters, or who have been forced to flee their homes or places of habitual residence, or who have not crossed an internationally recognized state border.”[3]

Explaining the difference between an internally displaced person and a refugee, UNHCR states that “A refugee is a person who is outside their country of origin and who is unable to return without risking their life or freedom because of conflict or persecution. Refugees have certain individual rights and protections under international law. Internally displaced persons (IDPs) are those who have been forced to flee their homes to escape conflict, persecution or disaster, but have not crossed an international border and remain within their own country. Their national government is responsible for their protection. They should be granted the same rights and freedoms as citizens and permanent residents of their country. Displacement can often be permanent: A person who is internally displaced (IDP) may cross an international border to seek safety, and if they are able to do so, or if the situation worsens, they may become a refugee. Similarly, a refugee may be able to return to their country of origin but not return to their area of origin and therefore be classified as an IDP.[4]

According to UNHCR's Refugee Information Retrieval Center, the number of refugees and internally displaced people at the end of 2025 was 117.8 million, of whom approximately 45 million (38%) were children under the age of 18. This figure includes both internal displacement within the country's borders and forced displacement across borders.

Conclusion

World experience shows that, especially in the initial stage of displacement, it is very difficult, sometimes even impossible, to find shelter and accommodation, to benefit from the necessary level of food, clean water and health services. This is not welcomed unambiguously by the people living in the areas where the displaced persons are settled. Refugees and internally displaced persons are greeted with caution even in their homeland by the established residents of the areas where they are settled, which

[2] Ришар Перрушу. «Глоссарий терминов в области миграции». Международная организация по миграции (МОМ), Женева, 2005, с. 67 (98с.)
[3] Global Report on Internal Displacement 2026. https://www.internal-displacement.org/
[4] https://www.unhcr.org/about-unhcr/who-we-protect/internally-displaced-people

has a significant impact on the process of their mutual adaptation. Although internally displaced persons and refugees, who initially created a social crisis in the areas where they are settled, have received certain privileges, they have to face difficulties related to employment, family provision, etc.

Not only local governments, but also UNHCR, are implementing certain planned measures for the social protection of internally displaced persons.

A STUDY ON CRISIS MANAGEMENT PRACTICES IN CHEMICAL, BIOLOGICAL, RADIOLOGICAL, AND NUCLEAR (CBRN) THREAT SITUATIONS

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ABSTRACT

Introduction and Purpose: Chemical, biological, radiological, and nuclear (CBRN) incidents are complex and multidimensional crises that can cause severe negative effects on human health, the environment, critical infrastructure, and public order. This study aims to develop a systematic planning and evaluation framework for the management of CBRN crises through artificial intelligence (AI)-assisted scenario modeling.

Materials and Methods: A scenario-based analytical approach was employed in this study. A phosgene gas release from a high-risk industrial facility was modeled using an AI-generated representative urban map. Meteorological conditions, population density, residential areas, critical infrastructure, and transportation networks were evaluated, and the crisis management process was examined across three phases: pre-crisis preparedness, the acute crisis phase, and post-crisis recovery.

Results: The analyses conducted in this study revealed that risk assessment, early warning, evacuation, interagency coordination, decontamination, healthcare delivery, environmental monitoring, and psychosocial support should be implemented in an integrated manner. Based on the literature review, the Şenel-Elitok Spectrum Model, a three-phase crisis management and societal impact simulation matrix were developed.

Discussion and Conclusion: AI-assisted scenario modeling represents a practical approach that can enhance risk assessment, resource planning, evacuation management, and decision-support processes during CBRN incidents. The proposed model provides a comprehensive conceptual and operational framework that integrates all phases of crisis management.

Keywords: Artificial Intelligence, CBRN Crisis Management, Decision Support Systems, Scenario-Based Analysis, Şenel-Elitok Spectrum Model

EVALUATION OF NEW FLIGHT ROUTE SELECTION CRITERIA FOR AIRLINES USING BUCKLEY'S FUZZY AHP METHOD: INTEGRATION OF THE CONTRAIL EFFECT INTO THE DECISION MODEL

HAVAYOLU İŞLETMELERİNDE YENİ UÇUŞ ROTASI SEÇİM KRİTERLERİNİN BUCKLEY BULANIK AHP YÖNTEMİYLE DEĞERLENDİRİLMESİ: YOĞUŞMA İZİ ETKİSİNİN KARAR MODELİNE ENTEGRASYONU

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ÖZET

Yeni uçuş rotası seçimi, havayolu işletmeleri için yüksek finansal risk taşıyan ve birbiriyle çelişen çok sayıda ölçütün eş zamanlı olarak değerlendirilmesini gerektiren stratejik bir karar problemidir. Küresel iklim gündemiyle birlikte bu karara çevresel boyutun da eklenmesi kaçınılmaz hâle gelmiş; ancak karbondioksit dışı etkilerin en önemlilerinden olan yoğuşma izleri (contrails) rota seçim modellerinde büyük ölçüde ihmal edilmiştir. Bu çalışmanın amacı, havayolu işletmelerinin yeni uçuş rotası seçiminde etkili olan yakıt tüketimi, potansiyel pazar büyüklüğü, rota mesafesi ve yoğuşma izi etkisi kriterlerinin göreli önem ağırlıklarını Buckley bulanık Analitik Hiyerarşi Prosesi (Bulanık AHP) yöntemiyle belirlemektir. Havacılık sektöründe görev yapan dört uzmandan Saaty 1-9 ölçeğiyle toplanan ikili karşılaştırma yargıları üçgensel bulanık sayılara dönüştürülmüş, geometrik ortalama ile birleştirilmiş ve Buckley yöntemiyle ağırlıklandırılmıştır. Bulgulara göre en önemli kriter potansiyel pazar büyüklüğü olurken; bunu yakıt tüketimi, rota mesafesi ve yoğuşma izi etkisi izlemiştir. Tüm bireysel matrislerde ve birleşik matriste tutarlılık oranı 0,10 eşiğinin altında kalmıştır. Sonuçlar, sürdürülebilirlik söylemine karşın uzmanların karar önceliklerinde ticari ve operasyonel kaygıların baskın olduğunu; çevresel kriterin modele girmekle birlikte düşük öncelik aldığını göstermektedir. Çalışma, yoğuşma izi etkisini havayolu rota seçimi karar modeline kriter olarak entegre eden öncü çalışmalardan biri olma özelliği taşımaktadır.

Anahtar Kelimeler: Yeni Rota Seçimi, Çok Kriterli Karar Verme, Bulanık AHP, Yoğuşma İzi, Havayolu İşletmeleri

ABSTRACT

New flight route selection is a strategic decision problem for airlines that involves high financial risk and requires the simultaneous evaluation of numerous conflicting criteria. With the global climate agenda, incorporating the environmental dimension into this decision has become inevitable; however, condensation trails (contrails), the most significant non-CO2 climate effect of aviation, have been largely neglected in route selection models. The aim of this study is to determine the relative importance weights of fuel consumption, potential market size, route distance and contrail effect criteria in new flight route selection using Buckley's fuzzy Analytic Hierarchy Process (Fuzzy AHP). Pairwise comparison judgements collected from four aviation experts on Saaty's 1-9 scale are converted into triangular fuzzy numbers, aggregated by the geometric mean operator and weighted using Buckley's method. According to the findings, the most important criterion is potential market size, followed by

fuel consumption, route distance and contrail effect. The consistency ratio remained below the 0.10 threshold in all individual matrices and in the aggregated matrix. The results reveal that, despite the sustainability discourse, commercial and operational concerns dominate experts' decision priorities, while the environmental criterion, although included in the model, receives low priority. This study is one of the pioneering works integrating the contrail effect as a criterion into the airline route selection decision model.

Keywords: New Route Selection, Multi-Criteria Decision Making, Fuzzy AHP, Contrails, Airlines

GİRİŞ

Havayolu taşımacılığı, ekonomik düzenlemelerin serbestleşmesiyle birlikte yoğun bir uluslararası rekabet ortamına taşınmış; işletmelerin pazar paylarını koruyabilmeleri, büyük ölçüde kurguladıkları uçuş ağı stratejilerine bağlı hâle gelmiştir.[1] Uçuş ağının temel yapı taşı olan yeni rota ve destinasyon seçimi ise yüksek yatırım tutarları nedeniyle telafisi güç sonuçlar doğurabilen stratejik kararlardan biridir.[2] Bu karar potansiyel talep, maliyet yapısı, operasyonel kısıtlar ve çevresel etkiler gibi farklı ölçü birimlerine sahip, birbiriyle çelişen çok sayıda ölçütün aynı anda değerlendirilmesini gerektirmekte; bu nedenle uzman yargılarını sistematik biçimde sayısallaştırabilen Çok Kriterli Karar Verme (ÇKKV) yöntemleri hem akademik hem de uygulamalı açıdan gereklilik hâline gelmektedir.[3,4]

Rota planlaması uzun yıllar boyunca uçuş süresinin ve işletme maliyetlerinin en aza indirilmesine odaklanmış olsa da, günümüzde çevresel sürdürülebilirlik havayolu stratejilerinin merkezine yerleşmiştir.[5] Güncel bilimsel bulgular, sektörün toplam ışınsal zorlama etkisinin önemli bir bölümünün karbondioksit dışı etkilerden, özellikle de yoğuşma izleri (contrails) ve bunların dönüştüğü yapay bulutlardan kaynaklandığını göstermektedir.[6] Jet motoru egzozundaki su buharının yüksek irtifada yoğunlaşmasıyla oluşan bu izler, buz açısından aşırı doygun atmosfer bölgelerinde saatlerce kalıcı olabilmekte ve net ısınma etkisi yaratmaktadır.[7,8] Buna karşın yoğuşma izi etkisi, havayolu işletmelerinin rota seçim modellerinde bir karar kriteri olarak çok az yer almaktadır.

Bu çerçevede çalışmanın amacı; yeni uçuş rotası seçiminde etkili olan yakıt tüketimi, potansiyel pazar büyüklüğü, rota mesafesi ve yoğuşma izi etkisi kriterlerinin göreli önem ağırlıklarını, havacılık uzmanlarının yargılarına dayalı olarak Buckley[9] bulanık Analitik Hiyerarşi Prosesi (Bulanık AHP) yöntemiyle belirlemektir. Çalışmanın literatüre katkısı üç başlıkta özetlenebilir: (i) havacılığın karbondioksit dışı en önemli iklim etkisi olan yoğuşma izi, yeni rota seçimi karar modeline açık bir kriter olarak entegre edilmektedir; (ii) ticari-operasyonel kriterler ile çevresel kriter arasındaki öncelik ilişkisi deneysel olarak ortaya konmakta ve sürdürülebilirlik söylemi ile karar pratiği arasındaki açık tartışılmaktadır; (iii) grup kararının bulanık ortamda tutarlılığı hem bireysel hem birleşik matris düzeyinde hesaplanıp raporlanmaktadır.

Çalışma 5 bölümden oluşmaktadır. Giriş bölümünün ardından ikinci bölümde literatür taramasına yer verilmiştir. Üçüncü bölüm Buckley Bulanık AHP Yöntemi ile ilgili detaylı bilgilendirme içermektedir. Dördüncü bölümde uygulama yer almakta olup, beşinci bölüm tartışma, altıncı bölüm ise sonuç ve değerlendirmeleri içermektedir.

LİTERATÜR TARAMASI

Bu bölümde literatürde gerek havayolu rota ve destinasyon seçimi, gerekse havacılığın iklim etkisi ve yoğuşma izleri konulu güncel çalışmalara yer verilmiştir.

Havayolu Rota ve Destinasyon Seçiminde ÇKKV Uygulamaları

Havayolu rota ve destinasyon seçimi problemi, ÇKKV literatüründe farklı yöntem bileşimleriyle ele alınmıştır. Lu ve Liu[10] Tayvan Boğazı hatlarının genişletilmesini AHP temelli pazar fırsatı analiziyle, Deveci vd.[11] Türkiye-Kuzey Amerika yeni rota seçimini aralık tip-2 bulanık TOPSIS ile, Chang vd.[12] Tayvan-Avrupa hattını uzlaşık programlama ile incelemiştir. Türkçe yazında Özcan[4] yeni destinasyon seçimini hibrit bir ÇKKV modeliyle, Bayraktar[13] Türkiye pazarında yeni rota seçimini tez kapsamında ele almıştır. Yakın dönemde bulanık yaklaşımların yaygınlaştığı görülmektedir: Koma vd.[14] Türk Hava

Yolları örneğinde Pisagor bulanık AHP ile WASPAS yöntemlerini melezleştirmiş, Athab[2] benzer problemi Pisagor bulanık AHP ve MOORA bileşimiyle çözmüş, Mızrak vd.[15] destinasyon seçiminde stratejik bir ÇKKV çerçevesi geliştirmiştir. Havacılığın diğer karar problemlerinde de ÇKKV kullanımı yaygındır[16-19]; kapsamlı bir değerlendirme Dožić[3] tarafından sunulmuştur. Bu çalışmalarda kullanılan yöntemler ve uygulama alanları Tablo 1'de özetlenmiştir.

Tablo 1. Havayolu rota/destinasyon seçimi ve ilgili karar problemlerinde ÇKKV uygulamaları.

Çalışma	Yöntem	Uygulama alanı
Lu ve Liu[10]	AHP temelli pazar fırsatı analizi	Tayvan Boğazı hatlarının genişletilmesi
Deveci vd.[11]	Aralık tip-2 bulanık TOPSIS	Türkiye-Kuzey Amerika yeni rota seçimi
Sennaroğlu ve Varlık Çelebi[18]	AHP + PROMETHEE + VIKOR	Askeri havalimanı yer seçimi
Özcan[4]	Hibrit ÇKKV	Havacılıkta yeni destinasyon seçimi
Bayraktar[13]	ÇKKV	Türkiye pazarında yeni rota seçimi
Chang vd.[12]	Uzlaşık programlama	Tayvan-Avrupa yeni rota seçimi
Athab[2]	Pisagor bulanık AHP + MOORA	Havayolu yeni rota seçimi
Koma vd.[14]	Pisagor bulanık AHP + WASPAS	THY örneğinde yeni rota seçimi
Mızrak vd.[15]	Bütünleşik ÇKKV çerçevesi	Havayolu destinasyon seçimi
Kanmaz[17]	Bulanık BWM + bulanık MARCOS	Dispeçer rotalamasının sürdürülebilirliği
Gürtürk ve Çelik[5]	Hibrit ÇKKV	Hava kargo rota optimizasyonu
Dönmez vd.[16]	Veri güdümlü ÇKKV	Uçak sıralama-çizelgeleme amaç fonksiyonu seçimi

2.5. 2.2. Havacılığın İklim Etkisi ve Yoğuşma İzleri

Havacılığın iklim etkisine ilişkin güncel değerlendirmeler, sektörün toplam etkili ışınsal zorlamasının karbondioksit dışı bileşenler tarafından domine edildiğini ve en büyük payın yoğuşma izlerine ait olduğunu ortaya koymaktadır.[6,7] Kaçınma stratejileri literatürde uzun süredir tartışılmaktadır: Gierens vd.[20] stratejileri derlemiş; Teoh vd.[8], küçük ölçekli rota sapmalarıyla iz kaynaklı iklim zorlamasının önemli ölçüde azaltılabileceğini göstermiş; Sausen vd.[21] küçük irtifa değişikliklerinin gerçek operasyon ortamında uygulanabilirliğini sınamış; Castino vd.[22] eko-verimli yörüngeler için SolFinder karar destek modülünü geliştirmiştir. Elmourad[23] ise kaçınma manevralarının ek yakıt tüketimi ile önlenen iz etkisinin küresel ölçekte değerlendirmiş ve net iklim faydasının ek karbondioksit etkisinden büyük olduğunu raporlamıştır.

Bu çalışmalar değerlendirildiğinde belirgin bir boşluk ortaya çıkmaktadır: yörünge optimizasyonu literatürü yoğuşma izini operasyonel bir kısıt olarak modellerken, ÇKKV temelli rota seçimi literatürü kriter setlerini ağırlıklı olarak talep, maliyet ve rekabet göstergeleri üzerine kurmakta; yoğuşma izinin stratejik rota seçimi kararına kriter olarak entegre edildiği çalışma sayısı oldukça sınırlı kalmaktadır. Bu çalışma söz konusu boşluğu doldurmayı amaçlamaktadır.

YÖNTEM

Analitik Hiyerarşi Prosesi ve Tutarlılık Denetimi

Saaty[24] tarafından geliştirilen AHP, karar problemini hedef, kriterler ve alternatiflerden oluşan hiyerarşik bir yapıya ayırmakta ve karar vericinin kriter çiftlerini 1-9 temel ölçeği üzerinden karşılaştırmasına dayanmaktadır. Karşılaştırma matrisinden öz vektör yaklaşımıyla ağırlıklar elde edilmekte; yargıların mantıksal tutarlılığı, tutarlılık göstergesi (CI) ve tutarlılık oranı (CR) ile denetlenmektedir.[24,25] CI ve CR değerleri sırasıyla Eşitlik (1) ve Eşitlik (2) ile hesaplanmakta; burada

λ_{maks} matrisin en büyük öz değerini, *n* kriter sayısını, *RI* ise matris boyutuna bağlı rastgele tutarlılık göstergesini ifade etmektedir.

$$CI = \frac{\lambda_{maks} - n}{n - 1} \quad (1)$$

$$CR = \frac{CI}{RI} \quad (2)$$

Hesaplanan CR değerinin 0,10'dan küçük olması, yargıların kabul edilebilir düzeyde tutarlı olduğunu göstermektedir. Dört kriter içeren matrisler için rastgele tutarlılık göstergesi *RI*=0,90 olarak alınmaktadır.[24]

Bulanık Küme Teorisi ve Üçgensel Bulanık Sayılar

Bulanık küme teorisi, kesin sınırlarla tanımlanamayan ve öznellik içeren durumların modellenmesi amacıyla Zadeh[26] tarafından ortaya konmuştur. Bulanık kümelerde her eleman kümeye 0 ile 1 arasında değişen bir üyelik derecesiyle kısmen ait olabilmekte; bu özellik "biraz daha önemli" gibi dilsel yargıların matematiksel temsilini mümkün kılmaktadır. Uygulamada en yaygın kullanılan bulanık sayı biçimi olan üçgensel bulanık sayı (ÜBS), alt, orta ve üst değerlerden oluşan M = (l, m, u) üçlüsüyle tanımlanmaktadır. İki ÜBS'nin toplamı bileşen bazında toplamayla, çarpımı yaklaşık olarak bileşen bazında çarpmayla, tersi ise $M^{-1} \approx (1/u, 1/m, 1/l)$ biçiminde elde edilmektedir.[9,27] Karar vericilerin Saaty ölçeğindeki yargıları, Tablo 2'de verilen dönüşüm kullanılarak ÜBS'lere aktarılmıştır.[27,28]

Tablo 2. Saaty ölçeğinin üçgensel bulanık sayılara dönüşümü.

Saaty değeri	Dilsel ifade	ÜBS (l, m, u)	Ters ÜBS
1	Eşit derecede önemli	(1, 1, 1)	(1, 1, 1)
3	Biraz daha önemli	(1, 3, 5)	(1/5, 1/3, 1)
5	Kuvvetli derecede önemli	(3, 5, 7)	(1/7, 1/5, 1/3)
7	Çok kuvvetli derecede önemli	(5, 7, 9)	(1/9, 1/7, 1/5)
9	Kesin (mutlak) derecede önemli	(7, 9, 9)	(1/9, 1/9, 1/7)

Kaynak: Chang[27] ve Kwong ve Bai[28] çalışmalarından uyarlanmıştır.

2.6. 3.3. Buckley Bulanık AHP Yöntemi

AHP'nin bulanık ortama ilk uyarlaması van Laarhoven ve Pedrycz[29] tarafından önerilmiş; Buckley[9], satır bulanık geometrik ortalamalarına dayanan ve tam bulanık ağırlıklar üreten yöntemi geliştirmiştir. Buckley yönteminin tercih edilmesinin temel gerekçesi, genişletme analizine dayalı yaklaşımların aksine kriterlere sıfır ağırlık atama riski taşımaması ve grup kararlarında kararlı sonuçlar üretmesidir. Yöntemde ilk olarak her uzmanın Saaty ölçeğindeki yargıları Tablo 2'deki dönüşümle ÜBS'lere çevrilerek uzman bazında, karşılıklılık özelliği korunan bulanık karşılaştırma matrisleri oluşturulur. Ardından K uzmanın yargıları, geometrik ortalama operatörüyle Eşitlik (3) kullanılarak tek bir birleşik bulanık matriste birleştirilir.[9,30]

$$a_{ij} = \left(\prod_{k=1}^{K} a_{ij}^{(k)} \right)^{\frac{1}{K}} \quad (3)$$

Birleşik matristen her kriter için satır bulanık geometrik ortalaması Eşitlik (4) ile hesaplanır; her kriterin bulanık ağırlığı, satır ortalamasının tüm satır ortalamaları toplamının tersiyle çarpılmasıyla Eşitlik (5) yardımı ile elde edilir.[9]

$$r_i = \left(\prod_{j=1}^{n} a_{ij} \right)^{\frac{1}{n}} \quad (4)$$

$$w_i = r_i \otimes (r_1 \oplus r_2 \oplus \ldots \oplus r_n)^{-1} \quad (5)$$

Bulanık ağırlıklar, ağırlık merkezi (BNP) yöntemiyle Eşitlik (6) kullanılarak kesin sayılara dönüştürülür ve toplamları 1 olacak biçimde normalize edilir. Son olarak her uzmanın kesin matrisi ile birleşik

matrisin orta (m) değerlerinden oluşturulan kesin matris üzerinde Eşitlik (1)-(2) uygulanarak CR değerleri hesaplanır ve CR < 0,10 koşulu denetlenir.[24,28]

$$BNP = \frac{l + m + u}{3} \quad (6)$$

UYGULAMA VE BULGULAR

Karar Problemi ve Kriterler

Çalışmada karar problemi, bir havayolu işletmesinin yeni bir uçuş rotasını değerlendirirken dikkate alacağı kriterlerin önem ağırlıklarının belirlenmesi olarak tanımlanmıştır. Kriter seti; ilgili literatürde en sık kullanılan ve üretilen tezin dokuz kriterli modelinde en yüksek önem ağırlıklarına sahip olan ticari-operasyonel ölçütler (potansiyel pazar büyüklüğü, yakıt tüketimi, rota mesafesi) ile literatürde ihmal edilen çevresel bir ölçüt olan yoğuşma izi etkisinin bir araya getirilmesiyle dört kriter olarak yapılandırılmıştır. Kriter sayısının sınırlı tutulması, ikili karşılaştırma sayısını azaltarak uzman yargılarının tutarlılığını güçlendirmekte ve modelin odağını ticari öncelikler ile çevresel öncelik arasındaki ödünleşime yöneltmektedir. Kriterlere ilişkin tanımlar aşağıda sunulmuştur.

Yakıt Tüketimi (K1): Jet yakıtı, birçok bölgede havayolu işletme giderlerinin yaklaşık %25-30'unu oluşturan en önemli maliyet kalemidir[31]; en aza indirilmesi hem kârlılığı hem de tüketimle doğru orantılı olan karbondioksit salımını etkileyen kritik bir değişkendir.[16,17]

Potansiyel Pazar Büyüklüğü (K2): İki nokta arasında taşınacak mevcut ve gelecekteki yolcu, yük ve posta trafiğinin oluşturduğu toplam pazar hacmini ifade etmekte; noktaların nüfusu, ekonomik etkileşimi ve gelir düzeyi tarafından belirlenmekte olup, yeni hat kararlarının en temel stratejik ölçütlerinden birini ifade etmektedir.[1]

Rota Mesafesi (K3): Güzergâh üzerindeki ardışık yer işaretleri arasındaki fiziksel uzaklığı zaman odaklı en uygun uçuş yollarını kapsamaktadır[32]; mesafenin uzaması blok süresini, yakıt tüketimini ve uçak kullanım maliyetlerini birlikte artırmaktadır.

Yoğuşma İzi Etkisi (K4): Egzoz kaynaklı su buharının yüksek irtifada yoğunlaşmasıyla oluşan bulut izleri, aşırı doygun bölgelerde kalıca hale gelerek net ısınma etkisi yaratmaktadır.[7,8] Dikey/yatay rota sapmalarıyla bu bölgelerden kaçınmak mümkündür ve önlenen iz etkisinin net iklim faydası, sapmaların ek yakıt etkisinden büyüktür.[21-23] Kriter, ticari hedeflerle çevresel sorumluluk arasındaki dengeyi temsilen değerlendirme sürecine dahil edilmiştir.

Veri Toplama ve Uzman Görüşü

Araştırma verileri, havacılık sektöründe uçuş operasyonları, uçuş planlama ve rota optimizasyonu alanlarında görev yapan dört uzmandan edinilmiştir. Uzmanlardan, dört kriteri Saaty 1-9 ölçeği üzerinde ikişerli olarak karşılaştırmaları istenmiş; her uzman C(4,2) = 6 karşılaştırma yapmıştır. Uzman yargılarını içeren başlangıç karar matrisi Tablo 3'te sunulmuştur.

Tablo 3. Uzmanların ikili karşılaştırma yargıları (Saaty ölçeği).

Karşılaştırma	Uzman 1	Uzman 2	Uzman 3	Uzman 4
K1 - K2	1/3	1/7	1	1/3
K1 - K3	3	1/3	3	3
K1 - K4	5	3	5	5
K2 - K3	7	5	5	3
K2 - K4	5	7	5	5
K3 - K4	3	5	5	3

Not: Değerler satırdaki ilk kriter lehine yorumlanır; kesirli değerler ikinci kriterin daha önemli bulunduğunu gösterir. K1: Yakıt Tüketimi, K2: Potansiyel Pazar Büyüklüğü, K3: Rota Mesafesi, K4: Yoğuşma İzi Etkisi.

Analiz ve Bulgular

İlk aşamada dört uzmanın Saaty ölçeğindeki yargıları Tablo 2'deki dönüşümle ÜBS'lere çevrilmiş ve uzman bazında 4×4 bulanık karşılaştırma matrisleri elde edilmiştir. Her uzmanın kesin matrisi üzerinden hesaplanan tutarlılık oranları sırasıyla 0,088; 0,089; 0,098 ve 0,073 olup tüm matrisler CR<0,10 koşulunu sağlamaktadır. İkinci aşamada uzman matrisleri Eşitlik (3)'teki geometrik ortalama operatörüyle birleştirilmiş; elde edilen birleşik bulanık karşılaştırma matrisi Tablo 4'te sunulmuştur. Birleşik matrisin orta değerlerinden oluşturulan kesin matriste λ_{maks} = 4,151; CI = 0,050 ve CR = 0,056 olarak hesaplanmış, grup yargısının da tutarlı olduğu saptanmıştır.

Tablo 4. Birleşik bulanık karşılaştırma matrisi (l; m; u).

Kriter	K1	K2	K3	K4
K1	(1,000; 1,000; 1,000)	(0,258; 0,355; 0,669)	(0,669; 1,732; 3,344)	(2,280; 4,401; 6,435)
K2	(1,495; 2,817; 3,873)	(1,000; 1,000; 1,000)	(2,590; 4,787; 6,853)	(3,409; 5,439; 7,454)
K3	(0,299; 0,577; 1,495)	(0,146; 0,209; 0,386)	(1,000; 1,000; 1,000)	(1,732; 3,873; 5,916)
K4	(0,155; 0,227; 0,439)	(0,134; 0,184; 0,293)	(0,169; 0,258; 0,577)	(1,000; 1,000; 1,000)

Üçüncü aşamada her kriterin satır bulanık geometrik ortalaması Eşitlik (4) ile, bulanık ağırlıkları Eşitlik (5) ile hesaplanmış; bu ağırlıklar Eşitlik (6)'da yer alan ağırlık merkezi yöntemiyle durulaştırılarak normalize edilmiştir. Sonuçlar ve kriter önem ağırlıkları Tablo 5'te sunulmuştur.

Tablo 5. Satır bulanık geometrik ortalamaları, bulanık ağırlıklar, BNP ve normalize ağırlıklar.

Kriter	r̃i (l; m; u)	w̃i (l; m; u)	BNP	w	Sıra
K1	(0,792; 1,283; 1,948)	(0,105; 0,239; 0,562)	0,302	0,249	2
K2	(1,906; 2,926; 3,750)	(0,251; 0,546; 1,082)	0,627	0,516	1
K3	(0,524; 0,827; 1,359)	(0,069; 0,154; 0,392)	0,205	0,169	3
K4	(0,244; 0,322; 0,522)	(0,032; 0,060; 0,151)	0,081	0,067	4
Toplam	(3,466; 5,358; 7,580)	—	1,215	1,000	—

Bulgulara göre kriterlerin önem sıralaması; potansiyel pazar büyüklüğü (0,516), yakıt tüketimi (0,249), rota mesafesi (0,169) ve yoğuşma izi etkisi (0,067) biçiminde gerçekleşmiştir. Potansiyel pazar büyüklüğü tek başına toplam ağırlığın yarısından fazlasını alırken, ticari-operasyonel nitelikteki ilk üç kriterin birikimli ağırlığı 0,933'e ulaşmakta; çevresel kriter olan yoğuşma izi etkisi son sırada yer almaktadır. Bulanık ağırlık aralıkları da bu tabloyu desteklemektedir: pazar büyüklüğünün alt sınırı (0,251) dahi diğer kriterlerin orta değerlerinin üzerindeyken, yoğuşma izinin üst sınırının (0,151) yakıt tüketiminin orta değerinin (0,239) altında kalması, düşük çevresel önceliğin genel bir yargı olduğunu göstermektedir.

TARTIŞMA

Bulgular, yeni rota seçiminde uzman önceliklerinin belirgin biçimde ticari değişkenler üzerinde yoğunlaştığını ortaya koymaktadır. Potansiyel pazar büyüklüğünün açık farkla ilk sırada yer alması; hattın var olma gerekçesinin talep olduğu, maliyet ve operasyon değişkenlerinin ise bu talebi kârlı biçimde taşımanın araçları olarak görüldüğü şeklinde yorumlanabilir. Bu sonuç, rota ve destinasyon seçiminde pazar ve talep göstergelerini ön sıralara yerleştiren önceki çalışmalarla uyumludur.[10,11,14,15] Yakıt tüketiminin ikinci sırası da jet yakıtının işletme giderleri içindeki yüksek payıyla[31] örtüşmektedir. Bulgular, üretilen tezin dokuz kriterli modelinin sonuçlarıyla da tutarlıdır: o modelde de pazar büyüklüğü ve yakıt tüketimi ilk iki sırayı alırken çevresel kriterler son sıralarda yer almış; kriter seti ve uzman paneli değiştiği hâlde öncelik örüntüsünün korunması, ticari-çevresel öncelik açığının rastgele olmadığını düşündürmektedir.

Çalışmanın en dikkat çekici bulgusu, yoğuşma izi etkisinin 0,067 ağırlıkla son sırada yer almasıdır. Güncel iklim bilimi bulguları, havacılığın toplam iklim etkisinde yoğuşma izlerinin karbondioksite yakın, hatta bazı değerlendirmelere göre daha büyük bir paya sahip olduğunu göstermektedir.[6,7] Buna karşın uzman yargılarında çevresel kriterin ticari kriterlerin gerisinde konumlanması, sürdürülebilirlik söylemi ile karar pratiği arasında ölçülebilir bir açık bulunduğuna işaret etmektedir. Bu açık; çevresel dışsallıkların fiyatlanmamasıyla, yoğuşma izi tahmininde süregelen belirsizliklerle[7] ve kaçınma manevralarının doğrudan maliyet doğurmasına karşın faydasının işletme bilançosuna yansımamasıyla açıklanabilir.[21,23] Öte yandan yoğuşma izinin sıfırdan farklı bir ağırlık alması, çevresel kriterin karar havuzuna dahil olmaya başladığının; ancak düzenleyici teşvikler olmaksızın kendiliğinden öncelik kazanmasının mümkün olamayacağının bir göstergesi olarak değerlendirilebilir.

SONUÇ VE ÖNERİLER

Bu çalışmada, havayolu işletmelerinin yeni uçuş rotası seçiminde etkili olan dört kriterin göreli önem ağırlıkları, dört havacılık uzmanının yargılarına dayalı olarak Buckley bulanık AHP yöntemiyle belirlenmiştir. Sonuçlara göre potansiyel pazar büyüklüğü (0,516) en önemli kriter olurken; bunu yakıt tüketimi (0,249), rota mesafesi (0,169) ve yoğuşma izi etkisi (0,067) izlemiştir. Çalışma; yoğuşma izi etkisini rota seçimi karar modeline kriter olarak entegre etmesi ve sürdürülebilirlik söylemi ile karar pratiği arasındaki açığı deneysel olarak ortaya koyması bakımından literatüre katkı sunmaktadır. Uygulayıcılar açısından temel çıkarım, çevresel kriterlerin karar süreçlerine dahil olmaya başladığı, ancak kaçınma maliyetini telafi eden teşvik mekanizmaları veya düzenleyici çerçeveler olmaksızın ticari değişkenler karşısında öncelik kazanmasının beklenemeyeceğidir. Yoğuşma izi tahmin araçlarının doğruluğunun artırılması ve uçuş planlama sistemlerine entegrasyonu bu dengeyi işletmeler lehine değiştirebilecektir.

Çalışmanın kısıtları; uzman sayısının dört ile sınırlı olması, kriter setinin dört kriterden oluşması ve bulguların belirli bir ülke içerisinde yaşayan uzman görüşlerine dayanmasıdır. Gelecek çalışmalarda daha geniş uzman panelleriyle çalışılması, kriter setinin genişletilerek duyarlılık analizleriyle sınanması ve elde edilen ağırlıkların TOPSIS, VIKOR veya MARCOS gibi sıralama yöntemleriyle bütünleştirilerek gerçek aday rotaların değerlendirilmesi önerilmektedir.

Bu çalışma, Erciyes Üniversitesi Sosyal Bilimler Enstitüsü Havacılık Yönetimi Anabilim Dalı bünyesinde hazırlanan "Havayolu İşletmelerinde Yeni Rota Seçimi Probleminin Çok Kriterli Karar Verme Yöntemleri İle Değerlendirilmesi" başlıklı yüksek lisans tezinden üretilmiştir.

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PATIENT SAFETY COUNSELING FOR ORAL ISOTRETINOIN USE: AN EVALUATION OF LARGE LANGUAGE MODEL RESPONSES

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ABSTRACT

Introduction and Purpose: Oral isotretinoin is an effective treatment for acne vulgaris but requires careful patient counseling because of potential risks such as teratogenicity, laboratory abnormalities, psychiatric symptoms, drug interactions, and systemic adverse effects. As patients increasingly use large language models (LLMs) to obtain health-related information, this study aimed to evaluate the responses of three LLMs to patient-style questions about oral isotretinoin use.

Materials and Methods: In this cross-sectional evaluation study, 25 patient-style questions were developed and grouped into seven categories: pregnancy/contraception, psychiatric symptoms, laboratory monitoring/systemic adverse effects, drug interactions, mucocutaneous adverse effects, lifestyle/cosmetic procedures, and urgent warning symptoms. Each question was submitted to ChatGPT, Gemini, and DeepSeek using the same standardized prompt and separate chat sessions. A total of 75 responses were evaluated. Responses were scored from 0 to 2 across five domains: accuracy, completeness, inclusion of critical safety warnings, appropriateness of physician/emergency referral, and patient-level comprehensibility. Total scores ranged from 0 to 10.

Results: The overall mean score was 9.69/10. Mean scores were 9.48 for ChatGPT, 9.76 for Gemini, and 9.84 for DeepSeek. All ChatGPT responses were classified as appropriate. For Gemini and DeepSeek, 24 responses were appropriate and one response was partially appropriate/incomplete for each model. No response was classified as inadequate. Potentially harmful advice or missing critical safety warnings were not detected. The highest category score was observed for drug interactions (10/10), while the lowest was observed for lifestyle/cosmetic procedures (9.17/10).

Conclusion: The evaluated LLMs generally provided accurate, understandable, and safety-oriented responses regarding oral isotretinoin use. However, minor deficiencies were observed, particularly in lifestyle and cosmetic procedure-related scenarios. LLMs may support patient education, but they should not replace physician evaluation.

Keywords: Isotretinoin; large language models; artificial intelligence; patient safety; acne vulgaris; dermatology.

THE SACRED SOUND: MUSIC AS AN INSTRUMENT OF PROCLAMATION IN MYSTERY PLAYS

KUTSAL SES: GİZEM (MYSTERY) OYUNLARINDA MÜZİĞİN TEBLİĞ İŞLEVİ

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ÖZET

Orta Çağ Avrupası'nda Hristiyan inancının halka aktarılması yalnızca vaaz ve kutsal metin okumasıyla sınırlı kalmamıştır. 10. ve 16. yüzyıllar arasında kilise litürjisinden kamusal alanlara taşınan mystery oyunları, bu sürecin en güçlü araçlarından biri haline gelmiştir. Bu oyunlar kilise litürjisinin tek sesli ve kutsal müzik geleneğinden doğmuştur. Ne var ki aynı dönemde troubadour geleneği müziği dünyevi konulara taşımaya başlamıştı. Kilise de bu değişen anlayışa, mystery oyunlarıyla uzun soluklu ve zorunlu bir yanıt vermiştir. Bu çalışmada müziğin mystery oyunlarındaki tebliğ işlevi tarihsel ve dramaturjik bir perspektiften incelenmiştir; çünkü müzik, dinî mesajı sözlü ve metinsel yöntemlerden daha etkili biçimde, duygusal, bedensel (ses ve ritmin fiziksel deneyimi aracılığıyla) ve kolektif düzeyde aktarmaktadır.

Bu amaç doğrultusunda çalışma beş temel mekanizmayı ele almaktadır. Hafıza aracı olarak müzik, okuryazarlığın büyük ölçüde sınırlı olduğu Orta Çağ toplumunda kutsal bilginin ezgisel tekrar ve koro söyleyişi yoluyla kalıcı biçimde aktarılmasını mümkün kılmıştır. Katılım aracı olarak müzik, pasif konumdaki seyirciyi aktif bir cemaat üyesine dönüştürerek tebliği kolektif bir deneyime taşımıştır. Duygu aracı olarak müzik, soyut teolojik öğretiyi yaşanmış ve hissedilmiş bir gerçekliğe çevirmiş; vaazın ve yazılı metnin yapısal olarak ulaşamadığı bir etki derinliği yaratmıştır. Bilinçli sessizlik olarak müzik ise York Döngüsü'nün 35. oyunu olan Crucifixio Christi'de örneklendiği üzere yokluğuyla da anlam üretmiştir. Son olarak müzik, hizmet ettiği amaca göre ruhun da nefsin de sesi olabilmiş; bu beşinci boyut, kutsal ile günahkâr olan arasındaki teolojik ayrımı ortaya koymuştur.

Çalışma ayrıca neden vaazın ve yazılı metnin bu işlevi yeterince yerine getiremediğini sorgulamaktadır. Latince'nin halk üzerindeki dil engeli, okuryazarlığın kısıtlılığı, soyut dinî öğretinin somutlaştırılma ihtiyacı ve bireysel alımlamanın yapısal sınırlılıkları, mystery oyunlarının müzikle birlikte aştığı temel sorunlar olarak ele alınmaktadır. Bu çalışma, mystery oyunlarını müzik ile tebliğin tarihsel olarak en güçlü biçimde bütünleştiği örneklerden biri olarak konumlandırmakta ve müziğin bu gelenekteki işlevinin pedagojik, teolojik ve ritüel bir zemine oturduğunu ortaya koymaktadır.

Anahtar Kelimeler: mystery oyunları, litürjik drama, Orta Çağ müziği, dinî tebliğ, kolektif deneyim

ABSTRACT

In medieval Europe, the transmission of the Christian faith to the public was not limited to sermons and scriptural readings. Between the 10th and 16th centuries, mystery plays, which moved from church liturgy into public spaces, became one of the most powerful instruments of this process. These plays emerged from the church liturgy's monophonic and sacred musical tradition. In the same period, however, the troubadour tradition had begun carrying music toward worldly themes. The Church responded to this changing taste through mystery plays, in a long and necessary process. This study examines the role of music in the proclamation function of mystery plays from a historical and dramaturgical perspective; music conveyed the religious message more effectively than verbal and textual methods alone, transmitting it at an emotional, bodily (through the physical experience of sound and rhythm), and collective level.

The study examines five key mechanisms. As a tool of memory, music enabled the permanent transmission of sacred knowledge through melodic repetition and choral singing in a society with severely limited literacy. As a tool of participation, music transformed passive spectators into active members of a worshipping community. As a tool of emotion, music converted ABSTRACT theological doctrine into lived reality, achieving a depth of impact unavailable to the sermon. As a tool of deliberate silence, music produced meaning through its own conscious absence, as exemplified in the Crucifixio Christi of the York Cycle. As a tool of theological distinction, music served as the voice of either the soul or the self depending on its purpose, revealing the boundary between the sacred and the sinful.

The study also interrogates why the sermon and the written text could not enough fulfil this function. The language barrier of Latin, limited literacy, and the need to render doctrine concrete were fundamental problems overcome by mystery plays through music. This study positions mystery plays as one of the most powerful historical examples of the integration of music and religious proclamation, defining music's role as pedagogical, theological, and ritual in nature.

Keywords: mystery plays, liturgical drama, medieval music, religious proclamation, collective experience

GİRİŞ

Orta Çağ Avrupası'nda dinî tebliğ, vaaz kürsüleriyle ve kutsal metin okumalarıyla sınırlı kalmamıştır. 10. ve 16. yüzyıllar arasında Hristiyan kilisesi, inancını halka aktarmak için dramatik ve müzikli performansı da devreye sokmuştur. Bu girişimin en önemli ürünlerinden biri mystery oyunlarıdır. İncil anlatılarını sahneleyen bu oyunlar, zamanla kilise içinden şehir meydanlarına taşınmış ve Orta Çağ'ın en güçlü dinî-pedagojik yapılarından biri haline gelmiştir.

Ne var ki bu oyunları vaazdan ya da ders niteliğindeki metinlerden ayıran en belirleyici unsur müziktir. Mystery oyunlarında müzik, sahneye eşlik eden dekoratif bir öğeden ibaret kalmamış; kutsal anlatının bizzat taşındığı ses olarak işlev görmüştür. Başka bir deyişle müzik, bu yapılarda söylenen her şeyden önce duyulan, hissedilen ve toplulukça yaşanan kutsal sesin kendisi olmuştur. Craig'in belirttiği gibi litürji, dinî dramanın yaratıcı sürecinde yol gösterici ve denetleyici güç olarak her zaman var olmuştur; seçilen dramatik konular bile özgür bir tercihten çok, litürjinin belirlediği sınırlardan kaynaklanmaktadır.[1] Bu çalışmanın çıkış noktası: Müzik, bu yapı içinde salt estetik bir eşlik unsuru değildir. Aksine, Hristiyan tebliğini sözlü ve metinsel yöntemlerden daha etkili kılan temel bir araçtır; çünkü dinî mesajı bilişsel değil, duygusal, bedensel ve kolektif düzeyde içselleşmesine vesile olur.

Bu iddianın anlaşılabilmesi için önce mystery oyunlarının içinden doğduğu tarihsel bağlamın ortaya konması gerekmektedir. Bunu takiben, müziğin bu yapı içindeki temel işlevleri (hafıza, katılım, duygu, bilinçli sessizlik ve ruh ile nefis arasındaki teolojik ayrım) ayrıntılı biçimde incelenecektir. Son olarak, neden vaaz ve yazılı metnin bu işlevi yeterince yerine getiremediği sorusuna yanıt aranacaktır.

GELİŞME

Bağlam: Orta Çağ'da Müziğin Dönüşümü

Müziğin Kilise Kökenli Yapısı

Orta Çağ'ın başlarında müzik, kilise ile iç içe bir olguydu; bu yakınlığın en açık göstergesi Gregoryen koral geleneğiydi. Bu gelenekte müzik tek sesliydi, çünkü tek ses Tanrı'nın birliğini simgeliyordu. Bu nedenle çok seslilik ya da ayrışan melodiler kabul görmüyordu, zira teolojik bir ayrılığı çağrıştırıyorlardı. Güfteler de bu bütünlüğü yansıtacak biçimde doğrudan İncil'den ya da kutsal metinlerden alınırdı. Sonuç olarak müzik; inancın sesi, ayinin ruhu ve cemaatin ortak nefesi haline gelmişti.

Bu yapı içinde müzik bir sanat formundan çok bir ibadet aracı olarak var oluyordu; çünkü amaç estetik deneyim değil, Tanrı'ya yöneliş ve kutsal metni seslendirmekti. Bu anlayış doğrultusunda kilise, müzik üzerine titiz bir denetim uyguluyor; hangi melodilerin, hangi sözlerle, hangi törenlerde kullanılacağını önceden belirliyordu. Böylece müzik, denetlenebilen ve anlamı bilinen bir alan haline gelmişti.

Troubadour Geleneği ve Dünyevileşme Süreci

11. yüzyıldan itibaren, özellikle Güney Fransa'daki saray çevrelerinde farklı bir müzik geleneği doğmaya başladı: troubadour geleneği. Bu geleneğin müzik anlayışı kilise müziğinden temelden ayrılıyordu, çünkü temaları aşk, doğa, şövalyelik ve bireysel duyguydu; bu müziklerde hitabet Tanrıya ve kutsal olana değil, sarayın aristokratik çevresineydi. Böylece müzik, ilahi konulardan insani konulara, manevi olandan dünyeviye doğru kaymaya başlamıştı.

Bu dönüşümün arka planında daha eski ve köklü bir gelenek yatmaktadır. Hopper ve Lahey'in aktardığı üzere 7. yüzyılda Isidore of Seville, tiyatronun fiilen yok olmasına karşın jongleur (şarkı söyleyip hikâye anlatan gezgin şarkıcı), histrion (taklit ve canlandırma yoluyla performans sergileyen gezgin oyuncu), müzik aletleri çalanlar ve masal anlatıcıları geleneğinin canlılığını koruduğuna tanıklık etmiştir. 14. yüzyıl başında Salisbury'li din adamı Thomas de Cabham bu gezgin sanatçıları ahlaki statülerine göre üç sınıfa ayırmıştır. Üçüncü ve en saygın sınıfı ise azizlerin hayatlarını ve kahraman prenslerin destanlarını söyleyenler oluşturuyordu. [3] Bu sınıflandırma, kutsal içerikli müzikle dünyevi müzik arasındaki gerilimin Orta Çağ boyunca ne denli belirleyici olduğunu gözler önüne serer. Troubadour geleneği bu gerilimi derinleştirmiş; müziği saray çevrelerinde aristokratik bir estetik aracına dönüştürerek kilise denetiminin dışına çıkarmıştır.

Bu dönüşüm yalnızca saray çevresinde kalmadı. Troubadour geleneği zamanla halkın estetik ve duygusal taleplerini de etkiledi. Müzik, artık bedensel arzuyu, bireysel tutkuyu ve dünyevi yaşamın sevincini dile getirebilen bir araca dönüşmüştü. Yerel dillerin müzikle buluşması, Latince'nin geri plana ittiği sanatı halkın diliyle yeniden canlandırdı. Bu durum, kilisenin müzik üzerine kurduğu anlam tekelini ciddi biçimde sarstı.

Halkın Dönüşümü ve Kilisenin Konumu

10. ve 16. yüzyıllar arasında Orta Çağ toplumu kültürel açıdan önemli bir dönüşüm geçirdi. Halk, kilisenin sunduğu soyut ve Latinceye dayalı litürjiyle yetinmemeye başlamıştı. Tiyatroya ve dramaya olan ilgi artıyordu; şehir meydanlarında gezgin topluluklara ait gösteriler ve halk eğlencesi yaygınlaşıyordu. Müzik ise bu eğlencenin ayrılmaz parçasıydı.

Kilise bu gelişme karşısında bir ikilemle yüz yüze geldi. Dünyevi tiyatroyu ve müziği yasaklamak ya da dışlayıcı bir tavır sergilemek, halkı kiliseden uzaklaştırma riskini barındırıyordu. Öte yandan bu eğilimi görmezden gelmek de mümkün değildi. Hopper ve Lahey'in de belirttiği gibi bu süreçte drama kilisenin doğrudan denetiminden çıktı. Latince'nin yerini konuşulan diller aldı, oyunlar daha dünyevi bir ton kazandı. Ama özündeki ciddi ve saygın dinî amaç hiçbir zaman terk edilmedi.[3] Kilisenin tercih ettiği yol ne yasaklama ne de teslim olmaktı; halkın talep ettiği biçimi benimseyip içini kutsal içerikle doldurmayı seçti. Mystery oyunları bu tercihin somut ürünüydü.

Mystery Oyunları ve Tebliğ

Litürjiden Kamusal Sahneye: Quem Quaeritis'ten Şehir Meydanına

Mystery oyunlarının kökeni kilise litürjisine dayanır. Orta Çağ'ın dinî törenlerinde İncilde geçen olaylar sadece okunmakla kalmaz; zaman zaman müzikli diyaloglar ve törensel hareketlerle de canlandırılırdı. Bu litürjik drama geleneğinin en bilinen ve en erken örneği Quem Quaeritis tropudur; adını Latince'de "Kimi arıyorsunuz?" anlamına gelen açılış sözcüklerinden alır. Bu kısa müzikli diyalog, Paskalya sabahı litürjisinin bir parçası olarak icra edilirdi ve en eski tanıklıklarından biri, yaklaşık 970 yılına ait Regularis Concordia'da yer almaktadır.[2] Craig'in vurguladığı üzere trope geleneği, kilise litürjisine yapılan eklemeler ve güzelleştirme girişimlerinden doğmuştur; bunlar arasında Quem Quaeritis, dramatik formun üç temel unsurunu (diyalog, canlandırma ve eylem) ilk kez bir arada barındırması bakımından ayrı bir öneme sahiptir.[1]

Diller'in de vurguladığı üzere Quem Quaeritis, kilise litürjisinin öngördüğü zorunlu bir metinden ziyade, antifonal söyleyişten doğan bir trope, yani litürjiye sonradan eklenmiş bir ara metindir.[2] Paskalya töreninde melek ile mezarı ziyarete gelen kadınlar arasındaki karşılaşma sahnelenir. Sözcükler konuşularak değil, ezgisel biçimde seslendirilir. Üstelik metnin icrasına törensel hareketler de eşlik ederdi: Sunağa yaklaşmak, tütsü kaplarını taşımak, kefeni kaldırıp cemaate göstermek. Diller'in dikkat

çektiği üzere bu nesneler, tütsü kapları ve kefenler hem dramatik birer sahne unsuru hem de litürjik sembollerdir.[2] Müzik, hareket ve kutsal nesne tek bir ritüel eylemde birleşiyordu.

Bu yapı mütevazı görünse de içerdiği dramatik tohum oldukça güçlüdür. Craig, dinî dramanın yaratılmasındaki itici gücün sanatsal ya da tiyatral değil, dinî olduğunu açıkça belirtir; dramatik başarılar bu dinî içeriğin kaçınılmaz bir sonucu olarak ortaya çıkmıştır.[1] Diller'in belirttiği gibi bu ilk litürjik drama, yer ve zamanı temsil etmekten çok yeniden-canlandırma ilkesiyle işler: Paskalya sabahı kilisede yaşanan an, İncil'deki o sabahla özdeşleştirilir; temsil ile gerçek aynı anda var olur.[2] Carpenter, Diller'in bu yaklaşımını değerlendirirken önemli bir noktaya dikkat çeker: Diller, litürjik drama ve mystery döngülerini edebi değil tiyatral bir perspektiften ele alan ilk akademisyenlerden biridir. Onun dramatik konuşmanın semiyotik (işaret ve anlam) boyutlarına gösterdiği ilgi, alanda kalıcı bir iz bırakmıştır.[8]

Zamanla bu litürjik dramatizasyonlar genişledi, çeşitlendi ve kilise mekânlarından şehir meydanlarına taştı. Sahne arabaları şehrin sokaklarında dolaşmaya başladı; sahneleme görevi dinî kurumlardan şehrin lonca ve kentsel örgütlenmelerine devredildi. York ve Wakefield döngüleri alay düzeninde (processional), sabahın erken saatlerinde başlayıp geceye dek süren gösterimlerle sunulurdu.[3] Nitekim Hopper ve Lahey'in de belirttiği gibi orta çağ dünyevi draması litürjik dramadan, litürjik drama ise trope geleneğinden doğmuştur; bu zincirin her halkasında müzik kurucu bir rol üstlenmiştir.[3] Bu bağlamda Helmers'in gösterdiği üzere York döngüsü, 1370'lerde Corpus Christi Bayramı çevresinde şekillenmiş ve oyunlar dinî bir tören olmaktan çok, kentin bütününü ortak bir imana kavuşturan toplumsal bir pratik olarak işlev görmüştür.[4] Litürjiden kamusal sahneye uzanan bu yolculukta müzik hem taşıyıcı hem dönüştürücü bir güçtü. Quem Quaeritis'in önemi tam olarak şuradan gelir: Mystery oyunlarının dramatik dili en başından itibaren müzikle iç içe olmuştur, çünkü müzik bu geleneğe sonradan eklenmiş bir unsur değil, anlatının bizzat taşındığı biçim olmuştur. Nitekim litürjiden dramaya geçiş, soyut bir süreç değil; Quem Quaeritis'in o kısa ezgili diyaloğunda somutlaşan, gerçekten yaşanmış bir andır.

Tebliğin Aracı Olarak Drama

Mystery oyunlarının tebliğ işleyişi vaazdan bütünüyle farklıdır. Vaaz sözlü ve tek yönlüdür; bir kimse konuşur, kalabalık dinler. Drama ise görsel, işitsel ve bedenseldir. Seyirci bir sahne karşısında yalnızca kulağıyla değil, gözleriyle de devrededir. Happé'nin de belirttiği üzere bu oyunların yazarlarının birincil amacı edebi olmaktan çok dinî ve didaktikti; drama bu amacın gerçekleştirilme biçimidir.[5] Günahın sahnelendiğini gören, tövbenin yaşandığını izleyen, diriliş coşkusunu hisseden biri, sözle anlatılmış bir öğretiden çok yaşanmış bir deneyimi taşır. Happé'nin ifadesiyle bu oyunlar özünde "öğretme ve ibadet eyleminin bir bütünü" olarak tasarlanmıştır.[5] Bu dramatik yapının içinde müziğin payı da büyüktü. Duffin'in de vurguladığı gibi, mystery oyunlarının büyük çoğunluğunda müzik önemli bir yer tutuyordu. Bunun en somut ve en erken kanıtlarından biri, Coventry'deki Koyuncu ve Terziler Loncası'nın sahnelediği oyundan günümüze ulaşan 'Coventry Carol' adlı ilahidir.[6]

Mystery oyunlarının tebliğ amacı, dönemin kendi kaynaklarında da açıkça dile getirilmiştir. 14. yüzyıl başında kaleme alınan Handlynge Synne'de Robert Mannyng, Diriliş oyununun kilisede neden sahnelenmesi gerektiğini şöyle açıklar: "To make men be yn beleue gode / Pat he ros with flesshe and blode"; yani amaç, insanları Hz. İsa'nın etiyle ve kanıyla dirildiğine inandırmaktır.[1] Craig'in aktardığı 15. yüzyıl din eğitimi kitabı Dives and the Pauper ise bu görüşü daha da netleştirir: Asıl meşruiyet, İnsanlara Tanrı'yı daha çok sevmeyi öğreten, saygı, dürüstlük ve neşe içinde icra edilen mystery oyunlarınındır.[1] Bu iki kaynak, mystery oyunlarının bilinçli bir tebliğ aracı olarak açıkça kabul gördüğünü dönemin kendi sesiyle doğrulamaktadır. Bu yapı içinde müzik belirleyici unsurdur. Mystery oyununu vaazdan ayıran yalnızca görsellik değildir; müziktir. Meryem'in ağıtı, diriliş sekansında yükselen koro ve Günah ile Ölüm'ü temsil eden figürlerin huzursuz edici melodileri, seyirciyi işitsel bir dünyaya sokar, onu duygulandırır ve o duygu üzerine inancını inşa etmesini sağlar. Nitekim Happé, yaklaşık iki yüz yıl boyunca büyük kentlerin tüm kaynaklarını seferber ederek ürettikleri bu oyunların gerçek başarısının ancak bir Orta Çağ performansında deneyimlenerek kavranabileceğini vurgular.[5]

Müziğin Güçlendirici İşlevi

Hafıza Aracı Olarak Müzik

Orta Çağ Avrupası'nda okuryazarlık oranı çok düşüktü. Halkın büyük çoğunluğu kutsal metinleri doğrudan okuyamazdı. Bu koşullar altında dinî bilginin aktarılması için işitsel ve yazıya dayanmayan kanallar hayati önem taşıyordu. Müzik, bu ihtiyacı karşılayan en güçlü araçlardan biriydi. Ezgiyle söylenen bir metin, düz konuşulan bir metinden çok daha kalıcıdır. Bu, yalnızca Orta Çağ'a özgü bir durum değildir; insan belleğinin temel özelliklerinden biridir. İlahi, koro ve ezgisel tekrar, kutsal metni hafızaya işler. Tekrarlanan bir ilahiyi beş kez dinleyen biri, o ilahinin taşıdığı mesajı bir vaazı beş kez dinlemekten çok daha derin içselleştirebilir. Zira ezgi, anlamı değil, duyguyu kodlar. Duyguyla kodlanan bilgi ise çok daha geç silinir.

Mystery oyunlarında bu mekanizma bilinçli biçimde kullanılmıştır. Responsorial söyleyişler, yani bir öncü sesin ardından kalabalığın cevap vermesi üzerine kurulan yapı, dinî metinleri cemaatin diliyle buluşturuyordu. Tekrar edilen ezgisel kalıplar, o gün sahneyi izleyen birinin yıllar sonra hâlâ hatırlayacağı şekilde dinî içeriği belleğine kazıyordu. Müzik burada bir eşlik unsurunun ötesinde, bir hafıza teknolojisiydi. Bu anlayışın kökleri çok derine uzanır: Jeffery'nin de gösterdiği üzere bu, İncil geleneğinin en eski katmanlarına kadar uzanan bir bağlantıdır.[9] Müzik, kutsal bilgiyi taşıyan bir kanal olarak baştan beri işlev görmüş; Orta Çağ kilisesi bu işlevi mystery oyunlarına taşımıştır.

Katılım Aracı Olarak Müzik

Tebliğin en büyük sorunu, alan ile veren arasındaki mesafedir. Vaazda bu mesafe yapısaldır: Bir kişi konuşur, diğerleri pasif biçimde dinler. Drama bu mesafeyi kısmen aşar; seyirci artık izleyen biridir, dinleyen biri değil. Ama müzik bu mesafeyi bütünüyle ortadan kaldırabilir.

Koro söyleyişi, toplu ilahi ve ezgisel katılım, seyirciyi pasif alıcıdan aktif katılımcıya dönüştürür. Birlikte söylenen bir ilahide birey, bir an için tebliğin hedefi olmaktan çıkıp tebliğin taşıyıcısı haline gelir. İnancı alan değil, inancı seslendiren biri olur. Diller'in seyircinin hitap edilme, dahil edilme ve yönlendirilme biçimleri üzerine yürüttüğü analize değinen Carpenter, bu yaklaşımın mystery oyunlarının işleyişini anlamak açısından alanda kalıcı bir katkı sağladığına dikkat çeker.[8] Bu dönüşümün tebliğ açısından önemi çok büyüktür: İnsanlar söyledikleri şeylere, duydukları şeylerden daha çok iman edebilirler; çünkü duyulan bir söz henüz içselleştirilmemiş bir bilgi olarak kalabilirken, aşkla ve şevkle söylenen bir söz, kişinin artık ona iman ettiğinin göstergesi olarak nitelendirilebilir. Bir başka deyişle duymak imana giden yolun başlangıcı olabilir, ama içselleştirip söylemek ve bir de söylediğini tatbik edebilmek imanın en güçlü göstergesi sayılabilir.

Mystery oyunlarında bu yapı çok katmanlıydı. Bazı sahnelerde koro kilise şarkıcılarından oluşurken, bazı bölümlerde izleyicinin de katılması bekleniyordu. Hopper ve Lahey'in ortaya koyduğu üzere ritüel drama ile sıradan tiyatro burada ayrışır: Sıradan tiyatroda oyuncu ile seyirci birbirinden kesin çizgilerle ayrılırken, ritüel dramada bu sınır ortadan kalkar; seyirci aktif bir ibadet ruhuyla hem huzurlu hem de manevi bir katılım içindedir.[3] Bu gerçek, mystery oyunlarının modern bir prodüksiyon olarak yeniden sahnelendiği bir deneyimde de gözlemlenmiştir. Helmers'in aktardığına göre, Toronto'da 1977 yılında yapılan böyle bir gösterimde Johnston şunu fark etmiştir: Dar orta çağ sokaklarında sahne arabasının durduğu her istasyondaki seyirciler, önlerine gelen sahneyi kendi aralarına alıyor, izliyor ve ardından yolcu ediyordu. Böylece oyuncular ile seyirciler ortaklaşa bir kutlamanın parçası hâline geliyordu.[4] Müzik bu ortaklaşmanın en güçlü bağıydı; birlikte söylenen ezgi, topluluğu görünmez bir bağ ile birbirine bağlıyordu.

Duygu Aracı Olarak Müzik

Müziğin ölçülmesi en güç olan işlevi, duygu üzerindeki etkisidir. Bir öğretiyi anlamak ile onu hissetmek arasında, insan davranışı açısından önemli bir fark olabilir. Örneğin bilişsel düzeyde öğrenilen bir bilgi zamanla sorgulanabilir ya da unutulabilir; oysa duygusal düzeyde yaşanan bir deneyim çok daha kalıcı izler bırakabilir ve kişinin kimliğinin bir parçası hâline gelebilir.

Müzik, duygu üzerinde doğrudan ve kaçınılmaz bir etki yaratır. Bu etki, düşünme yoluyla değil, algı yoluyla gerçekleşir. Passion sahnelerinde duyulan Meryem'in ağıtı, o sahnenin anlamını sözlerden önce iletir. Diriliş bölümünde yükselen koro cemaati coşkuya taşırken, bu coşku anlatılan mucizenin

gerçekliğine duyulan inancı da beraberinde getirir. Bu duygusal derinliğin en köklü örneği Planctus Mariae geleneğidir. Bunlar Meryem Ana'nın Hz. İsa'nın çarmıha gerilişindeki acısını dile getiren lirik müzikal ağıtlardır. Craig'in belirttiği üzere bu ağıtlar Passion oyunlarının en başından itibaren sahnede yer almış ve oyunların güzelliğine büyük katkı sağlamıştır.[1] Bazen Meryem ile Aziz Yuhanna arasındaki diyalog biçimini alan bu planctus'lar, müziğin tebliğdeki duygu işlevinin en güçlü tarihsel kanıtıdır: Acıyı anlatmak yerine hissettirmiş, bilgiyi aktarmak yerine yüreğe işlemiştir.

Bu açıdan müzik, mystery oyunlarında teolojik bir işlev üstlenir. Kutsal anlatı, müzik aracılığıyla seyircinin bedenine ve duygusuna ulaşır. İnanç, soyut bir öğreti olarak zihinden ziyade; yaşanmış bir deneyim olarak beden ve ruhla içselleştirilebilir. Bu, vaazın yapısal olarak ulaşamadığı bir etkidir.

Müziğin teolojik konumu, Chester Döngüsü'nün Nuh oyununda çarpıcı biçimde somutlaşır. Oyunda Nuh'un gemisine taşınan hayvanlar tek tek sayılırken en son olarak müzik yapan kuşlara yer verilir: “And each fowl that music makes / In this ship men may find.”[3] Bu dize rastgele seçilmemiştir. Müzik yapan her kuşun gemide yer bulması, müziğin Nuh'un tufanından korunmaya değer bir unsur olarak sayıldığını gösterir. Müzik burada bir sanat formu olmaktan çok; Tanrı'nın düzeninde korunmaya değer bir unsur olarak yorumlanabilir.

Bu duygusal derinlik sırf ağıt ve koro sahneleriyle sınırlı değildi. Towneley Döngüsü'nün Wakefield ustasına atfedilen Birinci Çobanlar Oyunu, müziğin seyirci üzerinde yarattığı etkiyi farklı bir açıdan gözler önüne serer. Duffin'in aktardığı üzere oyunda çobanlar meleğin Gloria in excelsis ilahisini işittikten sonra yalnızca müziği övmekle kalmaz; meleğin uzun notaları ne denli ince ve ustalıklı işlediğini tartışır.[6] Bu sahne dikkat çekicidir: Bir yanda kutsal varlığın sesi olarak müzik, öte yanda o sesi işiten sıradan insanların derin bir hayranlık ve duygulanma içinde kalması. Müzik burada vaazın tek başına yapamayacağı şeyi yapar: Kutsalı duyulur ve hissedilir kılar. Bu örnekler, müziğin mystery oyunlarındaki duygusal gücünün ne kadar çeşitli biçimlerde ortaya çıktığını gösterir. Müzik kimi zaman bir ağıtla acıyı hissettirir, kimi zaman bir ilahiyle hayranlık uyandırır, kimi zaman da kutsal düzenin bir parçası olarak seyirciyi Tanrı'nın uyumuna dahil eder. Ama müziğin bu gücü yalnızca sesiyle değil, bazen de sessizliğiyle kendini gösterir.

Yokluğuyla Konuşan Müzik: Bilinçli Sessizlik

Müziğin mystery oyunlarındaki güçlendirici işlevi yalnızca varlığıyla değil, yokluğuyla da anlaşılır. Orta Çağ tiyatrosunda müzik rastgele kullanılmaz ne zaman devreye gireceği ve ne zaman çekileceği bilinçli bir sanatsal ve teolojik kararla belirlenir. Bu bilinçli sessizliğin en çarpıcı örneği, York Döngüsü'nün 35. oyunu olan Crucifixio Christi'dir.[7]

Dönemin Hristiyan inanışına göre müzik, Tanrı'nın evrene koyduğu kusursuz uyumu, yani Kürelerin Müziği'ni (gezegenlerin hareketiyle oluştuğuna inanılan kozmik uyum) temsil eder. Bu nedenle York Döngüsü'nde müziğin en yoğun kullanıldığı sahneler, meleklerin şarkı söylediği Yaratılış, Doğum ve cennet kapılarının açıldığı sahnelerdir. Ama 35. oyun olan Çarmıha Gerilme sahnesi tam tersini yapar: Burada hiç ilahi, koro ya da ezgi yoktur. Sahne, dört askerin soğukkanlı ve sıradan bir iş konuşması gibi ilerleyen çıplak bir diyalogla kuruludur. Müziğin yerini çivilerin çakılma sesi, iplerin gıcırtısı ve askerlerin homurtusu alır.

Bu tercihin ardında teolojik bir hesaptan öte, gerçek bir dramatik dehanın izleri yatmaktadır. York Döngüsü'nde 35. oyunun sahnelenmesi görevi, iğne ve çivi üreten Pinners loncasına, yani Çivicilere verilmişti. Bu seçim tesadüfi değildi: Çarmıha gerilme sahnesi ile çivi ustalarının gündelik mesleği arasındaki doğrudan ilişki, sahneye özgün bir gerçekçilik kazandırıyordu. Nitekim oyundaki dört asker, Hz. İsa’yı çarmıha gererken sanki sıradan bir marangozluk işi yapıyormuş gibi davranır. Çivinin tam oturup oturmadığını kontrol eder, ipin gevşekliğinden yakınır, deliğin yanlış yerden delindiğini fark ederler. Bu teknik ve gündelik diyaloglar, sahneye tuhaf ve rahatsız edici bir sıradanlık katar. İşte bu sıradanlık sayesinde, müziğin yokluğu mystery geleneğinin en güçlü dramatik kararlarından biri olarak değerlendirilebilir. Çarmıha gerilme sahnesinde melodik bir müzik yerine, çekiç darbelerinin yarattığı endüstriyel ve acımasız bir ritim hâkimdir: Çekiç iner, çivi girer, asker homurdanır. Bu sesler müziksel değildir, ama kendi içlerinde soğuk, mekanik ve insanlıktan uzak bir ritim taşırlar. Seyirci bu ritmi duyduğunda, Hz. İsa’nın acısını melodik bir ağıt yerine gündelik bir işin sesleriyle deneyimler. Bu durum seyircide çok daha derin bir dehşet uyandırır; çünkü işlenen kötülük olağandışı bir olay gibi değil, sıradan bir iş gibi sunulmaktadır

Bu yokluk tesadüf değildir. Çarmıha gerilme anı, insanlığın günahının zirve noktasıdır; karanlığın ve acının hüküm sürdüğü bir andır. Hopper ve Lahey'in de işaret ettiği gibi York Döngüsü, karanlık ile ışığı, ölüm ile dirilişi sürekli karşı karşıya koyan bir kozmik döngü üzerine kuruludur; tıpkı baharın kış karanlığını dağıtması gibi, Paskalya sabahının zaferi de çarmıhtaki karanlığı geride bırakır.[3] Bu ölüm-diriliş karşıtlığı, döngünün temel eksenini oluşturur. İşte bu nedenle, Tanrısal uyumun koptuğu çarmıh anına müzik eklemek teolojik bir çelişki yaratırdı. Happé'nin dikkat çektiği üzere, York döngüsünde Çarmıha Gerilme sekansını yeniden yazan yazar, döngünün başka hiçbir yerinde görülmeyen bir gerçekçilik ve dehşet yaratmayı başarmıştır.[5] Müziğin bu sahneden bilinçli olarak çekilmesi, tam da bu gerçekçiliğin ve dehşetin temel aracıdır; çünkü müziğin yokluğu, seyircinin dikkatini tamamen çivilerin çakılma sesine ve yaşanan fiziksel acıya yöneltir.

Bu örnek, mystery oyunlarında müziğin ne denli özenle hesaplandığını gösterir. Müzik rastgele değil, tam olması gereken yerde vardır ve tam olmaması gereken yerde yoktur. Bu stratejik seçicilik, müziğin tebliğdeki güçlendirici işlevinin en açık kanıtı sayılabilir: Müzik yalnızca bir anlam taşımakla kalmaz, o anlamı aynı zamanda çerçeveler. Varlığıyla kutsalı işaretler, yokluğuyla ise günahı ve acıyı derinleştirir. Aynı mantığın modern yorumlarda da sürdüğünü görürüz. Örneğin Jedermann sahnelemesinde litürjik müzik, fanfar, org, çanlar ve karşılıklı antifonal korolar bir bütün olarak kullanılmış; müzik, tiyatro mekânını âdeta bir katedral deneyimine dönüştürmüştür.[3]

Bu teolojik anlayışın köklerinin Orta Çağ'ın çok daha erken dönemlerine uzandığı görülmektedir. Hildegard von Bingen'in yaklaşık 1151 yılında kaleme aldığı Ordo Virtutum, yani Erdemlerin Oyunu, bu bağlamda oldukça aydınlatıcıdır. Gardiner'ın analizinin de ortaya koyduğu üzere Hildegard'ın bu müzik-dramasında oyunun tüm karakterleri şarkı söylerken yalnızca bir karakter şarkıdan yoksundur: Şeytan. Şeytan'ın rolü konuşarak, hatta homurdanarak seslendirilir; zira müzik ilahi uyumun ve Tanrısal düzenin simgesidir; kötü olan ise bu uyumdan pay alamaz.[12] Bu dramatik tercih, bilinçli sessizlik argümanımızı tarihsel olarak derinlemesine destekler: Kutsal ses hem kendini kirlilikten korur hem de kötü varlığı ilahi uyumdan mahrum bırakır. Ordo Virtutum'dan York Döngüsü'ne uzanan bu çizgi, müziğin Orta Çağ drama geleneğinde tutarlı ve bilinçli bir teolojik dil olarak işlev gördüğünü göstermektedir.

Ruh ile Nefis Arasında Müzik: Teolojik Bir Ayrım

Mystery geleneğinde müziğin tek bir sabit anlamı yoktur. Aynı müzikal dil, bazen kutsalın bazen de günahın sesi olabilir. Bu görünürdeki çelişki aslında tutarlı bir teolojik anlayışa dayanır: Müziğin hangi amaca hizmet ettiği, onun ruhla mı yoksa nefisle mi icra edildiğine bağlıdır. Bu çift yönlü kullanım yalnızca İngiliz mystery geleneğine özgü değildir; Fransız hagiografik mystery oyunlarında da aynı örüntü görülür. Hamblin ve Corrigan'ın üç Fransız oyun üzerinde yürüttüğü karşılaştırmalı çalışma bunu somut biçimde gösterir: Cennet sahnelerinde org, vielle ve psalterion gibi yumuşak enstrümanlarla ahenkli müzik icra edilirken, Lucifer ve şeytanların sahneye girişinde “fors espouventable a ouyr”, yani “duyulması gerçekten korkunç” sesler yükselir.[11] Bu keskin ses karşıtlığı, mystery geleneğinde müzikal dilin bizzat teolojik bir dile dönüştüğünü açıkça ortaya koyar.

Castle of Perseverance adlı morality oyununda bu ayrım çarpıcı biçimde sahnelenir. Oyunun kritik bir anında Kötü Melek, İnsanoğlu'nu İyi Melek'in yanından uzaklaştırmayı başarır; tam bu sırada Dünya adlı karakter sahneye çıkar ve müzik eşliğinde konuşmaya başlar. Dünya, kral, şövalye ve imparatorların efendisi olduğunu böbürlenerek ilan eder. Ardından yanındaki üç ayartıcı figürü, Şehvet, Sefahat ve Ahmaklık'ı, halkı günaha çekmeleri için sahneye gönderir.[3] Burada devreye giren müzik, önceki kutsal örneklerden köklü biçimde farklıdır: Bu, ruhun değil nefsin sesidir. Müzik burada Tanrı'ya yönelten bir araç değil, tam tersine seyirciyi dünyevi zevklere, bedensel arzulara çeken bir ayartma aracı olarak kullanılır. Günahı itici değil çekici kılan, onu iğrenç değil câzip gösteren bir ses işlevi görür. Böylece aynı sahne gösterir ki, müziğin gücü yalnızca kutsalı yüceltmekle sınırlı değildir; aynı güç, günahı da inandırıcı ve baştan çıkarıcı kılabilmektedir.

Oysa mystery döngülerinde Hz. İsa’nın doğumunu, diriliş sahnesini ya da cennet kapılarının açılışını müzikle donatan ses, tamamen farklı bir kaynaktan beslenir: İlahi düzene yönelik, ruhu yücelten ve Tanrı'ya açan bir ses. Nitekim daha önce ele aldığımız Chester Nuh örneğindeki müzikli kuşlar da bu ruhani sesin bir başka yansımasıydı; müzik orada da Tanrı'nın düzeninde korunmaya değer bir unsur olarak beliriyordu.[3]

Bu teolojik ayrım, kilisenin troubadour geleneğine neden mesafeli durduğunu da açıklar. Troubadour müziği dünyevi aşkı, bedensel arzuyu ve bireysel tutkuyu dile getiriyordu; yani ilgisi Tanrı'ya değil, insanın dünyevi yaşamınaydı. Kilisenin karşı olduğu şey aslında müziğin kendisi değil, onun taşıdığı bu dünyevi içerikti. Mystery oyunları ise aynı müzikal dili alıp ruhun hizmetine soktu; böylece müzik, ayartmanın aracı olmaktan çıkıp tebliğin aracına dönüştü. Bu dönüşümün temelinde, ruh ile nefis arasındaki bu köklü teolojik ayrım yatar. Ancak müziğin gücünü tam olarak kavrayabilmek için, tebliğin karşısındaki bir diğer aracı da incelemek gerekir: Vaazın kendisi. Vaaz neden aynı etkiyi yaratamadı?

Neden Vaaz Yetmiyordu

Dilin Engeli: Latince ve Halk Arasındaki Uçurum

Orta Çağ kilisesinin tebliğ dili Latince'ydi. Kutsal metinler bu dilde okunur, ayinler bu dilde yürütülür, vaazlar çoğunlukla bu dilde verilirdi. Oysa halk Latince bilmiyordu. Bu durum, dinî tebliğin önündeki en temel engeldi. Anlatılanı anlamayan biri için vaaz, manevi bir etkiden çok bir ses fonuna dönüşürdü; sözcükler duyulur ama anlam ulaşmazdı. Happé'nin de belirttiği üzere 14. yüzyıl, İngilizce'nin sanatsal ve edebi bir dil olarak yükseldiği dönemdir; mystery oyunlarının yerel dillere geçişi de bu kültürel dönüşümün bir parçasıdır.[5] Bu dil engelinin somut sonucunu Mathews de doğrular: Kilise ayinleri halkın anlamadığı bir dilde yürütülüyordu. Bu koşullarda bazı yenilikçi din adamlarının tablolar aracılığıyla ayini görsel biçimde aktarmaya çalışması doğal bir gelişmeydi.[10]

Müzik bu engeli farklı bir kanaldan aşıyordu. Bir ilahi ya da ezgisel diyalog, sözlerin tam olarak kavranmasa bile duygusal düzeyde etkisini gösterir. Jeffery'nin daha önce de gösterdiği üzere İncil geleneğinde şarkı söylemek peygamberlikle ve ilahi vahyin deneyimiyle köklü biçimde bağlantılıdır; müzik, insanı Tanrı'nın mesajına açan bir kanaldı.[9] Bu teolojik köken, müziğin Orta Çağ kilisesinde estetiğin yanı sıra, ruhsal bir araç olarak konumlandırılmasının zeminini oluşturur. Gregoryen koralin tek sesli yapısı, sözlerin anlamından bağımsız olarak bir huzur, yücelik ya da huşu hissi yaratabilirdi. Bu anlamda müzik, dil bariyerini aşabilen evrensel bir iletişim biçimiydi. Mystery oyunları ise bunu bir adım öteye taşıdı: Yerel dillere geçerek hem sözü hem müziği halkın kendi diliyle sundu ve tebliğin iki kanalını, sözel ve müzikal olanı, aynı anda etkin hale getirdi.

Okuryazarlığın Sınırları ve İşitsel Bilgi

Yazılı metne erişim Orta Çağ'da büyük ölçüde kısıtlıydı. Kitaplar el yazmasıyla çoğaltılır, manastır kütüphanelerinde saklanır ve yalnızca din adamları ile üst sınıf tarafından okunabilirdi. Halk için kutsal bilgiye ulaşmanın tek yolu kulaktan kulağa aktarılan sözlü gelenek ya da kilise törenlerinde anlayamadan duyulan metinlerdi. Bu koşullarda yazılı metin bir tebliğ aracı olarak neredeyse işlevsizdi. Mystery oyunları bu boşluğu doldurmak için tam anlamıyla biçilmiş kaftandı. Hem sözlü hem görsel hem de müzikal olan bu yapı, okuryazarlık gerektirmiyordu. İzlemek, duymak ve hissetmek yeterliydi. Müzik bu üçlü içinde özellikle belirleyiciydi; çünkü hem işitsel hem de bedensel olarak deneyimlenen tek unsurdu.

Soyutluktan Somutluğa: Müziğin Köprü İşlevi

Vaazın bir diğer yapısal sınırı soyutluktur. Günah nedir, kurtuluş nedir, ilahi adalet nasıl işler? Bu soruların sözlü yanıtları, halkın büyük çoğunluğu için kavranması güç soyutlamalar olarak kalır. Kavramlar, deneyime dönüşmediği sürece gerçek bir inanç değişimine yol açmaz.

Mystery oyunları bu sorunu dramayı kullanarak çözdü: Günahı tanımlamak yerine sahneledi, kurtuluşu anlatmak yerine yaşattı. Ama bu somutlaştırmayı duygusal düzeyde tamamlayan müzikti. Helmers'in aktardığı Davidson'ın tespiti bu bağlamda dikkate değerdir: Corpus Christi oyunları, tıpkı kiliselerdeki heykel ve vitray sanatı gibi, kurtuluş tarihinin olaylarını cemaatin belleğine kazımak üzere tasarlanmıştır.[4] Sahne yalnızca görsel bir anlatı sunarken, müzik o anlatıyı seyircinin iç dünyasına taşıdı. Passion sahnesinin görüntüsü beyne kaydolurken, Meryem'in ağıtı kalbe işledi. İkisi birlikte, vaazın hiçbir zaman ulaşamayacağı bir derinlikte tebliği gerçekleştirdi.

Bu noktada müziğin işlevi bir köprüye benzetilebilir: Soyut teolojik içerik ile halkın somut duygusal deneyimi arasında kurulan bir köprü. Vaaz bu köprüyü kuramaz; çünkü yalnızca sözlü düzeyde kalır.

Drama köprünün görsel ayağını kurar. Müzik ise köprüyü tamamlayan duygusal zemin olarak işlev görür. Üçü bir arada olduğunda tebliğ, seyircinin yalnızca aklına değil; tüm benliğine ulaşır.

Kolektif Deneyim ve Cemaat Bilinci

Vaazın bir başka sınırı, bireysel alımlamaya dayanmasıdır. Bir vaazı dinleyen kalabalık, aslında aynı anda yüzlerce bireysel dinleme deneyimi yaşar. Herkes kendi zihninde, kendi anlayışı çerçevesinde o vaazı işler. Müzik ise tam tersine kolektif bir deneyim üretir. Aynı anda aynı ezgiyi duyan, aynı ilahiyi söyleyen bir kalabalık, tek bir bedene dönüşmüş gibi aynı duyguyu yaşar.

Mystery oyunlarında bu kolektif deneyim, tebliğin en güçlü boyutlarından birini oluşturuyordu. Hopper ve Lahey'in aktardığı üzere döngü, Orta Çağ halkı tarafından dünyanın yıllık yenilenmesi olarak algılanırdı: Yaratılış'tan Kıyamet'e uzanan bu ritüel açılım, her yıl yeniden sahnelenerek geçmişi ve geleceği tek bir anda birleştirirdi.[3] Bu kolektif deneyimi güçlendiren bir başka unsur, sahnelerin loncalara dağılma biçimiydi. Helmers'in gösterdiği üzere her lonca kendi mesleğiyle örtüşen bir sahneyi üstleniyordu: Gemi yapımcıları Nuh'un Gemisi'ni, Fırıncılar Son Akşam Yemeği'ni, Çiviciler ise Çarmıha Gerilme'yi sahneliyordu.[4] Bu meslek-sahne örtüşmesi tesadüfi değildi: Mathews'in Chester döngüsünü incelerken belirttiği gibi bu atamalar rastgele değildi; her birinde ya açık bir uygunluk ya da ince bir ironi seziliyordu. Amaç kutsal anlatıyı gündelik hayatın dokusuna işlemekti.[10] Bu bütünsel yapı sayesinde şehir meydanında binlerce kişi aynı anda aynı müziği duyuyor, aynı sahneye bakıyor ve zaman zaman aynı ilahiye katılıyordu. Böylece bireysel inanç deneyimi toplumsal bir kimliğe dönüşüyordu; müzik de bu kolektif deneyimin en güçlü üreticisiydi.

SONUÇ

Mystery oyunlarında müzik, süsleyici bir eşliğin ötesinde bizzat tebliğin taşındığı kutsal sestir. Bu çalışma boyunca ortaya konulan beşli çerçeve (hafıza, katılım, duygu, bilinçli sessizlik ve ruh ile nefis arasındaki ayrım) müziğin mystery oyunlarındaki güçlendirici işlevini farklı boyutlardan açıklamaktadır. Her boyut, vaazın ve yazılı metnin yapısal olarak ulaşamadığı bir alana karşılık gelmekte; birlikte ele alındığında ise tek bir bütünleşik tablo ortaya çıkmaktadır: Müzik, dinî tebliğin en derin ve en kalıcı aracı olma özelliğini taşımaktadır.

Hafıza boyutunda müzik, okuma yazma bilmeyen bir halkın kutsal metni içselleştirebilmesini mümkün kılmıştır; çünkü ezgi, sözcüğün taşıyamadığı kalıcılığı sağlar. Katılım boyutunda pasif dinleyiciyi aktif katılımcıya dönüştürerek tebliği kolektif bir deneyime taşımıştır; çünkü birlikte söylenen bir ilahi, birlikte duyulan bir vaazdan çok daha derin bir cemaat bilinci üretir. Duygu boyutunda soyut dinî öğreti, yaşanmış ve hissedilmiş bir gerçekliğe dönüştürülmüştür; çünkü müzik düşünce yoluyla değil, algı yoluyla etkiler. Bilinçli sessizlik boyutunda ise müziğin yokluğu, varlığı kadar güçlü bir anlam aracı olarak işlev görmüştür. Ve ruh ile nefis arasındaki teolojik ayrım boyutunda müzik, hizmet ettiği amaca göre kutsalın da günahın da sesi olabilmiştir. Quem Quaeritis'ten York Döngüsü'nün Çarmıha Gerilme sahnesine uzanan bu gelenek, müziğin hem varlığıyla hem yokluğuyla hem ruhun hem nefsin diliyle anlam ürettiğini somut biçimde ortaya koymaktadır.

Bu tablo aynı zamanda, mystery oyunlarının neden yalnızca bir tiyatro tarihi meselesi olmadığını da göstermektedir. Bu oyunlar, bir kurumun kendi öğretisini halka aktarma sorunuyla yüzleştiği ve bu sorunu müziğin gücüne başvurarak çözdüğü tarihsel bir laboratuvardır. Kilise, vaazın dil engelini, okuryazarlık sorununu, soyutluk problemini ve bireysel alımlamanın kısıtlılığını, dramatik ve müzikal bir araçla aştı. Halkın talep ettiği biçimi benimsedi; ama o biçimin içini kutsal bir içerikle doldurdu. Bu strateji, 10.-16. yüzyıllar boyunca süren uzun ve zorunlu bir uyumun ürünüdür.

Müziğin tebliğ içindeki bu rolü, aynı zamanda müziğin insan üzerindeki etkisine ilişkin evrensel bir gerçeği de açığa çıkarmaktadır. İnsanlar yalnızca anlayan değil, hisseden varlıklardır ve hissettikleri şeylere, anladıklarından çok daha sıkı tutunma eğilimindedirler. Mystery oyunları bu gerçeği yüzyıllar önce sezmiş ve sahneye taşımıştır. Bir trop'un ezgisel diyaloğundan şehir meydanlarına yayılan büyük döngülere uzanan bu yolculuk, müzik ile imanın nasıl birbirini güçlendirebileceğinin belki de en eski ve en güçlü kanıtıdır.

Bu güçlü geleneğin sonu kurumsal bir kararla geldi; dışarıdan gelen bir toplumsal baskının sonucu olmaktan çok, kilisenin kendi tercihiydi. Happé'nin aktardığı üzere mystery oyunları Reformasyon'un yeni doktriniyle bağdaşmaz bulunarak bizzat kilise otoritesi tarafından bastırıldı: York'ta 1569'da, Chester'da 1575'te, Coventry'de ise 1580'de son gösterimler yapıldı.[5] Bu son, aynı zamanda önemli bir sonucu da ortaya koymaktadır: Yüzyıllarca süren bir geleneğin resmî bir kararla bastırılmış olması, onun toplumsal ve dinî etkisinin ne denli güçlü olduğunu göstermektedir. Bu bulgular, müziğin dinî tebliğ süreçlerindeki rolünün yalnızca Orta Çağ'a özgü değil, disiplinler arası araştırmalara açık, kapsamlı bir konu olduğunu ortaya koymaktadır.

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EVALUATION OF DIFFERENT COATING MATERIALS FOR THE MICROENCAPSULATION OF *LACTOBACILLUS ACIDOPHILUS* ATCC 4356 AND ITS STABILITY UNDER SIMULATED GASTROINTESTINAL CONDITIONS

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ABSTRACT

Introduction and Purpose: The growing evidence supporting the beneficial effects of probiotics on human health has increased. However, probiotic microorganisms are highly susceptible to adverse environmental conditions, which may considerably reduce their survival. Microencapsulation is considered an effective approach to enhance probiotic stability by providing physical protection against these unfavorable conditions. Therefore, this study aimed to evaluate the encapsulation performance of different coating materials and the stability of microencapsulated *Lactobacillus acidophilus* ATCC 4356 under simulated gastrointestinal conditions.

Materials and Methods: *Lactobacillus acidophilus* ATCC 4356 was microencapsulated by the coacervation method using alginate-based coating materials supplemented with either inulin or fructooligosaccharide (FOS). Encapsulation efficiency was determined. The survival of free and microencapsulated probiotic cells was evaluated following exposure to simulated gastric conditions (pH 1.5) and 2% bile solution. The reduction in viable probiotic cell counts under simulated gastrointestinal conditions was statistically analyzed.

Results: The encapsulation efficiencies of the FOS- and inulin-coated microcapsules were 87.81% and 88.85%, respectively, indicating high encapsulation efficiency for both formulations. Although the difference was not statistically significant, the inulin-coated microcapsules exhibited a slightly higher encapsulation efficiency than the FOS-coated microcapsules. Under simulated gastrointestinal conditions, free probiotic cells showed approximately a 2 log CFU/g greater reduction in viability than the microencapsulated groups ($p < 0.05$). No statistically significant difference in viability loss was observed between the two encapsulating materials; however, the reduction in viable cell counts was greater in the FOS-coated group than in the inulin-coated group. **Discussion and Conclusion:** The findings demonstrated that both inulin and fructooligosaccharide are effective coating materials for the coacervation-based microencapsulation of *Lactobacillus acidophilus* ATCC 4356. Nevertheless, considering both encapsulation efficiency and the preservation of probiotic viability under simulated gastrointestinal conditions, inulin provided a slightly greater protective effect than FOS.

Key Words: *Lactobacillus acidophilus* ATCC 4356; Microencapsulation; Coacervation; Encapsulation Efficiency; İnulin; Simulated Gastrointestinal Conditions

ABSTRACT

Introduction and Purpose: The health-promoting effects of probiotic bacteria in functional dairy products depend on maintaining adequate viability throughout production and storage. Microencapsulation has been widely employed to improve the survival of probiotic microorganisms under adverse environmental conditions. Therefore, this study aimed to investigate the effects of

coacervation-based microencapsulated *Lactobacillus acidophilus* ATCC 4356 on probiotic viability and the microbiological quality of functional Lor cheese during refrigerated storage.

Materials and Methods: *Lactobacillus acidophilus* ATCC 4356 was microencapsulated by the coacervation method using alginate-based coating materials supplemented with either inulin or fructooligosaccharide (FOS). Free and microencapsulated probiotic cultures were incorporated into Lor cheese. The cheese samples were stored at 4 °C for 30 days. At predetermined storage intervals, probiotic viable counts, total mesophilic aerobic bacteria (TMAB), and yeast and mold counts were determined using standard microbiological methods.

Results: The initial probiotic count was approximately 8 log CFU/g and remained above this level throughout the 30-day storage period, exceeding 9 log CFU/g in some treatment groups. Although probiotic counts increased in all samples during storage, cheeses containing microencapsulated probiotics exhibited higher viable counts than those containing free cells. Probiotic populations remained above the minimum recommended level for functional foods throughout storage. TMAB counts increased during storage as a result of the natural maturation process; however, no significant differences were observed among the treatment groups ($p > 0.05$). In contrast, yeast and mold counts decreased in all samples, and the reduction was significantly greater in cheeses containing microencapsulated probiotics ($p < 0.05$).

Discussion and Conclusion: Microencapsulation by the coacervation method effectively preserved the viability of *Lactobacillus acidophilus* ATCC 4356 during refrigerated storage of functional Lor cheese. Furthermore, the incorporation of microencapsulated probiotics contributed to maintaining the microbiological quality of the product, demonstrating the potential of this approach for the development of functional dairy products with enhanced probiotic stability.

Key Words: *Lactobacillus acidophilus* ATCC 4356; Coacervation; Microencapsulation; Lor Cheese; Probiotic Viability; Functional Dairy Products

LEBANESE EDUCATIONAL LEGISLATION IN FACING THE CHALLENGES OF DIGITAL EDUCATION AND ARTIFICIAL INTELLIGENCE: AN ANALYTICAL STUDY FOR DEVELOPING A CONTEMPORARY EDUCATIONAL LEGAL FRAMEWORK

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ABSTRACT

This study examines the capacity of Lebanese educational legislation to address the challenges posed by digital education and the rapid advancement of Artificial Intelligence (AI) technologies. As educational systems worldwide undergo significant digital transformation, Lebanese educational laws and regulations face increasing pressure to adapt to emerging issues such as data privacy, digital equity, ethical use of AI, cybersecurity, academic integrity, and the evolving roles of teachers and learners. Using a descriptive-analytical approach, the study reviews the current Lebanese educational legal framework governing technology integration and evaluates its effectiveness in responding to contemporary digital challenges. The research identifies legislative gaps that hinder the development of a secure and innovative digital learning environment and explores international best practices. The findings indicate that existing Lebanese legislation remains insufficient to fully address the complexities of digital education and AI-driven learning environments. The study proposes a modern legal framework aligned with international standards, emphasizing ethics, governance of AI, digital citizenship, institutional accountability, and educational equity.

Keywords: Digital Education; Artificial Intelligence; Educational Law; Lebanon; Policy Reform; E-learning Governance; Digital Transformation in Education

WAVELET ANALYSIS OF SEA LEVEL VARIABILITY AT MARMARA SEA TIDE GAUGE STATIONS

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ABSTRACT

Marmara Sea level variability is driven by atmospheric forcing, basin-scale circulation, seasonal changes, and water exchanges through the Turkish Straits System. Understanding these fluctuations is essential for coastal management, marine operations, and climate impact assessments. This study utilizes wavelet analysis on tide gauge records from the Marmara Sea to characterize temporal variability and identify dominant oscillation periods. Since wavelet analysis is particularly effective for examining non-stationary time series, it allows for the precise detection of periodic signals over time. We applied the Continuous Wavelet Transform to define dominant frequencies and their temporal evolution, focusing on seasonal, interannual, and short-term variability. By analyzing wavelet power spectra, we evaluated the strength and persistence of various oscillation bands and compared stations to highlight spatial differences in sea level behavior. Our results indicate that sea level variability is characterized by strong seasonal signals and short-period fluctuations driven by meteorological forcing. The observed commonalities suggest basin-wide influences, while local differences underscore the role of coastal morphology and regional atmospheric conditions. Overall, this wavelet-based approach successfully delineates the evolution of sea level oscillations, providing insights that conventional statistical methods often overlook.

Keywords: Marmara Sea, Sea Level, Tide Gauge, Wavelet Analysis, Coastal Oceanography

INTRODUCTION

Study Area

The Marmara Sea (Figure 1) is a semi-enclosed basin with a strong two-layer flow system, connecting the Black Sea and the Mediterranean Sea. Sea level variability in this basin is directly influenced by atmospheric forcing, basin-scale circulation, seasonal changes, and water exchanges through the Turkish Straits System. In this micro-tidal system, the primary drivers of sea level energy fluctuations are barometric pressure, wind stress, and water budget dynamics rather than astronomical tides (Beşiktepe et al., 1994; Yaman & Çokacar, 2025).

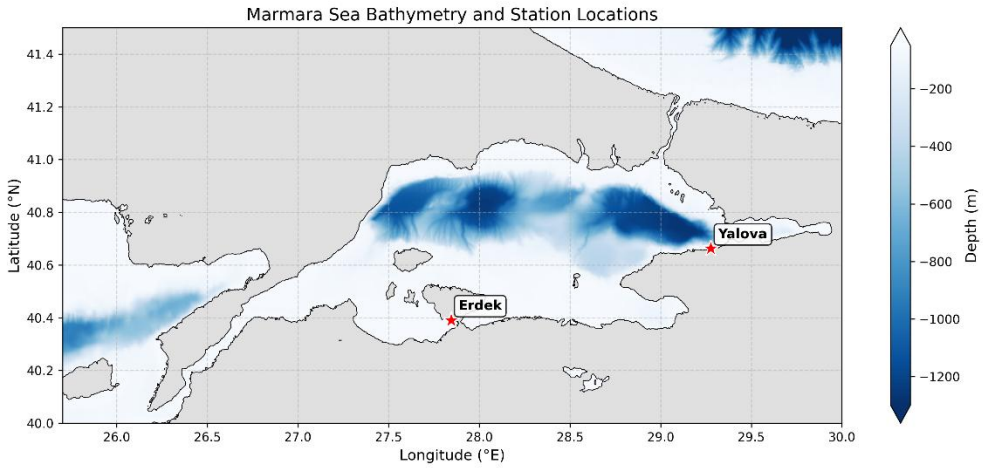

Figure 1. Bathymetric map of the Marmara Sea and the study area. The red stars indicate the locations of the Erdek (open basin) and Yalova (enclosed gulf) tide gauge stations used in the sea level analysis. Depth contours and coastline boundaries were derived from the GEBCO bathymetry dataset.

Methodological Approach

Sea level time series are inherently non-stationary. Conventional spectral methods, such as the Fourier transform, often obscure temporal information, making them insufficient for detecting episodic energy bursts linked to synoptic storms or seasonal forcing. The Continuous Wavelet Transform addresses this limitation by resolving periodic signals in both time and frequency. Building on prior applications of the Morlet-wavelet framework to coastal sea level records (Aydın & Beşiktepe, 2022), this work establishes a methodological continuity across adjacent basins. The Marmara-scale physical basis, on the other hand, is grounded in the foundational hydrographic and circulation documentation of Beşiktepe et al. (1994). Here we apply this integrated framework to characterize the temporal evolution of dominant sea level oscillations and to quantify the basin's topographic and hydrodynamic responses through Welch PSD, classical harmonic analysis, cross-correlation, and skewness-based extreme asymmetry analysis (Mathias et al., 2004).

DATA AND METHODS

This study analyzes 2014 hourly sea-level data from the Erdek and Yalova tide gauge stations, which represent the diverse coastal morphology of the Marmara Sea. The records were detrended to isolate subtidal and meteorological signals and interpolated to an hourly frequency. To determine the time-frequency evolution of transient phenomena, the Continuous Wavelet Transform (CWT) based on the Morlet wavelet was applied, selected for its balanced localization in both time and frequency domains. To support the wavelet power spectra, complementary statistical analyses were performed: the Welch method (PSD) for absolute energy distribution in the frequency domain, classical harmonic analysis based on Least Squares for the resolution of astronomical amplitudes, cross-correlation for wave propagation dynamics, and Probability Density Function (PDF) analysis for extreme value asymmetry (Mathias et al., 2004).

RESULTS AND DISCUSSION

Time-Frequency Evolution and Meteorological Dominance

The CWT analysis (Figure 2) illustrates the temporal development of dominant oscillation periods in the Marmara Sea. Spectral energy is primarily concentrated in long-period bands associated with seasonal variations, water budget transfers, and synoptic-scale storms. The minimal persistence and low

energy within the short-period tidal band throughout the year confirm that meteorological forcing is the dominant driver of basin variability (Aydın & Beşiktepe, 2022; Yaman & Çokacar, 2025).

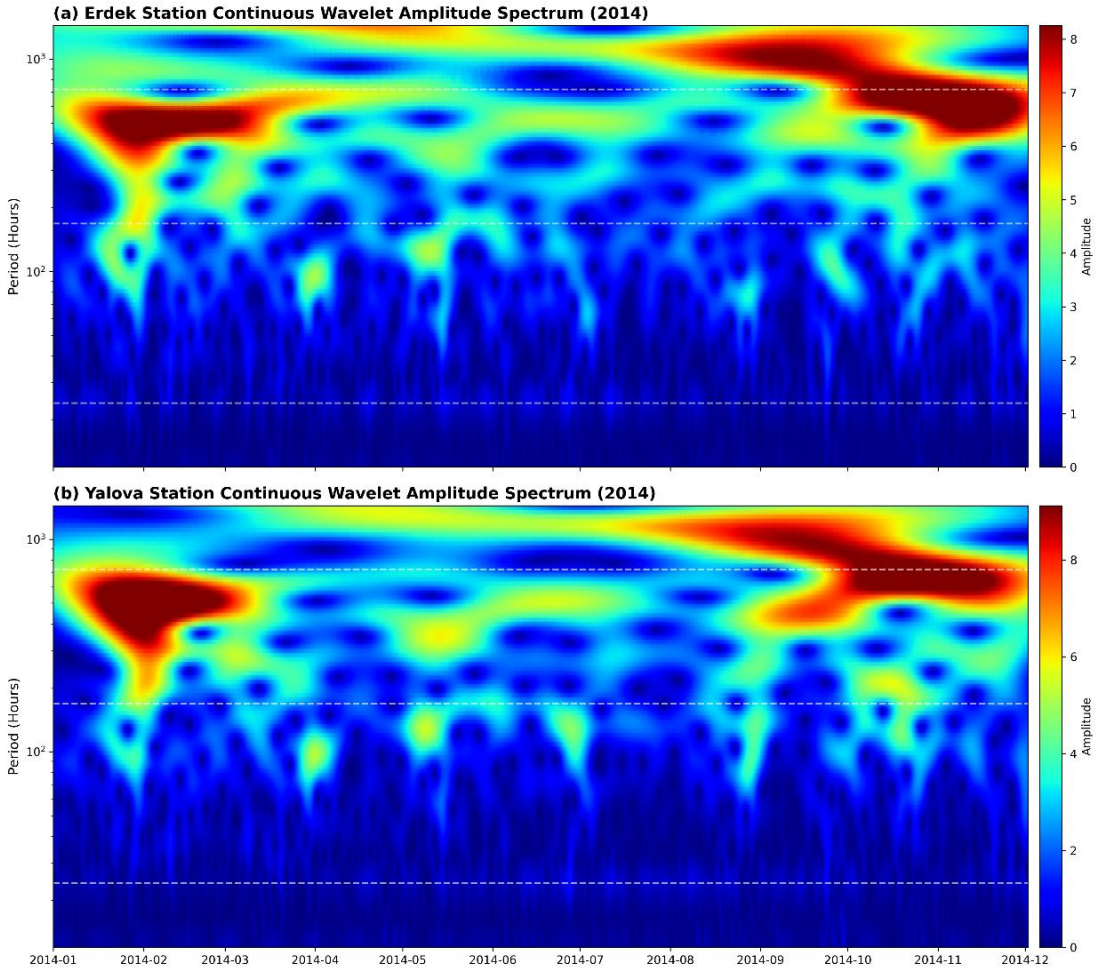

Figure 2. Continuous Wavelet Amplitude Spectra (CWT) of sea level anomalies for 2014: (a) Erdek and (b) Yalova tide gauge stations. The dashed lines indicate the 24-hour (diurnal), 168-hour (weekly), and 720-hour (monthly) periods. The spectra highlight the dominance of low-frequency meteorological forcing over astronomical tidal signals throughout the study period.

Topographic Funneling and Energy Asymmetry (PSD and Harmonics)

Welch PSD analysis (Figure 3) supports the CWT findings by demonstrating that the majority of variance is concentrated in low-frequency meteorological events. However, an examination of the 12- and 24-hour peaks in the PSD plot reveals that Yalova exhibits a significant energy surplus compared to Erdek within the semi-diurnal (M2, S2) band (Tiede et al., 2025).

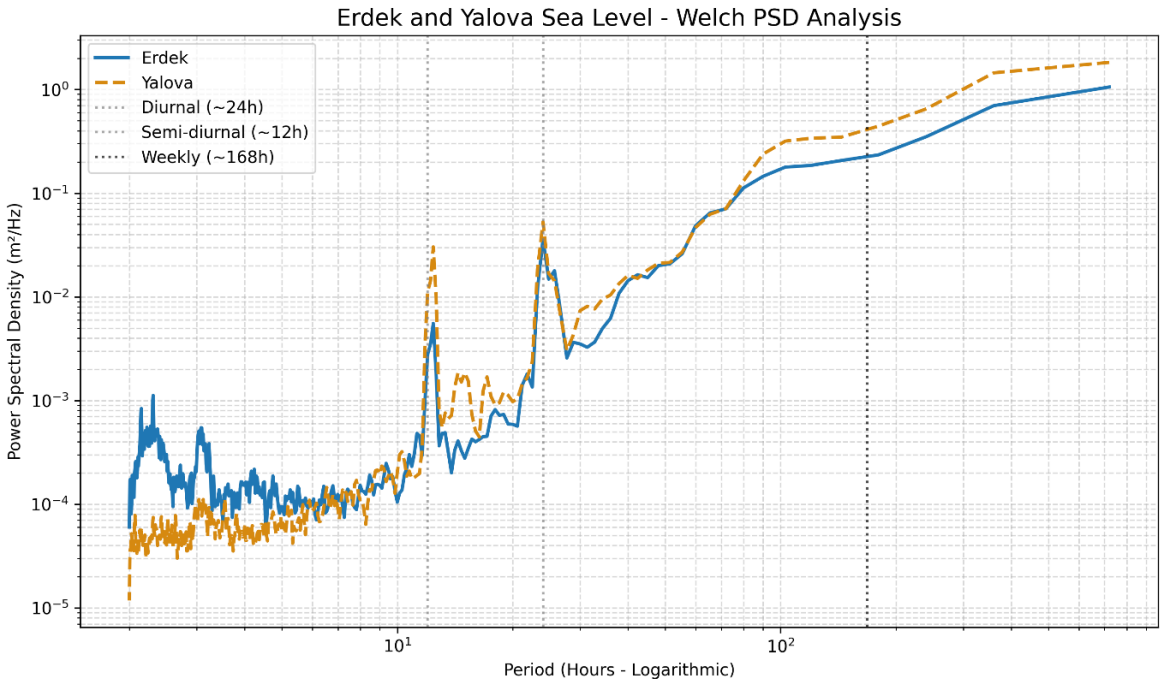

Figure 3. Power Spectral Density (PSD) analysis of sea level records using the Welch method: The plot compares the spectral energy distribution between Erdek and Yalova stations. The marked peaks indicate significant oceanographic periods, demonstrating higher semi-diurnal energy concentration at the Yalova station compared to Erdek.

Harmonic analysis results (Figure 4) confirm the micro-tidal structure (M2 < 1.25 cm). The fact that the M2 and S2 amplitudes in Yalova reach nearly three times those of Erdek proves that the eastward-propagating barotropic wave is subject to "funneling" and reflection dynamics at the gulf entrance, induced by narrowing and shallowing.

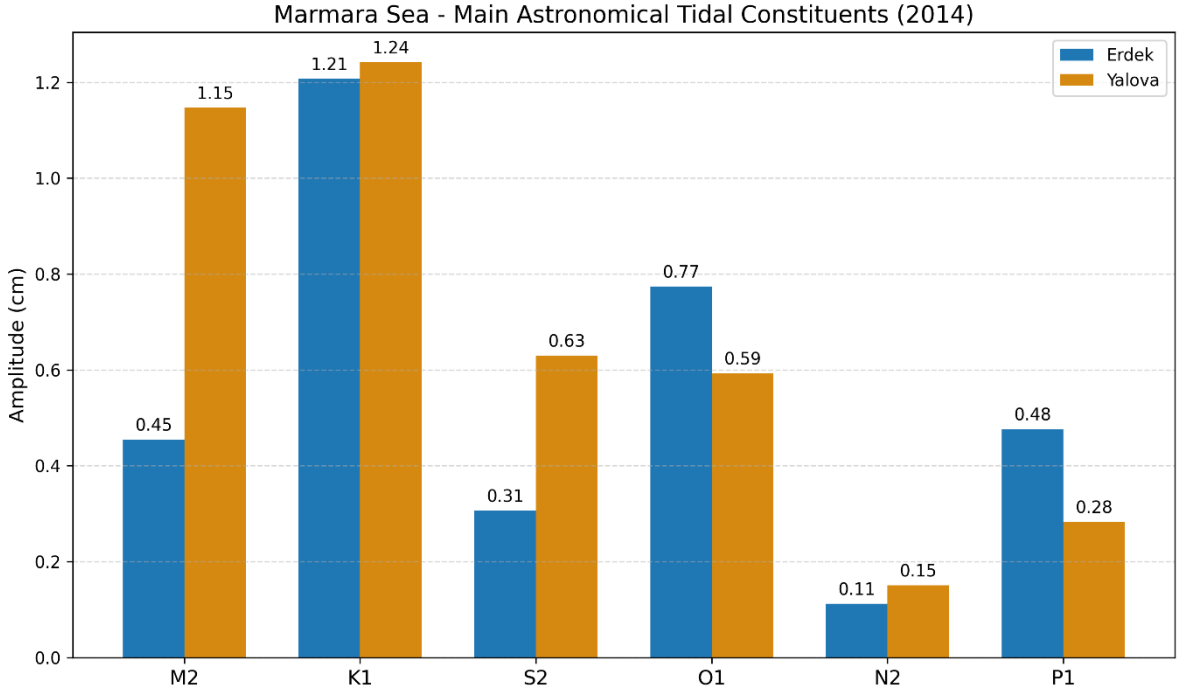

Figure 4. Comparison of main astronomical tidal constituent amplitudes (cm): The bar chart illustrates the harmonic analysis results for 2014. The significant amplitude increase in the M_2 and S_2 constituents

at Yalova, compared to Erdek, provides evidence of topographic funneling and reflection dynamics within the gulf.

Spatial Coherence and Extreme Value Asymmetry

Cross-correlation analysis (Figure 5) demonstrates that sea level anomalies propagate eastward between the stations, characterized by a mean phase lag of 1 hour. This consistent correlation pattern indicates that sea level variability is predominantly influenced by basin-wide processes rather than localized wind effects (Gerkema & Duran-Matute, 2017; Sasaki et al., 2014).

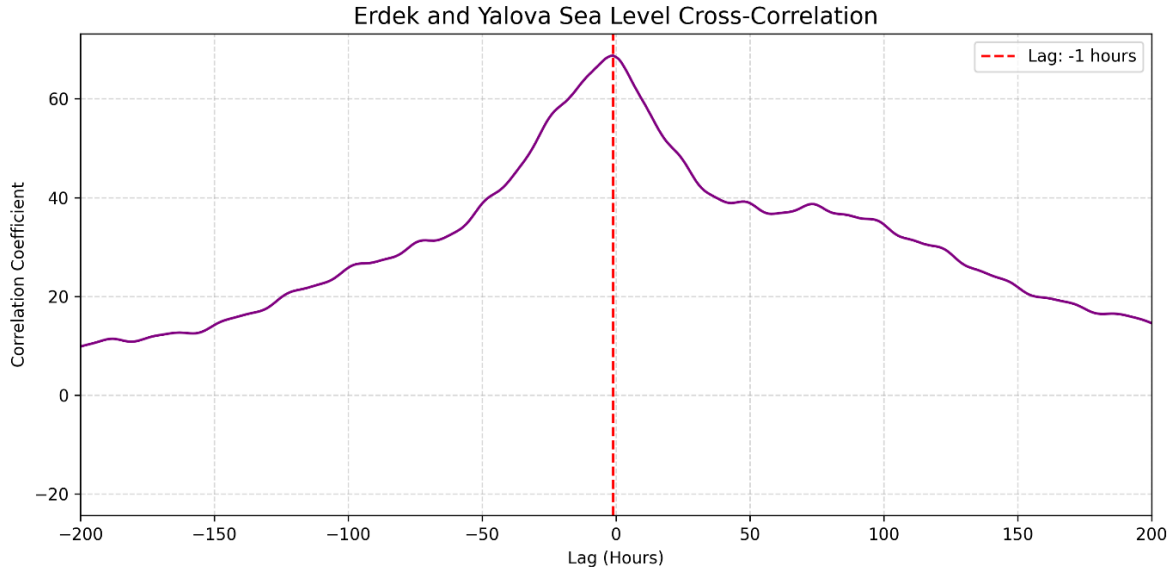

Figure 5. Cross-correlation function of sea level anomalies between Erdek and Yalova stations: The peak at a -1 hour lag indicates the eastward propagation of sea level disturbances from the Erdek station toward the Yalova station, suggesting basin-scale atmospheric forcing influence.

The negative skewness identified in the PDF analysis (Figure 6) underscores the influence of coastal morphology and regional atmospheric conditions on sea level variability. Notably, the pronounced negative skewness at Yalova indicates that its confined, narrow gulf geometry results in a more asymmetric and amplified response to extreme negative sea level anomalies compared to open-basin coastal areas.

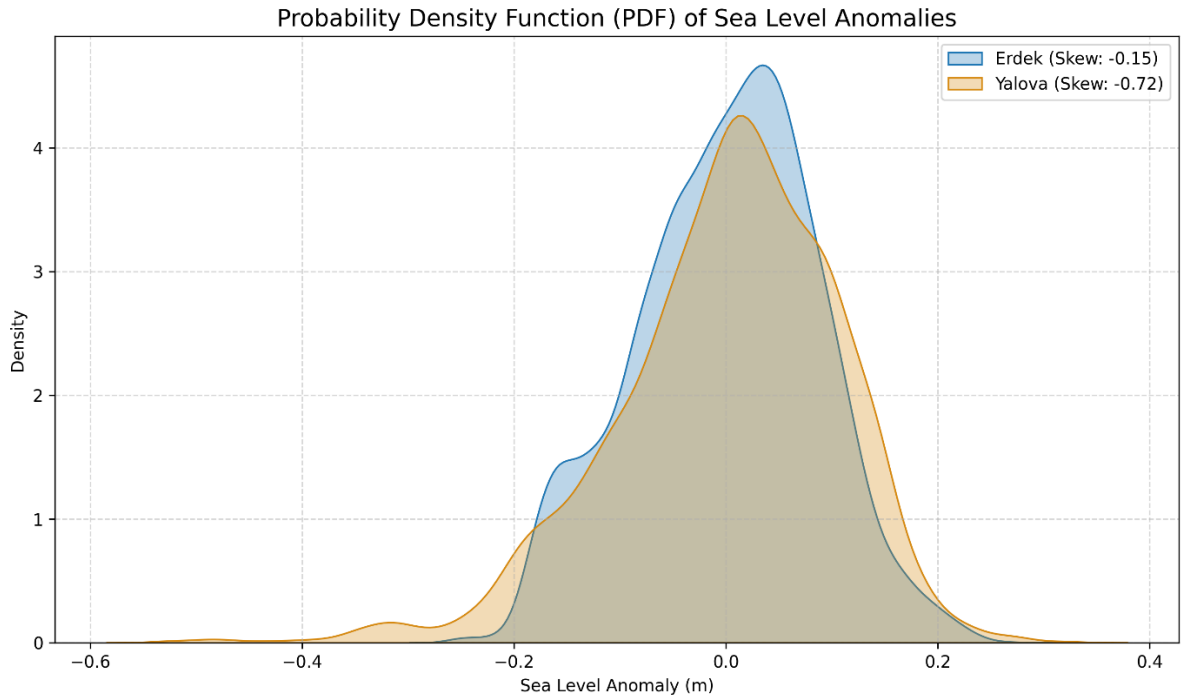

Figure 6. Probability Density Function (PDF) of sea level anomalies for 2014**:** The distributions show negative skewness for both stations, with a significantly higher negative skew at Yalova (-0.72) compared to Erdek (-0.15). This asymmetry suggests that the enclosed gulf topography induces a more sensitive response to extreme negative sea level anomalies (e.g., rapid retreats) compared to open-basin coastal areas.

CONCLUSION

Applying wavelet analysis and complementary statistical methods to Marmara Sea tide gauge data, this study demonstrates that sea-level variance is primarily driven by synoptic and seasonal atmospheric forcing rather than astronomical tides. Although sea-level disturbances propagate eastwards across the basin, regional coastal morphology significantly modulates the hydrodynamic response. Specifically, eastern gulf stations like Yalova show amplified semi-diurnal tidal energy (M2, S2) via topographic "funneling" and increased vulnerability to meteorological anomalies, evidenced by high negative skewness. This wavelet-based approach clarifies complex time-frequency dynamics beyond the resolution of conventional statistical methods, offering a robust framework for future coastal oceanographic research.

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DATA CAPITALIZATION ON *MEDICAGO SATIVA*: PHYTOCHEMICAL COMPOSITION AND PHARMACOLOGİCAL POTENTIAL

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ABSTRACT

Medicago sativa Linn., commonly known as alfalfa or "father of all foods," is a perennial herbaceous leguminous plant belonging to the Fabaceae family, widely cultivated throughout the world as a fodder plant and traditional herbal medicine. This study aims to systematically review and capitalize on reliable published data concerning the phytochemical composition and pharmacological potential of *M. sativa*.

According to published studies, *M. sativa* contains a diverse array of bioactive compounds including saponins, flavonoids, phytoestrogens, coumarins, alkaloids, amino acids, phytosterols, vitamins, digestive enzymes and terpenes. The plant exhibits remarkable hypocholesterolemic and antiatherosclerotic activity, with saponin extracts significantly reducing total cholesterol and LDL-cholesterol levels (up to 85.1% and 88% respectively) in hypercholesterolemic rabbits. The antioxidant and cerebroprotective effects have been demonstrated through significant reduction of cerebral infarct size, oxidative stress markers and restoration of antioxidant enzyme levels in ischemia-reperfusion models. The hypoglycemic activity has been confirmed via stimulation of insulin secretion from pancreatic beta cells and increased glucose uptake in muscle tissues. Estrogenic activity has been documented through MCF-7 breast cancer cell proliferation assays and preferential agonist activity toward estrogen receptor β. Antimicrobial activity has been reported against Gram-positive bacteria and yeasts, with medicagenic acid identified as the main active constituent. Additional pharmacological activities include immunopotentiating, antiulcer, nematicidal, and antiviral properties against HIV reverse transcriptase.

Medicago sativa thus emerges as a promising source of bioactive compounds with significant therapeutic potential in cardiovascular diseases, diabetes, neurodegenerative disorders, cancer, and infectious diseases. These findings provide a scientific basis for its traditional uses. However, further research is warranted, including isolation of individual active constituents, detailed mechanistic studies, and comprehensive toxicity evaluations, particularly concerning canavanine-induced systemic lupus erythematosus-like syndrome.

Keywords: *Medicago sativa*, alfalfa, Fabaceae, saponins, hypocholesterolemic, antioxidant, neuroprotective, antidiabetic, phytoestrogens.

MEGALIN RECEPTOR AND ITS CLINICAL BIOCHEMICAL SIGNIFICANCE

MEGALİN RESEPTÖRÜ VE KLİNİK BİYOKİMYASAL ÖNEMİ

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Özet

Megalin düşük yoğunluklu lipoprotein reseptör ailesine ait çok ligandlı bir endositik reseptördür. Böbrekte filtre edilen proteinler, peptitler ve vitamin taşıyıcı proteinler gibi moleküllerin geri emiliminde görev alması nedeniyle böbrek homeostazının sürdürülmesinde kritik bir rol üstlenmektedir. Megalin, özellikle kubilin ile birlikte çalışarak reseptör aracılı endositoz süreçlerini düzenlemekte ve glomerüler filtrattan geçen çok sayıda ligandın geri kazanılmasını sağlamaktadır. Ayrıca megalinin lipotoksik ve glikotoksik maddelerin hücre içine alınmasında görev alması nedeniyle metabolik stres koşullarında böbrek hasarının şekillenmesinde etkili olabileceği belirtilmektedir. Son yıllarda yapılan çalışmalar, idrar megalin düzeylerinin özellikle diyabetik böbrek hastalığında erken tübüler hasarın değerlendirilmesinde potansiyel bir biyobelirteç olarak kullanılabileceğini göstermiştir.Megalinin fizyolojik işlevlerinden biri de vitamin D metabolizmasının düzenl enmesidir. Vitamin D bağlayıcı protein ile taşınan vitamin D metabolitlerinin proksimal tübüllerde geri emilimi büyük ölçüde megalin aracılığıyla gerçekleşmektedir. Bu mekanizmadaki bozuklukların vitamin D eksikliği ve mineral metabolizması bozuklukları ile ilişkili olabileceği bildirilmiştir. Megalinin klinik önemini ortaya koyan bir diğer durum ise megalini kodlayan LRP2 genindeki mutasyonlar sonucunda gelişen Donnai-Barrow sendromudur. Bu sendromda megalin fonksiyonunun bozulmasına bağlı olarak düşük molekül ağırlıklı proteinüri, böbrek fonksiyon bozuklukları ve çoklu organ tutulumları görülebilmektedir. Sonuç olarak megalin; protein geri emilimi, vitamin taşınımı, endositoz mekanizmaları ve böbrek homeostazının sürdürülmesinde temel rol oynayan çok işlevli bir reseptördür. Böbrek hastalıklarının patogenezindeki rolü, nefrotoksik ajanlarla etkileşimi ve biyobelirteç potansiyeli nedeniyle megalin üzerine yapılan çalışmalar giderek artmaktadır. Mevcut veriler, megalinin hem tanısal hem de terapötik açıdan önemli bir hedef olduğunu göstermekte olup, gelecekte yapılacak çalışmaların bu molekülün böbrek hastalıklarındaki yerinin daha iyi anlaşılmasına katkı sağlayacağı düşünülmektedir.

Anahtar Kelimeler: Megalin, LRP2, Endositoz, Nefrotoksisite, D Vitamini, Proteinüri

ABSTRACT

Megalin is a multi-ligand endocytic receptor belonging to the low-density lipoprotein receptor family. It plays a critical role in maintaining renal homeostasis by facilitating the reabsorption of molecules such

as proteins, peptides, and vitamin transporters filtered in the kidney. Megalin, particularly in conjunction with cubilin, regulates receptor-mediated endocytosis and facilitates the recovery of numerous ligands from the glomerular filtrate. Furthermore, megalin's involvement in the uptake of lipotoxic and glycotoxic substances into cells suggests it may contribute to the development of renal damage under conditions of metabolic stress. Recent studies have shown that urinary megalin levels can be used as a potential biomarker for assessing early tubular damage, especially in diabetic kidney disease. One of megalin's physiological functions is regulating vitamin D metabolism. The reabsorption of vitamin D metabolites transported by vitamin D-binding protein in the proximal tubules largely occurs via megalin. Disruptions in this mechanism have been reported to be associated with vitamin D deficiency and mineral metabolism disorders. Another situation that highlights the clinical importance of megalin is Donnai-Barrow syndrome, which develops as a result of mutations in the LRP2 gene encoding megalin. In this syndrome, low molecular weight proteinuria, renal dysfunction, and multiple organ involvement can be observed due to impaired megalin function. In conclusion, megalin is a multifunctional receptor that plays a fundamental role in protein reabsorption, vitamin transport, endocytosis mechanisms, and the maintenance of renal homeostasis. Studies on megalin are increasing due to its role in the pathogenesis of kidney diseases, its interaction with nephrotoxic agents, and its biomarker potential. Current data indicate that megalin is an important target both diagnostically and therapeutically, and it is thought that future studies will contribute to a better understanding of the role of this molecule in kidney diseases.

Keywords: Megalin, LRP2, Endocytosis, Nephrotoxicity, Vitamin D, Proteinuria

Giriş

Böbrek proksimal tübül epiteli yüksek metabolik aktiviteye sahip olup böbrek fonksiyonunun ve metabolik homeostazın sürdürülmesinde kritik öneme sahiptir (Nicholson ve ark., 2024). Proksimal tübül epitel hücreleri, glomerüler filtrattan geçen veya bu hücreler tarafından salgılanan protein, peptit ve temel maddelerin apikal endositozu için özelleşmiştir ve bu sayede söz konusu moleküllerin idrarla kaybını önlemektedir (Goto ve ark., 2023).

Düşük molekül ağırlıklı proteinlerin glomerülden süzülmesi ve proksimal tübülde geri emilmesi böbrek fizyolojisinin normal süreçlerinden biridir. Bu süreç, temel moleküllerin homeostazının korunmasına ve protein kaybının önlenmesine katkı sağlamaktadır. Bu geri emilim, LDL reseptör ailesinin bir üyesi olan ve böbreğin proksimal tübüllerinde yüksek düzeyde eksprese edilen hızlı geri dönüşümlü endositik taşıyıcı bir molekül olan megalin tarafından gerçekleştirilmektedir (Kulkarni ve Hussain, 2025).

Megalin, LDL reseptör ailesinin glikoprotein yapısındaki büyük bir üyesidir. Böbrekte daha çok proksimal tübül epitel hücrelerinin apikal membranında eksprese edilmekte olup beyin, akciğer, plasenta ve tiroid bezi gibi farklı organlarda da varlığı belirlenmiştir (Goto ve ark., 2023).

Proksimal tübüller, primer glomerüler filtrattan proteinlerin geri kazanılmasını sağlayan çoklu ligand reseptörleri olan megalin ve kubilini eksprese etmektedir (Nicholson ve ark., 2024). Megalin tek başına işlev gösterebildiği gibi, kompleks olarak hücre membranına bağlanan kubilin ile birlikte de görev yapmaktadır (Kulkarni ve Hussain, 2025).

Megalin, fizyolojik açıdan önemli ligandların hücre içine alınmasına aracılık ederken, bazı nefrotoksik maddelerin de proksimal tübül hücrelerine alınmasında rol oynayabilmektedir (Goto ve ark., 2023). Bunun yanında megalinin yokluğunun veya fonksiyon bozukluğunun endositik taşınımı bozduğu ve metabolizma ile inflamasyonla ilişkili gen ekspresyonunda değişikliklere yol açabildiği bildirilmiştir. Ayrıca özellikle metabolik stres koşullarında böbrek içinde ve dışında homeostazın sürdürülmesinde önemli bir role sahip olduğu belirtilmektedir (Nicholson ve ark., 2024).

Megalin'in Tanımı ve Genel Özellikleri

Megalin, LRP2 (düşük yoğunluklu lipoprotein reseptör ilişkili protein 2) geni tarafından kodlanan, dolaşımdaki çeşitli bileşiklerin seviyelerini düzenleyen çoklu ligand alım reseptörüdür (Kantarci ve ark., 2007). Megalin, yaklaşık 600 kDa molekül ağırlığında ve 4665 amino asitten oluşan büyük bir

transmembran glikoprotein olup düşük yoğunluklu lipoprotein reseptör ailesine homologdur. İnsan megalininin hücre dışı bölgesi ligand bağlama özelliklerine sahip olup bu özellik içerdiği tekrar dizilerinden kaynaklanmaktadır. Ayrıca megalin, 23 amino asitten oluşan tek bir transmembran bölgeye ve 209 amino asitten oluşan bir C-terminal sitoplazmik kuyruğa sahiptir. Böbrekte özellikle proksimal tübül epitel hücrelerinin apikal membranlarının fırçamsı kenarında yoğun olarak bulunduğu bildirilmektedir (Khan ve ark., 2022).

Megalin ayrıca böbrek dışındaki çeşitli absorptif epitel dokularında da bulunarak geniş bir dağılım göstermektedir. Megalinin bu yaygın ekspresyonu çoklu ligand temizleyici reseptör olarak tanımlanan rolü ile uyumludur (Khan ve ark., 2022). Lipoproteinler, steroller, vitamin bağlayıcı proteinler ve hormonlar dahil çok sayıda ligandın geri alımında görev alırlar (Kantarci ve ark., 2007). Ayrıca albumin, hemoglobin, insülin, retinol bağlayıcı protein ve vitamin D bağlayıcı protein gibi fizyolojik açıdan önemli çeşitli moleküller megalin için ligand olarak tanımlanmıştır (Khan ve ark., 2022).

Megalinin Yapısal Özellikleri

LRP2/megalin, düşük yoğunluklu lipoprotein reseptörü (LDLR) ailesinin en büyük üyesidir (Beenken ve ark., 2023). Megalin ve LDLR ailesinin diğer üyeleri ortak yapısal motifleri paylaşmaktadır (Zhang ve Zhang, 2025). LRP2, 8 β-propeller alanı (P1–P8), 17 EGF-benzeri alan (E1–E17) ve dört ayrı kümede (R1–R4) düzenlenmiş 36 LDL reseptör tipi A tekrarından (L1–L36) oluşan tek geçişli bir transmembran proteindir (Beenken ve ark., 2023).

Hücre dışı bölge, ligand bağlayıcı alanlar (LBD I–IV) olarak adlandırılan dört olası fonksiyonel bölge içermektedir (Goto ve ark., 2024). Megalin, ligand bağlayıcı tekrarlar, epidermal büyüme faktörü (EGF) tekrarları, YWTD alanları, tek bir transmembran alan ve kısa bir sitoplazmik alandan oluşmaktadır (Zhang ve Zhang, 2025).

Megalinin yapısı modüler özellik göstermekte olup ligand bağlanması ve endositozdaki çeşitli görevlerini düzenleyen çok sayıda fonksiyonel alan içermektedir (Zhang ve Zhang, 2025). YWTD motifi içeren β- propeller ve LDL reseptör tipi A tekrarları (L)'dır. Ligand bağlayıcı L tekrarları korunmuş bir Ca^{2+} koordinasyon bölgesi taşımaktadır. Ayrıca β- propeller yapıları YWTD tekrarları ile karakterizedir (Beenken ve ark., 2023).

Megalinin Fizyolojik Fonksiyonları ve Endositozdaki Rolü

Megalin çok sayıda ligandın hücre içine alınmasına aracılık etmektedir. Proksimal tübüller primer glomerüler filtrattan proteinlerin geri kazanılmasını sağlayan megalin ve kübilin gibi çoklu ligand reseptörlerini eksprese etmektedir (Nicholson ve ark., 2024). Megalin, çeşitli ligandların endositozuna aracılık etmek üzere kübilin ile kompleks oluşturabilmektedir. Megalin'e bağlanan ligandlar arasında taşıyıcı proteinler, hormonlar, enzimler ve diğer çeşitli moleküller bulunmaktadır (Zhang ve Zhang, 2025).

LRP2, klatrin aracılı endositozu takiben endozomlardan hücre zarına geri dönüştürülmektedir (Beenken ve ark., 2023). Proksimal tübül hücrelerinde megalin geninin yoksunluğu endositik trafiği bozmakta ve metabolizma ile inflamasyonda rol alan yolakların gen ekspresyonunda önemli değişikliklere neden olmaktadır. Megalin, özellikle metabolik stres koşullarında böbrekte ve böbrek dışındaki dokularda homeostazın sürdürülmesinde rol oynamaktadır (Nicholson ve ark., 2024).

Megalin ve Böbrek Hastalıkları

Proteinüri ve Tübüler Protein Geri Emilim Bozuklukları

Filtrelenmiş proteinlerin proksimal tübül tarafından alınması vitamin, hormon, enzim ve ilaçların geri kazanımı açısından gerekli olup, bu süreçte megalin ve kubilin temel endositik reseptörler olarak işlev görmektedir (Nielsen ve ark., 2016). Birçok glomerüler hastalığa eşlik eden proteinüri zamanla tübüler yapılarda hasar gelişmesine yol açmaktadır. Tübüler hasarın ilerleyici böbrek fonksiyon kaybı ile

yakından ilişkili olduğu ve proteinüri düzeyinin son dönem böbrek yetmezliği gelişme riskini öngörebildiği bildirilmektedir. Megalinin küçük ve büyük molekül ağırlıklı proteinlerin geri emiliminde önemli rol oynadığı ve filtrelenmiş proteinlerin yeniden emiliminin tübül hasarına yol açabilecek olayları tetikleyebildiği gösterilmiştir (Motoyoshi ve ark., 2008).

Protein geri emilimi, proksimal tübülde reseptör aracılı endositoz ile gerçekleşmektedir ve bu süreç megalin, kubilin ve amnionless proteinlerinden oluşan fonksiyonel bir kompleks tarafından yürütülür. Albümin geri emiliminde kubilinin temel reseptör olduğu, megalinin ise kubilin-albümin komplekslerinin hücre içine alınmasını sağlayan başlıca yapı olarak görev yaptığı bildirilmiştir. Kubilin noksanlığı bulunan farelerde proksimal tübül hücreleri tarafından albümin alımının belirgin şekilde azaldığı ve bunun albüminüri ile sonuçlandığı gösterilmiştir (Amsellem ve ark., 2010).

Kronik Böbrek Hastalığı ve Diyabetik Nefropati

Diyabet üzerine yapılan çoğu çalışma, böbreklerde megalin ekspresyonunun arttığını göstermiştir. Özellikle streptozotosin ile indüklenen tip 1 diyabetli ratlarda ve tip 2 diyabet modeli oluşturulan Zucker obez ratlarında böbrek megalin mRNA ekspresyonunun arttığı bildirilmiştir. Yüksek glukoz konsantrasyonu ve oksidatif stresin hücre metabolizmasında kritik bir hücre içi sinyal iletim mekanizması olan fosfoinositid 3-kinaz (PI3K) /Akt yolu aracılığıyla megalin ekspresyonunun yukarı regülasyonunu tetiklediği öne sürülmüştür (Kulkarni ve Hussain, 2025).

İdrardaki C-megalin düzeylerinin normoalbuminürili hastalarda anlamlı derecede yüksek olduğu, albuminüri artışı ile paralel olarak yükseldiği ve tahmini glomerüler filtrasyon hızı (eGFR) ile idrar albümininden daha güçlü bir ilişki gösterdiği bildirilmiştir. Ayrıca idrardaki C-megalin düzeylerinin plazma inorganik fosfat düzeyleri ile pozitif, hemoglobin düzeyleri ile ise negatif ilişkili olduğu belirlenmiştir. C-megalin testi ile idrar megalin atılımının azalan eGFR ile yakından ilişkili olduğu, diyabetik nefropatinin şiddeti, fosfat düzensizliği ve anemi ile bağlantılı olduğu gösterilmiştir (Ogasawara ve ark., 2012).

Diyabetli ve diyabetli olmayan bireyler arasında idrar megalin düzeyleri bakımından anlamlı farklılık bulunurken, mikroalbüminürili diyabetli hastalarda idrar megalin düzeylerinin diyabetli olmayan bireylere göre anlamlı derecede farklı olduğu bildirilmiştir (Jagennath ve ark., 2024).

Yüksek idrar A-megalin/Cr düzeylerine sahip bireylerde eGFR düşüş hızının, düşük idrar A-megalin/Cr düzeylerine sahip bireylere göre daha yüksek olduğu belirlenmiştir. Benzer şekilde, yüksek C-megalin/Cr düzeylerine sahip bireylerde de eGFR düşüş hızının düşük C-megalin/Cr düzeylerine sahip bireylere göre daha yüksek olduğu gösterilmiştir. Bu sonuçlar, idrar A-megalin/Cr ve C-megalin/Cr düzeylerinin diyabetik böbrek hastalığının ilerlemesinin öngörülmesinde prognostik biyobelirteçler olabileceğini göstermektedir. Ayrıca A-megalin/Cr ve C-megalin/Cr düzeylerinin birlikte değerlendirilmesinin diyabetik böbrek hastalığı progresyonunun öngörülmesinde daha etkili olduğu bildirilmiştir (Iida ve ark., 2022).

Bununla birlikte, IgA nefropatisi (Berger hastalığı) olan hastalarda böbrek megalin mRNA'sı ve miR-148b ekspresyonunun azaldığı, bu durumun kronik böbrek hastalığının ilerlemesi ile ilişkili olduğu gösterilmiştir (Kulkarni ve Hussain, 2025).

Megalin Aracılı Nefrotoksisite

Kolistin Kaynaklı Nefrotoksisite

Kolistinin megalin ile etkileşiminin incelendiği çalışmalarda, tipik bir megalin ligandı olan sitokrom c'nin kolistinin megaline bağlanmasını rekabetçi olarak inhibe ettiği gösterilmiştir. Ratlarda megalin ekspresyonunun düşük seyrettiği durumlarda böbrek proksimal tübüllerinde kolistin birikiminin anlamlı düzeyde azaldığı, buna karşılık idrardaki kümülatif kolistin miktarının arttığı bildirilmiştir. Ayrıca kolistin ile sitokrom c veya albümin parçalarının birlikte uygulanmasının, böbrek tübül hasarının bir göstergesi olan idrar N-asetil-β-D-glukozaminidaz (NAG) atılımını anlamlı düzeyde azalttığı gösterilmiştir (Suzuki ve ark., 2013).

Gentamisin Kaynaklı Nefrotoksisite

Gentamisinin böbreğe alımının renal megalin aktivitesi ile doğrudan ilişkili olduğu ve reseptörden yoksun farelerde bu alımın tamamen ortadan kalktığı görülmüştür. Ayrıca reseptör eksikliği bulunan hayvanlarda böbrekte anlamlı düzeyde gentamisin birikimi gözlenmemiştir. Megalinin yokluğu, aminoglikozit alım için tek ana yolun ortadan kalkmasına neden olmuş ve antibiyotiğin böbrekte birikmesine karşı koruma sağlamıştır. Ayrıca elde edilen veriler, aminoglikozit alımında görev alan yolların farklı türlerde benzer olduğunu ve megalinin ratlarda ve insanlarda aminoglikozitlerin böbrek tarafından alınmasında ve nefrotoksisitesinde önemli rol oynadığını göstermektedir (Schmitz ve ark., 2002).

Gentamisin alımının megalin ekspresyonu ve fonksiyonelliği ile doğrudan ilişkili olduğu, megalinin ortadan kaldırılmasının ise gentamisin alımını büyük ölçüde azalttığı bildirilmiştir. Bu durum, endositozun böbrekte gentamisin birikiminin ve buna bağlı nefrotoksik etkinin temel yolu olduğunu ortaya koymuştur. Gentamisin uygulanan grupta ClC-5 ve megalin protein ekspresyonlarının kontrol grubuna oranla sırasıyla %77,61 ve %363 oranında arttığı gösterilmiştir. Tedavi edici ajanın uygulanması ile birlikte bu proteinlerin ekspresyonlarını gentamisin grubuna kıyasla sırasıyla %43,13 ve %62,15 oranında azalttığı bildirilmiştir (Azouz ve ark., 2022).

Megalinin ayrıca aminoglikozitler, polimiksin B ve kolistin gibi nefrotoksik ilaçların hücre içine alınmasında rol oynadığı bildirilmiştir (Hori ve ark., 2017).

Sisplatin Kaynaklı Nefrotoksisite

Yapılan çalışmalar, sisplatinin de böbrek tarafından alınımının ve buna bağlı gelişen nefrotoksisitenin kısmen megalin aracılığıyla gerçekleştiğini göstermiş, sisplatinin megalinin bir ligandı olduğu ortaya konulmuştur. Ayrıca fareler üzerinde gerçekleştirilen bir çalışmanın neticesinde megalin eksprese eden proksimal tübül epitel hücrelerinde sisplatin kaynaklı hasar gelişirken, megalinden yoksun hücrelerde bu hasarın oluşmadığı gösterilmiştir. Bu bulgular, megalinin sisplatin kaynaklı nefrotoksisitenin gelişiminde birincil rol oynadığını düşündürmektedir (Shoji ve ark., 2019).

Megalin ve Vitamin D Metabolizması

Vitamin D Metabolizmasında Megalinin Rolü

Megalin ve kubilin vitamin D metabolizmasında da önemli fonksiyonlara sahiptir. Bu reseptörlerin vitamin D bağlayıcı proteinin (DBP) glomerüler filtratlardan geri emiliminde ve ardından 25-hidroksivitamin D3'ün [25(OH)D3] biyolojik olarak aktif formu olan 1α,25-dihidroksivitamin D3'e [1,25(OH)2D3] hücre içi dönüşümünde rol oynadığı belirlenmiştir. Megalin, glomerüler filtratlardan DBP alımına aracılık etmekte ve böylece öncü molekül olan 25(OH)D3'ün aktif form olan 1,25(OH)2D3'e hücre içi dönüşümünü kolaylaştırmaktadır (Khan ve ark., 2022). DBP'nin lizozomlarda parçalanmasının ardından, 25(OH)D3 hücre içerisinde 1,25(OH)2D3'e dönüştürülerek dolaşıma salınmaktadır. Bu bulgular, vitamin D metabolizmasının yalnızca serbest hormonlar üzerinden gerçekleştiğini öne süren serbest hormon hipotezinin yeniden değerlendirilmesine neden olmuştur (Kaseda ve ark., 2011).

İnsan proksimal tübül epitelyumunda gerçekleştirilen çalışmalarda, 25(OH)D3'ün D vitamini bağlayıcı proteine bağlı haldeyken megalin aracılı endositoz yoluyla hücre içine taşındığı doğrulanmıştır. Ayrıca fare proksimal tübül epitel hücrelerinde 25(OH)D3'e erişimin temel yolunun DBP'ye bağlı prohormonun glomerüler ultrafiltrattan megalin aracılı endositozu olduğu bildirilmiştir. Megalin fonksiyonunun inhibe edilmesi ise D vitamini bağlayıcı protein ve 1α,25(OH)2D3 varlığında sitokrom P450 24A1 protein düzeyleri ile 24-hidroksilasyon aktivitesinin 1α,25(OH)2D3 aracılı indüksiyonunu azaltmıştır (Chapron ve ark., 2018).

Megalinin yalnızca böbrekte değil, D vitamini metabolizmasında görev alan çeşitli böbrek dışı dokularda da eksprese edilmesi, megalin aracılı D vitamini alımı ile bu dokularda bulunan D vitamini metabolize eden enzimlerin aktivitesi arasında işlevsel bir ilişki bulunduğunu göstermektedir (Khan ve ark., 2022).

Megalin-Kubilin Kompleksi

Megalin ve kubilin çeşitli dokularda birlikte eksprese edilmekte ve farklı biyolojik işlevlerin yerine getirilmesinde etkileşim içerisinde görev aldığı, çeşitli kubilin ligandlarının hücre içine alınmasının megalin tarafından önemli ölçüde kolaylaştırıldığı belirlenmiştir. Kubilinin, intrinsik faktör-kobalamin kompleksi (IF-B12), albümin, transferrin, hemoglobin, immünoglobulin hafif zincirleri, apolipoprotein A-I/yüksek yoğunluklu lipoprotein (HDL) ve DBP gibi çok sayıda liganda bağlanabildiği gösterilmiştir (Christensen ve Birn, 2002).

Hücre dışı bir protein olan kubilin, membran lokalizasyonu ve endositoz için diğer membran proteinleri ile etkileşime ihtiyaç duyar. Ayrıca kubilinin doğru membran lokalizasyonu için amnionless (AMN) adı verilen tek transmembran proteine bağımlı olduğu belirtilmektedir (Nielsen ve ark., 2016).

Megalin, sitoplazmik kuyruğunda klatrin aracılı endositoz için gerekli sinyalleri taşımaktadır. Ligandların hücre içine alınmasının ardından bu moleküller endositik veziküllerde serbest bırakılmakta ve daha ileri işlenmek üzere lizozomlar gibi hücresel kompartımanlara taşınmaktadır. Buna karşılık megalin ve kubilin reseptörleri yoğun apikal tübüller aracılığıyla yeniden apikal membrana geri dönmektedir (Nielsen ve ark., 2016). Ayrıca böbrek proksimal tübül hücrelerinde megalin ve kubilinin endositik aparat boyunca birlikte lokalize olduğu bildirilmiştir (Christensen ve Birn, 2002).

Megalin Eksikliği ve Vitamin D Homeostazı

Megalinin, 25-(OH)D3-DBP kompleksinin proksimal tübüllerde geri emilimindeki etkin süreci, 25-(OH)D3'ün korunması ve hücrelere aktif D vitamini sentezi için gerekli öncü maddenin ulaştırılması açısından gereklidir. Megalin eksikliği bulunan farelerde bu komplekslerin geri kazanılamadığı, bunun sonucunda D vitamini eksikliği ve çeşitli kemik metabolizması bozukluklarının geliştiği bildirilmiştir (Nykjaer ve ark., 1999).

Megalin özellikle DBP'e benzer şekilde retinol bağlayıcı protein (RBP) gibi küçük plazma taşıyıcı proteinlerinin alımına da aracılık etmektedir. Megalin eksikliği bulunan farelerde gözlenen tübüler rezorpsiyon bozukluğu sonucu idrarla düşük molekül ağırlıklı plazma proteinlerinin atıldığı belirlenmiştir. Bu nedenle megalin eksikliği olan farelerde taşıyıcı proteinlerin idrarla kaybı, bu proteinlere bağlı lipofilik vitaminlerin de eş zamanlı olarak kaybedilmesine yol açmaktadır (Leheste ve ark., 1999).

Reseptör eksikliği bulunan farelerin idrarında işaretlenmiş 25-OH D3 düzeylerinin yaklaşık altı kat arttığı belirlenmiştir (Nykjaer ve ark., 1999).

Böbrekte megalin ekspresyonunun bulunmaması plazma D vitamini eksikliğine, hipokalsemiye ve şiddetli kemik hastalığına yol açmaktadır. Bu kemik hastalığı; kemik mineral içeriğinde azalma, osteoid yüzeylerde artış ve mineralizasyon aktivitesinde azalma ile karakterizedir. D vitamini eksikliğine bağlı olarak gelişen bu bulguların osteomalazi ile uyumlu olduğu görülmektedir (Leheste ve ark., 2003).

Kronik Böbrek Hastalığında Megalin ve Vitamin D İlişkisi

Kronik böbrek hastalığında (KBH), 25-hidroksivitamin D [25(OH)D]'nin böbrek tarafından alımındaki bozukluklar sistemik kalsitriol eksikliğine önemli ölçüde katkıda bulunmaktadır. Megalin aracılı vitamin D geri alımındaki bozukluklar bu süreci daha da ağırlaştırabilmektedir. KBH'de glomerüler filtrasyon hızında meydana gelen ileri düzeyde azalmaların yanı sıra böbrek megalin ekspresyonundaki azalmanın da 25(OH)D'nin renal alımındaki bozukluğu artırdığı bildirilmiştir (Dusso, 2011).

Proteinüri, D vitamini eksikliğinin patogenezinde etkili faktörlerden biridir. Vitamin D bağlayıcı protein (VDBP) ile 25(OH)D kompleksleri glomerülde filtre edilmekte ve proksimal tübüle ulaşmaktadır. Bu komplekslerin geri emilimi, fırçamsı kenar düzeyinde megalin ve kubilinin görev aldığı reseptör aracılı bir mekanizma ile gerçekleşmektedir. Proteinüri bulunan hastalarda idrarla VDBP atılımında artış görüldüğü, ayrıca proksimal tübüllerde megalin ve kubilin aracılı protein geri alımında bozulma meydana gelebildiği bildirilmiştir. Bu nedenle megalin ve kubilin kaybının, kronik böbrek hastalığı ve proteinüri varlığında D vitamini eksikliğinin gelişimine katkıda bulunabileceği belirlenmiştir (Gois ve ark., 2018).

İdrar Megalini ve Klinik Önemi

Proksimal tübül hücrelerindeki (PTC) fenotipik değişiklikler diyabetik nefropatinin erken bulguları arasında yer almakta olup, buna eşlik eden tübülointerstisyel hasarın son dönem böbrek hastalığının gelişiminde merkezi bir rol oynadığı bildirilmektedir. Bununla birlikte, diyabette PTC disfonksiyonunu yansıtan etkili biyobelirteçler henüz tam olarak tanımlanamamıştır. İdrara salındığı bilinen megalinin potansiyel bir biyobelirteç olabileceği düşünülmüştür (Ogasawara ve ark., 2012).

Megalin idrarla ektodomain (A-megalin) ve tam uzunlukta (C-megalin) olmak üzere iki formda atılmaktadır. Diyabetik böbrek hastalığında (DBH) proksimal tübülopatinin hastalığın temel tetikleyicilerinden biri olarak kabul edilmesi, bu yapıyı yansıtan biyobelirteçlere olan ilgiyi artırmıştır (Iida ve ark., 2022).

Erken dönemde diyabetik nefropatinin belirlenmesi hastalığın ilerlemesini durdurmak veya yavaşlatmak açısından büyük önem taşımaktadır. Bu nedenle serum kreatinin, üre ve albüminüri gibi geleneksel belirteçlerin yanı sıra yeni biyobelirteçlere yönelik ilgi giderek artmaktadır. Özellikle diyabetik nefropatili hastaların yaklaşık %30'unda albüminüri bulunmaması, yalnızca albüminüriye dayalı değerlendirmenin bazı hastalarda yetersiz kalabileceğini göstermektedir. Albüminürik olmayan diyabetik nefropati formlarının tanımlanması, böbrek hasarının değerlendirilmesinde tahmini glomerüler filtrasyon hızının ve yeni biyobelirteçlerin birlikte kullanılmasının önemini ortaya koymaktadır (Concepción ve ark., 2024).

İnsan idrarında bulunan C-megalin formunun sağlıklı bireylerde daha düşük düzeylerde bulunduğu, tip 2 diyabetli hastalarda ise arttığı, albüminüri derecesine bağlı olarak yükselme eğiliminde olduğu ve normoalbüminürik hastalarda dahi sağlıklı kontrollere göre anlamlı derecede yüksek olduğu gösterilmiştir. Üriner C-megalin düzeyleri azalmış eGFR ile anlamlı derecede ilişkilidir ve eGFR ile olan korelasyonunun üriner albümininkinden daha güçlü olduğu bildirilmiştir. Aynı zamanda üriner C-megalin düzeylerinin diyabetik nefropatinin şiddeti ile pozitif korelasyon gösterdiği saptanmıştır. Normoalbüminürik hastalarda dahi yüksek düzeylerde bulunması nedeniyle diyabetik nefropatinin erken tanısında veya hastalık gelişiminin öngörülmesinde kullanılabilecek duyarlı bir biyobelirteç olabileceği bildirilmiştir (Ogasawara ve ark., 2012).

Megalinin, lipotoksik ve glikotoksik maddelerin böbreğe alınmasında bir "geçit" görevi gördüğü ve bu nedenle diyabetik böbrek hastalığının gelişim ve ilerlemesinde rol oynayabileceği öne sürülmüştür. Ayrıca A-megalin ve C-megalinin idrara farklı mekanizmalarla atıldığı ve bu iki formun diyabetik böbrek hastalığında değişken biyolojik süreçleri yansıtabileceği belirtilmektedir. Bu nedenle üriner megalin atılımının iki formunun da diyabetik böbrek hastalığı için ayırt edici biyobelirteçler olarak kullanılabileceği bildirilmiştir (Iida ve ark., 2022).

Donnai-Barrow Sendromu ve LRP2 Mutasyonları

Donnai-Barrow sendromu (DBS), korpus kallozum agenezisi, konjenital diyafragmatik herni, yüz dismorfizmi, oküler anomaliler, sensörinöral işitme kaybı ve gelişimsel gecikme ile karakterize (Kantarci ve ark., 2007) ve LRP2 genindeki mutasyonlardan kaynaklanan nadir görülen otozomal resesif bir bozukluktur (Yuan ve ark., 2023).

LRP2 tarafından kodlanan megalinin yokluğu veya anormal işlevi, böbrek proksimal tübüllerinde megalin ligandlarının normal geri emilimini engellemektedir. Bunun sonucunda Donnai-Barrow sendromlu bireylerde düşük molekül ağırlıklı proteinlerin idrarla aşırı atılımı gerçekleşmektedir. İdrarda artmış düzeylerde saptanan proteinler arasında RBP ve VDBP de yer almaktadır. DBS'li bireylerin büyük çoğunluğunda asemptomatik düşük molekül ağırlıklı proteinüri görülmektedir. Hastalıkta hiperkalsiüri, nefrokalsinozis, nefrolitiyazis ve fokal segmental glomerüloskleroz gibi renal bulgular da bildirilmiştir. Nefropati ve son dönem böbrek hastalığına ilerleme nadir görülmekle birlikte yaşamı tehdit eden bir komplikasyon olarak tanımlanmıştır (Longoni ve ark., 2018).

Yuan ve ark. (2023), erken başlangıçlı yüksek miyopi ile başvuran bir olguda Donnai-Barrow sendromu ile ilişkili iki yeni bileşik heterozigot LRP2 varyantı tanımlamıştır (Yuan ve ark., 2023).

SONUÇ

Son yıllarda yapılan çalışmalar, megalinin yalnızca fizyolojik süreçlerde değil, aynı zamanda çeşitli böbrek hastalıklarının patogenezinde de önemli görevler üstlendiğini ortaya koymuştur. Kronik böbrek hastalığı ve diyabetik böbrek hastalığında megalin ekspresyonu ve fonksiyonunda meydana gelen değişikliklerin tübüler hasar, proteinüri ve böbrek fonksiyon kaybı ile ilişkili olduğu gösterilmiştir. Ayrıca megalinin gentamisin, kolistin ve sisplatin gibi çeşitli nefrotoksik ajanların proksimal tübül hücrelerine alımına aracılık etmesi, ilaç kaynaklı böbrek hasarının gelişiminde önemli bir rol oynadığını düşündürmektedir. Megalin aynı zamanda vitamin D metabolizmasının düzenlenmesinde temel görev üstlenmekte olup, vitamin D bağlayıcı protein aracılığıyla taşınan vitamin D metabolitlerinin geri emiliminde kritik rol oynamaktadır. Bu mekanizmadaki bozuklukların vitamin D eksikliği, mineral metabolizması bozuklukları ve kemik patolojilerinin gelişimine katkıda bulunabileceği bildirilmektedir. Bunun yanında, LRP2 genindeki mutasyonlar sonucunda gelişen Donnai-Barrow sendromunda görülen klinik bulgular, megalinin insan gelişimi ve çoklu organ fonksiyonlarının sürdürülmesindeki önemini açıkça ortaya koymaktadır.

Sonuç olarak megalin; böbrek fizyolojisi, vitamin homeostazı ve reseptör aracılı endositoz mekanizmalarının sürdürülmesinde merkezi rol oynayan önemli bir moleküldür. Üriner megalin formlarının erken tübüler hasarın değerlendirilmesinde biyobelirteç olarak kullanılabilme potansiyeli ve megalin aracılı yolakların nefrotoksisiteyi azaltmaya yönelik yeni tedavi stratejilerine hedef oluşturabilmesi, bu reseptörün gelecekte tanısal ve terapötik açıdan önemini daha da artıracaktır.

K**aynakça**

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APPROACHES TO RENEWABLE ENERGY APPLICATIONS IN THE HOSPITALITY SECTOR: A CONCEPTUAL EVALUATION

KONAKLAMA SEKTÖRÜNDE YENİLENEBİLİR ENERJİ UYGULAMALARINA YÖNELİK YAKLAŞIMLAR: KAVRAMSAL BİR DEĞERLENDİRME

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ABSTRACT

Accommodation businesses have a distinctive energy profile because many services must run without interruption throughout the day. Heating, cooling, hot water supply, lighting, kitchen operations, laundry, pool and spa services create a steady demand for energy and place pressure on operating budgets as well as on environmental performance. Starting from this point, the present paper offers a conceptual discussion of renewable energy applications in the hospitality sector. It focuses on solar, wind, biomass and geothermal energy and considers how these sources may be used in accommodation facilities for energy management, cost control, carbon footprint reduction and sustainable tourism. The paper is based on the literature and on the theoretical framework of an ongoing thesis study. Rather than presenting renewable energy as a ready-made technical solution, the discussion emphasizes the need to match each technology with the location, service type, consumption pattern and managerial capacity of the facility. Solar energy is relevant for electricity generation and hot water supply; wind energy can support facilities located in areas with sufficient wind potential; biomass energy may be linked to organic waste management; and geothermal resources are especially meaningful for heating, hot water and spa services in thermal tourism destinations. The evaluation indicates that renewable energy applications can offer environmental and economic gains, provided that planning, financing, maintenance, monitoring and institutional commitment are handled together. In this respect, the paper provides a concise basis for future survey-based research and for decision-making in the hospitality sector.

Keywords: Renewable Energy; Hospitality Sector; Sustainability; Carbon Footprint; Energy Management

ÖZET

Konaklama işletmelerinde enerji talebi, hizmetlerin gün boyunca kesintisiz sürdürülmesi nedeniyle sürekli ve çok yönlü bir yapı göstermektedir. Isıtma, soğutma, sıcak su, aydınlatma, mutfak, çamaşırhane, havuz ve spa gibi birimler hem işletme maliyetlerini artırmakta hem de çevresel performansı doğrudan etkilemektedir. Bu çalışmada, konaklama sektöründe yenilenebilir enerji uygulamalarına yönelik yaklaşımlar kavramsal bir çerçevede ele alınmaktadır. Güneş, rüzgâr, biyokütle ve jeotermal enerji kaynakları; enerji yönetimi, maliyet kontrolü, karbon ayak izinin azaltılması ve sürdürülebilir turizm hedefleri açısından tartışılmaktadır. Çalışma, literatüre ve yürütülen tez çalışmasının kuramsal çerçevesine dayalı bir değerlendirme niteliğindedir. Metinde yenilenebilir enerji uygulamaları hazır bir teknik çözüm olarak değil; tesisin bulunduğu bölge, hizmet türü, enerji tüketim profili, finansal olanakları, bakım kapasitesi ve yönetsel kararlılığıyla birlikte değerlendirilmesi gereken bir uygulama alanı olarak ele alınmaktadır. Güneş enerjisi elektrik üretimi ve sıcak su temini için öne çıkarken, rüzgâr enerjisi uygun potansiyele sahip bölgelerde destekleyici bir kaynak olabilir. Biyokütle enerjisi organik atık yönetimiyle, jeotermal enerji ise özellikle termal turizm bölgelerinde ısıtma, sıcak su ve spa hizmetleriyle ilişkilendirilebilir. Değerlendirme, yenilenebilir enerji yatırımlarının çevresel ve ekonomik fırsatlar sunduğunu; ancak bu fırsatların yerel koşullara uygun planlama, finansman, izleme ve kurumsal sahiplenme ile anlam kazanacağını göstermektedir.

Anahtar Kelimeler: Yenilenebilir Enerji; Konaklama Sektörü; Sürdürülebilirlik; Karbon Ayak İzi; Enerji Yönetimi

GİRİŞ

Konaklama işletmelerinde enerji tüketimi, hizmetin kesintisiz yürütülmesiyle doğrudan bağlantılıdır. Misafir odaları, yiyecek-içecek birimleri, çamaşırhane, sıcak su sistemleri, havuz, spa, iklimlendirme ve aydınlatma gibi alanlar günün farklı saatlerinde enerji talebi oluşturur. Bu yapı, enerji yönetimini yalnızca teknik servis biriminin sorumluluğunda kalan bir konu olmaktan çıkarır; maliyet kontrolü, hizmet kalitesi ve çevresel performansla birlikte ele alınması gereken stratejik bir karar alanına dönüştürür. Avrupa otelleri üzerine yapılan değerlendirmeler de enerji kullanımının çok sayıda hizmet birimine yayıldığını ve enerji verimliliği ile yenilenebilir enerji uygulamalarının birlikte düşünülmesinin gerekli olduğunu göstermektedir [1,2].

Turizmde sürdürülebilirlik tartışması, doğal kaynakların korunmasının yanında işletmelerin enerji tüketimini nasıl yönettiğini, emisyonlarını hangi araçlarla azalttığını ve çevresel sorumluluğu kurumsal işleyişe ne ölçüde yerleştirdiğini de kapsar. Oteller açısından yenilenebilir enerji, enerji giderlerini düşürme arayışıyla çevreye duyarlı müşteri beklentilerini aynı düzlemde buluşturan bir uygulama alanıdır. Sürdürülebilirlik yönetiminin rekabet avantajı üzerindeki etkisini inceleyen çalışmalar, çevresel uygulamaların işletme imajı, paydaş beklentileri ve uzun vadeli kurumsal dayanıklılık bakımından belirleyici sonuçlar doğurabildiğini ortaya koymaktadır [3].

Bu bildiride, konaklama sektöründe yenilenebilir enerji uygulamalarına ilişkin yaklaşımlar kavramsal düzeyde incelenmektedir. Güneş, rüzgâr, biyokütle ve jeotermal enerji kaynaklarının konaklama işletmeleri açısından sunduğu imkânlar çevresel, ekonomik ve yönetsel boyutlarıyla tartışılmıştır. Çalışma, tez kapsamında oluşturulan kuramsal çerçeveden hareketle hazırlanmış kısa bir değerlendirme niteliğindedir; saha verisi üretmeyi değil, ileride yapılacak anket temelli araştırmalar için konu alanını daha anlaşılır hâle getirmeyi amaçlamaktadır.

GELİŞME

Yenilenebilir enerji kaynakları, doğal süreçler içinde kendini yenileyebilen ve fosil yakıtlara göre daha düşük çevresel etki potansiyeli taşıyan kaynaklar olarak tanımlanır. Güneş, rüzgâr, biyokütle ve jeotermal enerji; konaklama işletmelerinde elektrik üretimi, sıcak su temini, ısıtma, atık yönetimi ve karbon azaltımı gibi farklı ihtiyaçlara karşılık gelebilir. Türkiye'de yenilenebilir enerji kaynaklarını destekleyen düzenlemeler bu alanın yasal zeminini güçlendirmektedir [6,7]. Ancak bir kaynağın

yenilenebilir olması, tek başına sürdürülebilir bir uygulama anlamına gelmez. Kurulum, işletme, bakım, kaynak kullanımı ve kullanım ömrü sonundaki etkiler de değerlendirme sürecine dâhil edilmelidir.

Güneş enerjisi, konaklama işletmeleri için özellikle elektrik üretimi ve sıcak su temini bakımından uygulanabilir bir seçenektir. Çatı alanı uygun olan şehir otelleri, tatil köyleri ve büyük ölçekli tesisler fotovoltaik sistemlerle elektrik tüketimlerinin bir bölümünü yerinde karşılayabilir. Güneş termal sistemleri ise banyo, mutfak, çamaşırhane, havuz ve spa gibi sıcak su ihtiyacının yoğunlaştığı birimlerde destekleyici çözüm sunar. Fotovoltaik sistemlerin çevresel performansı değerlendirilirken yalnızca kullanım aşaması değil, panel üretimi, taşıma, kurulum, bakım ve geri dönüşüm süreçleri de yaşam döngüsü yaklaşımıyla incelenmelidir [9,10]. Bu bakış açısı, güneş enerjisi yatırımlarını kurulu güç hesabının ötesine taşıyarak tesisin tüketim profili ve uzun vadeli sürdürülebilirlik hedefleriyle ilişkilendirir.

Rüzgâr enerjisi, yeterli rüzgâr potansiyeline sahip kıyı bölgelerinde, açık alanlarda veya topoğrafik olarak elverişli destinasyonlarda konaklama işletmeleri için destekleyici bir kaynak hâline gelebilir. Yatırımın uygulanabilirliği rüzgâr hızı, türbin seçimi, arazi yapısı, bakım gereksinimi ve şebeke bağlantısı gibi teknik değişkenlere bağlıdır. Bununla birlikte, otel çevresinde kurulacak bir türbinin görsel etkisi, gürültü düzeyi, ekolojik hassasiyetler ve çevreyle uyumu da yatırım kararında dikkate alınmalıdır. Rüzgâr ve güneş kaynaklarının birlikte kullanıldığı hibrit sistemler ise enerji arzının sürekliliği açısından tesislere daha esnek bir planlama olanağı sunabilir [13,14].

Biyokütle enerjisi, organik maddelerin enerjiye dönüştürülmesine dayandığı için konaklama işletmelerinde atık yönetimiyle doğal bir ilişki kurar. Büyük ölçekli otellerde mutfak atıkları, bahçe ve peyzaj artıkları ya da benzeri organik materyaller uygun teknik koşullar sağlandığında biyokütle veya biyogaz süreçleri için kaynak oluşturabilir. Bu uygulamanın sürdürülebilirliği ise kullanılan atığın türüne, toplama ve taşıma düzenine, dönüşüm teknolojisine ve yerel çevresel etkilere bağlıdır. Bu yüzden biyokütle her koşulda çevresel açıdan avantajlı kabul edilmemeli; kaynak yönetimi ve yaşam döngüsü etkileri birlikte değerlendirilmelidir [10].

Jeotermal enerji, özellikle termal turizm bölgelerinde konaklama işletmeleri için güçlü bir seçenek sunar. Sıcak su, ısıtma, spa ve sağlık turizmi hizmetleri jeotermal kaynaklarla doğrudan ilişkilendirilebilir. Bu tür uygulamalarda kaynağın sıcaklığı, debisi, sürdürülebilir kullanım kapasitesi, reenjeksiyon uygulamaları ve çevresel etkiler belirleyicidir. Jeotermal enerjinin tesis ölçeğinde kullanımı, ısı ihtiyacının yüksek olduğu bölgelerde fosil yakıt tüketimini azaltabilir; buna karşılık her yatırımın yerel jeolojik koşullar üzerinden ayrı ayrı analiz edilmesi gerekir.

Yenilenebilir enerji uygulamalarının çevresel karşılığı, büyük ölçüde karbon ayak izinin azaltılmasıyla ilişkilidir. Oteller elektrik, ısıtma, soğutma ve sıcak su gibi hizmetlerde fosil yakıt ağırlıklı kaynaklara bağımlı kaldığında doğrudan ve dolaylı sera gazı emisyonları artar. Yenilenebilir enerji kullanımı bu emisyonların düşürülmesine ve çevresel performansın daha izlenebilir hâle gelmesine yardımcı olabilir. Sürdürülebilir turizm literatürü, enerji ve kaynak kullanımını destinasyonların çevresel taşıma kapasitesiyle birlikte tartıştığı için konaklama işletmelerindeki enerji kararları daha geniş bir turizm politikası bağlamında anlam kazanır [4].

Ekonomik boyut, çevresel gerekçeler kadar belirleyicidir. Enerji giderleri konaklama işletmelerinin faaliyet maliyetleri içinde kayda değer bir paya sahiptir. Bu nedenle uzun vadede maliyetleri azaltabilecek, fiyat dalgalanmalarına karşı koruma sağlayabilecek ve enerji arz güvenliğini güçlendirebilecek çözümler işletmeler için cazip hâle gelmektedir. Buna karşılık ilk yatırım maliyeti, finansman kaynaklarına erişim, bakım giderleri ve geri dönüş süresi karar sürecini sınırlayabilir. Ekonomik fizibilite yalnızca ekipman bedeli üzerinden değil; doluluk oranı, mevsimsellik, enerji tüketim profili ve beklenen tasarruf potansiyeliyle birlikte yapılmalıdır.

Başarılı uygulama, teknik kurulumun yanında kurumsal yönetim kapasitesini de gerektirir. Enerji performansının izlenmesi, tüketim verilerinin düzenli kaydedilmesi, personelin bilinçlendirilmesi ve bakım süreçlerinin aksatılmadan yürütülmesi sistemin sürekliliğini etkiler. Akıllı şebekeler, enerji yönetim sistemleri ve dijital izleme araçları, tesislerin üretim ve tüketim verilerini daha görünür hâle getirerek yönetsel kararları destekleyebilir [8]. Türkiye Sürdürülebilir Turizm Programı ve GSTC kriterleri de konaklama tesislerinde enerji yönetimini, çevresel performansı ve sürdürülebilirlik uygulamalarını kurumsal bir çerçevede ele almaktadır [11,12].

Yeşil sertifikasyon ve çevre etiketleri, konaklama işletmelerinin sürdürülebilirlik uygulamalarını görünür kılan araçlardır. Ancak bu araçların yalnızca tanıtım veya pazarlama amacıyla kullanılması, uygulamaların güvenilirliğini zayıflatabilir. Sertifikasyonun anlamlı olabilmesi için gerçek performans iyileştirmesi, düzenli ölçüm, şeffaf raporlama ve denetim süreçleriyle desteklenmesi gerekir. Bu alandaki çalışmalar, çevre etiketlerinin işletmeleri sürdürülebilir uygulamalara yöneltebildiğini; ancak güvenilirlik için ölçülebilir kriterlere ve izlenebilir performans verilerine ihtiyaç olduğunu göstermektedir [5,15].

Son olarak, yenilenebilir enerji uygulamalarının sürdürülebilir turizmle ilişkisi yalnızca çevreci bir imaj üretme meselesi değildir. Ölçülebilir enerji tasarrufu, emisyon azaltımı, atıkların değerlendirilmesi ve kaynak kullanımının izlenmesi, sürdürülebilirlik iddialarının güvenilirliğini artırır. Bu açıdan çevre etiketleri ve sertifikasyon sistemleri, yalnızca tanıtım aracı olarak değil, işletmenin enerji performansını düzenli biçimde takip etmesini sağlayan bir yönetim çerçevesi olarak görülmelidir. Böyle bir yaklaşım, konaklama sektöründe yenilenebilir enerji uygulamalarının hem akademik araştırmalar hem de uygulayıcılar açısından daha somut biçimde değerlendirilmesine imkân tanır.

Finansal açıdan bakıldığında ise yatırım maliyeti kadar geri dönüş süresi ve finansman modeli de değerlendirilmelidir. Küçük ve orta ölçekli konaklama işletmeleri için yüksek ilk yatırım bedeli caydırıcı olabilir. Bu durumda leasing, enerji performans sözleşmeleri, kamu destekleri, yeşil kredi olanakları veya tedarikçi temelli bakım anlaşmaları daha erişilebilir seçenekler oluşturabilir. Ancak her finansman modeli tesisin doluluk oranı, mevsimsellik, enerji fiyatları ve öz tüketim kapasitesi dikkate alınarak değerlendirilmelidir. Aksi durumda çevresel açıdan olumlu görünen bir yatırım, işletme bütçesi üzerinde beklenmeyen bir yük oluşturabilir.

Yenilenebilir enerji uygulamalarında yönetsel sahiplenme de teknik tasarım kadar belirleyicidir. Sistemin kurulması, sürecin tamamlandığı anlamına gelmez; düzenli bakım, üretim-tüketim verilerinin izlenmesi, personelin kullanım alışkanlıklarının geliştirilmesi ve enerji performansının dönemsel olarak raporlanması gerekir. Özellikle otellerde mutfak, çamaşırhane, ön büro, teknik servis ve kat hizmetleri gibi birimlerin enerji tüketimindeki payları farklıdır. Bu nedenle çalışanların sürece dahil edilmediği uygulamalar, teknik olarak doğru kurulmuş olsa bile beklenen tasarruf düzeyine ulaşamayabilir.

Konaklama işletmeleri açısından süreklilik ve güvenilirlik, yenilenebilir enerji planlamasının merkezinde yer alır. Misafir memnuniyeti, oda konforu, sıcak su arzı, gıda güvenliği ve güvenlik sistemleri enerji kesintilerinden doğrudan etkilenmektedir. Bu nedenle güneş veya rüzgâr gibi değişken üretim karakterine sahip kaynaklar çoğu zaman şebeke bağlantısı, depolama, yedek kazan veya hibrit sistemlerle birlikte düşünülmelidir. Hibrit kurgu, yenilenebilir enerji kullanımını daha uygulanabilir hâle getirirken işletmenin hizmet kalitesinden ödün vermeden enerji maliyetini azaltmasına yardımcı olabilir.

Bu noktada enerji verimliliği ile yenilenebilir enerji yatırımlarının birbirinden ayrı fakat tamamlayıcı iki alan olduğu unutulmamalıdır. Enerji tüketimindeki kayıplar azaltılmadan kurulan yenilenebilir sistemler, beklenen ekonomik karşılığı her zaman üretmeyebilir. Isı yalıtımı zayıf, sıcak su hattı verimsiz, aydınlatma kontrolü yetersiz veya bakım düzeni aksayan bir işletmede yenilenebilir enerji yatırımı tek başına yeterli olmayacaktır. Bu nedenle yenilenebilir enerjiye geçiş, önce tüketimin nerede ve neden yoğunlaştığını gösteren bir enerji etüdüyle desteklenmeli; ardından hangi kaynağın hangi hizmet birimine daha uygun olduğu belirlenmelidir.

Konaklama işletmelerinde yenilenebilir enerji kararları çoğu zaman yalnızca teknik kapasite üzerinden tartışılmaktadır. Oysa aynı teknoloji, farklı tesis türlerinde farklı sonuçlar doğurabilir. Şehir otellerinde sınırlı çatı alanı ve yüksek elektrik tüketimi fotovoltaik sistemleri öne çıkarırken, resort otellerde açık alan kullanımı, havuz ve rekreasyon birimleri enerji talebinin yapısını değiştirmektedir. Termal otellerde ise sıcak su ve ısıtma ihtiyacının sürekliliği jeotermal kaynakların veya güneş termal sistemlerinin daha anlamlı biçimde değerlendirilmesine olanak tanır. Bu nedenle yatırım kararının ilk aşamasında tesisin enerji yük profili, hizmet modeli ve yıl içindeki doluluk değişimleri birlikte okunmalıdır.

Bu değerlendirmeler, yenilenebilir enerji uygulamalarının konaklama sektöründe tek boyutlu bir teknoloji tercihi olmadığını göstermektedir. İşletme ölçeği, hizmet yapısı, finansman kapasitesi, çalışan farkındalığı, bakım organizasyonu, sertifikasyon süreçleri ve destinasyon koşulları aynı karar alanının parçalarıdır. Dolayısıyla konuya ilişkin akademik çalışmaların, yalnızca hangi kaynağın kullanıldığını

değil, bu kaynağın hangi koşullarda, hangi beklentilerle ve hangi işletme kapasitesiyle uygulandığını da sorgulaması gerekmektedir.

Konunun bir diğer boyutu da yenilenebilir enerji uygulamalarının iletişim ve pazarlama alanındaki karşılığıdır. Çevreye duyarlı turistlerin artması, işletmeleri yeşil uygulamalarını görünür kılmaya yöneltmektedir. Ancak bu görünürlük, gerçek performans verileriyle desteklenmediğinde güven sorunu yaratabilir. Bu nedenle konaklama işletmelerinin yenilenebilir enerji yatırımlarını yalnızca tanıtım materyallerinde kullanılan bir çevreci ifade olarak değil, ölçülebilir enerji üretimi, tasarruf, emisyon azaltımı ve bakım kayıtlarıyla desteklenen bir yönetim pratiği olarak sunması gerekir.

Destinasyon ölçeği de uygulama başarısını etkileyen ayrı bir değişkendir. Aynı bölgede yer alan oteller benzer iklim koşullarına sahip olsa da yönetim anlayışı, yatırım kapasitesi, müşteri profili ve hizmet çeşitliliği bakımından farklılaşabilir. Bu nedenle yenilenebilir enerji uygulamalarına yönelik politikaların yalnızca genel teşvikler üzerinden değil, bölgesel kaynak potansiyeli ve işletme tipolojileri dikkate alınarak tasarlanması daha gerçekçi sonuçlar üretecektir. Özellikle güneşlenme süresi yüksek, jeotermal potansiyeli bulunan veya organik atık miktarı fazla olan destinasyonlarda teknoloji seçimi daha yerel bir değerlendirme gerektirir.

Bildiri, devam eden tez çalışmasının kuramsal zemininden hareket ettiği için ampirik bulgudan çok, ileride yürütülecek saha araştırmasına yön verecek değişkenleri belirginleştirmeyi amaçlamaktadır. Bu çerçevede işletmelerin yenilenebilir enerjiye ilişkin bilgi düzeyi, mevcut kullanım durumu, yatırım kararını etkileyen engeller, maliyet algısı ve çevresel duyarlılık düzeyi birlikte değerlendirilmesi gereken başlıklardır. Anket temelli bir çalışma bu başlıkları sayısal olarak görünür kılabilir; ancak elde edilecek verilerin işletme türü, doluluk oranı ve tesis ölçeği gibi değişkenlerle birlikte yorumlanması gerekir.

SONUÇ

Konaklama sektöründe yenilenebilir enerji uygulamaları, teknik tercihlerin ötesine geçen çok boyutlu bir karar alanıdır. Güneş, rüzgâr, biyokütle ve jeotermal enerji kaynakları farklı kullanım olanakları sunsa da her tesis için aynı düzeyde uygun değildir. Bölgesel koşullar, iklim, enerji tüketim profili, hizmet türü, doluluk oranı, finansman olanakları ve kurumsal sürdürülebilirlik hedefleri yatırım kararlarını doğrudan şekillendirir.

Bu kavramsal değerlendirme, yenilenebilir enerji uygulamalarının çevresel sorumlulukla sınırlı olmayan; maliyet yönetimi, enerji arz güvenliği, marka imajı ve sürdürülebilir turizm politikalarıyla bağlantılı bir alan olduğunu göstermektedir. Uygulamanın başarılı olabilmesi için teknik fizibilite, bakım planlaması, personel eğitimi, performans izleme ve kurumsal sahiplenme birlikte ele alınmalıdır. Gelecekte yapılacak ampirik çalışmalarda konaklama işletmelerinin yenilenebilir enerji kullanım düzeyleri, karşılaştıkları engeller, yöneticilerin bilgi ve farkındalık düzeyi ile müşteri beklentileri arasındaki ilişkinin anket ve saha verileriyle incelenmesi, literatüre daha somut ve uygulanabilir sonuçlar sağlayacaktır.

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CRITIQUING RATIONAL REASON IN ISLAMIC THOUGHT: TAHA ABDURRAHMAN AS A CASE STUDY

İSLAM DÜŞÜNCESİNDE RASYONEL AKIL ELEŞTİRİSİ TAHA ABDURRAHMAN ÖRNEĞİ

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ÖZET

İslam düşüncesinde bilgi ve hakikate ulaşma, tarih boyunca yalnızca çıkarımsal (istidlâlî) akla dayandırılmamış; bunun yanında kalbin idrak eden, sezgisel ve hikmet boyutuna da epistemolojik bir değer atfedilmiştir. Nitekim Kur'an-ı Kerim, akletme fiilini sadece zihne değil kalbe de nispet etmekte ve insanın hakikati kavrayışında kalbin merkezi rolüne dikkat çekmektedir. Bu yaklaşım, İslam düşüncesinde rasyonel aklın bütünüyle reddedilmesi anlamına gelmemiş; aksine onun sınırlarının belirlenmesi ve ahlaki-ilahi ilkeler doğrultusunda işlevsel kılınması yönünde sürekli bir eleştiri geleneği oluşturmuştur. Bu çalışmanın amacı, İslam düşüncesinde ilk dönemden itibaren dile getirilen rasyonel akıl eleştirilerini ana hatlarıyla ortaya koymak ve bu eleştirilerin çağdaş dönemde Faslı düşünür Taha Abdurrahman'ın eserlerinde nasıl sistematik bir çerçeveye kavuştuğunu göstermektir.Araştırma, klasik ve çağdaş İslam düşüncesini birlikte değerlendiren nitel bir literatür incelemesine dayanmaktadır. Kur'an-ı Kerim'in akıl ve kalp ilişkisine dair yaklaşımı temel referans olarak ele alınmış; Meşşâî filozoflar, Gazzâlî ve tasavvuf geleneğinin akıl anlayışları karşılaştırmalı biçimde incelenmiştir. Ardından Taha Abdurrahman'ın modern rasyonalite, araçsal akıl ve ahlak ilişkisine dair görüşleri analiz edilerek klasik eleştiri geleneğiyle irtibatı değerlendirilmiştir. Çalışma, İslam düşüncesinde aklın hiçbir zaman dışlanmadığını; ancak ahlaktan, vahiyden ve kalbin hikmetinden bağımsızlaşan araçsal-rasyonel aklın eleştiri konusu yapıldığını ortaya koymaktadır. Bu bağlamda Taha Abdurrahman'ın modern rasyonaliteye yönelttiği eleştirilerin, İslam düşüncesinde asırlardır devam eden akıl eleştirilerini günümüz şartlarında yeniden yorumlayan ve özetleyen bir düşünce çizgisini temsil ettiği sonucuna ulaşılmaktadır.

Anahtar Kavramlar: İslam düşüncesi, Rasyonel akıl, epistemoloji, Taha Abdurrahman, Ahlak

ABSTRACT

In Islamic thought, the pursuit of knowledge and truth has never been based solely on inferential (istidlālī) reason. Alongside discursive reasoning, the heart (qalb), with its cognitive, intuitive, and wisdom-oriented capacities, has been regarded as possessing epistemological significance. Indeed, the Qur'an attributes the act of reasoning not only to the intellect but also to the heart, emphasizing its central role in the human apprehension of truth. This perspective does not imply a rejection of rational reason in Islamic thought; rather, it reflects a long-standing tradition of critiquing reason by defining its limits and situating it within a moral and divine framework. The aim of this study is to outline the major critiques of rational reason articulated throughout the history of Islamic thought and to demonstrate how these critiques are systematically reformulated in the works of the contemporary Moroccan thinker Taha Abdurrahman. This research is based on a qualitative literature review that examines both classical and contemporary Islamic thought. The Qur'anic understanding of the relationship between reason and the heart serves as the primary point of reference. The conceptions of reason developed by the Peripatetic philosophers, al-Ghazālī, and the Sufi tradition are comparatively analyzed. Subsequently, Taha

Abdurrahman's views on modern rationality, instrumental reason, and morality are examined in order to evaluate their continuity with the classical tradition of critique. The study concludes that reason has never been rejected within Islamic thought. Rather, the object of criticism has been instrumental rationality detached from morality, revelation, and the wisdom of the heart. In this respect, Taha Abdurrahman's critique of modern rationality represents a contemporary reformulation and synthesis of a long-standing tradition of criticizing reason in Islamic intellectual history.

Keywords: Islamic Thought, Rational Reason, Epistemology, Taha Abdurrahman, Morality.

ADVANCES IN SMART PACKAGING FOR REAL-TIME QUALITY MONITORING AND SHELF-LIFE EXTENSION OF MEAT PRODUCTS

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ABSTRACT

Objectives: Ensuring the quality and safety of meat products throughout the supply chain remains a significant challenge because of their susceptibility to microbial contamination, lipid oxidation, and physicochemical deterioration. Recent progress in smart packaging has created new opportunities for continuous quality monitoring while supporting shelf-life extension and reducing food waste. This review critically examines recent advances in smart packaging technologies and their applications in meat quality assessment and preservation.

Methods: A comprehensive review of recent peer-reviewed studies was conducted to evaluate the principles, applications, and performance of intelligent packaging systems used for meat products. Particular attention was given to freshness indicators, time-temperature indicators, gas sensors, biosensors, and nanotechnology-enabled sensing materials. The review also explored the complementary role of active packaging systems incorporating antimicrobial and antioxidant agents.

Results: Current evidence demonstrates that smart packaging technologies provide rapid, non-destructive, and real-time information on meat freshness by detecting quality-related changes such as pH variation, volatile metabolite formation, gas composition, and microbial activity. The integration of intelligent sensing systems with active packaging enhances product stability and contributes to improved food safety and shelf-life extension. Despite these advantages, several barriers, including production costs, regulatory requirements, large-scale industrial implementation, and consumer acceptance, continue to limit widespread commercial adoption.

Conclusions: Smart packaging has emerged as an effective approach to improving the quality management of meat products while supporting sustainable food systems by reducing spoilage and waste. Future progress will depend on developing cost-effective sensing platforms, harmonizing regulatory frameworks, and accelerating the industrial translation of advanced intelligent packaging technologies.

Keywords: Smart packaging; Intelligent packaging; Meat products; Quality monitoring; Shelf-life extension; Biosensors

INTRODUCTION

Meat and meat products are highly perishable foods whose quality can deteriorate through microbial growth, lipid oxidation, proteolysis, pigment changes, moisture loss, and other physicochemical reactions. These processes are strongly influenced by temperature, oxygen availability, packaging atmosphere, water activity, storage time, and handling conditions. The cold chain is therefore central to maintaining quality, yet temperature abuse and interruptions can occur between processing, transport, retail, and household storage. Ren et al. (2022) emphasized that maintaining meat quality across the cold chain requires not only appropriate packaging materials but also continuous quality perception, monitoring, prediction, and control.

Conventional packaging mainly provides a passive barrier against physical damage and environmental contamination. Although conventional labels usually communicate a fixed date, they do not necessarily reflect the actual history of the product after packaging. Smart or intelligent packaging adds an information function by monitoring conditions inside or around the package and translating changes into a readable signal. Freshness indicators, time-temperature indicators (TTIs), gas sensors, biosensors, and

data-enabled labels are therefore being investigated as tools for more dynamic quality management (Khodaei et al., 2023; Shao et al., 2021).

An important distinction exists between intelligent packaging and active packaging. Intelligent systems primarily sense, record, or communicate information about food or its environment, whereas active packaging is designed to interact with the packaged food or headspace by releasing or absorbing substances. In practice, the two concepts can be combined. For meat, a package may simultaneously indicate the accumulation of spoilage metabolites and contain an antimicrobial or antioxidant system that slows the underlying deterioration. Such integration is particularly attractive because monitoring alone does not prevent spoilage, whereas preservation without feedback may not reveal the product's real-time condition (Du et al., 2023; Li et al., 2022).

The objective of this review is to synthesize recent evidence on smart packaging for meat products, with emphasis on the mechanisms used to monitor freshness, the role of active packaging in shelf-life extension, and the opportunities and barriers associated with commercialization. Particular attention is given to colorimetric freshness indicators, TTIs, gas and biosensor technologies, natural pigments and biopolymer matrices, nanotechnology-enabled systems, and the integration of smart packaging with digital tools.

The main components and functional relationships of smart packaging systems for meat quality management are summarized in Figure 1. The framework illustrates how freshness indicators, time–temperature indicators, gas sensors, biosensors, and active packaging can provide complementary information or preservation functions, while digital tools can support interpretation and decision-making throughout the cold chain.

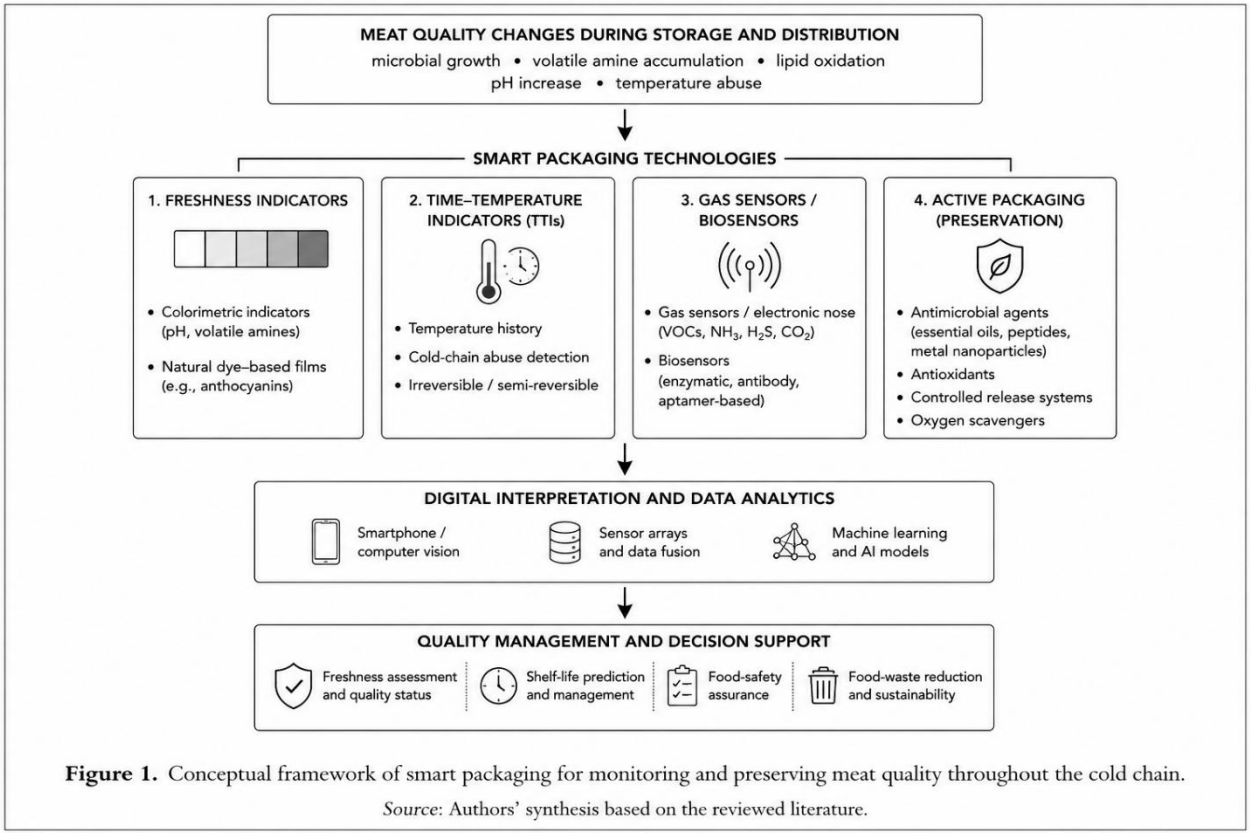

Figure 1. Conceptual framework of smart packaging for monitoring and preserving meat quality throughout the cold chain.

Source: Authors' synthesis based on the reviewed literature.

MATERIALS AND METHODS

This paper was prepared as a narrative critical review based on the ABSTRACT supplied by the authors and an expanded search of peer-reviewed literature on smart and intelligent packaging for meat products. The literature was selected to cover both foundational studies and recent reviews addressing meat

spoilage, freshness indicators, gas sensing, active packaging, anthocyanin-based materials, cold-chain monitoring, and regulatory or consumer considerations.

Priority was given to peer-reviewed journal articles indexed in established scholarly databases and to official European Union regulatory documents for statements concerning food-contact materials. The evidence was organized thematically into: (1) deterioration mechanisms and measurable freshness markers; (2) intelligent packaging technologies; (3) active packaging and combined systems; (4) nanotechnology and digital integration; and (5) safety, regulatory, economic, and consumer barriers. The purpose was synthesis rather than quantitative meta-analysis; therefore, numerical performance values are reported only when they are directly supported by the cited literature.

RESULTS AND DISCUSSION

MEAT DETERIORATION AND TARGETS FOR SMART MONITORING

The effectiveness of smart packaging depends on whether the sensed variable is sufficiently correlated with actual product quality. Microbial spoilage is accompanied by biochemical transformations that generate volatile basic nitrogen compounds, amines, ammonia, sulfur-containing compounds, alcohols, aldehydes, and ketones. The composition and concentration of these metabolites depend on the dominant microorganisms, meat type, packaging atmosphere, temperature, and storage time (Kang et al., 2026). Consequently, headspace gases provide an attractive non-destructive source of information.

pH is another useful quality-related parameter, although its interpretation must be product-specific. Changes in pH can accompany microbial metabolism and protein degradation, and therefore pH-responsive indicators can convert an otherwise invisible chemical change into a visual signal. Total volatile basic nitrogen (TVB-N), volatile amines, carbon dioxide, hydrogen sulfide, and other volatile compounds have also been investigated as freshness-related markers. For example, Balamatsia et al. (2007) demonstrated relationships between volatile amines, microbiological development, and sensory quality in modified-atmosphere-packaged chicken fillets.

Temperature deserves separate consideration because it affects the rate of nearly all relevant deterioration processes. A TTI does not directly measure microbial load or chemical spoilage; rather, it records the cumulative effect of time and temperature through a visible or measurable response (Liu et al., 2023). This makes TTIs valuable for cold-chain verification, but they should not be interpreted as a universal substitute for direct freshness sensing (Khodaei et al., 2023; Ren et al., 2022).

FRESHNESS INDICATORS AND COLORIMETRIC SYSTEMS

Freshness indicators are among the most accessible forms of intelligent packaging because they can provide a visible response without requiring an external instrument. Chemical indicators may respond to volatile amines, carbon dioxide, sulfur compounds, or pH changes. Their signal can be produced by synthetic dyes or natural pigments immobilized in a film, label, hydrogel, or other matrix. Shao et al. (2021) reviewed freshness indicators as a means of providing real-time information without damaging the food, while Luo et al. (2022) highlighted the importance of indicator dye chemistry, preparation method, immobilization, and application conditions.

Natural pigments, especially anthocyanins, have received substantial attention because their molecular structures undergo reversible or semi-reversible transformations with changes in acidity. Anthocyanins can therefore generate easily recognized color transitions while also contributing antioxidant activity. Recent reviews show that anthocyanin-containing films have been investigated with meat and other perishable foods, and that their performance depends strongly on pigment source, concentration, polymer matrix, film microstructure, moisture, light, and storage conditions (Xu et al., 2024; Xiong et al., 2024).

Despite their simplicity, colorimetric indicators have important limitations. A color change must be sufficiently large, reproducible, and stable to be interpreted consistently by consumers and supply-chain personnel. Natural pigments may be sensitive to light, temperature, oxygen, and moisture. Moreover, a

single pH or gas response may not perfectly represent microbiological safety because different microorganisms and meat systems can produce different spoilage trajectories. For this reason, indicator calibration against microbiological, physicochemical, and sensory reference measurements is essential before commercial deployment.

An emerging direction is the use of smartphone cameras and computer vision to convert a qualitative color change into a quantitative digital signal. Recent work has demonstrated integration of anthocyanin-based colorimetric films with deep learning and a smartphone-web platform for real-time beef freshness assessment (He et al., 2026). This approach may reduce subjective interpretation and allow data logging or automated decision-making (He et al., 2026). However, image capture is affected by illumination, camera characteristics, package geometry, and background color. Standardized imaging conditions and robust algorithms are therefore needed before smartphone-based labels can be treated as reliable analytical devices.

TIME-TEMPERATURE INDICATORS AND COLD-CHAIN MANAGEMENT

TTIs address one of the most important determinants of meat quality: the temperature history of the product (Liu et al., 2023; Ren et al., 2022). They are typically small labels or devices that undergo an irreversible physical, chemical, enzymatic, or diffusion-based change as a function of time and temperature (Liu et al., 2023). Their key advantage is that they can reveal whether a package has experienced temperature conditions inconsistent with the intended storage regime. This is particularly useful when the nominal expiry date assumes an uninterrupted cold chain.

However, TTIs provide an indirect measure of quality. A TTI may indicate excessive thermal exposure even when the food remains acceptable, or may fail to capture deterioration mechanisms that are driven by factors other than temperature. A more informative future system would combine TTI data with direct headspace or biochemical sensing. Ren et al. (2022) noted that dynamic quality prediction is important because current shelf-life models often rely on relatively constant conditions and may not adequately represent real supply-chain variability.

GAS SENSORS AND BIOSENSORS

Gas-sensing technologies are particularly suitable for meat because spoilage generates volatile compounds in the package headspace. Electrical gas sensors can be miniaturized and potentially integrated with wireless communication systems. Pereira et al. (2021) reviewed electrical gas sensors for meat freshness assessment and highlighted their potential combination with near-field communication (NFC) and radio-frequency identification (RFID). Such integration could allow a sensor to detect a change in the package atmosphere while a reader or smartphone retrieves the information.

Biosensors offer another route by using a biological recognition element, such as an enzyme, antibody, aptamer, or other selective component, coupled with an optical, electrical, or electrochemical transducer (Sionek et al., 2020). Their principal attraction is specificity: rather than responding broadly to changes in the headspace, a biosensor can be designed around a selected analyte or biological target (Sionek et al., 2020). Nevertheless, practical deployment requires attention to recognition-element stability, matrix effects, calibration, cross-sensitivity, response time, and manufacturing reproducibility.

An important development is the movement from single-parameter sensing toward sensor arrays. Meat spoilage is a multidimensional process, and no single marker is likely to be universally valid across beef, poultry, pork, processed meats, and different packaging atmospheres. Arrays that measure multiple volatile compounds or combine temperature, gas, and optical responses can provide richer information. Recent meat-quality studies show that electronic-nose data can be combined with chemometrics and machine-learning algorithms to classify freshness states (Munekata et al., 2023; Jia et al., 2024). The main scientific requirement is that such models be trained and validated on independent datasets representing realistic storage variability rather than only controlled laboratory conditions.

NANOTECHNOLOGY AND BIOPOLYMER-BASED MATERIALS

Nanotechnology can improve smart packaging in two complementary ways: by enhancing the sensing interface and by modifying the physical properties of the packaging matrix. Nanostructured materials can provide high surface area, tunable optical or electrical properties, and improved sensing performance, while nanocomposites can modify barrier and antimicrobial properties of packaging materials (Pattnaik et al., 2024). At the same time, nanocomposites can improve barrier properties against oxygen, moisture, and other factors that accelerate deterioration.

Biopolymer-based materials are especially relevant to sustainable intelligent packaging. Chitosan, gelatin, starch, cellulose derivatives, proteins, and other biodegradable matrices can serve as carriers for natural pigments or active compounds. Xiong et al. (2024) reviewed anthocyanin-based films, hydrogels, aerogels, and colorimetric sensor arrays for meat freshness monitoring and concluded that these systems have strong potential but still require improvements in sensitivity and stability. Xu et al. (2024) similarly emphasized that the performance of anthocyanin films depends on both pigment chemistry and interactions with the polymer matrix.

Nanotechnology nevertheless introduces a safety and regulatory dimension. The migration of nanoscale constituents from packaging into food, the fate of released particles, and possible toxicological effects must be assessed for each material and intended use (Gupta et al., 2024; Pattnaik et al., 2024). Therefore, high sensitivity alone is not sufficient for commercialization; the complete material system must demonstrate food-contact safety, adequate stability, and predictable migration behavior.

Table 1. Comparison of Smart Packaging Technologies for Meat Products

Technology	Primary target	Main advantage	Key limitation
Colorimetric freshness indicator	pH, amines, CO_2, sulfur compounds	Low cost; visual; non-destructive	Calibration, stability, subjective interpretation
Time-temperature indicator	Temperature history	Simple cold-chain verification	Indirect measure of actual freshness
Electrical gas sensor	Volatile compounds	Rapid; miniaturizable; wireless integration	Cross-sensitivity and calibration
Biosensor	Specific chemical/biological analyte	High selectivity potential	Stability, cost, matrix effects
Anthocyanin/biopolymer film	pH/spoilage metabolites	Biodegradable; visual; multifunctional	Light/moisture sensitivity; scale-up
Smart active packaging	Microbial/oxidative deterioration	Can sense and preserve	Regulatory and formulation complexity

ACTIVE PACKAGING AND INTEGRATION WITH INTELLIGENT SYSTEMS

Active packaging complements sensing by slowing the deterioration that the intelligent component detects. Antimicrobial systems may release or immobilize compounds that inhibit spoilage organisms, while antioxidant systems can reduce lipid oxidation. For meat, investigated active agents include essential oils and their components, organic acids, plant extracts, antimicrobial peptides, and other natural or synthetic compounds. Chacha et al. (2022) reviewed essential-oil-based polymer systems for beef and chicken and highlighted their antimicrobial and antioxidant potential, while also noting the importance of sensory effects.

Li et al. (2022) discussed active packaging in the context of meat shelf-life extension and emphasized the importance of matching packaging design to meat type, processing history, consumer practices, and market requirements. This point is critical because an active compound that works well in one product may be ineffective or organoleptically unacceptable in another. Release kinetics, package atmosphere, fat content, moisture, and temperature all influence performance.

The most promising concept is therefore not simply 'smart packaging' or 'active packaging' in isolation, but a responsive system in which sensing, decision-making, and preservation are connected. A package

could detect a rising concentration of spoilage gases, communicate the condition to a reader, and, where permitted and technically feasible, activate or increase release of a preservative or antioxidant. Such closed-loop systems are still emerging, but they represent a logical direction for future research in precision food preservation (Du et al., 2023).

SAFETY, REGULATION, ECONOMICS, AND CONSUMER ACCEPTANCE

Commercial adoption requires evidence that intelligent packaging does not create a new food-safety risk. Indicator dyes, printing inks, adhesives, nanoparticles, antimicrobial agents, and other components must be evaluated for migration, toxicity, stability, and intended-use conditions. The European Union provides a specific regulatory framework for active and intelligent food-contact materials. Commission Regulation (EC) No 450/2009 establishes specific requirements for marketing such materials, while Regulation (EC) No 1935/2004 provides the broader food-contact framework and states that active or intelligent materials should not mislead consumers about food condition.

Cost is another major barrier. Laboratory prototypes often use sophisticated fabrication methods or expensive sensing materials that are difficult to reproduce at the scale, speed, and cost required for high-volume meat packaging. Commercial solutions must also withstand automated packaging lines, refrigeration, humidity, mechanical handling, and distribution. Therefore, performance should be evaluated not only through analytical sensitivity but also through cost per package, shelf stability of the sensor, manufacturing yield, recyclability, and compatibility with existing packaging equipment.

Consumer acceptance is equally important. A smart label is useful only if consumers understand what the signal means and trust it. Recent literature on smart food labels suggests that perceived usefulness and ease of use can support adoption, while uncertainty, unfamiliarity, and lack of clear information can reduce willingness to use such technologies (Bonioli & Bazzani, 2025). For meat products, the label should therefore communicate a simple and actionable message rather than expose the consumer to unexplained technical data.

Sustainability also requires a systems perspective, because the environmental performance of smart packaging depends on both packaging impacts and the amount of food waste avoided (Stramarkou et al., 2022). A biodegradable indicator film may reduce material impacts, but its total environmental benefit depends on manufacturing inputs, food-contact safety, end-of-life behavior, and whether it actually reduces food waste (Stramarkou et al., 2022). Conversely, a highly sophisticated electronic label may improve monitoring but introduce additional materials and electronic waste. The preferred technology should therefore be selected according to the whole life cycle and the actual reduction in product loss.

FUTURE DIRECTIONS

Recent work points toward multimodal sensing, digital connectivity, and data-driven interpretation, building on electronic noses, electronic eyes, electronic tongues, and related approaches to meat-quality assessment (Munekata et al., 2023). Rather than relying on one indicator, packages may combine temperature history, volatile-gas patterns, optical signals, and product-specific metadata. NFC and RFID can provide communication between passive package components and external devices, while smartphone imaging can make visual sensors more quantitative. Machine-learning methods may convert complex sensor patterns into freshness classes or remaining-shelf-life estimates.

Another important direction is the development of sustainable materials that combine sensing and preservation. Anthocyanin-based biopolymer films are attractive because the same material platform can provide a visual pH response and antioxidant or antimicrobial functionality. Nevertheless, future studies should move beyond proof-of-concept color changes and report standardized validation against microbial counts, TVB-N, sensory evaluation, storage temperature, and relevant physicochemical parameters. Xiong et al. (2024) and Xu et al. (2024) both point to the need for improved stability and more rigorous translation toward practical applications.

Industrial research should also focus on interoperability and validation. A sensor that performs well in a laboratory refrigerator may behave differently on an industrial line, during transport vibration, or under variable humidity. Therefore, pilot-scale trials and real supply-chain validation are needed. Standardized performance criteria would make it easier to compare technologies and to establish confidence among regulators, manufacturers, retailers, and consumers.

CONCLUSION

Smart packaging has developed from a passive protective concept into a potential information and preservation platform for meat products. Current evidence supports the use of freshness indicators, TTIs, gas sensors, biosensors, and natural-pigment-based materials to obtain rapid, non-destructive information about product condition. Among these technologies, colorimetric indicators offer particular advantages in simplicity and consumer visibility, while electrical gas sensors and biosensors offer opportunities for more quantitative and connected monitoring.

The practical value of these technologies will depend on how well they work together. Intelligent sensing can indicate deterioration, active packaging can slow selected deterioration pathways, and digital connectivity can move package-level information into supply-chain decisions. However, commercialization requires rigorous calibration, food-contact safety assessment, regulatory compliance, cost control, manufacturing scalability, consumer education, and sustainability evaluation.

Overall, the evidence supports smart packaging as a complementary component of meat-quality management. It should not be considered a substitute for hygienic processing, validated preservation, refrigeration, or microbiological control. Its practical contribution will depend on reliable performance under realistic storage conditions and on a cost and complexity compatible with commercial packaging.

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DEVELOPMENT OF TIMELESS DESIGNS THROUGH MINIMALIST AESTHETICS IN FASHION ILLUSTRATION

MODA İLLÜSTRASYONUNDA MİNİMALİST ESTETİK YOLUYLA ZAMANSIZ TASARIMLARIN GELİŞTİRİLMESİ

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ABSTRACT

Fashion is not only a transient phenomenon reflecting the trends of a particular period, but also an important domain of aesthetic, cultural, and intellectual production. As the visual language of these symbols, fashion illustration is not limited to depicting a garment but serves as a creative design medium that communicates style, identity, emotion, and time through lines. The aim of this study is to examine how the minimalist aesthetic supports the concept of timeless design in fashion illustration and to develop original design proposals based on this approach. Today, individuals' desire to explore innovation, differentiate themselves, and express originality has made design an indispensable part of everyday life. In this context, minimalism is regarded as an aesthetic approach that establishes a balance between "less" and "more," enhances the expressive power of visual simplicity, and supports the concept of timeless design. This study investigates how minimalist aesthetics can be incorporated into fashion illustration through design principles such as linear simplicity, limited colour palettes, and simplified forms by employing visual analysis and practice-based design methods. In this process, a literature review is used to examine the formal and historical development of fashion illustration, as well as brands creating classic designs with a minimalist aesthetic. Design samples reflecting the originality of this study are developed. The findings present a design approach for developing timeless designs capable of preserving their aesthetic value beyond temporary fashion trends. Design boards consisting of sixteen looks representing the spring and autumn seasons were prepared and validated through expert evaluation. The findings indicate that minimalist illustration techniques simplify design while strengthening its aesthetic impact and creating a distinctive visual identity beyond temporary fashion trends. Accordingly, this study contributes to minimalist aesthetics through timeless designs in fashion illustration and offers guiding recommendations for the design field by integrating a conceptual framework with practice-based design studies.

Key Words: Fashion illustration, Minimalist Aesthetics, Timeless Design, Practice-based Illustration.

ÖZET

Moda, yalnızca dönemin eğilimlerini yansıtan geçici bir olgu değil; estetik, kültürel ve düşünsel üretimin önemli bir ifade alanıdır. Bu üretimin görsel dili olan moda illüstrasyonu, yalnızca bir giysiyi betimlemekle kalmayıp tarzın, kimliğin, duygunun ve zamanın çizgiler aracılığıyla aktarılmasını sağlayan yaratıcı bir tasarım aracıdır. Bu araştırmanın amacı, minimalist estetik anlayışının moda illüstrasyonunda zamansız tasarım yaklaşımını nasıl desteklediğini ortaya koymak ve bu anlayış doğrultusunda özgün tasarım önerileri geliştirmektir. Günümüzde bireylerin yeniliği keşfetme, farklılaşma ve özgün olma isteği, tasarımı yaşamın vazgeçilmez bir unsuru hâline getirmiştir. Bu bağlamda minimalizm, "az ile çok" arasındaki dengeyi kurarak görsel sadeliğin ifade gücünü artıran ve zamansız tasarım anlayışını destekleyen önemli bir estetik yaklaşım olarak değerlendirilmektedir. Araştırmada, minimalist estetiğin moda illüstrasyonuna çizgisel yalınlık, sınırlı renk paleti ve formda

sadeleşme gibi tasarım ilkeleri doğrultusunda nasıl aktarılabileceği görsel analiz ve uygulamalı tasarım yöntemiyle incelenmiştir. Süreç kapsamında moda illüstrasyonunun tarihsel ve biçimsel gelişimi ile minimalist estetik anlayışı doğrultusunda zamansız tasarımlar geliştiren markalar literatür kapsamında değerlendirilmiş, ardından araştırmanın özgün yaklaşımını yansıtan tasarım örnekleri hazırlanmıştır. Araştırma sonucunda, geçici moda eğilimlerinden bağımsız, uzun süre estetik değerini koruyabilecek zamansız tasarımların geliştirilmesine yönelik bir tasarım yaklaşımı ortaya konulmuştur. Uzman görüşleri doğrultusunda onaylanan, ilkbahar ile sonbahar dönemlerini kapsayan 16 görünümden oluşan tasarım paftaları hazırlanmıştır. Bulgular, minimalist illüstrasyon tekniklerinin tasarımı sadeleştirirken estetik etkiyi güçlendirdiğini ve geçici moda akımlarının ötesinde özgün bir görsel kimlik oluşturduğunu göstermektedir. Bu yönüyle araştırma, minimalist estetiğin moda illüstrasyonunda zamansız tasarım üretimine katkısını ortaya koymakta; kavramsal çerçeve ile uygulamalı tasarım çalışmalarını bütünleştirerek tasarım alanına yol gösterici öneriler sunmaktadır.

Anahtar Kelimeler: Moda illüstrasyonu, minimalist estetik, zamansız tasarım, uygulamalı illüstrasyon.

GİRİŞ

Günümüzde moda, yalnızca belli dönemlere özgü eğilimlerin geçici birer ifadesi olarak değil, aynı zamanda ait olduğu zamanın estetik ve düşünsel dünyasını yansıtan kültürel bir anlatı biçimi olarak değerlendirilmektedir. Moda tasarımı; dönemin sosyokültürel yapısından, bireysel kimlik inşasına kadar uzanan çok katmanlı bir yapıya sahiptir (Cherevach, 2023, s. 88). Moda illüstrasyonu ise yalnızca giysi tasarımlarını betimlemekle kalmayıp, aynı zamanda tasarımcının estetik yaklaşımını, döneme dair fikirlerini ve kavramsal duruşunu ifade etme aracı hâline gelmiştir. Özellikle 19. yüzyılın sonlarından itibaren hız kazanan giyim reformları ve 20. yüzyılın başında sanat akımlarının moda üzerindeki etkisi, illüstrasyonlarda biçim, doku, renk ve çizgi kullanımını derinleştirmiştir. Art Nouveau'nun organik hatlarından Bauhaus'un işlevsel yalınlığına kadar farklı sanat eğilimleri, moda illüstrasyonunun anlatım dilini dönüştürmüştür. Bu tarihsel gelişim, günümüzde sadeleşme ve anlam yoğunluğu arasında bir denge arayan **minimalist estetik** anlayışının doğmasına zemin hazırlamıştır. Moda illüstrasyonunda minimalizm, yalnızca görsel sadeliği değil; zamandan bağımsız bir tasarım dili kurmayı da hedefleyerek, estetik değer ile işlevselliği bir arada kurgulayan zamansız tasarım yaklaşımlarının önünü açmaktadır (Şenol & Elmas, 2022, s. 946). Küresel moda endüstrisi, dijitalleşmenin hız kazanması, tüketici beklentilerinin sürekli evrilmesi ve estetik algıların değişmesiyle birlikte biçimsel bir dönüşüm sürecine girmiştir. Bu dönüşüm, modayı yalnızca fiziksel giyim ihtiyacını karşılayan bir alan olmaktan çıkararak, kültürel, psikolojik ve sanatsal bir ifade biçimine dönüştürmüştür. Moda tasarım süreci içerisinde yer alan illüstrasyonlar da bu dönüşümden etkilenmiş; sadece tasarımların görsel sunumu değil, aynı zamanda tasarımın düşünsel altyapısını, duygusal boyutunu ve estetik anlatımını aktaran bir araç hâline gelmiştir. Günümüzde moda illüstrasyonu, trendlerin hızla tüketildiği bir ortamda, anlam derinliği taşıyan, sade ve kalıcı anlatımlar üretme zorunluluğuyla karşı karşıyadır. Bu noktada minimalist estetik yaklaşım, yalnızca biçimsel değil, aynı zamanda kavramsal düzeyde bir çözüm önerisi sunmaktadır.

Minimalizm, temel olarak "sadeleşerek özü bulma" fikrine dayanmaktadır. Moda illüstrasyonuna uygulandığında, gereksiz detayların ayıklanmasıyla ortaya çıkan yalın kompozisyonlar, izleyici ile daha doğrudan bir bağ kurar ve tasarımlara zamansızlık niteliği kazandırır. Böylece minimalist illüstrasyonlar, sadece görsel sadelik değil; aynı zamanda kültürel süreklilik ve estetik sürdürülebilirlik taşıyan bir ifade biçimi hâline gelmektedir. Minimalist yaklaşım, bu direnci görsellik üzerinden inşa ederken, moda illüstrasyonunu da kalıcılık ve özsel değer üretme bakımından stratejik bir araç hâline getirmektedir. Moda illüstrasyonunda sadeleşme, yalnızca teknik bir stil tercihi değil; aynı zamanda yaratıcı düşüncenin ve estetik anlayışın bir arınma biçimi olarak değerlendirilir. Bu da illüstrasyonun sanatsal niteliğini güçlendirirken, tasarımın duygusal ve kültürel boyutlarını daha görünür kılmaktadır. Özellikle Z kuşağı gibi görsel iletişime duyarlı yeni nesil tüketicilerin, sadelikle harmanlanmış anlamlı tasarım dillerine olan ilgisi, minimalist illüstrasyonların zamansız tasarımlar üretmedeki potansiyelini artırmaktadır. Ancak mevcut literatürde, moda illüstrasyonlarının zamansızlık ilkeleri doğrultusunda nasıl dönüştürücü bir rol üstlenebileceği üzerine sınırlı sayıda araştırma bulunmaktadır. Bu nedenle minimalist estetik ile moda illüstrasyonu arasında kurulan ilişkinin kavramsal ve görsel düzeyde analiz edilmesi, alan için önemli bir katkı sağlayacaktır. Bu doğrultuda, minimalist illüstrasyon tekniklerinin

anlatım gücü, estetik derinliği ve kültürel sürekliliğe katkısı değerlendirilecek; sadelik ve zamansızlık arasındaki bağ görsel analizlerle desteklenecektir. Ayrıca, bu yaklaşımın yaratıcı süreçlerdeki işlevselliği ve çağdaş tüketici beklentileriyle olan uyumu tartışılacaktır.

Moda İllüstrasyonunun Tanımı

"İllüstrasyon" terimi, İngilizcede "illustration", Almancada "Illustrierung" ve Fransızcada yine "illustration" biçiminde kullanılırken, Türkçeye bu biçimiyle geçmiştir. Temel olarak, bir metni açıklamak veya yorumlamak amacıyla kullanılan görsel anlatımları ifade etmektedir. Türkçede bu kavrama en yakın karşılık "resimleme" terimidir (Kürşad, 2008, s. 4). Etimolojik açıdan incelendiğinde, "illustration" kelimesi 13. yüzyılda "parlaklık" veya "dikkat çeken unsur" anlamında kullanılmaya başlanmıştır. 15. yüzyılın başlarına gelindiğinde ise bu terim "belirti" ve "gösterge" gibi anlamlar kazanmıştır. Eski Fransızcada "görünüş" olarak ifade edilen bu sözcük, kökenini Latince "illustratio" teriminden alır. Latince kökenli bu ifade, "ışıltılı sunum" anlamına gelmekte olup, "aydınlatmak", "açıklamak" ve "göz önüne sermek" fiilleriyle ilişkilidir. Modern İngilizcede ise "illustration" kavramı yalnızca görsel anlatımı değil, aynı zamanda soyut bir düşüncenin örneklenerek açıklanması işlevini de içerecek biçimde genişlemiştir (Sunerli, 2017, s. 5).

Moda illüstrasyonu (fashion illustration), tasarımın duygu ve ruhunu yansıtan, stilize ve sanatsal bir görsel anlatım biçimidir. Bu çizimler, tasarım sürecinin hem öncesinde hem de sonrasında oluşturulabilir. Bir giysi ya da koleksiyonun formunu, kesimini, renklerini, kumaş dokusunu ve genel stilini ifade etmeyi amaçlayan bu görseller, tasarım fikirlerinin somutlaştırılmasında önemli bir araçtır. Aynı zamanda tanıtım ve pazarlama süreçlerinde de işlevselidir; özellikle koleksiyon sunumları, moda dergileri ve defile öncesi görsel materyallerde sıkça kullanılmaktadır (Okur & Başaran, 2021, s. 708).

Estetik kaygı ve biçimsel değişimin bütünleştiği bir kavram olarak moda, özellikle 19. yüzyılın sonlarında gelişen güzellik anlayışıyla birlikte sanatsal etkilerden yoğun biçimde beslenmeye başlamıştır. Bu dönemde ortaya çıkan başlıca sanat akımları, yalnızca görsel sanatları değil, giysi tasarımına da yön vermiş; farklı üslupların moda alanında ifade bulmasına olanak sağlamıştır. Tasarımcıları, dönemin estetik normlarını yorumlayarak giysi tasarımlarına yansıtmış ve böylece yenilikçi tarzların oluşmasına zemin hazırlamışlardır. Bu sanatsal dönüşümle eşzamanlı olarak moda illüstrasyonu da bir temsil biçimi olarak öne çıkmıştır. İllüstrasyon, yalnızca görsel bir betimleme değil; yorumlayan, fikir aktaran ve detayları vurgulayan anlatımsal bir çizim türü olarak tanımlanır. Moda illüstrasyonu ise, insan bedeninin sanatsal bir biçimde ele alındığı ve tasarım düşüncesinin çizgisel estetikle harmanlandığı özgün bir anlatım biçimi sunmaktadır. Bu illüstrasyonlar, yalnızca teknik sunum araçları değil, aynı zamanda tasarımın fikrî boyutunu ve estetik algısını görselleştiren anlatılar olarak değerlendirilmektedir. 20. yüzyıl Avrupa'sında kişisel moda illüstrasyonları, dönemin sanatsal ve kültürel iklimi içinde farklı moda yönelimlerinin doğmasına katkıda bulunmuş ve özellikle moda dergilerinde yaygın biçimde kullanılarak kitle iletişiminde etkili bir araç hâline gelmiştir. Bu süreçte, moda illüstrasyonu yalnızca giyimin sunumu değil, aynı zamanda dönemin estetik anlayışının temsilcisi olarak işlev kazanmıştır. Bu tarihsel bağlam, günümüzde minimalist estetik ekseninde gelişen zamansız tasarım yaklaşımlarının da temelini oluşturur. (Şenol & Elmas, 2022, s. 1945).

Moda İllüstrasyonunun Tarihsel Gelişimi

Moda illüstrasyonu, 16. yüzyılda küresel keşiflerle artan kültürel etkileşim sonucunda farklı toplumların giyim tarzlarına duyulan ilgiden doğmuştur. Bu dönemde gravür ve tahta baskılar, toplumsal çeşitliliği yansıtarak modern moda illüstrasyonunun temellerini oluşturmuştur. Jacques Callot ve Abraham Bosse gibi sanatçılar, dönemin kostümlerini ayrıntılı biçimde belgeleyerek bu gelişime katkı sağlamıştır. 17. yüzyılın sonlarında Fransa ve İngiltere'de yayımlanan *Le Mécure Gallant* ve *La Gallerie des Modes* gibi dergiler, modanın güncel eğilimlerini tanıtarak illüstrasyonun yaygınlaşmasına öncülük etmiştir (Goethe-Jones, 2019, s. 2). Bu süreçte Avrupa'da ortaya çıkan "fashion plates" olarak bilinen gravür tabanlı görseller, özellikle Fransız aristokrasisi arasında stil bilgilendirmesi amacıyla kullanılmıştır (Balvas & Tarashevçenko, 2021, s. 7).

Sanayi Devrimi sonrasında artan tekstil üretimi ve sınıfsal farklılaşma, modanın daha geniş kitlelere yayılmasını sağlamış; bu durum, illüstrasyonun da daha işlevsel bir kimlik kazanmasına yol açmıştır. 20. yüzyılın başlarında, özellikle Paul Poiret gibi öncü modacıların illüstratörlerle çalışması sayesinde, moda illüstrasyonları birer sanat eseri olarak değerlendirilmiş; René Gruau ve Erté gibi sanatçılar bu dönemin estetik anlayışını şekillendirmiştir (Sunerli, 2017, s. 22). 1900'lü yılların başında, moda dünyası ve moda illüstrasyonu geleceğe yönelik bir vizyon inşa etmekten ziyade, geçmişe yönelmiş ve 19. yüzyılın estetik anlayışını yeniden yorumlamayı tercih etmiştir. Bu dönemde, Avrupa ve Kuzey Amerika'daki aristokrat ve varlıklı kesimin giyim tarzı, modernleşmeden ziyade 1890'larda şekillenen Art Nouveau estetiğinin izlerini taşımıştır. Özellikle dönemin modasına yönelik farkındalığı düşük olan geniş okur kitlelerine hitap eden dergilerde, kadınlara kendi gardıroplarını oluşturabilmeleri için dikiş teknikleri ve giysi tarifleri sunulmuştur. Bu yayınlarda yer alan moda tasarımları, modacılar tarafından değil, illüstratörler aracılığıyla görselleştirilmiştir. Yazılı tariflerin sınırlı kaldığı noktada, moda illüstrasyonları giysilerin görünümünü aktarmada temel bir iletişim aracı olmuştur (Blackman, 2007, s. 8). II. Dünya Savaşı sonrası dönemde ise fotoğraf teknolojisinin gelişmesiyle illüstrasyon, moda dergilerindeki baskın konumunu büyük ölçüde yitirmiştir. Ancak 1980'lerden itibaren sanatla daha fazla ilişkilendirilerek yeniden önem kazanmış, dijital araçların gelişmesiyle birlikte çağdaş illüstratörler hem analog hem de dijital tekniklerle kişisel anlatımlar üretmeye başlamıştır. 2000 ve Sonrası, dijital araçların gelişmesiyle moda illüstrasyonu, Photoshop, Procreate gibi yazılımlar aracılığıyla yeniden canlandı. Instagram gibi sosyal medya platformları, illüstratörlerin doğrudan moda evleri ve geniş kitlelerle buluşmasını sağladı. Günümüzde moda illüstrasyonu; nostalji, stilizasyon, grafik sanatlar ve animasyon gibi pek çok disiplinle iç içe geçmiştir. (Kang & Kim, 2002, s. 100).

Moda İllüstrasyonunda Sanat ve Tasarım İlişkisi

Moda illüstrasyonu, sanat ve tasarım disiplinleri arasında tarihsel kökenleri derinlere uzanan dinamik bir etkileşimin ürünüdür. Moda ile sanat arasındaki yakın ilişki yüzyıllar öncesine dayanmakta ve bu iki alanın karşılıklı olarak birbirini beslediği görülmektedir. On dokuzuncu yüzyılda "moda tasarımcısı" kavramı ortaya çıkmadan önce ressamlar, modanın hem yaratıcıları hem de görsel temsilcileri olarak önemli bir rol üstlenmişlerdir. Bu etkileşim, *haute couture*'ün doğuşuyla birlikte daha belirgin hâle gelmiş; Worth ve Poiret gibi tasarımcıların kendilerini sanatçı olarak konumlandırma çabalarıyla kurumsal bir nitelik kazanmıştır (Kurkdjian, 2019, s. 383). Moda illüstrasyonu, çizgi, biçim, renk ve doku gibi görsel öğeleri bir araya getirerek moda ve tekstil tasarımı dâhil olmak üzere birçok tasarım disiplinini bütünleştiren çok yönlü bir sanatsal ifade biçimidir. Farklı çizim teknikleri ve grafik etkiler aracılığıyla özgün izlenimler oluşturur; böylece tasarım sürecine estetik bir derinlik ve sanatsal yorum gücü kazandırmaktadır. Moda illüstrasyonu, sanatın estetik ve ifade edici yönünü tasarımın planlı ve işlevsel yapısıyla birleştiren yaratıcı bir süreçtir. Tasarım, estetik değerlere dayalı bir planlama süreci olarak ele alınırken; sanat, düşünce ve duyguların görsel biçimler aracılığıyla aktarılmasını sağlar. Moda illüstrasyonu, tasarımın ölçülebilir ve işlevsel yapısını sanatın özgün yorum gücüyle bütünleştirerek iki alan arasında dinamik bir etkileşim oluşturur (Öden, 2022, s. 1634).

Günümüzde moda tasarımı, sanatın yaratıcılığa ilham veren yapısından beslenerek bu tarihsel bağı sürdürmektedir. Sanat, çağdaş moda tasarımında yalnızca estetik bir referans değil, aynı zamanda araştırma, ifade ve deney alanı olarak da işlev görmektedir. Moda illüstrasyonu ise bu etkileşimin görsel bir yansıması olarak, sanatın duyusal ve estetik yönünü tasarımın işlevsel yapısıyla birleştirerek özgün bir anlatım dili oluşturur. (Varol & Ertürk, 2016, s. 437).

Moda İllüstrasyonunun İfade Aracı Olarak Rolü

Moda illüstrasyonu, yalnızca giysinin biçimsel özelliklerini betimleyen bir görsel temsil aracı olmanın ötesinde, duyguların, atmosferin ve tasarımcının estetik vizyonunun aktarımını mümkün kılan bir ifade biçimi olarak değerlendirilmektedir. Bu illüstrasyonlar, giysinin biçimsel yapısını ön plana çıkarırken aynı zamanda izleyici üzerinde duygusal ve anlamsal bir etki oluşturur. İllüstratör, kumaşın dokusu, kesimi ve hareketi gibi unsurları vurgulayarak tasarımın özünü görsel dile dönüştürür; buna karşılık, önemsiz ayrıntılar çoğunlukla sadeleştirilmiş ya da stilize edilmiştir. İfade aracı olarak moda

illüstrasyonu, tasarımcının yaratıcı düşünme sürecini somutlaştıran özgün bir görsel dil oluşturur. Bu süreç, bir yandan sanatçının sezgisel duyarlılığıyla şekillenen duygusal anlatımı, diğer yandan tasarım ilkelerine dayalı analitik bir yaklaşımı içerir. Böylece illüstrasyon hem duygusal hem de kavramsal düzeyde bir iletişim biçimine dönüşerek izleyiciyle estetik bir etkileşim kurar. Moda illüstrasyonunun bu özelliği, sanatçının içsel dünyasındaki duygusal enerjiyi yansıtarak izleyicide karşılık bulan bir sanatsal deneyim yaratır (Khramova-Baranova, Khutka, Kudrevych ve Ishchenko, 2022, s. 175). Bu ifade gücü, izleyici üzerinde estetik, biçimsel ve sembolik anlamlar taşıyan noktalar, çizgiler ve yüzeyler gibi grafik unsurlar aracılığıyla ortaya çıkmaktadır (Kuhnen & dos Santos, 2019, s. 274).

Minimalizm ve Estetik

Fransızca kökenli *minimum* sözcüğünden türeyen "minimalizm" terimi, ilk kez 1961'de Richard Wollheim tarafından "içeriği en aza indirgenmiş sanat" anlamında kullanılmıştır. 1950'lerin sonlarında Frank Stella'nın eserleriyle görünürlük kazanan bu sanat anlayışı, 1960'lar ve 1970'lerde Donald Judd, Sol LeWitt, Agnes Martin ve Carl Andre gibi sanatçıların katkılarıyla biçimsel bir sanat akımına dönüşmüştür. Dışavurumculuğun duygusal yoğunluğuna karşı bir tepki olarak doğan minimalizm; sadelik, netlik ve biçimsel saflığı sanatın temel ilkeleri hâline getirmiştir (Erzen, 1997, s. 1260; akt. Şenol, 2018, s. 438). Zen felsefesinin dinginlik, denge ve yalınlık ilkelerinden etkilenen minimalizm, II. Dünya Savaşı sonrasında sanat, mimarlık ve tasarım alanlarında bir estetik yönelim olarak önem kazanmıştır (Ersan, 2021, s. 1194). Bu anlayış, sanatın anlatımcı niteliğini geri plana iterek biçimsel saflığı ön plana çıkarmıştır. Mimar Ludwig Mies van der Rohe'nin "Az çoktur" (*less is more*) sözü, minimalizmin felsefi temelini özetleyen bir motto hâline gelmiştir. Van der Rohe'ye göre minimalizm, eksiklik değil; bilinçli bir seçicilik, denge ve arınmış bir estetik tercihidir (Kamal & Nasir, 2022, s. 285). Minimalist estetik, biçim, renk, çizgi ve malzemeyi gereksiz öğelerden arındırarak nesnenin özünü görünür kılan bir anlatım dilidir. Resim ve heykelde yüzey yalınlığına; mimarlıkta ise mekân, ışık ve malzemenin doğrudan ilişkisine vurgu yapar. Bu yaklaşım, izleyiciyi dinginlik, denge ve içsel bütünlük üzerine düşünmeye davet eden bir ifade biçimi hâline gelmiştir (VanEenoo, 2011, s. 8). Gündelik yaşamda çoğu zaman "güzellik" kavramıyla eş anlamlı biçimde kullanılan estetik, gerçekte felsefi bir disiplin ve bağımsız bir bilim dalıdır. Duyular aracılığıyla algılama sürecini ifade eden bu kavram, görme, işitme, dokunma, tatma ve koklama gibi tüm duyusal deneyimleri kapsar. Baumgarten, estetiği "duyusal bilginin bilimi" olarak tanımlamış ve güzelliğin, duyular yoluyla algılanan bir olgu olduğunu vurgulamıştır. Estetik deneyim, sanat eserlerinin algılanması, anlamlandırılması ve değerlendirilmesinde temel bir unsur olarak sanatın özünü oluşturmaktadır (Tunalı, 2012, s. 14).

Zamansız Tasarım Kavramı

Literatürde zamansız tasarım kavramı, moda değişimlerinden ve kısa ömürlü stilistik eğilimlerden etkilenmeyen; uzun süreli bir estetik deneyim sunarak ürünlerin duygusal ve psikolojik dayanıklılığını artıran, dolayısıyla kullanım ömrünü uzatan bir tasarım anlayışı olarak tanımlanmaktadır (Flood Heaton ve McDonagh, 2017, s. 111). Sözlük tanımında ise zamansızlık, zamanın geçişinden etkilenmeme niteliğiyle açıklanmaktadır. Zamansız tasarım; moda, teknoloji veya dönemin estetik akımlarına bağlı olmaksızın, gözlemcinin ürünün tasarım tarihini belirleyemediği, tarihlendirilemeyen bir ürün estetiğini temsil etmektedir (Dumitrescu, 2024, s. 3). Böyle bir yaklaşım, ürünün yalnızca görsel açıdan değil, aynı zamanda işlevsel ve duygusal boyutlarda da uzun ömürlülüğünü desteklemektedir (Wallner, Magnier ve Mugge, 2020, s. 3). Zamansız Tasarım, ürünün işlevselliği ve görünümü olmak üzere iki temel boyutta değerlendirilmektedir. İşlevsellik açısından zamansız tasarım, ürünün onarılabilir ve yükseltilebilir biçimde tasarlanmasıyla sağlanırken; görünüm açısından zamansız tasarım, benzersiz bir tasarım yaratmak veya dönemin popüler estetik unsurlarından uzak durmakla elde edilmektedir. Bu yaklaşım, ürünün hem fiziksel hem de algısal anlamda zamanın etkilerine karşı dirençli olmasını hedeflemektedir (Lobos, 2014, s. 3).

Zamansız Moda Anlayışı ve Tasarım Kriterleri

Zamansız moda, geçici trendlerin ötesinde konumlanarak estetik ve işlevsel kalıcılığı esas alan bir tasarım paradigması olarak değerlendirilmektedir. Bu yaklaşım, biçimsel sürekliliği koruyan estetik unsurların, sürdürülebilir tasarım ilkelerinin, işlevsel çok yönlülüğün ve kültürel açıdan evrim gösteren anlatıların dengeli bir biçimde bütünleşmesiyle ortaya çıkan kapsamlı bir tasarım anlayışına dayanmaktadır. Bu yaklaşım, modanın geçici eğilimlerinin ötesine geçerek, estetik değerini zaman içinde koruyabilen ve farklı kültürel bağlamlarda anlamını sürdürebilen tasarımlar oluşturmayı hedeflemektedir. Zamansız moda anlayışı, estetik ile işlev arasındaki dengeyi merkeze alır. Biçimsel güzellik ile işlevsel verimliliğin uyum içinde tasarlandığı bu yaklaşım, ürünün uzun ömürlü olmasını ve kullanıcıyla kalıcı bir duygusal bağ kurmasını amaçlar. Bu doğrultuda zamansız tasarımın temel kriterleri; estetik kalıcılık, işlevsel sürdürülebilirlik, uyum ve kullanıcıyla duygusal etkileşim gibi unsurlardan oluşmaktadır. Bu kriterler, modanın geçici doğasından bağımsız, uzun süre değerini koruyabilen ve kültürel sürekliliğe katkı sağlayan ürünlerin tasarlanmasını mümkün kılmaktadır (Casto ve DeLong, 2019, s. 109). Giyimde sürdürülebilirliği destekleyen bir yaklaşım, zamansızlık algısının güçlendirilmesi yoluyla giysilerin daha uzun süre kullanılmasının teşvik edilmesidir (Shedroff, 2009, s. 284).

Minimalist Estetik ile Zamansızlık Arasındaki İlişki

Minimalist estetik, özünde sadelik, verimlilik ve tasarımı temel unsurlara indirgeme ilkelerine dayanan bir yaklaşımdır. Bu anlayış, zamana karşı dirençli, kalıcı bir estetik çekicilik sergileyen ve trendlere bağımlılığı azaltan tasarım biçimleriyle yakından ilişkilidir. Görsel sadeliğin ve biçimsel tutarlılığın ön planda olduğu minimalist tasarımlar, gereksiz süslemelerden arındırılarak zihinsel kolaylığı ve algısal netliği destekler; böylece izleyicide zamansızlık hissini güçlendirmektedir (Best, 2006, s. 128). Deneysel araştırmalar, tasarımlarda algılanan verimlilik ve düzenin estetik beğeniyi artırdığını göstermekte; kuramsal ve uygulamalı çalışmalar ise minimalizmin ürün, mimari ve iç mekân tasarımlarında sürdürülebilirlik ve uzun ömürlülük kavramlarını destekleyen bir estetik strateji olarak işlev gördüğünü ortaya koymaktadır. Bununla birlikte, tasarımcıların ürün ömrünü uzatmak amacıyla estetiği tam anlamıyla benimsememelerinin nedenlerinden biri, estetik açıdan zamansız eserler yaratmanın güvenilir bir biçimde oldukça güç olmasıdır. Zamansız bir görünüm, farklı biçimsel ve kavramsal yöntemlerle elde edilebilmekte; ancak formun yalınlaştırılması ve gereksiz unsurlardan arındırılması, zamansızlığa ulaşmanın en etkili yollarından biri olarak öne çıkmaktadır (Flood Heaton, & McDonagh, 2017, s. 112).

Minimalist Estetik Yoluyla Zamansız Tasarımların Temsil Edildiği Moda Markaları

Moda illüstrasyonlarında zamansız tasarımlar, minimalist estetik anlayışın etkisiyle yalın fakat derin bir görsel ifade biçimi ortaya koymaktadır. Minimalizm, en az öğe kullanımıyla en yüksek estetik etkiyi yaratma ilkesi doğrultusunda, tasarımın özünü ön plana çıkarırken aynı zamanda sadelik içerisinde dengeli bir kompozisyon oluşturmaktadır. Bu yaklaşım, geçici moda eğilimlerinin ötesine geçerek, sade biçimlerin kullanımı aracılığıyla kalıcılık, zarafet ve bütünlük duygusunu vurgulamaktadır (Kosanić vd., 2013, s. 383). Minimalist estetik yaklaşımının moda alanındaki öncü temsilcileri arasında Jil Sander, Calvin Klein, Helmut Lang ve Yohji Yamamoto gibi markalar öne çıkmaktadır. Bu tasarımcı ve markalar, sade form kullanımını, nötr renk paletlerini ve detaydan çok yapısal bütünlüğü merkeze alan tasarım anlayışlarıyla zamansız bir görsel kimlik yaratmış; aynı zamanda minimalist estetiğin moda illüstrasyonlarındaki yansımasına önemli ölçüde katkıda bulunmuşlardır (Botzem, & Schimmer, 2021, s. 16).

Jil Sander



Görsel 1: Jil Sander, Kadın ve Erkekler İçin İlkbahar/Yaz 2026 Koleksiyonu (Jil Sander, 2025).

Görsel 1'de sunulan, Jil Sander'in İlkbahar/Yaz 2026 koleksiyonundan seçilmiş parçaları içermekte olup markanın minimalist estetik yaklaşımını nötr tonlar ve yalın silüetlerle bütünleştirerek zamansız tasarım anlayışını görünür kılmaktadır. Koleksiyonda hem kadın hem erkek giyimine yönelik estetik bütünlük ile sadeliğin dengelendiği; keskin hatlara sahip modern formların öne çıkarıldığı bir tasarım dili benimsenmektedir. Görsel, seminer kapsamında tartışılan "minimalist estetik aracılığıyla zamansız tasarım geliştirme" temasını destekleyen güncel ve nitelikli bir tasarım örneği teşkil etmektedir.

Calvin Klein



Görsel 2: Calvin Klein, İlkbahar 2026 Hazır Giyim Koleksiyonu (Calvin Klein, 2025).

Görsel 2'de sunulan, Calvin Klein'in İlkbahar 2026 Hazır Giyim Koleksiyonu, markanın minimalizme dayalı tasarım kimliğini yansıtarak yalın hatları işlevsellikle bütünleştiren zamansız bir yaklaşım ortaya

koymaktadır. Nötr tonların, sade silüetlerin ve dengeli oranların tutarlı kullanımı, koleksiyonun hem estetik hem de kullanım odaklı sürdürülebilir bir tasarım dili benimsediğini göstermektedir. Calvin Klein'in söz konusu koleksiyonu, seminer kapsamında ele alınan minimalist estetiğin zamansız tasarım geliştirmedeki rolüne güncel bir örnek niteliği taşımaktadır.

Helmut Lang



Görsel 3: Helmut Lang, Sonbahar/Kış 2025 Koleksiyonu (Helmut Lang, 2025).

Görsel 3'te sunulan, Helmut Lang'in Sonbahar/Kış 2025 koleksiyonundan seçili tasarımları bir arada göstermektedir. Koleksiyon, markanın karakteristik minimalizm anlayışını korurken, kumaş dokuları, kesim hatları ve siluetlerdeki modernist yaklaşımlar aracılığıyla işlevsellik ile estetiği bir araya getirmektedir. Görselde yer alan tasarımlar; asimetrik kesimlerin öne çıktığı gece elbiseleri, nötr tonlarda yapılandırılmış takım elbiseler ve akıcı drapeli üst parçalar gibi farklı giyim kategorilerini kapsamaktadır. Bu çeşitlilik, koleksiyonun hem cinsiyetler arası giyilebilirliğe hem de güncel moda pratiklerine uyum sağlama amacını yansıtmaktadır.
Koleksiyonda dikkat çeken bir diğer unsur, malzeme kullanımındaki kontrastlardır. Mat ve parlak yüzeylerin bir arada kullanılması hem dokusal hem de görsel derinlik sunarken, tasarımlarda tercih edilen yalın renk paleti, markanın sadeliğe dayalı tasarım felsefesi ile uyumludur. Koleksiyonun genelinde sofistike bir modernlik duygusu hâkimdir. Şekildeki modellerin duruş ve styling unsurları, kıyafetlerin yapısal niteliklerini vurgulamaya yönelik olarak kurgulanmış olup, koleksiyonun hem yüksek moda hem de pratik kullanım alanlarına hitap eden yönlerini desteklemektedir.

Yohji Yamamoto



Görsel 4: Yohji Yamamoto İlkbahar 2026 Hazır Giyim koleksiyonu (Yohji Yamamoto, 2025).

Görsel 4'te sunulan, Yohji Yamamoto'nun İlkbahar 2026 Hazır Giyim Koleksiyonu'ndan seçili tasarımları göstermektedir. Koleksiyon, tasarımcının karakteristik avangart estetiğini sürdüren bir biçimde, asimetrik siluetler, dekonstre kesimler ve katmanlı yapıların öne çıktığı bir tasarım dili sunmaktadır. Siyah ve beyazın belirgin karşıtlığı, hem tasarımcının monokrom geleneğini devam ettirmekte hem de koleksiyonun dramatik anlatısını güçlendirmektedir. Yamamoto'nun bu koleksiyonunda kullanılan kumaşların akışkanlığı, modellerin yürüyüş esnasında yarattığı hareket etkisiyle birleşerek dinamik bir hacim algısı oluşturmakta; bu durum, koleksiyonun performatif yönünü desteklemektedir. Şekilde görülen parçalar, bedenle gevşek bir ilişki kuran formları ve bilinçli olarak tamamlanmamış izlenimi veren detaylarıyla, tasarımcının "kusurlu güzellik" yaklaşımını yansıtmaktadır. Ayrıca, koleksiyonda yer alan katmanlı elbiseler, franj detayları ve farklı dokusal yüzeyler, giysinin hem yapısal hem de kavramsal derinliğini artırmaktadır. Yamamoto'nun modaya ilişkin felsefesinin temel unsurlarını somutlaştırmakta; minimal renk paletiyle birlikte özgün biçimsel arayışları bir araya getirerek çağdaş moda söylemi içinde ayrıksı ama etkili bir estetik ortaya koymaktadır. Model duruşları ve podyum düzeni, koleksiyonun teatral niteliğini vurgularken, giysilerin hacimsel çeşitliliğini ve tasarımcının yenilikçi yaklaşımını görünür kılmaktadır.

YÖNTEM

Problem Durumu

Günümüz moda sektöründe hızlı tüketim kültürünün etkisiyle tasarımların yaşam döngüsü giderek kısalmakta, görsel ve kavramsal açıdan kalıcı nitelik taşıyan tasarımların üretimi zorlaşmaktadır. Moda illüstrasyonu, bu süreçte tasarımcıların estetik anlayışını yansıtan temel bir ifade aracı olmakla birlikte, çoğu zaman trend odaklı ve geçici stil yaklaşımlarının görselleştirilmesiyle sınırlı kalmaktadır. Minimalist estetik anlayışının moda illüstrasyonuna uygulanması ise gereksiz detayların ayıklanması, görsel sadeliğin güçlendirilmesi ve zamansızlık hissinin kuvvetlendirilmesi bakımından önemli bir araç olarak kullanılmaktadır. Bu araştırma, minimalist estetik yaklaşımının moda illüstrasyonunda zamansız tasarım üretimine nasıl katkıda bulunduğu konusunu esas alan problem durumuna odaklanmaktadır.

Problem Cümlesi ve Alt Problemler

Araştırmanın problem cümlesi, "Moda İllüstrasyonunda Minimalist Estetik yaklaşımı, zamansız tasarımların geliştirilmesine nasıl katkı sağlamaktadır?"

Belirlenen problem durumunu ele alınarak aşağıda sıralanan alt problemlere de açıklık getirilmeye çalışmıştır.

1. Moda illüstrasyonunda minimalist estetik hangi görsel ve kavramsal ilkelerle temsil edilmektedir?

2. Moda illüstrasyonunda, minimalist estetik, zamansızlık algısını hangi tasarım özellikleri üzerinden güçlendirmektedir?

3. Minimalist illüstrasyon teknikleri ile oluşturulan tasarımlarda kullanılan renk, çizgi, form ve oran ilişkileri zamansızlık ilkesini nasıl desteklemektedir?

4. Özgün illüstrasyon örnekleri üzerinden minimalist estetik yaklaşımın tasarım bütünlüğüne etkisi nasıl değerlendirilebilir?

Araştırmanın Amacı ve Önemi

Araştırmanın amacı, moda illüstrasyonunda minimalist estetik yoluyla zamansız tasarım üretimine katkı sağlayacak görsel ve kavramsal bir çerçeve geliştirmektir. Moda illüstrasyonunda minimalist estetik yaklaşımının sistematik biçimde analiz edilmesi, tasarım sürecinin niteliğinin artırılması ve üretilen görsel dilin sürekliliğinin sağlanması açısından önemli bir gereklilik hâline gelmiştir. Literatür incelemeleri, moda illüstrasyonu ve minimalist estetik kavramlarını ele alan çalışmaların mevcut olduğunu göstermektedir; ancak bu estetik yaklaşımın zamansız tasarım algısı üzerindeki etkisini uygulamalı illüstrasyon çalışmalarıyla bütüncül biçimde inceleyen araştırmaların sınırlı olduğu görülmektedir. Araştırma Moda illüstrasyonunda minimalist estetik anlayışının zamansız tasarım çalışmalarına olan katkısını ele alarak, alanda ilk kez uygulamaya dayalı bir değerlendirme sunması bakımından özgünlük taşımaktadır.

Araştırma kapsamında minimalist çizgi, oran, sade renk paleti ve form özelliklerinin illüstrasyonlarda zamansızlık algısını nasıl etkilediği incelenmektedir. Moda illüstrasyonunda sadelik ilkesinin yalnızca estetik değil, aynı zamanda sürdürülebilirlik, tasarım sürekliliği ve kültürel kalıcılık açısından da önemli bir araç olduğunu vurgulamaktadır. Bu yönüyle araştırma tasarımcılar ve akademik alanda çalışan araştırmacılar için özgün bir teorik ve görsel kaynak olacağı düşünülmektedir.

Sayıltılar

Araştırmada aşağıdaki sayıltılar benimsenmiştir:

Uzman değerlendirme formunu dolduran tasarım alanındaki akademisyenlerin, değerlendirmelerini bilimsel yeterlilikleri ve mesleki deneyimleri doğrultusunda, nesnel ve gerçek durumu yansıtacak biçimde yanıt verdikleri düşünülmektedir.

Uzman değerlendirme formunda yer alan ölçütlerin, minimalist estetik anlayışını ve moda illüstrasyonunda zamansızlık algısını değerlendirmek için uygun olduğu varsayılmıştır.

Araştırma kapsamında hazırlanan moda illüstrasyonu tasarımlarının, minimalist estetik ilkelerini temsil etme açısından yeterli ve açıklayıcı olduğu kabul edilmektedir.

Uzman görüşlerine dayalı değerlendirmenin, tasarım paftalarının özgünlüğünü ortaya koymada geçerli ve güvenilir sonuçlar verdiği varsayılmıştır.

Sınırlılıklar

Bu araştırma:

Minimalist estetik anlayışı doğrultusunda hazırlanan moda illüstrasyonu tasarımlarının, Selçuk Üniversitesi bünyesinde tasarım alanında görev yapan ve aktif olarak akademik çalışmalarını sürdüren akademisyenlere uygulanan uzman değerlendirme formu aracılığıyla elde edilen verilerle sınırlandırılmıştır.

Görüşme yapılan uzmanlar, Selçuk Üniversitesi'nde görev yapan ve tasarım alanında aktif olarak çalışan akademisyenlerle sınırlıdır.

Araştırmada kullanılan görsel kaynaklar, minimalist estetik anlayışını temsil ettiği kabul edilen seçili marka ve tasarımcıların (Jil Sander, Calvin Klein, Helmut Lang, Yohji Yamamoto) koleksiyonlarından alınan örnek görseller ile sınırlandırılmıştır.

Araştırmanın kapsamı, moda illüstrasyonlarının görsel temsil boyutu ile sınırlı tutulmuş; üretim teknikleri, uygulama süreçleri ve tüketici davranışları araştırma kapsamı dışında bırakılmıştır.

Araştırmada kullanılan görsel analiz yöntemi, seçili illüstrasyon ve tasarım örnekleriyle sınırlı bir değerlendirme sağlamaktadır.

Araştırma yalnızca minimalist estetik yaklaşıma odaklandığından, diğer akımlar ve tasarım anlayışları dışı bırakılmıştır.

Tanımlar

Moda İllüstrasyonu: Tasarımın biçim, hareket, doku ve stil özelliklerini çizgisel anlatımla görselleştiren sanatsal ifade biçimidir.

Minimalist Estetik: Gereksiz unsurların ayıklanması, sade form kullanımı, yalın çizgiler ve sınırlı renk paletlerinin tercih edilmesi temelinde gelişen estetik yaklaşım.

Zamansız Tasarım: Trendlerden bağımsız, uzun süre estetik değerini koruyan, biçimsel ve kavramsal olarak kalıcı nitelik taşıyan tasarım anlayışı.

Tasarım Paftası: Tasarım sürecinde geliştirilen çalışmanın kavramsal çerçevesini, görsel anlatımını ve estetik özelliklerini bir bütün olarak sunan; illüstrasyon, renk, kompozisyon ve açıklayıcı unsurları içeren sunum yüzeyidir.

Zamansızlık: Bir tasarımın belirli bir döneme ya da geçici moda eğilimlerine bağlı kalmadan uzun süre geçerliliğini ve estetik değerini koruyabilme niteliğidir.

Görsel Analiz: Görsel materyallerin biçim, renk, kompozisyon ve estetik özelliklerinin belirli ölçütler çerçevesinde incelenmesine dayanan nitel analiz yöntemidir.

Araştırmanın Modeli

Bu araştırma, nitel araştırma yöntemi kapsamında yürütülmüştür. Araştırmada veri toplama aracı olarak, minimalist estetik ilkeleri doğrultusunda hazırlanan moda illüstrasyonu tasarımlarının değerlendirilmesine yönelik geliştirilen uzman değerlendirme formu kullanılmıştır. Araştırmanın temel veri kaynağını, araştırmacı tarafından oluşturulan moda illüstrasyonu tasarım paftaları oluşturmaktadır. Bu tasarımlar, Selçuk Üniversitesi bünyesinde tasarım alanında görev yapan ve aktif olarak akademik çalışmalarını sürdüren akademisyenler tarafından değerlendirilmiştir.

Araştırma sürecinde, konuya ilişkin literatür taraması yapılarak araştırmanın temeli oluşturulmuş ve minimalist estetik ile zamansızlık ilkeleri çerçevesinde kavramsal çerçeve belirlenmiştir. Kavramsal çerçeve doğrultusunda değerlendirme ölçütleri oluşturularak uzman değerlendirme formu hazırlanmıştır. Araştırmada nitel veri toplama yöntemlerinden doküman incelemesi ve görsel analiz kullanılmıştır. Doküman incelemesi kapsamında, minimalist estetik anlayışını temsil eden seçili marka

ve tasarımcıların koleksiyonlarına ait görsel örnekler incelenmiş ve bu veriler araştırmanın temel altyapısını desteklemek amacıyla kullanılmıştır.

Uzman değerlendirme formu aracılığıyla elde edilen veriler, moda illüstrasyonlarının çizgi, renk, form, oran ve kompozisyon özellikleri doğrultusunda analiz edilmiştir.

Araştırmanın Evreni ve Örneklemi

Araştırmanın evrenini üç ana grup oluşturmaktadır:

1. Türkiye'de üniversitelerin tasarım alanlarında görev yapan akademisyenler,
2. Minimalist estetik anlayışını temel alan zamansız moda illüstrasyonu çalışmaları,
3. Minimalist estetik yaklaşımı ile ilişkilendirilen marka ve tasarımcıların koleksiyonlarına ait görsel kaynaklar.

Araştırmanın örneklemi, **amaçlı örnekleme (maksatlı örnekleme) yöntemi** ile belirlenmiştir. Buna göre araştırmanın örneklemini;

- Selçuk Üniversitesi bünyesinde tasarım alanında görev yapan 5 akademisyen,
- Araştırma kapsamında hazırlanan moda illüstrasyonu tasarım paftaları,
- Doküman incelemesi kapsamında minimalist estetik anlayışını temsil ettiği kabul edilen seçili marka ve tasarımcıların (Jil Sander, Calvin Klein, Helmut Lang, Yohji Yamamoto) koleksiyonlarından alınan örnek görseller

oluşturmaktadır.

Örneklem seçiminde, araştırmanın amacına uygunluk ve uzmanlık alanı dikkate alınmıştır.

Veri Toplama Süreci ve Veri Toplama Araçları

Araştırmada veriler, literatür taraması, dijital arşiv incelemesi ve uzman değerlendirmesine dayalı uygulamalar yoluyla toplanmıştır. Bu kapsamda, konuya ilişkin kuramsal altyapıyı oluşturmak amacıyla alan yazınında yer alan tezler, kitaplar ve bilimsel makaleler incelenmiştir.

Araştırmanın görsel verileri, minimalist estetik anlayışını temsil eden moda markalarının resmî internet siteleri ve dijital koleksiyon arşivlerinden elde edilen görseller ile araştırmacı tarafından hazırlanan özgün moda illüstrasyonu çalışmalarından oluşmaktadır.

Uzman görüşlerinin elde edilmesinde, araştırmacı tarafından geliştirilen **uzman** değerlendirme formu kullanılmıştır. Uzman değerlendirme formunda, moda illüstrasyonu tasarımlarının minimalist estetik ve zamansızlık ilkeleri doğrultusunda değerlendirilmesi amacıyla 2'li derecelendirme ölçeği kullanılmıştır. Ölçek, *"Katılıyorum"* ve *"Katılmıyorum"* seçeneklerinden oluşmaktadır. Elde edilen veriler, moda illüstrasyonu tasarımlarının minimalist estetik ve zamansızlık ilkeleri doğrultusunda değerlendirilmesinde kullanılmıştır.

Değerlendirme sürecinde sunulan illüstrasyon paftaları, dijital ortamda hazırlanmış ve akademisyenlerin incelemesine sunulmuştur.

Araştırma sürecinde kullanılan veri toplama araçları aşağıda sunulmuştur:

- Alan yazınına ait tez, kitap ve makaleler,
- Moda markalarının resmî internet siteleri ve dijital koleksiyon arşivleri,
- Araştırmacı tarafından oluşturulan moda illüstrasyonu paftaları,
- Adobe Illustrator programı,
- Adobe Photoshop programı,
- Procreate programı.

Bu araçlar, araştırmanın veri toplama ve görsel üretim sürecinin sistematik biçimde yürütülmesini sağlamıştır.

Veri Analizi

Analiz sürecinde, Selçuk Üniversitesi bünyesinde tasarım alanında görev yapan akademisyenlerin, araştırma kapsamında hazırlanan moda illüstrasyonu tasarım paftalarına ilişkin değerlendirmeleri dikkate alınmıştır. Uzman değerlendirme formu aracılığıyla elde edilen veriler, sistematik biçimde düzenlenerek analiz edilmiştir.

Uzmanlardan toplanan değerlendirme formları dijital ortama aktarılmış ve elde edilen veriler sınıflandırılarak incelenmiştir. Değerlendirme sürecinde, formda yer alan ölçütler doğrultusunda tasarımlar; hikâye panosu, minimalist estetik, zamansız tasarım ilkeleri ve moda illüstrasyonunun teknik özellikleri açısından ele alınmıştır.

Analiz aşamasında, uzman değerlendirme ölçeğinde yer alan "Katılıyorum" ve "Katılmıyorum" seçeneklerine verilen yanıtlar doğrultusunda bulgular düzenlenmiş ve tablolar hâlinde sunulmuştur. Bu süreç, minimalist estetik anlayışının moda illüstrasyonunda zamansız tasarımlara olan katkısını ortaya koymaya yönelik nitel değerlendirme sürecinin temelini oluşturmuştur.

Geçerlilik ve Güvenilirlik

Araştırmada veri çeşitliliğini sağlamak amacıyla birden fazla veri kaynağı kullanılmıştır. Bu kapsamda, uzman değerlendirme formu aracılığıyla elde edilen akademisyen görüşleri ile doküman incelemesi kapsamında incelenen görsel kaynaklar birlikte değerlendirilmiştir.

Uzman değerlendirme formunda yer alan ölçütler, araştırmanın kavramsal çerçevesi doğrultusunda hazırlanarak kapsam geçerliliği sağlanmıştır.

Değerlendirme sürecinde, formda yer alan maddeler tüm uzmanlara aynı şekilde uygulanarak veri toplama sürecinde tutarlılık sağlanmıştır.

Uzman görüşlerine dayalı değerlendirmeler, tablolar hâlinde sunularak bulguların açık ve izlenebilir olması sağlanmıştır.

İlgili Çalışmalar

Best (2006), minimalizmi estetik bir yaklaşım olarak ele aldığı çalışmasında, biçimsel sadeliğin görsel algı üzerindeki etkisini incelemiş ve minimal estetik anlayışın zamansız bir görsel dil oluşturmadaki rolünü vurgulamıştır.

Blackman (2007), moda illüstrasyonunun tarihsel gelişimini ele aldığı eserinde, farklı dönemlerde öne çıkan estetik yaklaşımları incelemiş; sade çizgi anlayışı ve sınırlı detay kullanımının özellikle modern ve çağdaş moda illüstrasyonlarında kalıcı bir ifade dili oluşturduğunu ortaya koymuştur.

Avcı (2022), illüstrasyon alanında minimalist yaklaşımları incelediği çalışmasında, görsel anlatımda azaltma ilkesinin anlamı güçlendirdiğini ve izleyici algısında netlik sağladığını belirtmiştir. Çalışma, minimalist estetiğin illüstratif anlatımda etkili bir iletişim aracı olduğunu ortaya koymaktadır.

Şenol (2018), minimalist sanat akımının moda üzerindeki etkilerini ele aldığı araştırmasında, minimalizmin moda tasarımında form, renk ve silüet üzerinden zamansızlık algısını desteklediğini ifade etmiştir. Çalışmada Minimalist estetik, geçici trendlerden bağımsız bir tasarım anlayışı olarak ele alınmıştır.

Qurashi (2021), minimalist çizim tekniklerinin moda tasarımındaki rolünü incelediği çalışmasında, sade çizgi ve sınırlı renk kullanımının tasarım bileşenlerini daha okunabilir kıldığını ve tasarımların estetik değerini artırdığını ortaya koymuştur.

Khramova-Baranova ve arkadaşları (2022), moda illüstrasyonu tasarımında stil ve estetik ilişkisini ele aldıkları çalışmalarında, minimalist yaklaşımların illüstrasyonlarda görsel bütünlük ve estetik denge sağladığını belirtmişlerdir.

Almanzar (2014) ve Lobos (2014), zamansız tasarım kavramını ürün ve görsel tasarım bağlamında ele almış; sade, işlevsel ve trend bağımlılığından uzak tasarım anlayışının uzun vadeli estetik değer yarattığını vurgulamışlardır. Bu çalışmalar, zamansızlık kavramının tasarım süreçlerindeki önemini desteklemektedir.

BULGULAR

İllüstrasyon Tasarım Paftaları Üzerinden Analizler

Bu bölümde, araştırmanın kavramsal çerçevesine yönelik bir hikâye panosu ve bu doğrultuda 8 İlkbahar–Yaz, 8 Sonbahar–Kış olmak üzere toplam 16 tasarım paftası hazırlanmıştır. Minimalist estetik ve zamansızlık ilkeleri doğrultusunda geliştirilen tasarımlar, uzman değerlendirme formuyla analiz edilmiştir.

Hikâye Panosu



Görsel 5: Hikâye Panosu Görseli.

Hikâye Panosu Teması: Minimalist Zarafet ve Yenilikçi Zamansızlık.

Hedef Kitlesi: 25–45 yaş aralığındaki, yaşamında sadelik, işlevsellik ve estetik dengeyi önceliklendiren modern kadınlardan oluşmaktadır. Bu kitle; hızlı tüketim eğilimlerinden uzak duran, zamansız parçaların değerini bilen ve gardırobunda uzun ömürlü tasarımlara yer vermeyi tercih eden bilinçli kullanıcı profilini temsil etmektedir.

Hikâye Panosu Manifestosu: Görsel 5'te sunulan hikâye panosu, modern kadının sade, zarif ve kararlı duruşunu minimalist estetik anlayışıyla yansıtmaktadır. Nötr renkler, yalın formlar, temiz kesimler ve işlevsel detaylar, tasarımların temel yaklaşımını oluşturmaktadır. Hikâye panosundan geliştirilen tasarımlar; sadelik, işlevsellik ve zamansızlık ilkeleri doğrultusunda modern kadının günlük yaşamına uyum sağlayan dengeli bir tasarım dili sunmaktadır.

İLKBAHAR- YAZ TASARIM PAFTALARI

Bu başlık altında, çalışmanın kavramsal çerçevesi doğrultusunda hazırlanan ilkbahar–yaz sezonuna ait toplam 8 adet tasarım paftası yer almaktadır. Tasarımlar, minimalist estetik anlayışı temel alınarak hafiflik, sadelik ve işlevsellik ilkeleri doğrultusunda geliştirilmiş; form, yüzey ve detay kullanımı açısından sezonun gerektirdiği yalın ve sade bir görsel dil benimsenmiştir.



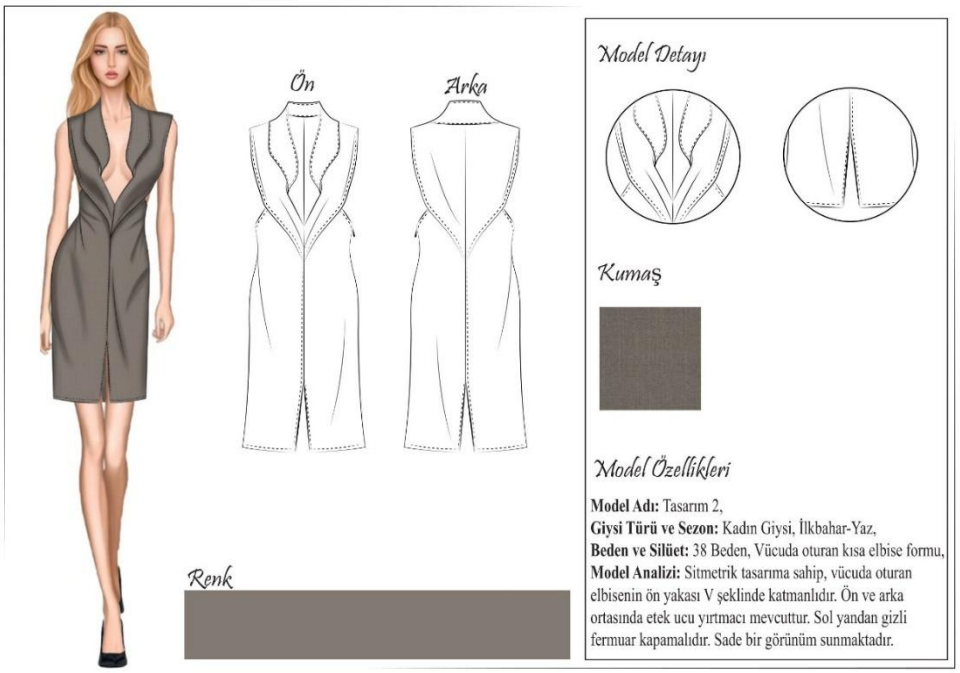
Görsel 6: Tasarım Paftası 1 (Rabia Aslan, 2026).

Tasarım Paftası 1: İki parçalı takım, dik yakalı, kolsuz ve asimetrik kapanışlı üst parça ile yüksek belli, geniş paça pantolondan oluşmaktadır. Üst parçada tek düğme, kup hatları ve kapaklı cep; pantolonda ise kemer köprüleri ve ön pililer bulunmaktadır.

Teknik Özellikler ve Kumaş Türü: Üst parça; dik yaka, asimetrik kapanış, kapaklı cep ve kup hatlarından, pantolon ise yüksek bel, ön pili ve geniş paça formundan oluşmaktadır. Üst parçada krep veya yün karışımlı, pantolonda ise viskon veya Tencel karışımlı krep kumaş tercih edilmiştir.

Renk paleti: Üst parçada kırık beyaz-ekru, pantolonda ise yumuşak adaçayı yeşili tonları tercih edilmiştir.

Özgün Bakış Açısı: Tasarımda asimetrik çizgiler ve farklı siluet özellikleri kullanılmıştır. Üst parçada çapraz kapanış, eğimli etek ucu ve kup hatları; alt parçada ise geniş paça ve dökümlü form yer almaktadır. Tasarım, sınırlı detay kullanımı, yalın renk paleti ve sade konstrüksiyon çizgileriyle oluşturulmuştur.



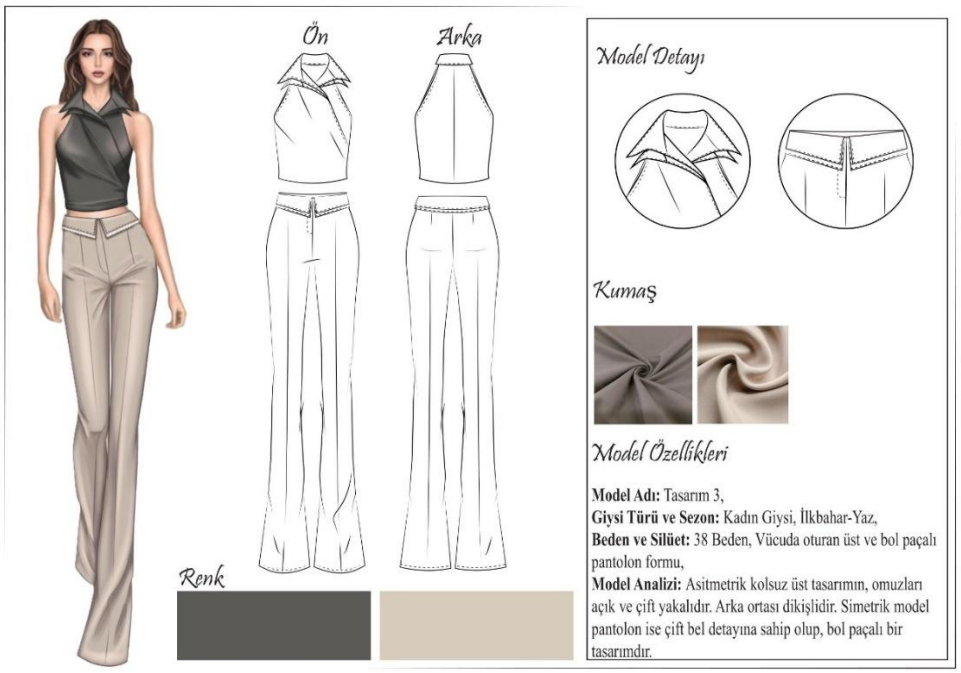
Görsel 7: Tasarım Paftası 2 (Rabia Aslan, 2026).

Tasarım Paftası 2: Elbise; derin V yaka, geniş ve katmanlı yaka formu ile dar kesim etek yapısından oluşmaktadır. Modelde kıvrımlı yaka konturları, ön ve arka yırtmaçlar ile yan dikişte gizli fermuar kullanılmıştır.

Teknik Özellikler ve Kumaş Türü: Elbise; derin V yaka, katlı yaka parçası, ön ve arka yırtmaçlar ile dikey dikiş hatlarından oluşmaktadır. Gövde için orta gramajlı krep veya yün karışımlı kumaş, astar için cupro veya ince viskon tercih eilmiştir.

Renk Paleti: Sıcak gri–taupe tonlarında bir gövde rengine sahiptir. Bu nötr ton, tasarımın modern minimal çizgisini yansıtırken aynı zamanda farklı aksesuarlarla kolayca eşleşebilir bir uyum sağlamaktadır.

Özgün Bakış Açısı: Tasarım, minimal form anlayışını hacimsel ve katmanlı yaka yapısıyla birleştirerek sade ama güçlü bir görünüm sağlamaktadır. Derin V yaka modele kontrollü bir vurgu katarken; temiz kesimler, gizli fermuar ve işlevsel yırtmaçlar tasarımın modern ve sofistike görünümünü desteklemektedir.



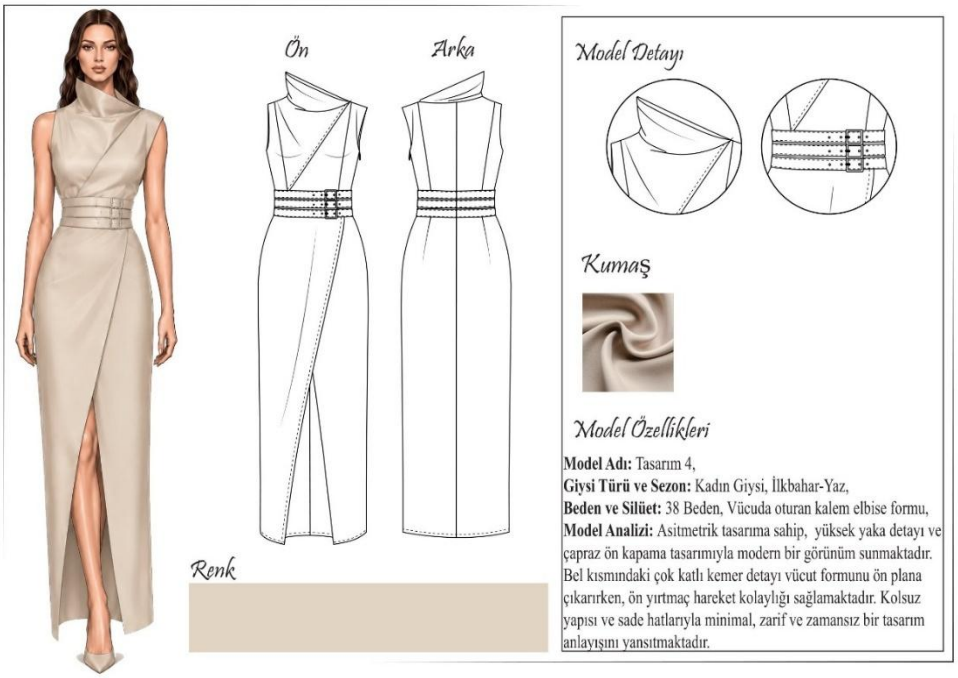
Görsel 8: Tasarım Paftası 3 (Rabia Aslan, 2026).

Tasarım Paftası 3: İki parçalı tasarım, çift katlı yakaya ve kruvaze kapamaya sahip kolsuz üst ile yüksek belli, bol paça pantolondan oluşmaktadır. Pantolonun bel bölümünde çift bant detayı bulunmaktadır.

Teknik Özellikler ve Kumaş Türü: Üst parça; çift katmanlı yaka, çapraz kapanış ve kolsuz formdan oluşmaktadır. Pantolon; yüksek bel, bel detayı, pensler ve geniş paça formundadır. Üst parçada orta gramajlı krep, yaka bölümünde tela destekli pamuk-saten veya poplin; pantolonda polyester-krep veya Tencel karışımlı krep tercih edilmiştir.

Renk Paleti: Görselde kullanılan palet; taupe (soğuk kahve-gri) tonlarında üst parça ve açık bej pantolon ile nötr, sakin bir kontrast oluşturmaktadır. Tonların yumuşaklığı, takımın minimal çizgilerini görsel olarak güçlendirirken, siyah ayakkabı kullanımı keskin bir denge oluşturmaktadır. Bu palet, hem ilkbahar-yaz sezonu hem de zamansız bir tasarım için tercih edilmiştir

Özgün Bakış Açısı: Tasarım, klasik gömlek yakasının yeniden yorumlanmış modern bir varyasyonu olup, asimetrik kapanma ile desteklenen üst form, konstrüktif bir bütünlük sergilemektedir. Üst parçanın bu teknik özelliği, akıcı düşüşe sahip geniş paça pantolonla birleşerek dengeli, oranlanmış ve zamansız bağımsızlığı yüksek bir siluet ortaya koymaktadır. Çift yaka tasarımı ile bel hattında konumlanan simetrik bant ve dikiş, tasarımın biçimsel kimliğini tanımlayan belirleyici unsurlar olarak işlev görmektedir. Minimalist estetik ile tasarlanmış üst form ile akışkan alt siluetin kontrollü etkileşimi, sürekliliği olan bir tasarım anlayışını benimsemektedir.



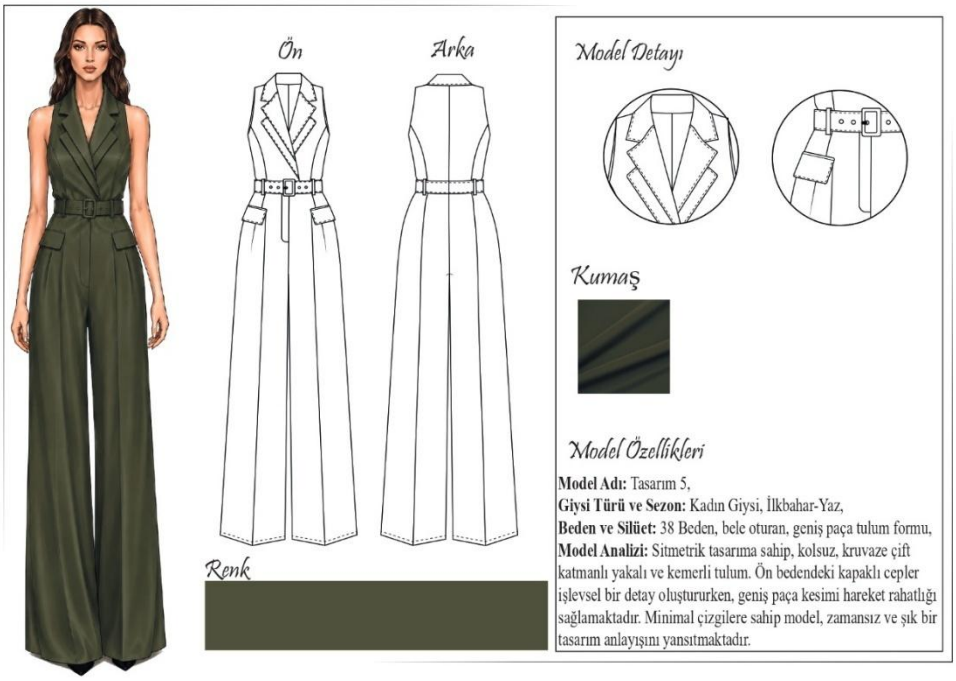
Görsel 9: Tasarım Paftası 4 (Rabia Aslan, 2026).

Tasarım Paftası 4: Elbise, kolsuz ve bedene oturan form, asimetrik yüksek yaka, çapraz kapanış hattı ve uzun etek yapısından oluşmaktadır. Bel bölümünde üç ince kemer ve toka, etek bölümünde ise çapraz ön açıklık bulunmaktadır.

Teknik Özellikler ve Kumaş Türü: Elbisenin teknik özellikleri; asimetrik yüksek yaka, çapraz ön kapanış, bel hattını çevreleyen üçlü kemer sistemi ve ön etekte devam eden çapraz açıklık üzerinden tanımlanmaktadır. Üst bedende kullanılan pens ve biçimlendirme hatları, modelin vücuda uyumunu desteklemektedir. Arka ortada yer alan dikey dikiş hattı, elbisenin konstrüksiyon bütünlüğünü tamamlamaktadır. Modelde hem yapılandırılmış formu koruyabilecek hem de vücut üzerinde düzgün bir döküm sağlayabilecek krep, yün-krep veya viskon karışımlı krep kumaş tercih edilebilir. İç yüzeyde ise kullanım konforunu artırmak amacıyla ince viskon veya cupro astar tercih edilmiştir.

Renk Paleti: Tasarımda açık bej ve ekru arasında yer alan nötr bir renk tonu tercih edilmiştir. Tek renk kullanımı, modeldeki asimetrik kesim ve kemer detaylarının ön plana çıkmasını sağlayarak sade ve bütüncül bir görünüm oluşturmaktadır.

Özgün Bakış Açısı: Tasarımda asimetrik kesimler, çapraz ön hat ve üçlü kemer detayı kullanılmıştır. Ön etekteki çapraz açıklık asimetrik yapıyı sürdürürken nötr renkler ve sınırlı detay kullanımı minimalist ve zamansız tasarım anlayışını desteklemektedir.



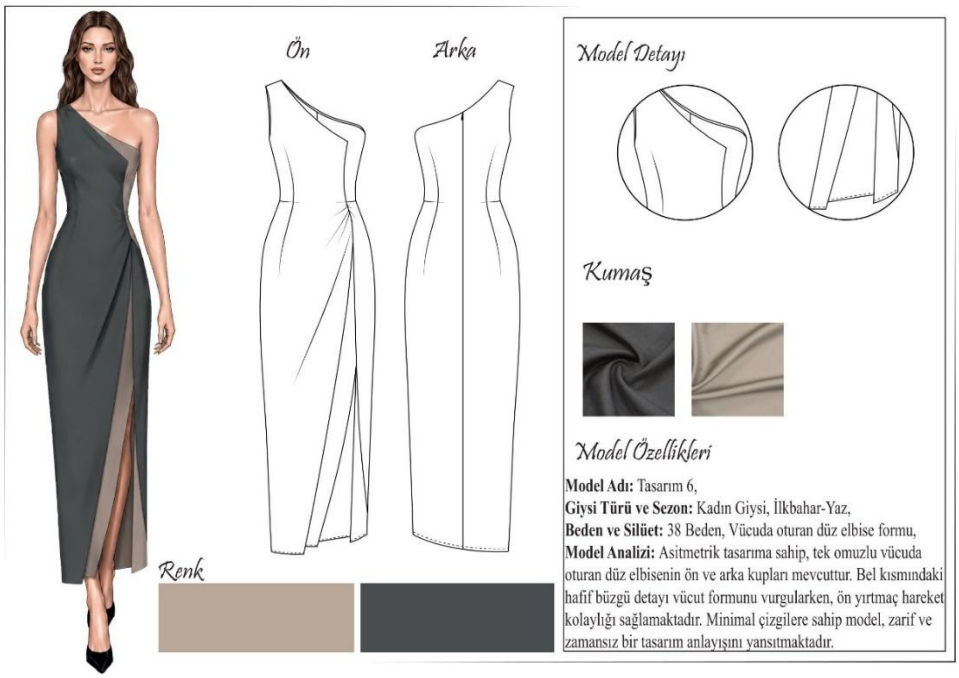
Görsel 10: Tasarım Paftası 5 (Rabia Aslan, 2026).

Tasarım Paftası 5: Tulum; kolsuz üst beden, katmanlı geniş yaka ve geniş paça pantolon formundan oluşmaktadır. Bel bölümünde tokalı kemer ve iki yanda kapaklı cep detayları bulunmaktadır.

Teknik Özellikler ve Kumaş Türü: tulumun kolsuz beden yapısı, katmanlı kruvaze yaka, bel kemeri, kemer köprüleri, tokalı kapanış ve iki yanda bulunan kapaklı cepler üzerinden tanımlanmaktadır. Ön pantolon bölümünde kullanılan pili ve dikey konstrüksiyon hatları, geniş paça formunun düzenli biçimde aşağı doğru devam etmesini sağlamaktadır. Arka bedende orta dikiş ve bel hattında kemer kullanılarak model bütünlüğü korunmuştur. Tasarımda formunu korurken yeterli dökümlülük sağlayabilecek viskon karışımlı krep, Tencel karışımlı dokuma veya ince yün-krep kumaş tercih edilmiştir

Renk Paleti: Tasarımın bütününde koyu hâkî ve zeytin yeşili arasında yer alan tek renkli bir palet tercih edilmiştir. Derin ve doğal renk tonu, katmanlı yaka ve konstrüksiyon detaylarının belirginliğini korurken tasarıma sade ve bütüncül bir görünüm kazandırmaktadır.

Özgün Bakış Açısı: Tasarım, klasik kruvaze yaka anlayışını katmanlı bir düzen içerisinde yeniden ele alarak minimalist forma karakteristik bir detay kazandırmaktadır. Üst bedendeki tekrarlanan yaka çizgileri görsel bir ritim oluştururken bel kemeri, siluetin oranlarını belirginleştiren yatay bir vurgu sağlamaktadır. Kapaklı cepler işlevsel ve görsel bir detay olarak tasarıma dahil edilirken geniş paça formu, yapılandırılmış üst bedenle dengeli bir karşıtlık oluşturmaktadır. Tek renk kullanımı, temiz konstrüksiyon çizgileri ve sınırlı aksesuar yaklaşımı; modelin modern, işlevsel ve zamansız tasarım anlayışını desteklemektedir.



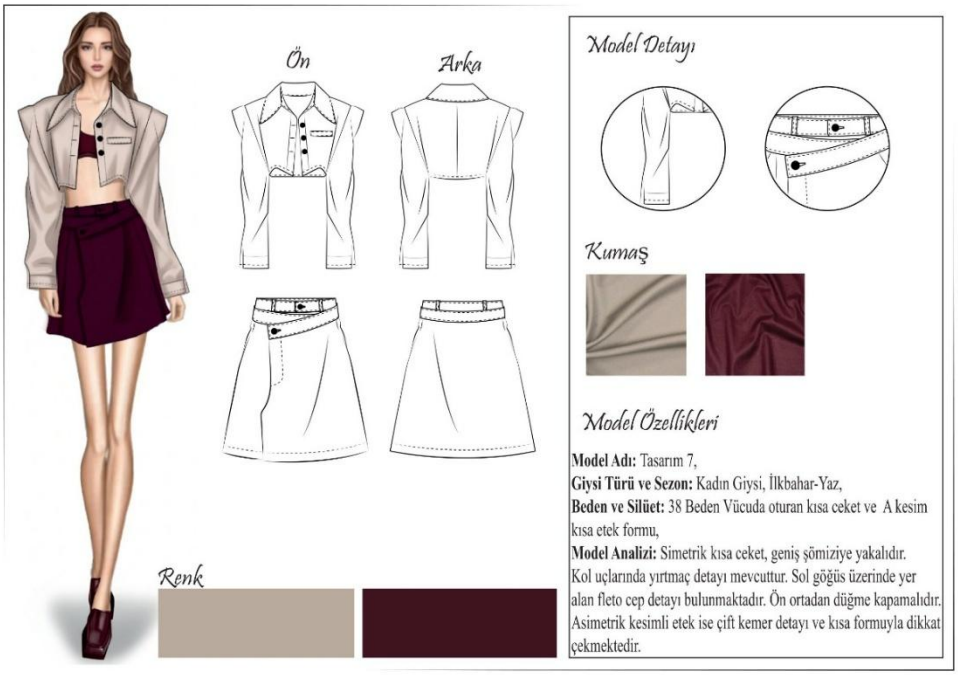
Görsel 11: Tasarım Paftası 6 (Rabia Aslan, 2026).

Tasarım Paftası 6: Elbise, tek omuzlu üst beden, çapraz katmanlı yaka, kup hatları ve uzun dar etek formundan oluşmaktadır. Bel bölümünde büzgü, etek bölümünde ise asimetrik katman ve ön yırtmaç bulunmaktadır.

Teknik Özellikler ve Kumaş Türü: Elbisenin teknik özellikleri; tek omuzlu asimetrik yaka, ön ve arka kup hatları, yan belde toplanan hafif büzgü, çapraz bindirmeli ön etek ve yırtmaç konstrüksiyonu üzerinden tanımlanmaktadır. Üst bedendeki çapraz yaka hattı iki katmanlı bir görünüm oluştururken yan dikişte toplanan etek parçası, ön yüzeyde kontrollü bir drape etkisi meydana getirmektedir. Modelde vücuda uyum sağlayabilecek ve aynı zamanda etek katmanının akıcı görünümünü koruyabilecek viskon karışımlı krep, krep-saten veya hafif elastan içeren krep kumaşlar tercih edilebilir. İç yüzeyde ince viskon veya cupro astar kullanılarak kullanım konforu desteklenebilir.

Renk Paleti: Tasarımda antrasit-koyu gri ana renk ile asimetrik yaka ve ön etek katmanında kullanılan açık vizon-bej tonu bir arada tercih edilmiştir. İki nötr rengin birlikteliği, modelin katmanlı ve asimetrik konstrüksiyonunu belirginleştiren dengeli bir kontrast oluşturmaktadır.

Özgün Bakış Açısı: Tasarım, minimalist estetik anlayışını tek omuzlu asimetrik form ve iki renkli katman kullanımıyla ele almaktadır. Yaka hattında başlayan çapraz yön, etek bölümündeki bindirmeli parçayla devam ettirilerek tasarımın üst ve alt bölümleri arasında görsel süreklilik sağlanmıştır. Yan beldeki kontrollü büzgü, düz ve vücuda oturan siluete sınırlı bir hareket kazandırırken ön yırtmaç işlevsel ve estetik bir unsur olarak kullanılmıştır. Sade yüzeyler, nötr renkler ve belirgin çapraz çizgiler modelin modern, zarif ve zamansız tasarım yaklaşımını desteklemektedir.



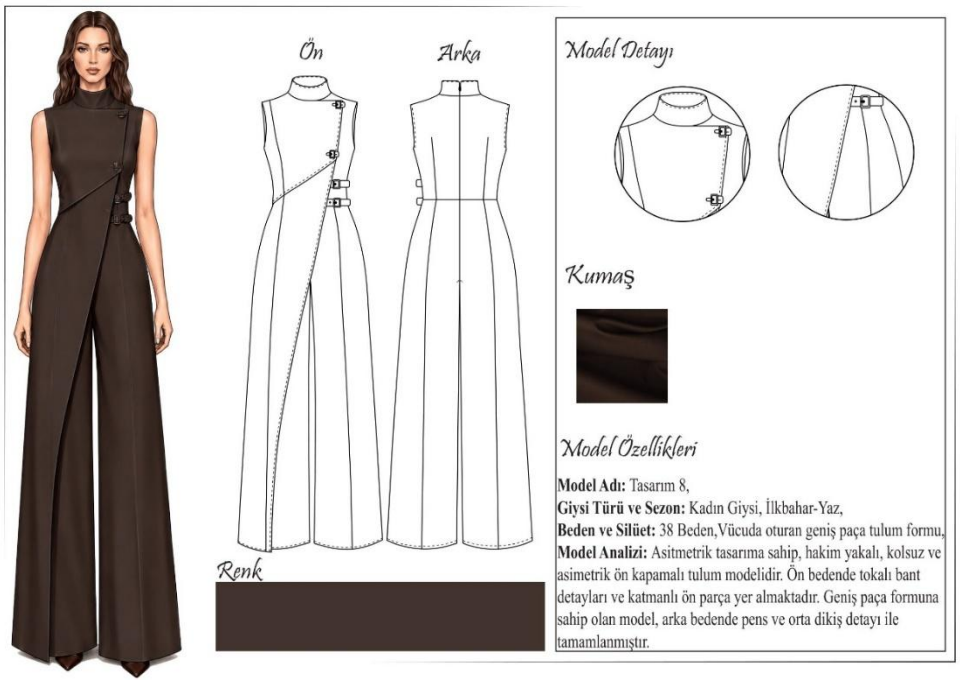
Görsel 12: Tasarım Paftası 7 (Rabia Aslan, 2026).

Tasarım Paftası 7: Tasarım paftasında sunulan takım, kısa ceket ve yüksek bel pileli etekten oluşan iki parçalı bir giysidir. Ceket, simetrik formu, kısa model boyu ve geniş manşetli kollarıyla üst bedende dengeli bir görünüm sunmaktadır. Sol göğüs hattında yer alan fleto cep, tasarımın işlevselliğini artırmaktadır. Etek, çift kemer detayı ve geniş pileli olup, tasarımda ceket formunun kısalığını tamamlayarak takımın dikey ve yatay çizgiler açısından uyumlu bir bütünlük oluşturmasını sağlamaktadır. Simetrik tasarım, modern minimalizmi sade çizgiler ve kontrollü pile hareketleriyle bir araya getiren dengeli bir yaklaşımı yansıtmaktadır.

Teknik Özellikler ve Kumaş Türü: Takım; gömlek yakalı, üç düğmeli kısa ceket ve yüksek belli pileli etekten oluşmaktadır. Cekette düşük kol, geniş manşet ve fleto cep; etekte çift kemer ve metal düğme detayları bulunmaktadır. Cekette pamuk-saten, etekte gabardin kumaş kullanılmıştır.

Renk Paleti: Takımda ceket için açık bej, etek için koyu bordo tercih edilmiştir. Bu kontrast, üst parçanın hafifliğini vurgularken alt parçaya güçlü bir bütünlük kazandırmaktadır.

Özgün Bakış Açısı: Tasarım, kısa ceket ile pileli eteğin orantısını temel alarak modern ve sade bir siluet sunmaktadır. Ceketin kısa formu ve geniş omuzları üst bedende belirgin bir çizgi oluştururken, eteğin belinde kullanılan çift kemer etkisi, iki parça arasındaki geçişi vurgulayarak tasarımın odak noktasını güçlendirmektedir. Öndeki detay yoğunluğunun, arka yüzeylerde sade bir düzenle dengelenmesi ise bütünsel bir minimal estetik sağlamaktadır.



Görsel 13: Tasarım Paftası 8 (Rabia Aslan, 2026).

Tasarım Paftası 8: Tasarım paftasında sunulan tulum, asimetrik kesim ve yapılandırılmış detaylar doğrultusunda hazırlanmıştır. Kolsuz üst beden, boynu çevreleyen hâkim yaka formuyla biçimlendirilmiştir. Ön bedende omuz hattından başlayarak bel bölgesine ve alt bedene doğru çapraz ilerleyen asimetrik kapama, tasarımın temel çizgisini oluşturmaktadır. Kapanış hattı üzerinde farklı seviyelerde konumlandırılan tokalı bant detayları, modelin karakteristik görünümünü güçlendirmektedir. Bel hattından sonra devam eden katmanlı ön parça, geniş paça pantolon formuyla bütünleşerek tulumun dikey ve uzun siluetini tamamlamaktadır. Arka beden ise pensler ve orta dikiş hattıyla daha sade bir konstrüksiyonda düzenlenmiştir.

Teknik Özellikler ve Kumaş Türü: Tulum; hâkim yaka, kolsuz beden, asimetrik ön kapama, tokalı bantlar, katmanlı ön parça ve geniş paça formundan oluşmaktadır**.** Orta gramajlı krep veya yün-krep kumaş ile ince viskon astar kullanılmıştır.

Renk Paleti: Tasarımın bütününde koyu kahverengi ve çikolata tonları arasında yer alan monokrom bir renk paleti tercih edilmiştir. Tek renk kullanımı, asimetrik kesim ve tokalı bant detaylarının ön plana çıkmasını sağlayarak modelde güçlü ve bütüncül bir görünüm oluşturmaktadır.

Özgün Bakış Açısı:

Tasarım; asimetrik kapama, tokalı bantlar, katmanlı ön parça, hâkim yaka ve geniş paça formundan oluşmaktadır.

SONBAHAR-KIŞ TASARIM PAFTALARI

Bu başlık altında, çalışmanın kavramsal çerçevesine uygun olarak hazırlanan sonbahar–kış sezonuna ait toplam 8 adet tasarım paftası sunulmaktadır. Tasarımlar, minimalist estetik yaklaşım doğrultusunda daha koruyucu formlar, dengeli oranlar ve sade yüzey anlayışıyla ele alınarak zamansızlık vurgusu ön planda tutulmuştur.



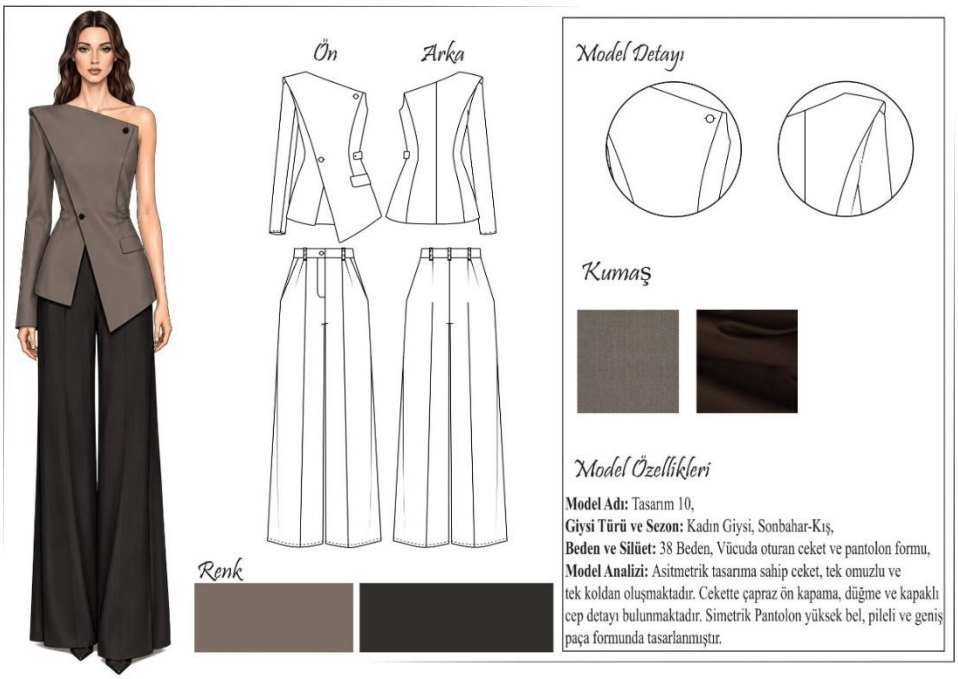
Görsel 14: Tasarım Paftası 9 (Rabia Aslan, 2026).

Tasarım Paftası 9: Tasarım paftasında sunulan elbise; hâkim yaka, uzun kol ve vücuda oturan düz siluet formunda tasarlanmıştır. Ön bedende kup çizgileri, belin yan bölümünde tokalı bant ve etek ucuna doğru ilerleyen asimetrik kapama hattı bulunmaktadır. Uzun kollarda iç hat boyunca açıklık kullanılmış, etek bölümü ise düz ve uzun formda tamamlanmıştır.

Teknik Özellikler ve Kumaş Türü: Elbise, hâkim yaka, vücuda oturan üst beden, asimetrik ön kapama, tokalı bant ve açıklıklı uzun kollardan oluşmaktadır. Ön kapama hattı belden etek ucuna çapraz biçimde uzanmaktadır. Arka bedende orta dikiş ve pensler bulunmaktadır. Modelde orta gramajlı krep veya yün-krep, iç yüzeyde ise ince viskon astar kullanılmıştır.

Renk Paleti: Tasarımda açık bej, taş ve kırık ekru tonları arasında yer alan monokrom bir renk paleti tercih edilmiştir. Açık nötr ton, asimetrik kesim ve kol detaylarının görünürlüğünü desteklerken tasarıma yalın ve bütüncül bir görünüm kazandırmaktadır.

Özgün Bakış Açısı: Tasarımda asimetrik kapama, tokalı bant ve açıklıklı uzun kol yapısı kullanılmıştır. Hâkim yaka, dikey hatlar, nötr renk kullanımı ve sınırlı aksesuar detayları tasarımın temel özelliklerini oluşturmaktadır.



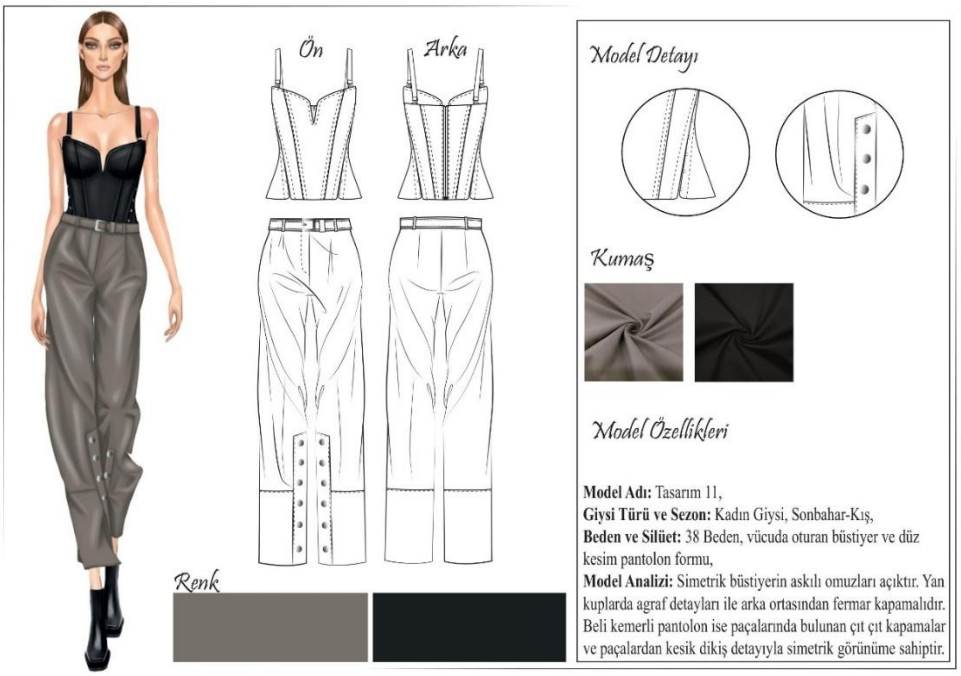
Görsel 15: Tasarım Paftası 10 (Rabia Aslan, 2026).

Tasarım Paftası 10: İki parçalı takım; asimetrik ceket ve geniş paça pantolondan oluşmaktadır. Ceket tek omuzlu, tek kollu, çapraz kapamalı ve asimetrik etek uçludur. Ön bedende düğme, tokalı bant ve kapaklı cep bulunmaktadır. Pantolon yüksek belli, pilili ve geniş paçalıdır.

Teknik Özellikler ve Kumaş Türü: Cekette asimetrik ön kapama, tek uzun kol, düğme, toka ve kapaklı cep detayları bulunmaktadır. Pantolonda kemer köprüleri, ön pililer ve geniş paça kullanılmıştır. Ceket için yün-krep veya gabardin; pantolon için viskon karışımlı krep veya dökümlü takım elbiselik kumaş tercih edilmiştir.

Renk Paleti: Cekette vizon-gri kahve, pantolonda koyu kahverengi kullanılmıştır.

Özgün Bakış Açısı: Tek omuzlu ceket, çapraz kapama ve asimetrik etek uçları modelin temel tasarım özellikleridir. Geniş paça pantolon ve nötr renk kullanımı tasarımı tamamlamaktadır.



Görsel 16: Tasarım Paftası 11 (Rabia Aslan, 2026).

Tasarım Paftası 11: Paftada sunulan takım, vücuda oturan büstiyer ile yüksek bel, düz kesim pantolondan oluşmaktadır. Büstiyer, simetrik formu, ince askıları ve göğüs hattındaki yapılandırılmış form detaylarıyla üst bedende belirgin ve güçlü bir siluet oluşturmaktadır. Yan panellerdeki metal aksesuarlar tasarıma modern ve dinamik bir karakter kazandırmaktadır. Pantolon, yüksek bel yapısı ve düz–hafif dökümlü formuyla üst parçanın vücut odaklı siluetini dengelemekte; paça üzerindeki metal düğme detayı tasarıma ritmik bir hareket katmaktadır.

Teknik Özellikler ve Kumaş Türü: Büstiyer, penslerle biçimlendirilmiş gövde yapısı, ön merkezdeki kapama hattı ve yan metal aksesuarlı panellerle tanımlanmaktadır. Pantolon, yüksek bel kemer, fermuar kapama, yan cepler ve paça hattında yer alan metal düğme detayıyla teknik olarak bütünlük sunmaktadır. Üst parçada formu koruyan orta gramajlı dokuma kumaş, alt parçada ise dökümlü ve dayanıklı kumaş tercih edilmiştir. Bot tarzı topuklu ayakkabı, takımın güçlü ve modern çizgisini desteklemektedir.

Renk Paleti: Büstiyer siyah tonlarda, pantolon ise nötr gri-kahve tonlarında çalışılarak dengeli, modern ve kontrast içermeyen monokrom bir görünüm elde edilmiştir.

Özgün Bakış Açısı: Tasarım, yapısal büstiyer formu ile metal düğme detaylı pantolonun birleşimi sayesinde güçlü, modern ve dinamik bir siluet sunar. Üst bedendeki yapılandırılmış form, alt parçadaki sade fakat detaylı yüzey düzeniyle dengelenerek minimal fakat iddialı bir estetik oluşturulmuştur



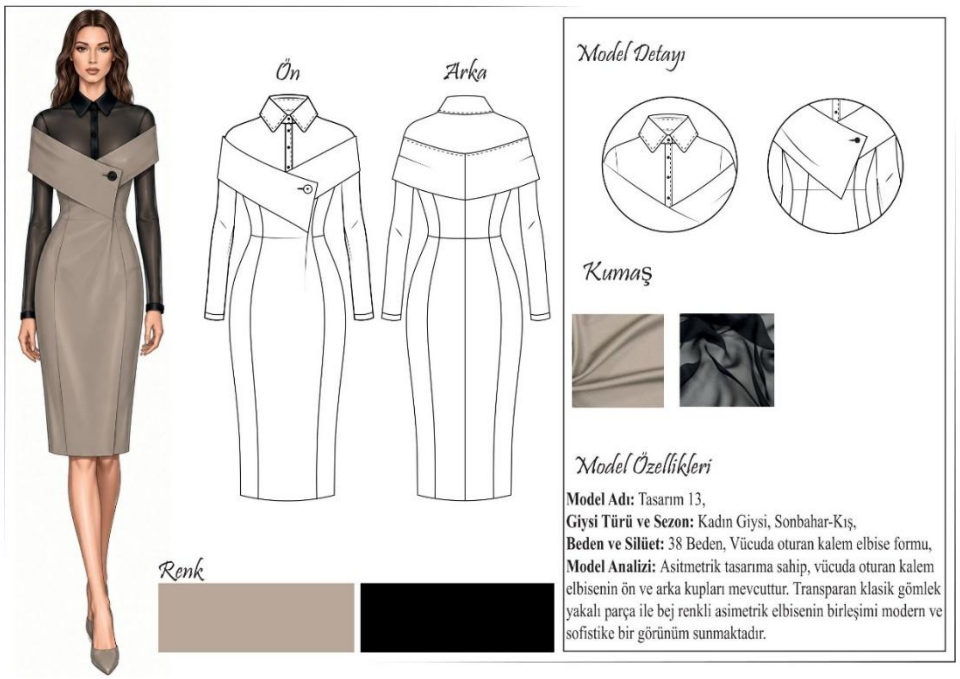
Görsel 17: Tasarım Paftası 12 (Rabia Aslan, 2026).

Tasarım Paftası 12: Paftada sunulan elbise, düşük omuz yapısı, vücuda oturan formu ve derin yan yırtmacıyla tanımlanan uzun bir siluete sahiptir. Göğüs hattındaki asimetrik pensler ve transparan üst bant detayı, üst bedende hem yapı hem de görsel hafiflik oluşturmaktadır. Kolların geniş manşetle açılan formu elbiseye akıcı bir hareket kazandırırken, alt bedende kontrollü daralan hatlar modern ve zarif bir görünüm sağlamaktadır.

Teknik Özellikler ve Kumaş Türü: Elbise, düşük omuz kesimi, gövdeyi saran kalıp yapısı ve ön ortadan yükselerek açılan yırtmacıyla teknik olarak tanımlanmaktadır. Arka beden sade tutulmuş, form bütünlüğünü koruyan uzun bir fermuar kapanışıyla tamamlanmıştır. Kollar geniş, volan etkili manşetle bitirilmiştir. Kullanılan orta gramajlı, esnek ve dökümlü kumaş elbisenin vücuda oturan formunu desteklemektedir. Ayakkabı olarak sivri burun, bordo tonlu yüksek topuklu model tercih edilerek siluetin şıklığı güçlendirilmiştir.

Renk Paleti: Elbise, nötr açık bej tonunda çalışılmış; ayakkabının koyu bordo rengi ile dengeli fakat dikkat çekici bir kontrast oluşturulmuştur.

Özgün Bakış Açısı: Tasarım, transparan üst bant, düşük omuz hattı ve uzun yırtmacın birleşimiyle modern, sade ve akıcı bir estetik sunmaktadır. Üst bedendeki detay yoğunluğu, alt formdaki yalın hatlarla dengelenerek bütünsel bir minimalizm yaklaşımı elde edilmiştir.



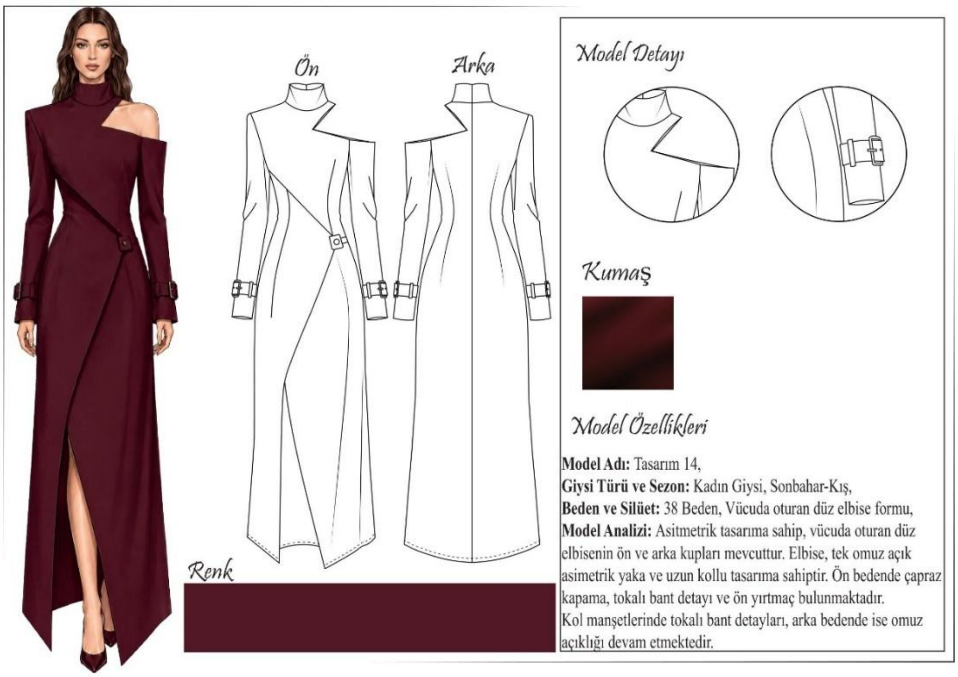
Görsel 18: Tasarım Paftası 13 (Rabia Aslan, 2026).

Tasarım Paftası 13: Elbise; standart gömlek yaka, transparan üst beden ve uzun kollar ile asimetrik panelden oluşmaktadır. Tek düğmeli kapanış ve gövde boyunca uzanan kup hatları kullanılmıştır. Alt bölüm, vücuda oturan ve diz hizasında daralan kalem etek formundadır.

Teknik Özellikler ve Kumaş Türü: Elbisenin teknik özellikleri, ön ve arka boyun eğrisinde birleşen geniş kuplu panel üzerinden tanımlanmaktadır. Ön ortada yer alan eğik dikiş hattı ile bu hatta entegre edilen tek düğme detayı, modelin form bütünlüğünü belirleyen ana etkendir. Uzun kollu yapı, omuzdan koltuk altına uzanan temiz ve düzenli dikiş hatlarıyla biçimlendirilmiştir. Arka orta dikiş, silueti dengeleyen tamamlayıcı bir konstrüksiyon unsuru olarak uygulanmıştır. Gövde bölümü için hafif elastikiyet sunan yün krepe (wool-crepe) veya T400 karışımlı krepe kumaş tercih edilmiştir. Transparan üst parçalarda ipek veya viskon şifon; alternatif olarak organza kumaş düşünülmüştür. Astar materyali olarak cupro veya ince viskon kullanılarak giysiye nefes alabilirlik ve konfor kazandırılmıştır.

Renk paleti: Camel-bej tonlarındaki gövde ile siyah transparan üst bölümün oluşturduğu sade fakat güçlü bir kontrast renk tercih edilmiştir.

Özgün Bakış Açısı: Tasarım, minimal form anlayışı içerisinde asimetrik düzenin estetik gücünü vurgulamaktadır. Kuplu yapı, vücut hatlarını kontrollü biçimde belirginleştirirken transparan gömlek detayı, modern bir kontrast etkisi yaratarak modele hem derinlik hem de görsel hafiflik kazandırmaktadır. Tek düğmeli kapanış ve temiz dikiş hatlarıyla desteklenen bu elbise, zamansızlık ilkesi doğrultusunda estetik dengenin birleştiği modern, sade ve zarif bir tasarım yaklaşımını temsil etmektedir.



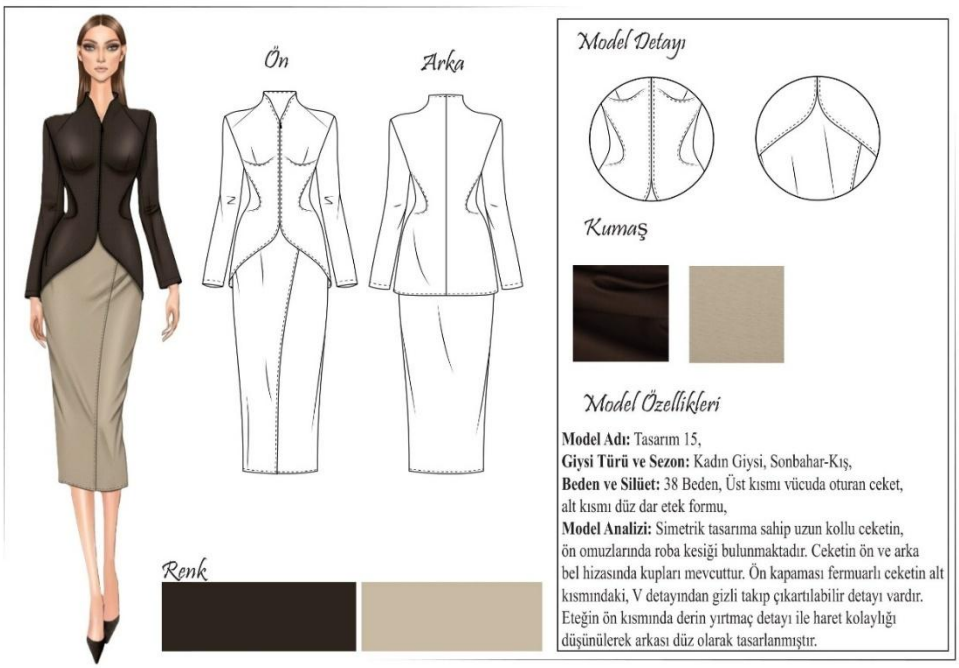
Görsel 19: Tasarım Paftası 14 (Rabia Aslan, 2026).

Tasarım Paftası 14: Paftada sunulan uzun elbise, asimetrik yaka, tek omuz açıklığı ve uzun kollu formdan oluşmaktadır. Ön bedende çapraz kesim, tokalı bant ve ön yırtmaç bulunmaktadır. Kol uçları tokalı manşetlerle tamamlanmıştır.

Teknik Özellikler ve Kumaş Türü: Modelde asimetrik yaka, kup hatları, çapraz ön parça, belde tokalı bant ve manşetlerde toka detayları kullanılmıştır. Ön etek bölümünde yırtmaç bulunmaktadır. Model için yün-krep, viskon karışımlı krep veya elastanlı krep kumaş tercih edilebilir.

Renk Paleti: Tasarımda bordo ve tonları kullanılmıştır.

Özgün Bakış Açısı: Tek omuz açıklığı, çapraz ön kesim ve tokalı detaylar modelin temel tasarım özellikleridir. Asimetrik etek ucu ve ön yırtmaç tasarımı tamamlamaktadır.



Görsel 20: Tasarım Paftası 15 (Rabia Aslan, 2026).

Tasarım Paftası 15: Paftada sunulan tasarım, vücuda oturan formda bir ceket elbiseden oluşan tek parça bir giysidir. Ceket, kıvrımlı ve aşağı doğru genişleyen simetrik ön formu, dar omuz hattı ve uzun kol yapısıyla üst bedende akıcı fakat kontrollü bir siluet oluşturmaktadır. Derin kıvrımlı ön kesim, etek formunun drape hareketleriyle bütünleşerek dengeli bir dikey akış yaratmaktadır. Etek, ön yüzeydeki serbest drapelerle hacim kazanarak tasarıma hareket ve yumuşaklık kazandırmaktadır.

Teknik Özellikler ve Kumaş Türü: Ceket Elbise, gövdeyi saran kalıpla çalışılmış olup ön bedende yumuşak kıvrımlı hatlar ve temiz dikiş çizgileriyle tanımlanmaktadır. Arka beden minimal tutularak form bütünlüğü korunmuştur. Etek, önde yoğun drape yerleşimi ve arkada daha sade düzeniyle dengeli bir yapıya sahiptir. Ceket için orta gramajlı, mat görünümlü dokuma kumaş; etek için ise dökümlülüğü destekleyen hafif esnek dokulu krep kumaş tercih edilmiştir.

Renk Paleti: Tasarımla uyumlu olarak ceket koyu kahve tonlarında, etek ise açık bej renk tercih edilmiştir. Bu ton kombinasyonu, üst bedende derinlik etkisi yaratırken alt formdaki yumuşak drapeyi öne çıkaran kontrast sunmaktadır.

Özgün Bakış Açısı: Tasarım, gövdeyi saran ceket formu ile eteğin akışkan yapısını bir araya getirerek modern, zarif ve minimal bir siluet oluşturmaktadır. Ön yüzeydeki kontrollü form yoğunluğu, arka yüzeydeki sade tasarım yaklaşımıyla dengelenmiş ve bütünsel bir estetik anlayış ortaya koymaktadır.



Görsel 21: Tasarım Paftası 16 (Rabia Aslan, 2026).

Tasarım Paftası 16: Tasarım paftasında sunulan trençkot; yüksek yaka, uzun kol ve asimetrik ön kapama formundan oluşmaktadır. Ön bedende kısa katmanlı parça, çift sıra düğme ve bel bandı bulunmaktadır. Etek bölümü genişleyerek uzun formda tamamlanmıştır

Teknik Özellikler ve Kumaş Türü: Modelde yüksek yaka, asimetrik kapama, çift sıra düğme, bel bandı ve tokalı kol bantları kullanılmıştır. Arka bedende rüzgârlık ve orta dikiş bulunmaktadır. Ana kumaş için gabardin, yün karışımlı dokuma veya krep; iç katmanda viskon astar tercih edilebilir.

Renk Paleti: Trençkotta taş-vizon, pantolonda siyah renk kullanılmıştır.

Özgün Bakış Açısı: Kısa üst katman, yüksek yaka ve asimetrik ön kapama modelin temel tasarım özelliklerini oluşturmaktadır. Bel bölümündeki geniş bant ve çift sıra düğmeler, üst ve alt beden arasındaki geçişi belirginleştirmektedir. Uzun ve genişleyen etek formu, kısa üst katmanla dengeli bir oran oluştururken tokalı kol detayları tasarım bütünlüğünü desteklemektedir. Asimetrik kesim ve katmanlı yapı, klasik trençkot formunun farklı bir biçimde ele alınmasını sağlamaktadır.

SONUÇ VE DEĞERLENDİRME

Minimalist estetik yaklaşımının moda illüstrasyonunda nasıl bir ifade gücü oluşturduğunu ve bu yaklaşımın zamansız tasarımlar geliştirmedeki rolünü ortaya koymak amaçlanmıştır. Çalışmanın literatür incelemesi, minimalist estetiğin yalnızca bir stil tercihi değil, aynı zamanda sadelik, denge, işlevsellik ve öz'e ulaşma arayışı üzerine kurulu felsefi bir yaklaşım olduğunu göstermiştir. Moda illüstrasyonunun tarihsel gelişimi ve sanatsal niteliği incelendiğinde, minimalist anlayışın güncel tasarım pratiklerinde giderek daha güçlü bir estetik referansa dönüştüğü anlaşılmaktadır. Araştırma kapsamında gerçekleştirilen görsel analizler ve oluşturulan mood board, minimalist çizgi dili, nötr renk paletleri ve sade form kurgusunun zamansızlık algısını belirgin biçimde güçlendirdiğini ortaya koymuştur. Minimalizm, moda illüstrasyonunda gereksiz detayları ayıklayarak tasarımın özünü görünür kılmış; çizgisel yalınlık ve dengeli kompozisyonlar aracılığıyla tasarımlara uzun ömürlü bir estetik karakter kazandırmıştır. Çalışmada incelenen güncel koleksiyon örnekleri de, minimalist yaklaşımın çağdaş moda endüstrisinde hem estetik hem de sürdürülebilir bir tasarım dili oluşturduğunu destekler niteliktedir. Özgün illüstrasyon tasarımlarına yönelik yapılan çözümlemeler, minimalist estetiğin tasarım sürecinde berraklık, netlik ve tutarlılık sağladığını göstermiştir. Tasarımlarda kullanılan sınırlı renk paleti, sade çizgiler ve temiz yüzey kullanımı, zamansız bir görünüm elde edilmesinde belirleyici unsurlar olarak öne çıkmıştır. Ayrıca minimalist yaklaşımın, illüstrasyonun anlatım gücünü artırarak

giysinin formunu ve karakterini daha doğrudan ifade etme imkânı sunduğu görülmüştür. Bu çalışmanın bulguları, moda illüstrasyonunda zamansızlık oluşturmanın yalnızca biçimsel sadelikle değil, aynı zamanda tasarımcının bilinçli estetik seçimleriyle ilişkili olduğunu ortaya koymaktadır. Minimalist yaklaşım, tasarımın özüne odaklanarak zamanla değişmeyen bir estetik değer oluşturmakta ve böylece hızlı tüketim döngülerine karşı daha kalıcı bir tasarım anlayışı sunmaktadır.

Sonuç olarak, minimalist estetik yoluyla geliştirilen moda illüstrasyonları, hem tasarım fikrinin daha derin ve açık bir biçimde ifade edilmesine olanak sağlamış hem de zamansızlık ilkesini destekleyen güçlü bir görsel dil ortaya koymuştur. Bu yönüyle çalışma, moda illüstrasyonu alanında sadelik ve kalıcılık arasında kurulabilecek uyuma dair hem teorik hem de uygulamalı bir çerçeve sunarak literatüre nitelikli bir katkı sağlamaktadır.

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STRATEGIES FOR EMISSION REDUCTION IN INDUSTRIAL STEAM GENERATION SYSTEMS

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ABSTRACT

Fire-tube steam boilers are widely used in industrial facilities due to their reliability, operational simplicity, and ability to meet thermal energy demands. However, inefficient combustion conditions and inadequate operating practices can lead to excessive atmospheric emissions, including carbon dioxide (CO_2), carbon monoxide (CO), nitrogen oxides (NO_x), and particulate matter, while also reducing overall energy efficiency. These emissions contribute to environmental pollution and increase operational costs associated with fuel consumption.

This study investigates the optimization of flue gas emissions from fire-tube steam boilers through the analysis and control of key operating parameters, including excess air ratio, combustion temperature, fuel quality, burner adjustment, and heat recovery efficiency. The objective is to minimize pollutant emissions while maintaining optimal steam production and improving boiler performance.

The proposed approach evaluates combustion efficiency, fuel consumption, flue gas composition, and thermal losses under different operating conditions. Particular attention is given to the implementation of combustion control strategies and energy recovery systems, such as economizers, to enhance heat utilization and reduce stack losses.

Results demonstrate that proper optimization of combustion parameters can significantly decrease CO and NO_x emissions, improve fuel efficiency, and lower greenhouse gas emissions. Furthermore, continuous monitoring and process control contribute to stable boiler operation and reduced environmental impact.

The optimization of fire-tube steam boiler emissions therefore represents an effective strategy for improving energy efficiency, reducing operational costs, and supporting sustainable industrial practices.

Keywords: fire-tube boiler, steam generation, combustion optimization, flue gas emissions, energy efficiency, NO_x reduction, environmental performance.

MONEY LAUNDERING IN REAL ESTATE AND CONSTRUCTION TRANSACTIONS: A COMPARATIVE ANALYSIS BETWEEN REPUBLIC OF MOLDOVA AND THE EUROPEAN UNION

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ABSTRACT

Money laundering in real estate and construction transactions represents a major global challenge, enabling illicit financial flows to be integrated into the formal economy. These sectors are particularly vulnerable due to high-value transactions, complex ownership structures, and the frequent involvement of intermediaries such as notaries, lawyers, and real estate agents. This study offers a comparative perspective between the Republic of Moldova and the European Union (EU), focusing on legal frameworks, institutional capacity, risk exposure, and enforcement effectiveness.

In the Republic of Moldova, despite notable progress in aligning national legislation with international and European anti-money laundering (AML) standards, significant structural vulnerabilities persist. The real estate sector remains highly exposed due to limited transparency in beneficial ownership, insufficient monitoring of transactions, and weak oversight of designated non-financial professions. Additionally, enforcement mechanisms are often constrained by limited institutional capacity and inconsistent implementation of reporting obligations.

By contrast, the European Union has developed a more comprehensive and harmonized AML framework, supported by successive directives and recent initiatives aimed at centralizing supervision. The establishment of a unified Anti-Money Laundering Authority (AMLA) reflects the EU's commitment to strengthening cross-border cooperation and ensuring consistent enforcement across member states. Enhanced due diligence requirements and the development of beneficial ownership registers further reduce systemic risks.

Overall, while Republic of Moldova has made important legislative advancements, the effectiveness of its AML regime remains limited compared to the EU, highlighting the need for stronger enforcement, increased transparency, and improved institutional coordination.

Keywords: money laundering, real estate, construction sector, AML framework, European anti-money laundering (AML) standards.

INTRODUCTION

Money laundering represents a complex process through which individuals or organized criminal groups attempt to conceal the illegal origin of financial assets obtained from criminal activities and introduce them into the legitimate economic system. The primary objective of money laundering is to create the appearance of legality for illicit proceeds, allowing offenders to use, invest, or transfer these assets without attracting the attention of law enforcement authorities. This process generally involves three interconnected stages: placement, which consists of introducing illegally obtained funds into the financial system; layering, involving multiple transactions designed to obscure the connection between the assets and their criminal source; and integration, whereby the laundered funds are reintroduced into the economy as apparently legitimate investments or financial resources.

Among the various sectors vulnerable to money laundering, real estate and construction activities represent particularly attractive areas for criminal exploitation due to the substantial financial values involved and the complexity of transactions. The acquisition of residential, commercial, or industrial properties provides criminals with opportunities to transform illicit proceeds into valuable assets that

may generate additional income through resale, rental, or further investment. Moreover, the construction sector presents additional risks because of the involvement of numerous actors, including developers, contractors, financial institutions, architects, public authorities, and professional intermediaries, which can create complex transactional chains that make the identification of illegal financial flows more difficult.

A significant factor contributing to the vulnerability of these sectors is the lack of transparency regarding the real beneficiaries of property ownership, especially when transactions involve legal entities, foreign companies, or offshore structures. The use of intermediaries, such as lawyers, notaries, real estate agents, and financial consultants, may further complicate the detection process, particularly when due diligence mechanisms are insufficient or inconsistently applied.

Both the Republic of Moldova and the European Union encounter substantial difficulties in preventing and combating money laundering within real estate and construction markets. However, the nature and intensity of these challenges differ depending on the level of regulatory development, institutional capacity, and effectiveness of enforcement mechanisms. While the European Union benefits from a more advanced and harmonized anti-money laundering framework, supported by extensive cooperation mechanisms and stricter supervisory standards, the Republic of Moldova continues to face challenges related to implementation, institutional resources, transparency, and practical enforcement of existing legislation. Consequently, a comparative analysis of these two legal environments provides valuable insights into existing vulnerabilities and possible strategies for improving the prevention and detection of money laundering risks in the construction and real estate sectors (Anti–money laundering, 2020).

MONEY LAUNDERING RISKS IN REAL ESTATE AND CONSTRUCTION

Real estate transactions constitute one of the most attractive mechanisms for concealing and legitimizing proceeds derived from criminal activities. The specific characteristics of the real estate market, including the high value of assets, the complexity of ownership arrangements, and the involvement of multiple professional actors, create favourable conditions for criminals seeking to disguise the illegal origin of their financial resources. Unlike many other forms of investment, real estate provides a tangible and relatively stable asset through which illicit funds can be transformed into apparently legitimate wealth, while also generating additional economic benefits through resale, rental activities, or further development projects.

One of the main factors increasing the vulnerability of real estate transactions is the significant volume of financial resources involved. Large-scale payments related to the acquisition, construction, renovation, or transfer of properties can conceal the movement of illegal funds among numerous legitimate transactions. Criminal actors may exploit the high monetary value of properties to integrate substantial amounts of illicit capital into the legal economy, making it more difficult for competent authorities to distinguish between legitimate investments and transactions intended for money laundering purposes.

Another important vulnerability is represented by complex ownership structures and the frequent use of legal entities, foreign companies, and offshore arrangements. Such structures may obscure the identity of the actual beneficial owners of properties and limit the ability of authorities to trace the origin of invested funds. The separation between the registered owner and the real beneficiary creates opportunities for individuals involved in criminal activities to hide their connection with valuable assets and avoid detection.

Furthermore, real estate transactions commonly involve various professional intermediaries, including notaries, lawyers, real estate agents, financial consultants, and other service providers. Although these professionals play an essential role in ensuring the legality and security of property transactions, insufficient compliance procedures or inadequate supervision may create opportunities for the misuse of their services for illicit financial operations. Effective customer due diligence, identification of beneficial owners, and reporting of suspicious transactions are therefore essential elements in preventing money laundering within this sector.

In the Republic of Moldova, these vulnerabilities are intensified by several structural and institutional challenges. The notarial and legal professions, which frequently participate in real estate operations, represent areas requiring increased attention due to risks associated with insufficient supervision mechanisms, limited reporting of suspicious activities, and the potential misuse of professional confidentiality. The combination of these factors may reduce the effectiveness of preventive measures and create difficulties in identifying illegal financial flows.

Moreover, real estate transactions involving non-resident individuals, foreign legal entities, or offshore companies significantly increase the complexity of financial investigations. Cross-border ownership arrangements and international transfers may hinder the verification of the source of funds and the identification of the ultimate beneficiaries. Consequently, strengthening transparency mechanisms, improving cooperation between institutions, and enhancing the monitoring of high-risk transactions remain essential priorities for reducing money laundering risks in Republic of Moldova's real estate and construction sectors (SPCSB, 2025).

LEGAL INSTITUTIONAL FRAMEWORK: REPUBLIC OF MOLDOVA VS. EUROPEAN UNION

The Republic of Moldova has undertaken significant efforts in recent years to strengthen its anti-money laundering (AML) framework and to align its national legislation and institutional mechanisms with international standards established by organizations such as the Financial Action Task Force (FATF) and the Council of Europe's MONEYVAL Committee. These reforms have been aimed at improving the prevention, detection, and investigation of money laundering activities, as well as enhancing the country's capacity to respond effectively to financial crimes affecting the national economy and financial system.

The foundation of Republic of Moldova's AML regime is represented by the national legislation on preventing and combating money laundering and terrorist financing, which has undergone multiple amendments in order to ensure greater compatibility with international requirements. These legislative improvements have introduced more detailed obligations regarding customer due diligence, identification and verification of beneficial owners, monitoring of suspicious transactions, and cooperation between public authorities and private entities. By incorporating FATF recommendations into domestic legislation, Republic of Moldova has attempted to create a more comprehensive preventive system capable of addressing both traditional and emerging forms of financial crime, including those involving real estate and construction sectors.

An important component of Republic of Moldova's AML policy has been the adoption and implementation of the National Strategy for Preventing and Combating Money Laundering and Terrorist Financing (2020–2025). This strategic document established national priorities aimed at reducing vulnerabilities within the financial and non-financial sectors, improving institutional coordination, increasing transparency of ownership structures, and strengthening mechanisms for the recovery of criminal assets. The strategy also emphasized the importance of a risk-based approach, requiring authorities and reporting entities to identify and manage sectors with increased exposure to money laundering activities.

The effectiveness of the AML system is further supported by the activity of the Financial Intelligence Unit (FIU), which plays a central role in collecting, analysing, and disseminating financial intelligence related to suspicious transactions. Through cooperation with law enforcement institutions, supervisory authorities, and international partners, the FIU contributes to the identification of complex financial schemes and supports criminal investigations involving illicit financial flows.

Recent reforms have contributed to measurable improvements in Republic of Moldova's compliance with international AML standards. Assessments conducted within the FATF/MONEYVAL framework indicate that Republic of Moldova has achieved "*compliant*" and "*largely compliant*" ratings for a significant number of recommendations, reflecting progress in strengthening legislative provisions, institutional arrangements, and preventive mechanisms. Nevertheless, despite these advances, challenges remain regarding the practical implementation of AML measures, particularly in high-risk

sectors such as real estate and construction, where enhanced supervision, transparency of beneficial ownership, and more effective enforcement mechanisms continue to be necessary (Council of Europe, 2025).

Despite the progress achieved in developing and modernizing the anti-money laundering (AML) framework, the practical implementation of existing regulations in the Republic of Moldova continues to face several challenges. Although the legal infrastructure has been gradually aligned with international standards, the effectiveness of AML measures remains affected by inconsistencies in enforcement practices, limited institutional capacity, and difficulties in ensuring uniform application of preventive mechanisms across all relevant sectors.

One of the main areas requiring further improvement concerns transparency regarding beneficial ownership. The identification of the individuals who ultimately control or benefit from legal entities and property assets represents a fundamental element in preventing money laundering. However, in practice, difficulties may arise in accurately determining the real beneficiaries behind complex corporate structures, foreign companies, or transactions involving intermediaries. Insufficient transparency in ownership arrangements can create opportunities for criminals to conceal their involvement in real estate investments, construction projects, and other high-value economic activities.

Another persistent challenge relates to the reporting and detection of suspicious transactions. While financial institutions and designated non-financial businesses and professions are subject to legal obligations regarding the identification and notification of potentially illicit activities, the effectiveness of these mechanisms depends largely on the quality, frequency, and accuracy of reports submitted to competent authorities. In some cases, weaknesses may occur due to limited awareness of AML obligations, inadequate risk assessment procedures, or insufficient monitoring of high-risk transactions, particularly those involving real estate, legal persons, and cross-border financial operations.

Furthermore, Republic of Moldova's AML system has been influenced by previous experiences with significant illicit financial flows and complex financial crime schemes. The country has historically faced large-scale cases of economic fraud and illegal capital movements that demonstrated vulnerabilities within the financial sector and affected public confidence in national institutions. Such events revealed the risks associated with weak control mechanisms, insufficient oversight of financial operations, and the misuse of legal and corporate structures for criminal purposes.

These historical challenges have contributed to the continued need for strengthening Republic of Moldova's institutional response to money laundering. Improving cooperation between law enforcement bodies, financial intelligence structures, supervisory authorities, and private sector actors remains essential for ensuring a more effective preventive system. In particular, enhanced monitoring of high-value transactions, increased transparency of property ownership, and more rigorous enforcement of reporting obligations are necessary measures for reducing the risks associated with money laundering in the real estate and construction sectors (UNICRI, 2021).

The European Union has established one of the most developed and continuously evolving anti-money laundering (AML) regulatory frameworks at the international level, based on a combination of legislative instruments, institutional cooperation mechanisms, and supervisory measures designed to prevent and combat financial crime. The EU's approach is characterized by the progressive harmonization of national legislation among Member States, with the objective of creating a unified system capable of addressing the increasingly complex nature of money laundering activities, including those involving cross-border transactions, real estate investments, and corporate structures.

The development of the European AML framework has been achieved through the adoption of several legislative instruments, particularly the Fourth and Fifth Anti-Money Laundering Directives, which introduced significant improvements in the prevention, detection, and reporting of suspicious financial activities. These directives established common standards regarding customer due diligence obligations, risk-based supervision, identification of beneficial owners, enhanced controls for high-risk transactions, and cooperation between financial intelligence units. The Fifth AML Directive further expanded transparency requirements by improving access to beneficial ownership information and strengthening controls related to transactions involving higher-risk jurisdictions and new financial technologies.

Recognizing the need to address remaining differences in national implementation and enforcement, the European Union has initiated a comprehensive reform process aimed at creating a more integrated and effective AML system. A central element of these reforms is the establishment of the Anti-Money Laundering Authority (AMLA), a new European supervisory body designed to enhance coordination, ensure consistent application of AML rules, and strengthen oversight of entities presenting significant risks.

The creation of AMLA represents an important step toward reducing fragmentation among Member States, as previous approaches relied heavily on national supervisory authorities with varying levels of effectiveness and resources. Through centralized supervision, AMLA is expected to improve the exchange of information, promote uniform compliance standards, and provide stronger oversight of financial institutions and other high-risk sectors.

Compared with countries that are still developing their AML systems, such as the Republic of Moldova, the European Union benefits from a more advanced regulatory environment, stronger institutional capacity, and more established mechanisms for cross-border cooperation. Nevertheless, challenges remain, particularly regarding the prevention of money laundering through complex international structures, real estate transactions, and emerging digital financial instruments. Therefore, the continuous modernization of the EU AML framework demonstrates the necessity of adapting regulatory responses to the evolving methods used by criminal actors to conceal and integrate illicit financial resources (Escudero, 2026).

The anti-money laundering (AML) framework of the European Union is distinguished by a high degree of regulatory harmonization, comprehensive preventive mechanisms, and increasingly coordinated institutional responses aimed at reducing vulnerabilities within the European financial and economic system. A fundamental characteristic of the EU approach is the establishment of common legal standards applicable across Member States, ensuring that national AML regimes operate according to shared principles and minimum requirements. This harmonized approach seeks to prevent regulatory disparities between jurisdictions and to limit opportunities for criminals to exploit differences in national legislation.

A central element of the European AML system is the implementation of strict customer due diligence (CDD) obligations. Financial institutions, as well as designated non-financial businesses and professions, are required to identify and verify their clients, assess potential risks, determine the source of funds, and apply enhanced monitoring measures in situations involving higher-risk activities. These procedures are particularly important in sectors characterized by significant financial flows, including real estate transactions, construction investments, and operations involving complex corporate structures. Through a risk-based approach, EU regulations aim to ensure that resources are directed toward areas where the probability of money laundering is considered higher.

Another important component of the EU framework is the development and improvement of beneficial ownership transparency mechanisms. Member States are required to maintain registers containing information about the individuals who ultimately own or control legal entities, trusts, and other organizational structures. Increased access to reliable ownership information contributes to the identification of hidden financial interests and reduces the possibility of using companies or property assets to conceal illicit proceeds. In the context of real estate and construction markets, beneficial ownership transparency plays a crucial role in preventing anonymous acquisitions and the misuse of corporate vehicles for money laundering purposes.

Furthermore, the European Union has progressively strengthened regulation and supervision of high-risk sectors, including the real estate market, construction activities, legal services, and other professional areas that may be vulnerable to financial crime. These sectors are subject to increased monitoring requirements, reporting obligations, and compliance standards designed to detect suspicious activities at an early stage.

Compared with the Republic of Moldova, the European Union benefits from a significantly stronger institutional framework, greater administrative capacity, and more developed mechanisms for cooperation between national and European authorities. The existence of specialized supervisory institutions, advanced financial intelligence networks, and established procedures for cross-border

information exchange contributes to a more consistent application of AML measures. While Republic of Moldova has made important progress in aligning its legislation with international standards, the EU model demonstrates the advantages of a more integrated system, where legislative harmonization, institutional effectiveness, and international cooperation operate together to combat money laundering risks more efficiently.

A COMPARATIVE ANALYSIS BETWEEN THE REPUBLIC OF MOLDOVA AND THE EUROPEAN UNION

The Republic of Moldova has undertaken substantial legislative and institutional reforms aimed at bringing its anti-money laundering (AML) framework closer to the standards and requirements established by the European Union. These efforts reflect Republic of Moldova's broader process of legal approximation and its commitment to strengthening mechanisms for preventing and combating financial crime. Through successive amendments to national legislation, Republic of Moldova has introduced provisions related to customer due diligence, suspicious transaction reporting, beneficial ownership identification, and cooperation between competent authorities, seeking to ensure greater compatibility with European and international AML principles.

However, despite these important developments, the effectiveness of the Moldovan AML system has historically been affected by certain inconsistencies in the interpretation and application of legal provisions. Differences in the definition of key concepts, variations in institutional practices, and difficulties in ensuring uniform implementation have created challenges for the practical enforcement of AML measures. In particular, gaps between legislative requirements and their practical application have limited the capacity of authorities and regulated entities to identify, investigate, and prevent sophisticated money laundering schemes.

One of the main difficulties has been the transition from formal legislative compliance to effective implementation. Although Republic of Moldova has adopted many international standards, the efficiency of the AML framework depends not only on the existence of appropriate legal rules but also on the capacity of supervisory institutions, law enforcement authorities, and private sector participants to apply these rules consistently. Challenges related to institutional coordination, risk assessment, monitoring of high-risk sectors, and transparency of ownership structures have affected the overall effectiveness of prevention mechanisms.

By comparison, the European Union operates within a much more developed and integrated AML legal environment. The EU framework is characterized by a high level of harmonization among Member States, where common regulatory principles and supervisory requirements are continuously updated to respond to new and evolving forms of financial crime. Through successive legislative instruments, including the Anti-Money Laundering Directives and recent regulatory reforms, the EU has established mechanisms capable of addressing emerging risks associated with globalization, digitalization, complex corporate structures, and cross-border financial operations.

Therefore, while Republic of Moldova has made significant progress in aligning its AML legislation with European standards, the EU experience demonstrates the importance of not only adopting advanced legal norms but also ensuring their consistent enforcement through strong institutions, effective supervision, and continuous adaptation to new money laundering techniques. This difference highlights the need for Republic of Moldova to further strengthen the practical application of AML measures, particularly in vulnerable sectors such as real estate and construction (Gaibu et. Knobel, 2018).

Although the Republic of Moldova has made considerable progress in strengthening its anti-money laundering (AML) legislation and aligning its regulatory framework with international standards, the practical effectiveness of these measures continues to be affected by challenges related to enforcement capacity and institutional efficiency. The existence of appropriate legal provisions does not automatically guarantee successful prevention and detection of money laundering activities, as their effectiveness largely depends on the ability of supervisory authorities, law enforcement institutions, and regulated entities to implement them consistently.

One of the main limitations affecting Republic of Moldova's AML system is associated with restricted institutional resources and operational capacity constraints. Certain authorities involved in prevention and investigation activities continue to face difficulties related to staffing, technical capabilities, specialized expertise, and interinstitutional coordination. These limitations may reduce the efficiency of monitoring mechanisms and hinder the identification of complex financial schemes, particularly those involving high-value assets, corporate structures, and cross-border transactions.

A persistent challenge concerns the quality and effectiveness of suspicious transaction reporting mechanisms. Although financial institutions and designated non-financial businesses and professions have legal obligations to report transactions that may indicate criminal activity, practical deficiencies remain regarding the identification, assessment, and timely notification of suspicious operations. In particular, sectors outside the traditional financial system, such as legal services, notarial activities, real estate agencies, and construction-related professions, require stronger supervision and increased awareness regarding AML responsibilities.

In contrast, the European Union has adopted a more integrated and coordinated approach to AML supervision. The creation of the Anti-Money Laundering Authority (AMLA) represents a significant institutional development intended to reduce differences between national supervisory practices and ensure a more consistent application of AML requirements throughout Member States. By introducing stronger centralized oversight, AMLA is expected to improve cooperation between national authorities, enhance monitoring of high-risk entities, and address fragmentation that has previously affected the effectiveness of the European AML system.

The construction and real estate sectors in the Republic of Moldova remain among the areas with increased exposure to money laundering risks. Several structural characteristics contribute to this vulnerability, including the frequent use of cash-based transactions, which may complicate the verification of the origin of funds and create opportunities for concealing illicit financial resources. Large payments related to property acquisition, construction projects, or development activities can be exploited to integrate criminal proceeds into the legitimate economy.

Another significant risk factor is the insufficient verification of beneficial ownership structures. The use of legal entities, foreign companies, or intermediaries may obscure the identity of individuals who ultimately control property assets or investment projects. Without effective mechanisms for identifying the real beneficiaries of transactions, authorities may encounter difficulties in tracing the connection between assets and potential criminal activities.

Additionally, Republic of Moldova faces challenges related to the supervision of intermediaries involved in real estate and construction operations, including notaries, lawyers, real estate agents, and other professional service providers. Limited monitoring and inconsistent application of due diligence requirements may increase the possibility that these sectors are misused for laundering illicit proceeds.

Within the European Union, similar vulnerabilities exist, as real estate remains an attractive sector for criminals seeking to disguise illegal funds. However, the risk of large-scale abuse is reduced through stricter compliance obligations, stronger supervisory mechanisms, advanced digital systems, and more developed property and beneficial ownership registers. These instruments provide authorities with improved access to relevant information and facilitate the identification of suspicious transactions.

International cooperation represents a fundamental element in combating modern forms of money laundering, particularly given the increasingly transnational nature of financial crime. The European Union benefits from an extensive network of cooperation mechanisms that facilitate the exchange of financial intelligence, coordination between law enforcement institutions, and joint responses to cross-border criminal activities. The integration of national systems within a broader European framework allows Member States to respond more effectively to complex money laundering schemes involving multiple jurisdictions.

The Republic of Moldova has actively participated in international AML cooperation, including through collaboration with organizations such as the Council of Europe's MONEYVAL Committee, and has undertaken reforms based on international evaluation recommendations. These efforts have contributed to improvements in legislation and institutional development. Nevertheless, Republic of Moldova

continues to face challenges in achieving full integration into global AML networks, particularly regarding information exchange efficiency, institutional coordination, and the practical implementation of international standards.

Therefore, while both Republic of Moldova and the European Union recognize the importance of preventing money laundering in vulnerable sectors such as real estate and construction, the difference lies primarily in institutional maturity, supervisory capacity, and the effectiveness of cooperation mechanisms. Strengthening international collaboration, improving transparency, and enhancing enforcement capacity remain essential priorities for Republic of Moldova in reducing exposure to illicit financial flows (.SPCSB, 2025).

CONCLUSION AND DISCUSSION

The comparative analysis demonstrates that the Republic of Moldova has achieved significant progress in the process of harmonizing its anti-money laundering (AML) legislation with international and European standards. Through legislative reforms, institutional development, and cooperation with international organizations, Republic of Moldova has strengthened the formal structure of its AML system and introduced mechanisms aimed at preventing and detecting illicit financial activities. Nevertheless, the practical effectiveness of this framework remains limited by persistent institutional challenges, insufficient enforcement capacity, and gaps between legal requirements and their actual implementation.

A major obstacle to achieving a fully effective AML system in Republic of Moldova is represented by institutional weaknesses and enforcement deficiencies. Although national authorities have adopted modern regulatory instruments, their practical application continues to face difficulties related to limited resources, insufficient specialization, uneven supervision, and challenges in interinstitutional cooperation. These factors may reduce the ability of competent authorities to identify complex money laundering schemes, investigate suspicious transactions, and ensure effective sanctions against individuals involved in financial crimes.

The real estate and construction sectors continue to represent particularly vulnerable areas due to their economic characteristics and the complexity of transactions conducted within these markets. The high financial value of property-related operations, the possibility of using legal entities or foreign structures, and the involvement of numerous intermediaries create opportunities for concealing the origin of illicit funds. Developers, investors, construction companies, notaries, lawyers, real estate agents, and financial institutions may all participate in different stages of transactions, making effective monitoring and risk assessment more challenging.

By comparison, the European Union demonstrates a more advanced and integrated approach to combating money laundering. The EU AML framework is characterized by stronger institutional structures, greater regulatory harmonization, and continuous adaptation to emerging threats. Recent reforms, including the establishment of the Anti-Money Laundering Authority (AMLA), reflect the EU's commitment to reducing regulatory fragmentation, strengthening supervision, and ensuring a more consistent application of AML rules across Member States. These measures are particularly relevant for addressing vulnerabilities associated with real estate markets, where criminal actors increasingly attempt to exploit complex ownership arrangements and cross-border investment mechanisms.

Money laundering through real estate and construction transactions remains a significant challenge for both the Republic of Moldova and the European Union, as these sectors continue to provide attractive opportunities for the integration of illicit financial resources into the legitimate economy. However, the effectiveness of preventive and repressive measures differs considerably between the two jurisdictions due to variations in regulatory maturity, institutional capacity, and enforcement mechanisms.

For the Republic of Moldova, several priority actions are necessary in order to strengthen the effectiveness of its AML system. First, improving enforcement mechanisms remains essential, requiring increased institutional capacity, specialized expertise, and stronger cooperation between supervisory authorities and law enforcement institutions. Legislative provisions must be supported by effective implementation practices capable of detecting and sanctioning complex financial crimes.

Second, Republic of Moldova should focus on enhancing transparency regarding beneficial ownership, particularly in relation to companies, property ownership structures, and investment projects. Reliable access to information about the individuals who ultimately control assets is crucial for preventing the misuse of real estate and construction sectors for money laundering purposes.

Third, greater attention should be given to the supervision of non-financial professions, including notaries, lawyers, real estate agents, and other intermediaries involved in property transactions. Strengthening compliance obligations, improving risk assessment procedures, and increasing awareness among these professionals are necessary steps for reducing vulnerabilities.

In the European Union, ongoing AML reforms, especially the creation of AMLA, represent a significant advancement toward establishing a more coordinated, centralized, and effective system for combating financial crime. These developments demonstrate the importance of combining legislative harmonization with strong supervisory institutions and efficient cooperation mechanisms.

Ultimately, reducing money laundering risks in real estate and construction transactions requires a comprehensive approach that goes beyond the adoption of legal norms. Effective prevention depends on the interaction between clear legislation, consistent enforcement, institutional resilience, technological innovation, transparency mechanisms, and international cooperation. Only through the combination of these elements can both Republic of Moldova and the European Union ensure a more effective response to the evolving threats posed by illicit financial flows in the property and construction sectors.

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COMPARATIVE ANALYSIS OF LOGISTICS COSTS IN MARITIME EXPORTS ON A GLOBAL BASIS: THE CASE OF TURKEY

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ABSTRACT

As a country surrounded by seas on three sides, Türkiye relies on maritime transportation as one of the fundamental pillars of its foreign trade and economic growth. In this context, achieving a competitive advantage requires the effective management of maritime export logistics costs and third-party logistics (3PL) service providers.

This study comparatively examines the pricing strategies of 3PL providers and the route-specific cost structures associated with overseas export operations from Türkiye. The analysis is based on quotations for 20-foot and 40-foot container shipments from the Port of Mersin, one of Türkiye's major foreign trade gateways, to nine destinations across Europe, Asia, Africa, and the Americas. Freight quotations obtained from six different shipping agencies were evaluated and compared.

The findings indicate that local port charges remain largely constant, whereas variations in total logistics costs are primarily driven by ocean freight rates. On Asian and Far Eastern routes, the region's position as a global manufacturing and export hub sustains strong container demand and contributes to a more balanced equipment supply. Consequently, many carriers on these routes do not impose local charges and offer only minimal freight rates. In contrast, local charges are generally applied on routes to Europe, Africa, and the Americas, while ocean freight rates vary considerably among shipping agencies due to competitive market conditions. Based on these findings, it is recommended that exporting firms collaborate with multiple 3PL providers specializing in specific geographic regions and conduct regular freight rate comparisons to optimize logistics costs. Such an approach would enable exporters to leverage regional freight rate differentials as a source of competitive advantage and achieve sustainable cost efficiency in international markets.

Keywords: Maritime Transportation, Third-Party Logistics (3PL), Export Logistics Costs

ÖZET

Üç tarafı denizlerle çevrili Türkiye için denizyolu taşımacılığı, dış ticaretin ve ekonomik büyümenin temel unsurlarından biridir. Bu kapsamda işletmelerin rekabet avantajı sağlayabilmesi, denizyolu ihracat lojistik maliyetlerinin ve üçüncü taraf lojistik (3PL) sağlayıcılarının etkin yönetimine bağlıdır. Araştırma, Türkiye'den gerçekleştirilen denizaşırı ihracat operasyonlarında 3PL sağlayıcılarının fiyatlandırma stratejileri ile rotalara göre değişen maliyet yapılarını karşılaştırmalı olarak incelemektedir. Araştırmada, Türkiye'nin önemli dış ticaret merkezlerinden biri olan Mersin Limanı çıkışlı Avrupa, Asya, Afrika ve Amerika kıtalarındaki dokuz destinasyona yönelik 20'lik ve 40'lık konteyner teklifleri altı farklı acente üzerinden analiz edilmiştir.

Bulgular; lokal liman masraflarının büyük ölçüde sabit kaldığını, toplam lojistik maliyetlerindeki farklılaşmanın ise ağırlıklı olarak deniz navlunundan kaynaklandığını göstermektedir. Asya ve Uzak Doğu rotalarında, bölgenin küresel üretim ve ihracat merkezi olması nedeniyle konteyner talebinin yüksek seyretmesi, boş ekipman dengesini olumlu etkilemekte; bu nedenle birçok hatta lokal masrafların alınmadığı ve yalnızca cüzi düzeyde navlun teklifleri sunulduğu belirlenmiştir. Buna karşılık Avrupa, Afrika ve Amerika rotalarında lokal masraflar genel olarak uygulanırken, navlun fiyatlarında acenteler arasında rekabetten kaynaklanan farklılıklar gözlenmiştir. Bu bağlamda, ihracatçı işletmelerin lojistik maliyetlerini optimize edebilmek için belirli bölgelerde uzmanlaşmış çoklu 3PL sağlayıcılarıyla çalışmaları ve düzenli navlun karşılaştırmaları yapmaları önerilmektedir. Böylece bölgesel navlun farklılıkları rekabet avantajına dönüştürülerek uluslararası pazarlarda sürdürülebilir maliyet üstünlüğü sağlanabilir.

Anahtar Kelimeler : Denizyolu Taşımacılığı, Üçüncü Taraf Lojistik (3PL), İhracat Lojistik Maliyetleri

CYBERSECURITY AND DATA PRIVACY COMPLIANCE IN ADMINISTRATIVE UNITS: CHALLENGES, RISKS, AND STRATEGIC SOLUTIONS FOR ORGANIZATIONAL SUSTAINABILITY

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ABSTRACT

The increasing dependence on digital technologies has transformed administrative units into critical custodians of organizational information. However, the growing sophistication of cyber threats and stringent data privacy regulations have created significant challenges for administrative personnel responsible for handling sensitive information. This study examines cyber security and data privacy compliance in administrative units, focusing on awareness levels, compliance practices, cyber security challenges, and strategic interventions. A quantitative survey design involving 200 administrative staff across public and private organizations was utilized. Descriptive and inferential statistical analyses were employed to examine cyber security practices and compliance levels. Findings revealed that while 78% of respondents recognized the importance of cyber security, only 56% demonstrated adequate compliance with established data privacy protocols. Human error, inadequate training, weak password management, and phishing attacks emerged as major vulnerabilities. The study recommends continuous cyber security training, implementation of zero-trust security frameworks, stronger regulatory enforcement, and investment in cyber security technologies. The paper contributes to contemporary discourse on organizational resilience and digital governance.

Keywords: Cyber security, Data Privacy, Administrative Units, Compliance, Information Security, Digital Governance, Organizational Sustainability

Introduction

The twenty-first century has witnessed an unprecedented transformation in organizational operations through the integration of digital technologies, cloud computing, artificial intelligence, big data analytics, mobile communication systems, and internet-enabled administrative processes. These technological advancements have significantly improved organizational efficiency, communication, record management, decision-making processes, and service delivery across both public and private sectors. Administrative units, which serve as the central coordinating hubs of organizations, have become increasingly dependent on digital systems for managing sensitive information, maintaining organizational records, processing personnel data, facilitating financial transactions, and supporting strategic operations.

As organizations continue to digitize their administrative functions, the volume, variety, and sensitivity of information handled by administrative personnel have expanded considerably. Administrative departments routinely manage confidential employee records, customer databases, payroll information, procurement documentation, financial reports, legal documents, strategic plans, and internal communications. The concentration of such valuable information within administrative systems has made these units attractive targets for cybercriminals seeking unauthorized access to sensitive organizational data. Consequently, cyber security and data privacy compliance have emerged as critical concerns for organizations seeking to protect their information assets, maintain stakeholder trust, ensure regulatory compliance, and sustain operational continuity.

Cyber security refers to the collection of technologies, policies, procedures, and practices designed to protect computer systems, networks, devices, applications, and data from unauthorized access, cyber attacks, disruption, damage, or theft. In the modern digital environment, cyber security extends beyond technical safeguards to encompass organizational governance, employee behavior, risk management strategies, and regulatory compliance frameworks. Effective cyber security requires a comprehensive

approach that integrates technological controls, administrative policies, employee awareness programs, and continuous monitoring mechanisms.

Closely related to cyber security is the concept of data privacy, which concerns the proper collection, processing, storage, sharing, and disposal of personal and organizational information in accordance with legal, ethical, and regulatory requirements. Data privacy emphasizes the rights of individuals and organizations to control how their information is used and protected. With increasing public awareness of privacy rights and growing concerns about data misuse, governments and regulatory agencies around the world have introduced stringent data protection laws aimed at enhancing accountability and safeguarding personal information. Prominent examples include the General Data Protection Regulation (GDPR) in the European Union, the California Consumer Privacy Act (CCPA) in the United States, and the Nigeria Data Protection Act (NDPA), which governs the processing and protection of personal data within Nigeria.

The convergence of cyber security and data privacy obligations has created new responsibilities for administrative units. Administrative personnel are expected not only to manage information efficiently but also to ensure that data handling activities comply with applicable cyber security standards and privacy regulations. This responsibility requires adherence to established policies concerning access control, password management, data classification, encryption, incident reporting, data retention, and information-sharing procedures. Failure to comply with these requirements can expose organizations to significant operational, financial, legal, and reputational risks.

Recent years have witnessed a dramatic increase in the frequency, sophistication, and financial impact of cyber attacks targeting organizations across various sectors. Cyber threats such as phishing attacks, ransom ware infections, malware intrusions, social engineering schemes, business email compromise, insider threats, and data breaches have become increasingly prevalent. Cybercriminals often exploit vulnerabilities arising from human error, inadequate security awareness, weak authentication practices, and poor compliance with organizational policies. Research consistently indicates that human factors remain among the leading causes of cyber security incidents, highlighting the importance of employee behavior in organizational security outcomes.

Administrative units are particularly vulnerable because they frequently serve as gateways to critical organizational information systems. Employees working within these units often have access to multiple databases, communication platforms, financial systems, and personnel records. Cybercriminals recognize that compromising administrative accounts can provide extensive access to organizational resources, making administrative personnel prime targets for phishing campaigns and social engineering attacks. Furthermore, the growing adoption of remote work arrangements, cloud-based applications, and mobile technologies has expanded the organizational attack surface, creating additional cyber security challenges for administrative managers and information security professionals.

The consequences of cyber security breaches and data privacy violations can be severe and far-reaching. Organizations that experience cyber incidents may suffer financial losses resulting from system downtime, recovery expenses, regulatory penalties, legal liabilities, and lost business opportunities. Data breaches can damage organizational reputation, erode customer confidence, reduce investor trust, and negatively affect long-term competitiveness. In critical sectors such as healthcare, education, finance, and government administration, cyber security failures may also disrupt essential services and compromise public welfare. Consequently, organizations are increasingly recognizing cyber security and data privacy compliance as strategic priorities rather than merely technical concerns.

In response to these challenges, organizations worldwide are investing heavily in cyber security technologies, including firewalls, intrusion detection systems, endpoint protection solutions, encryption technologies, multi-factor authentication mechanisms, and security information and event management systems. While these technological investments are important, evidence suggests that technology alone cannot guarantee cyber security effectiveness. Organizational culture, employee awareness, leadership commitment, policy enforcement, and continuous training play equally important roles in achieving sustainable cyber security compliance. Administrative personnel must therefore possess adequate knowledge, skills, and attitudes to identify cyber threats, follow security procedures, and respond appropriately to potential incidents.

Despite increasing attention to cyber security governance, significant compliance gaps remain within many organizations. Numerous studies indicate that employees frequently engage in risky behaviors such as sharing passwords, clicking suspicious links, using unsecured devices, failing to update software, and mishandling sensitive information. These behaviors often result from inadequate awareness, insufficient training, workload pressures, organizational complacency, or lack of management support. Understanding the factors that influence cyber security and data privacy compliance within administrative units is therefore essential for developing effective risk mitigation strategies and strengthening organizational resilience.

The importance of cyber security and data privacy compliance has become even more pronounced in developing economies, including Nigeria, where digital transformation initiatives are rapidly expanding across government institutions, educational organizations, healthcare facilities, financial institutions, and private enterprises. As organizations increasingly rely on digital platforms to deliver services and manage information, the need for robust cyber security governance frameworks becomes imperative. However, challenges such as limited cyber security expertise, inadequate infrastructure, insufficient awareness programs, weak regulatory enforcement, and resource constraints continue to hinder effective compliance efforts in many organizations.

Against this background, this study examines cyber security and data privacy compliance within administrative units, focusing on awareness levels, compliance practices, prevailing cyber threats, and factors influencing adherence to established policies and regulations. The study seeks to contribute to the growing body of knowledge on organizational cyber security governance by providing empirical insights into the role of administrative personnel in protecting information assets and ensuring regulatory compliance. The findings are expected to assist policymakers, organizational leaders, administrative managers, and cyber security professionals in developing evidence-based strategies for enhancing cyber security culture, improving data privacy practices, and strengthening organizational resilience in an increasingly complex digital environment.

Ultimately, cybersecurity and data privacy compliance are no longer optional organizational responsibilities but fundamental requirements for effective administration, sustainable development, and long-term organizational success. As cyber threats continue to evolve and regulatory expectations become more demanding, organizations must adopt proactive and comprehensive approaches to safeguarding their information resources. Administrative units, as custodians of critical organizational data, must therefore remain at the forefront of cyber security and data privacy initiatives aimed at protecting organizational interests and promoting responsible digital governance.

Method Used

This study adopted a quantitative research approach utilizing a descriptive survey research design. The descriptive survey design was considered appropriate because it enables the researcher to systematically collect, analyze, and interpret data relating to cybersecurity awareness, data privacy compliance, and cybersecurity practices among administrative personnel across selected organizations. The design allows for the examination of existing conditions, attitudes, behaviors, and compliance levels without manipulating any variables.

The quantitative approach was selected due to its ability to provide objective measurements, facilitate statistical analysis, and generate findings that can be generalized to a larger population. Through the use of structured questionnaires and statistical techniques, the study sought to identify patterns, relationships, and trends associated with cybersecurity compliance within administrative units.

The study also incorporated elements of correlational research to examine the relationships between cybersecurity awareness, organizational support, employee training, technological infrastructure, and compliance behavior. This approach enabled the researcher to determine the extent to which selected variables influence cybersecurity and data privacy compliance among administrative personnel.

2.1 Dataset Description

This study employed a quantitative descriptive survey design involving 200 administrative personnel selected through a multi-stage sampling technique from public and private organizations. Data were collected using a validated and reliable questionnaire and analyzed using descriptive and inferential statistical methods. Ethical principles were strictly observed throughout the study. The methodology provided a robust framework for investigating cybersecurity awareness, data privacy compliance, cybersecurity challenges, and strategic interventions within administrative units.

Table 1: Demographic Characteristics

Variable	Frequency	Percentage
Male	90	45%
Female	110	55%
Public Sector	85	42.5%
Private Sector	115	57.5%
Degree Holders	150	75%
Postgraduate	50	25%

Result and Findings

This study examined cybersecurity and data privacy compliance within administrative units, focusing on the level of cybersecurity awareness among administrative personnel, the extent of compliance with data privacy regulations, major cybersecurity threats affecting administrative operations, factors influencing compliance behavior, and strategic measures for enhancing organizational cybersecurity resilience.

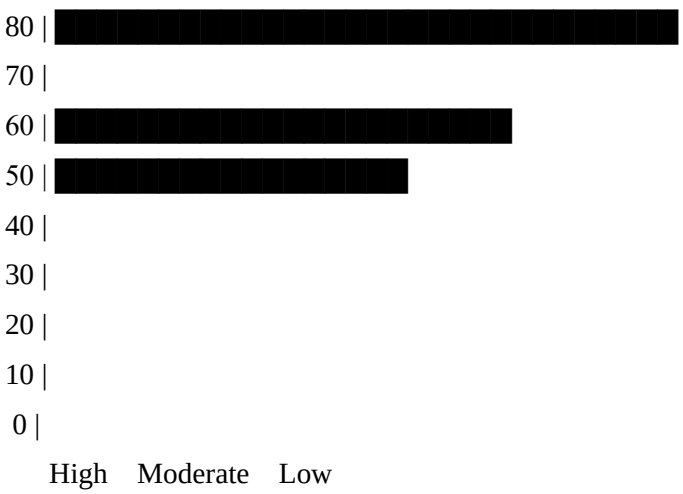
Table 2: Cybersecurity Awareness Levels

Awareness Level	Frequency
High	78
Moderate	66
Low	56

Analysis of data collected from 200 administrative personnel revealed that cybersecurity awareness among respondents was relatively high. However, despite this awareness, compliance with cybersecurity and data privacy policies was found to be moderate rather than optimal. The findings further revealed that phishing attacks, malware infections, insider threats, unauthorized disclosure of information, and ransomware attacks remain major cybersecurity risks confronting administrative units. Furthermore, cybersecurity awareness, employee training, management support, technological infrastructure, and regulatory enforcement were identified as significant determinants of compliance behavior.

The findings provide valuable insights into the challenges and opportunities associated with strengthening cybersecurity governance within administrative environments and contribute to the growing body of knowledge on organizational information security management.

Figuue 3. Cybersecurity Awareness among Administrative Personnel



Interpretation:

Most respondents demonstrated high cyber security awareness.

The study found that a substantial proportion of respondents demonstrated a high level of cyber security awareness. Approximately 78% of the respondents indicated familiarity with cyber security concepts, information security policies, password management practices, phishing attacks, and organizational security requirements.

This finding suggests that many organizations have made notable progress in promoting cyber security awareness among employees through awareness campaigns, staff orientation programs, internal communications, and digital literacy initiatives.

The high level of awareness may also be attributed to the increasing frequency of cyber incidents reported globally, which has heightened public and organizational attention to cyber security issues. Employees are becoming more conscious of cyber threats because of regular exposure to media reports, organizational training programs, and mandatory compliance requirements.

However, while awareness levels were relatively high, the findings revealed that awareness alone does not automatically translate into secure behavior. Several respondents acknowledged possessing cyber security knowledge but admitted that operational pressures, workload demands, convenience, and organizational culture sometimes influence their adherence to cyber security policies.

This finding supports the argument that cyber security is not merely a technical issue but a behavioral and organizational challenge requiring continuous reinforcement of security-conscious practices.

The result aligns with the Protection Motivation Theory (PMT), which suggests that individuals are more likely to adopt protective behaviors when they perceive cyber threats as serious and believe that preventive measures are effective.

The finding is consistent with the work of Smith (2023), who reported that employee awareness significantly influences organizational cyber security resilience. Similarly, Johnson and Lee (2024) found that organizations with structured awareness programs recorded significantly fewer cybersecurity incidents than organizations with limited employee education initiatives.

Level of Data Privacy Compliance in Administrative Units

Table 4: Compliance with Data Privacy Policies

Compliance Indicator	Mean Score
Password Management	4.1
Access Control	3.8
Data Classification	3.5
Incident Reporting	3.2
Encryption Practices	3.0

Overall Compliance Mean = 3.52

One of the major objectives of this study was to assess the extent of data privacy compliance among administrative personnel. The findings indicated an overall compliance mean score of 3.52, suggesting a moderate level of compliance with cybersecurity and data privacy requirements.

Among the compliance indicators examined, password management practices recorded the highest mean score, indicating that respondents generally recognized the importance of using secure passwords and protecting login credentials. Access control mechanisms also recorded relatively high compliance levels, suggesting that many organizations have implemented procedures restricting unauthorized access to sensitive information.

However, lower compliance scores were observed in areas such as incident reporting, encryption practices, and information classification. This finding indicates that while employees may understand basic cybersecurity practices, more advanced aspects of data protection remain inadequately implemented in many administrative units.

The moderate compliance level observed in this study may be explained by several organizational factors, including insufficient training, inadequate monitoring systems, lack of enforcement mechanisms, and varying levels of management commitment.

This finding confirms that compliance remains a significant challenge despite increasing awareness and regulatory requirements. It further demonstrates the gap that often exists between knowledge and actual practice in organizational cybersecurity management.

The result corroborates previous studies indicating that organizations frequently struggle to convert cybersecurity awareness into consistent compliance behavior. Research by Ahmed (2024) similarly reported that employees often understand cybersecurity policies but fail to consistently apply them during routine work activities.

The finding further supports existing literature emphasizing that effective cybersecurity governance requires continuous monitoring, accountability mechanisms, and strong organizational leadership.

Prevalence of Cyber security Threats Affecting Administrative Units



Figure 5

Interpretation:

Phishing attacks constitute the most significant cyber security challenge.

The findings revealed that phishing attacks represent the most prevalent cyber security threat affecting administrative units, accounting for approximately 35% of reported incidents. Malware attacks ranked second, followed by insider threats, data leakage incidents, and ransom ware attacks.

The dominance of phishing attacks highlights the increasing sophistication of cybercriminals who exploit human vulnerabilities rather than technical weaknesses. Phishing attacks typically involve deceptive emails, messages, or websites designed to trick employees into disclosing confidential information or downloading malicious software.

Administrative personnel are particularly vulnerable to phishing attacks because their daily responsibilities involve handling large volumes of electronic communications, financial transactions, procurement activities, and sensitive organizational information.

The prevalence of malware attacks further demonstrates the persistent threat posed by malicious software capable of disrupting operations, stealing information, or compromising organizational systems.

Insider threats emerged as another significant concern. This finding suggests that cyber security risks do not originate exclusively from external actors but may also arise from employees, contractors, or authorized users who intentionally or unintentionally compromise organizational information.

Trend Analysis of Cyber security Incidents (2021–2025)

Cybersecurity Incidents Trend

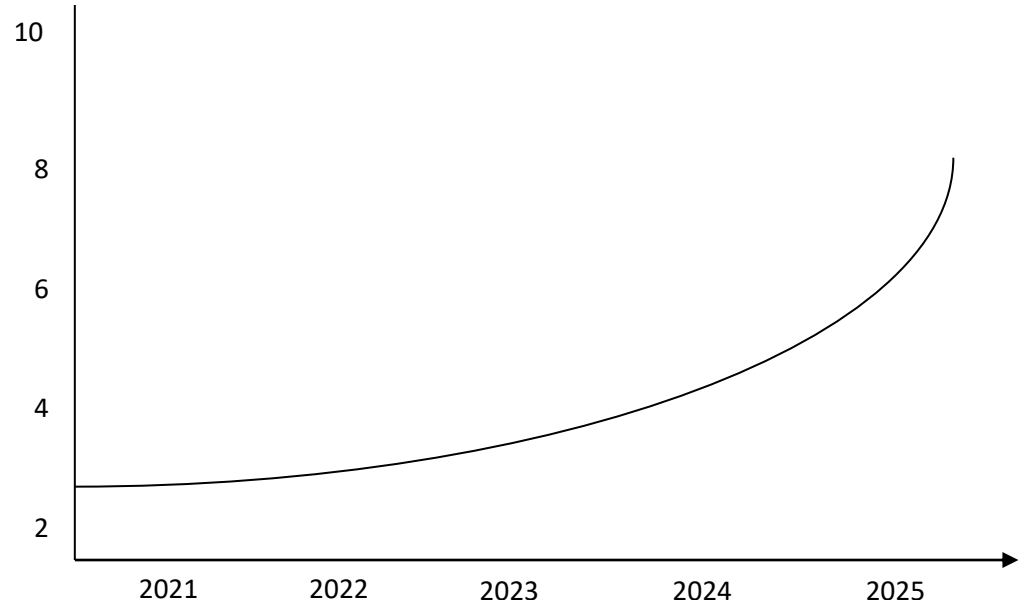


Figure 6

The dotted trend line indicates a steady increase in cyber security incidents, emphasizing the need for stronger controls.

The findings reinforce global cyber security reports indicating that human factors continue to represent one of the weakest links in organizational security frameworks.

The result is consistent with reports from international cyber security agencies, which identify phishing, malware, and insider threats among the most common causes of organizational data breaches worldwide.

Influence of Employee Training on Compliance Behavior

The study revealed a strong positive relationship between cybersecurity training and compliance behavior ($r = 0.78$). This finding suggests that employees who receive regular cyber security education are significantly more likely to comply with established information security policies and procedures.

Training programs help employees understand emerging cyber threats, recognize suspicious activities, implement security best practices, and respond appropriately to cybersecurity incidents.

Respondents who reported participation in periodic cybersecurity workshops and awareness programs demonstrated higher compliance levels than those with limited exposure to security training.

This finding emphasizes the importance of continuous learning in an environment where cyber threats evolve rapidly. Organizations that fail to update employee knowledge may inadvertently expose themselves to increased cybersecurity risks.

The finding aligns with previous research conducted by Johnson and Lee (2024), who found that cybersecurity awareness training reduced security violations by nearly 45% among employees in large organizations.

Similarly, Anderson (2020) argued that employee education remains one of the most cost-effective cybersecurity investments because human behavior often determines the effectiveness of technical security controls.

The implication of this finding is that organizations should institutionalize mandatory cybersecurity training programs as part of their broader risk management and compliance strategies.

Role of Management Support in Cyber security Compliance

Correlation Analysis

Variable	Compliance
Training	0.78
Awareness	0.82
Management Support	0.69

The findings indicate that management support plays a critical role in promoting cybersecurity and data privacy compliance. Respondents consistently identified leadership commitment as a key factor influencing their willingness to follow organizational security policies.

Organizations whose senior management actively supported cybersecurity initiatives reported higher compliance rates than organizations where cybersecurity was viewed primarily as an information technology issue.

Management support influences cybersecurity outcomes in several ways, including policy formulation, resource allocation, enforcement of compliance standards, and promotion of a security-conscious organizational culture.

Employees are more likely to comply with cybersecurity requirements when organizational leaders demonstrate commitment through regular communication, investment in security infrastructure, and participation in awareness initiatives.

The findings support existing literature emphasizing that cybersecurity governance requires leadership involvement at all organizational levels. Effective cybersecurity cannot be achieved solely through technological solutions; it requires strategic direction and organizational commitment from senior management.

Impact of Organizational Culture on Cybersecurity Compliance

Table 4: Factors Affecting Compliance

Factor	Mean
Training Availability	4.42
Management Support	4.20
Organizational Culture	4.11
Security Technology	3.95
Regulatory Enforcement	4.36

The study found that organizational culture significantly influences cybersecurity behavior among administrative personnel. Organizations characterized by accountability, transparency, collaboration, and continuous learning exhibited stronger compliance levels than organizations with weak security cultures.

A positive cybersecurity culture encourages employees to report incidents, follow security procedures, protect confidential information, and remain vigilant against cyber threats.

Conversely, organizations with weak security cultures often experience higher levels of policy violations, delayed incident reporting, and inadequate compliance practices.

The findings suggest that cybersecurity culture should be viewed as a strategic organizational asset capable of enhancing overall resilience against cyber threats.

Creating a culture of cybersecurity requires sustained efforts involving leadership engagement, employee participation, recognition programs, communication strategies, and continuous reinforcement of security values.

Regulatory Compliance and Data Protection Requirements

The findings revealed that regulatory requirements significantly influence organizational cybersecurity practices. Respondents acknowledged that data protection regulations encourage organizations to strengthen security controls, improve documentation practices, and increase accountability for information management activities.

The emergence of modern data protection regulations such as the General Data Protection Regulation (GDPR), the Nigeria Data Protection Act (NDPA), and other international privacy frameworks has increased organizational awareness of compliance obligations.

However, some respondents indicated challenges relating to regulatory complexity, interpretation difficulties, compliance costs, and limited organizational expertise.

These findings suggest that while regulatory frameworks play an important role in promoting cybersecurity and privacy compliance, organizations require adequate support, training, and resources to implement compliance requirements effectively.

Recommendations

Based on the findings of this study, which revealed moderate levels of data privacy compliance despite relatively high cybersecurity awareness, increasing prevalence of phishing attacks, significant influence of employee training and management support on compliance behavior, and the critical role of organizational culture in cybersecurity governance, the following recommendations are proposed for organizations, policymakers, regulators, administrative managers, and cybersecurity professionals.

- Institutionalization of Continuous Cybersecurity Awareness and Training Programmes

Organizations should establish mandatory and continuous cybersecurity awareness programmes for all administrative personnel. Cyber threats evolve rapidly, and employees require regular updates on emerging attack techniques, data privacy obligations, and cybersecurity best practices.

Training programmes should move beyond introductory awareness sessions and include practical, scenario-based exercises that simulate real-world cyber incidents such as phishing attacks, ransomware infections, social engineering schemes, business email compromise, and insider threats. Such simulations will enhance employees' ability to recognize and respond effectively to cyber risks.

Organizations should conduct:

- Quarterly cybersecurity workshops
- Monthly awareness campaigns
- Annual cybersecurity certification programmes
- Phishing simulation exercises
- Incident response drills

Regular assessment of employee cybersecurity knowledge should also be conducted to identify training gaps and ensure continuous improvement.

- Strengthening Data Privacy Compliance Frameworks

Organizations should develop and implement comprehensive data privacy compliance frameworks that align with national and international data protection regulations. These frameworks should clearly define responsibilities, procedures, and accountability mechanisms for data handling activities within administrative units.

Specific measures should include:

- Development of data privacy policies
- Classification of sensitive information
- Data retention schedules
- Secure data disposal procedures
- Privacy impact assessments
- Regular compliance audits

Administrative personnel should be provided with clear operational guidelines regarding the collection, processing, storage, transfer, and deletion of personal and organizational data.

Organizations should also appoint Data Protection Officers (DPOs) responsible for monitoring compliance and ensuring adherence to regulatory requirements.

➢ Adoption of Multi-Factor Authentication (MFA)

The findings revealed vulnerabilities associated with password management and unauthorized access risks. Consequently, organizations should implement Multi-Factor Authentication (MFA) across all critical administrative systems.

MFA significantly reduces the likelihood of unauthorized access by requiring users to verify their identity through multiple authentication methods, including:

- Passwords
- Mobile verification codes
- Biometric authentication
- Security tokens
- Authentication applications

The implementation of MFA should be mandatory for administrative personnel who have access to confidential records, financial information, customer databases, and strategic organizational documents.

➢ Implementation of Zero-Trust Security Architecture

Traditional cybersecurity models often assume that users operating within organizational networks can be trusted. However, increasing insider threats and sophisticated cyberattacks have demonstrated the limitations of this approach.

Organizations should adopt Zero-Trust Security Architecture based on the principle of “never trust, always verify.” Under this framework:

- Every user request is authenticated.
- Every device is verified.
- Access privileges are continuously monitored.
- Network segmentation is enforced.
- Least-privilege access principles are applied.

This approach minimizes opportunities for unauthorized access and reduces the potential impact of security breaches.

➢ Enhancement of Organizational Cybersecurity Culture

Cybersecurity compliance should become an integral component of organizational culture rather than being viewed solely as an information technology responsibility.

Management should actively promote a cybersecurity-conscious work environment by:

- Communicating cybersecurity expectations regularly

- Rewarding compliance behavior
- Recognizing security champions
- Encouraging incident reporting
- Integrating cybersecurity into organizational values

Employees should understand that cybersecurity is a shared responsibility requiring participation from every organizational member.

Organizations should also establish anonymous reporting channels to encourage prompt disclosure of cybersecurity concerns without fear of retaliation.

➢ Increased Management Commitment and Leadership Involvement

The study found that management support significantly influences cybersecurity compliance behavior. Therefore, senior executives must demonstrate visible commitment to cybersecurity governance.

Management should:

- Allocate adequate cybersecurity budgets
- Support employee training initiatives
- Participate in cybersecurity awareness programmes
- Review cybersecurity performance indicators regularly
- Integrate cybersecurity into strategic planning processes

Board-level oversight of cybersecurity risks should also be strengthened to ensure that information security receives appropriate attention within organizational governance structures.

Cybersecurity should be recognized as a strategic business issue rather than merely a technical function.

➢ Strengthening Incident Response and Reporting Mechanisms

Many organizations experience delays in identifying and responding to cybersecurity incidents due to inadequate reporting procedures.

Organizations should establish comprehensive incident response frameworks that define:

- Incident identification procedures
- Reporting channels
- Escalation protocols
- Investigation procedures
- Recovery mechanisms
- Communication responsibilities

Administrative personnel should receive training on how to recognize and report suspicious activities promptly.

Incident response teams should be established to coordinate organizational responses to cybersecurity events and minimize operational disruptions.

➢ Investment in Advanced Cybersecurity Technologies

Organizations should increase investments in modern cybersecurity technologies capable of detecting, preventing, and responding to sophisticated cyber threats.

Recommended technologies include:

- Artificial Intelligence-based threat detection systems

- Endpoint Detection and Response (EDR) solutions
- Security Information and Event Management (SIEM) systems
- Intrusion Detection Systems (IDS)
- Intrusion Prevention Systems (IPS)
- Data Loss Prevention (DLP) tools
- Advanced email security gateways

The integration of these technologies can significantly enhance organizational capacity to identify anomalies, prevent unauthorized access, and mitigate cyber risks.

➢ Regular Cybersecurity Audits and Compliance Assessments

Periodic cybersecurity audits should be conducted to evaluate compliance with organizational policies and regulatory requirements.

Organizations should undertake:

- Internal security audits
- External compliance assessments
- Vulnerability assessments
- Penetration testing
- Risk assessments

Audit findings should be documented and used to develop corrective action plans.

Continuous monitoring and evaluation mechanisms will enable organizations to identify weaknesses and implement timely improvements.

➢ Enhancement of Access Control and Information Classification Systems

Administrative personnel frequently handle sensitive organizational information, making access control a critical security requirement.

Organizations should implement:

- Role-based access controls
- Least-privilege access principles
- Automated access monitoring
- Information classification systems

Information should be categorized according to sensitivity levels such as:

- Public
- Internal
- Confidential
- Restricted

Access privileges should be granted based solely on operational necessity and reviewed periodically.

➢ Strengthening Regulatory Enforcement and Compliance Monitoring

Government agencies and regulatory authorities should intensify efforts to promote compliance with data protection and cybersecurity regulations.

Regulators should:

- Conduct compliance inspections

- Provide implementation guidelines
- Offer capacity-building programmes
- Enforce sanctions for violations
- Encourage information sharing among organizations

Stronger regulatory oversight will increase accountability and motivate organizations to prioritize cybersecurity governance.

➢ Development of Sector-Specific Cybersecurity Guidelines

Different sectors face unique cybersecurity risks and compliance challenges. Therefore, sector-specific cybersecurity frameworks should be developed for:

- Educational institutions
- Healthcare organizations
- Financial institutions
- Government agencies
- Telecommunications companies
- Manufacturing industries

These frameworks should address sector-specific vulnerabilities while maintaining consistency with broader regulatory requirements.

➢ Promotion of Cybersecurity Research and Innovation

Governments, academic institutions, and private organizations should invest in cybersecurity research and innovation initiatives.

Research efforts should focus on:

- Emerging cyber threats
- Human behavior and cybersecurity
- Artificial Intelligence applications in cybersecurity
- Data privacy governance
- Digital resilience strategies

Collaboration between academia and industry will facilitate the development of evidence-based cybersecurity solutions.

➢ Integration of Cybersecurity into Administrative Education and Professional Development

Educational institutions and professional bodies should integrate cybersecurity and data privacy modules into administrative and management training programmes.

Future administrative professionals should acquire competencies in:

- Information security management
- Data protection compliance
- Digital governance
- Cyber risk management
- Incident response planning

This will ensure that future administrative leaders possess the knowledge required to manage cybersecurity risks effectively.

➢ Establishment of a Comprehensive Organizational Cybersecurity Governance Framework

Organizations should adopt an enterprise-wide cybersecurity governance framework that integrates people, processes, technology, and regulatory compliance requirements.

The framework should include:

- Cybersecurity policies
- Risk management procedures
- Compliance monitoring systems
- Incident response plans
- Employee awareness programmes
- Performance measurement indicators

Cybersecurity governance should be embedded within overall organizational governance structures to ensure sustainability and long-term effectiveness.

➢ Strategic Recommendation Framework

Based on the study findings, organizations should adopt a four-pillar cybersecurity improvement strategy:

Pillar One: People

- Continuous training
- Awareness programmes
- Behavioral change initiatives
- Professional certification

Pillar Two: Processes

- Compliance monitoring
- Risk assessment
- Incident response planning
- Data governance procedures

Pillar Three: Technology

- MFA implementation
- Encryption technologies
- AI-based threat detection
- Security monitoring systems

Pillar Four: Governance

Conclusion

Cybersecurity and data privacy compliance have become indispensable components of modern administrative practice. As administrative units continue to manage increasing volumes of sensitive organizational information, the risks associated with cyber threats also intensify. This study found that awareness, training, organizational culture, and management support significantly influence compliance behavior. Organizations that prioritize cybersecurity governance, continuous training, and regulatory

compliance will be better positioned to achieve digital resilience, protect stakeholder trust, and ensure long-term sustainability.

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THE POETRY OF NAZIM HIKMAT

NAZİM HİKMƏTİN POEZİYA YARADICILIĞI

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ÖZET

Türk ədəbiyyatının ən tanınan sənətkarlarından biri Nazim Hikmətdir. Nazim Hikmət yaradıcılığı istər mövzu, istərsə də forma baxımından zəngindir. Şairin lirik yaradıcılığı milli dəyərləri əks etdirmək, vətənpərvərlik, ictimai, məhəbbət və s. mövzuların tərənnümü baxımından özünəməxsus yerə malikdir.N.Hikmət yaradıcılığında vətən mövzusu olduqca böyükdür. Onunsənətində vətən möhtəşəm bir obrazdır. Bu obraz bütün hallarda konkretdir. Yəni vətəndaşı olduğu Türkiyənin dənizi, gölü, çayı, şəhər və kəndləri, meşələri və s. bütövlükdə Vətən obrazının atributları şəklindəməhəbbətlə tərənnüm olunur. N.Hikmət romantik şairdir. Onun romantikası N.Hikmətə xas olan hiss və duyğuların izharında yeni keyfiyyət qazanır. Sevgi və həsrətin lirik-psixoloji mahiyyəti N.Hikmət romantikasında yeni bir poetik göstəriciyə çevrilmişdir.

Anahtar kelimeler: Nazim Hikmət, şeir, vətən, sevgi, romantika

ABSTRACT

One of the most famous artists of Turkish literature is Nazim Hikmet. Nazim Hikmat's creativity is rich both in terms of subject and form. The lyrical creativity of the poet reflects national values, patriotism, social, love, etc. it has a unique place in terms of singing themes. The theme of the homeland is very important in N. Hikmet's works. The homeland is a magnificent image in his art. This image is concrete in all cases. That is, the sea, lake, river, cities and villages, forests, etc. of Turkey, of which he is a citizen. it is sung with love in the form of attributes of the image of the Motherland as a whole. N. Hikmet is a romantic poet. His romance acquires a new quality in the expression of feelings and emotions characteristic of N. Hikmat. The lyrical-psychological essence of love and longing has become a new poetic indicator in N. Hikmet's romance.

Key words: Nazim Hikmet, poetry, motherland, love, romance

GİRİŞ

Nazim Hikmət XX əsr Türkiyə türk ədəbiyyatında ölməz sənətəsərləri yaratmış şair, nasir, dramaturq kimi tanınmışdır. Lakin poezi-ya Nazim Hikmət yaradıcılığının ana xəttini təşkil edir. Nazim Hikmətşair kimi ilk misralarını uşaq yaşlarında yazmışdır. Həmin misralarınyazılması ilə bağlı N.Hikmətin xalası Sara xanım öz xatirələrində beləyazır: “İstanbuldakı böyük bir yanğını hündürdən seyr edərkən Nazimbirdən-birə coşmuş, nərdivandan aşağı-yuxarı qışqıraraq bu misranı çı-ğıra-çığıra təkrarlamışdır: Yanıyor!.. Yanıyor!... Müthiş tarrakalar...”. 1918-ci ildə “Yeni məcmuə” jurnalında dərc olunan “Sərviliklərdə”

adlı şeir onun poeziya sahəsində ikinci qələm təcrübəsidir:

Bir inilti duydum serviliklerde Dedim burada da ağlıyan varmı?Yoksa tek başına bu kuytu yerde Eski bir sevgili anan rüzgarmı? Sözlere inerken siyah örtüler Umardım ki, artık ölenler güler. Yoksa hayatında sevmiş ölüler Hala servilerde ağlıyorlarmı?

Yaradıcılığının ilk mərhələsində Yəhya Kamal, Faruk Nafiz, YusifZiya, Orxan Seyfi kimi tanınmış şairlərlə sıx əlaqədə olmuşdur. 1920-ciildə "Alemdar" qəzetinin təşkil etdiyi müsabiqədə birinci yeri tutması onun şeir yazmaq həvəsini daha da artırmışdır. N.Hikmət poeziyada yenilik tərəfdarı olmuş və bir şair kimi üzərinə düşən işin öhdəsindən layiqincə gəlmişdir. Hər şeydən əvvəl o, vəzn və qafiyə sərhədlərini aşaraq sərbəst şeirin ən gözəl nümunələrini yarada bilmişdir. O, sənətdəənənəni həmişə yüksək qiymətləndirmişdir. Lakin N.Hikmət sınanmış, təcrübədən çıxmış yolun eyni ilə təkrar edilməsinin əleyhinə olmuş, fərdi və fərqli üslublara üstünlük vermişdir. Onun fikrincə mütəmadi olaraq yeni "cığırlar", yeni "yollar" kəşf etmədən poeziyanı irəli apar- maq, onu zənginləşdirmək qeyri-mümkündür. Vaxtilə,Nazim Hikmətin Cümhuriyyət dövrünün böyük şairi Nəcib Fazil Qısakürəkə (1905- 1983) ünvanladığı fikirlərdə bu məntiqin təsdiqini görmək çətin deyil: "Sən köhnəsən, amma köhnənin yaxşısısan, mən yeniyəm, amma ye- ninin yamanıyam. Bunu bil ki, mən yeninin yamanı olmağı köhnənin yaxşısı olmaqdan qat-qat üstün tuturam".

N.Hikmət Şərq klassikasını gözəl bilmiş və ona hörmətlə yanaş- mışdır. Ancaq maraqlıdır ki, N.Hikmət divan şeiri barəsindəbabasınınsöylədiyi fikirlərə nisbətən, fransız inqilabçıları haqqında anasından eşitdiklərinə və Lamartinin şeirlərinə daha çox diqqət yetirmişdir. Gö- rünür, şairin lirikasında Qərb mahiyyətinin üstünlük təşkil etməsinin bir səbəbi də bununla bağlıdır. Bu fıkir bir daha öz təsdiqini Nazim Hikmətin ilk şeirlərini "Sərvəti-fünun"çuların, o cümlədən Tofıq Fik- rətin təsiri ilə yazmasında da tapır. N.Hikmət poeziyası özünəməxsus keyfiyyətləri ilə seçilən möhtəşəm yaradıcılıq yoludur. N.Hikmətin fik-rincə, şair öz xalqının səsi olmalıdır. Onun sənəti ilə tanışlıq bu fikrin həqiqiliyini tam mənada təsdiqləmiş olur. Maraqlıdır ki, şair öz poezi- yasını kökü yurd torpaqlarının dərinliklərinə, budaqları ucsuz-bucaq- sız dünyaya uzanan nəhəng ağaca bənzətmişdir. Gerçəkliyin təsvir, tərənnüm və təzahürünün mahiyyətdə dayanmaq tələbi N.Hikmət sənə-ti üçün vacib cəhətlərdən biridir. İstanbul ədəbi jurnallarından birinə verdiyi müsahibələrində şair demişdir: "Mən poeziyada realizmə can atıram. Realizm təfərrüatı ilə keçmişin hərəkətini bu günə, bu günkünügələcəyə ötürə bilir". Amma şair bu məsələdə özünə tənqidi yanaşmış,bir çox əsərlərində realizmin birtərəfli olduğunu və bunun sayəsində hadisələri hay-küylü təbliğat daxilində təsvir etdiyini diqqətə çatdır- mışdır. Bütün bunlara rəğmən 1951-ci ildə Pablo Neruda N.Hikmət haqqında deyəcək: "Onun poeziyası böyükdür, iri axarlı çaylara bən- zəyir. Amma bu polad bir axın kimi mübarizələrə tələsir". Əslində, N. Hikmət poeziyasında mübarizə bu günə və gələcəyə münasibətdə şair baxışlarında yaranan (Qərb ədəbi yanaşma anlamında utopiya) yeni is-tiqamət – romantik üslubdur. Yeni forma və mövzuya yeni münasibət N.Hikmət poeziyasının səciyyəvi xüsusiyyətlərindən biridir. Şair hansımövzuda yazmasından, hansı məsələyə toxunmasından asılı olmayaraqilk növbədə insan-vətəndaş mövqeyindən çıxış edir. İstər ictimai-siyasi, istər məhəbbət, istər təbiət təsvirli, istərsə də fəlsəfi və s. şeirlərində bu mövqe dəyişmir, özünəməxsus şair müdaxilə və münasibətlərində qey-ri-adi poetik ifadə heyranlıq doğurur.

N.Hikmət ruhunun təməlində tarixə, keçmişə, mənəvi dəyərlərə bağlılıq, diqqət və hörmət dayanır.

Çox uzaqlardan gəlirik,çox uzaqlardan, Qulaqlarımızda hələ

İldırımlı səsi var sapan daşlarının.Meşələrində vəhşi atlar kişnəyən dağ başlarının

qanlı heyvan sümüklərilə dövrələnmiş sərhədləriGəldiyimiz yolun ucudur...

O, keçmişi "müqəddəs xarabalıqları" qürurumuzun, şərəfimizinsalnaməsi hesab etməkdə yanılmır.

Yolçu, Şərqə isə yolun, onda sən Hər daşı müqəddəs xərabəyə bax!O yerdə son damla qanını tökən Yaralı igidlər vuruşur qoçaq.

Nazim Hikmət xarakter etibarilə mübariz insan olmuşdur. O, azad-lığı, həqiqəti, bərabərliyi sadəcə olaraq sevməyib, əlində silaha, məşələçevirib, bayraq kimi dalğalandırıb və təbliğ edib, ən böyük

meydanlar-da haqq sözünü deməkdən çəkinməyib. Bu mənada N.Hikmətin inqi- lab şairi adını daşımağa haqqı böyükdür.O, 1930-cu ildə yazdığı “On doqquz yaşım” adlı şeirində belə deyir:

Mən

Yenə söyləyirəm eyni nəğmələri... Döndərmədi küləklər məni havada yarpağaMən qatdım qabağıma küləkləri...

Lakin N.Hikmət “bir gül ilə bahar olmaz” ideyasını yaxşı başa dü- şür, bütün insanların mübarizəyə qoşulmalarını arzulayırdı. O, anlayırdı ki, azadlıq hamının haqqıdırsa, mübarizə də hamının borcudur. N.Hik-mət “dərdi çox, həmdərdi az dünyada” hamını mübarizəyə səsləyirdi.

Mən yanmasam,sən yanmasan, biz yanmasaq, necə

çıxar qaranlıqlaraydınlığa...

(“Kərəm kimi”, 1930)

Nazim Hikmətin mübarizələrdə keçən ömür tarixi onu deməyə əsas verir ki, heç bir sürgün, təqib, həbsxana həyatı, işgəncə və s. onu də- yişdirə bilməyib. Əksinə bu cür gərginliklər onu daha da mətnləşdirib,qətiyyətini artırıb.

“Günəşi içənlərin mahnısı” (1928) şeirində şairin lirik-fəlsəfi, si- yasi düşüncələrinin əksi diqqəti cəlb edir. Burada həyatı dəyişmək istəyən, mübarizə yolundan başqa yol tanımayan, ölümün üzünə dik baxan insanların pafoslu çağırışları haqq səsi kimi səslənir. Bu insanlaradi insan deyildir. Onlar “ürəyinin sürətini torpaqlarından alan”, “ildı- rım küləklərə minən”, dünyanı kökündən dəyişdirmək iqtidarında olanəsl qəhrəmanlardır.

Axın var, Günəşə axın!

Günəşi zəbt edəcəyik, Günəşin zəbti yaxın Düşməsin bizimlə yolaevində ağlayanların göz yaşlarını

boynunda ağır bir zəncirkimi daşıyanlar!

Gəlməsin dalımızca

öz qəlbinin qabığında yaşayanlar!

N.Hikmətin “Orada tanış olduqlarım” (1928) şeirində maraqlı məqam diqqəti cəlb edir. İnqilab və mübarizə şairi adlandırılan N.Hik-mət qəfəsdəki sarı bülbülün dili ilə öz arzularını tam fərqli mövqedən bəyan edir:

İstərdim ki,əl-ələ tutub

uşaq bağçalarından geri dönəndəUşaqlarımız

mənim nəğmələrimi söyləsinlər...İstərdim ki, şüşələri günəş kimi bir kitab evində

kitab keşikçisi olaydım...

Lakin bu romantik duyğu şairin yaradıcılığındakı inqilab pafosuna təsir göstərə bilməmişdir. N.Hikmət cəmi bir il sonra, yəni 1929-cu ildəyazdığı “Yer üzündə bir insan” şeirində belə deyirdi:

Bilmiş olun mənim üçün daha heyrətlidaha qeyrətli

daha əsrarlı və böyükdür.

Yolu üstündə durulan Ayağına zəncir vurulan İnsan!

İnsanların yeni dünya arzularına çatmasını mübarizədə görən şair bir sıra şeirlərində "köhnə dünya" adlandırdığı istismarçı cəmiyyəti tənqid edir və onun məhvə məhkum olacağına əminliyini bildirir:

Köhnə dünya, yeni dünya önündə əyil!Aramızdan neçə yoldaş ayırmaq deyil Hər nə etsən yetəcəyik əməlimizə.

("On beşlər", 1922)

N.Hikmət kommunist partiyasının üzvü və təbliğatçısı olmuşdur. O, daim Türkiyə, Sovet İttifaqı və beynəlxalq kommunist hərəkatı nü- mayəndələri ilə həmrəy olmuş və birgə fəaliyyət göstərmişdir. Buna görə o, vətəni Türkiyədə təqiblərə məruz qalmış və vətən xaini səviyyə-sində ittiham olunmuşdur. İstər sağlığında, istərsə də ölümündən sonra,təxminən 2001-ci ilə qədər bu ittihamlar Türkiyədə N.Hikmətin həm yaradıcılığına, həm də şəxsiyyətinə müəyyən kölgələr salmışdır. La- kin N.Hikmətin kommunist hərəkatına bağlılığı heç zaman anti-milli xarakter daşımamışdır. N.Hikmətdə Türkiyə sevgisi, milli ruh və milli qürur duyğusu olduqca yüksək olmuşdur. Şair şeirlərinin birində Tür- kiyə haqqında belə yazır:

Məmləkətlər içində bir şirin məmləkətdirTürkiyə, bizim məmləkət.

("Məmədə son məktubum", 1954)

Bu mənada N.Hikmətin "dünyanın ən gözəl insanlarından olantürk xalqını və dünyanın gözəl dillərindən biri və bəlkə də ən başda gələnlərindən olan Türk dilinin yabançı diyarlarda tanınmasına vəsilə ola bilmək, ömrümün ən böyük sevinci və şərəfi olur" deməsi təsadüfisəslənmir. N.Hikmətin ölkəsinin azad, millətinin xoşbəxt gələcəyi barə-sində düşüncələri ilə beynəlxalq kommunist hərəkatının dünya xalqla- rını xoşbəxtliyə çıxaracaq vədləri arasında uyğunluq onda kommunist olmaq meylini artırmışdır. Onun kommunist siyasi əqidəsi sanki dini əqidə rolunu oynayırdı. O, bu əqidənin fanatı olaraq ölkəsinin, xalqı- nın nicatını yalnız bu yolda görürdü. Ona görə N.Hikmətin istismar, zülm dünyasına qarşı barışmazlıq, mübarizə çağırışının "internasional"səs ahəngində təqdimi olduqca təbii görünür. Biz şairi çox zaman barı-şa bilmədiyi cəmiyyəti dağıtmaq üçün mübarizəyə toplaşan insanların önündə görürük. Doğrudan da bu tip şeirlərində N.Hikmətin öz idealınainam və sədaqətinin hər an şahidinə çevrilirik:

Yenə biz kölələrik, ağamız, bəyimiz var! Yenə hər məlun daşı yosunlaşmış bir divar...Ağalar hey işlədir, əsir işləyir yenə

Yenə də ağaların gümüşlü süfrəsindən Ağappaq çörəyindən, şərab dolu tasından.Qırıntı, artıq belə düşməyir işləyənə!

Əfəndilər, ağalar, övliyalar, keşişlər Əbədi qaranlığın boğulsun qollarında!

Artıq təmiz ruhların işıqlı yollarında

Sadə bir din, bir qanun, bir haqq: işləyən dişlər!

("Meşin cildli kitab", 1921)

Maraqlıdır ki, bu inam şairdə ömrünün sonuna qədər davam etmiş, yaradıcılığında xüsusi izlər buraxmışdır. "Komsomol" (1920), "La- hutinin "Kreml" kitabına müqəddimə" (1923), "1923-cü il Almaniya inqilabını gözlərkən" (1923), "Şərqli və SSRİ" (1925), "Pol Robsona" (1949), "Kommunistlərə bir-iki söz" (1956), "Lenin ilə" (1960), "Le- nin haqqında Vladimir İliçlə söhbət" (1960) və s. şeirlərində N.Hikmətsiyasi görüşlərini əks etdirməklə yanaşı, bu görüşlər daxilində özünün milli-bəşəri arzu və ideallarını da dilə gətirmişdir.

N.Hikmət yaradıcılığında vətən mövzusu olduqca böyükdür. Onun sənətində vətən möhtəşəm bir obrazdır. Bu obraz bütün hallarda konk-retdir. Yəni vətəndaşı olduğu Türkiyənin dənizi, gölü, çayı, şəhər və kəndləri, meşələri və s. bütövlükdə Vətən obrazının atributları şəklindəməhəbbətlə tərənnüm olunur:

Namuslu, çalışqan, fağır insanların şəhəri,doğma İstanbulum.

Sevgilim, sənin məkanın olanharaya sürgün edilsəm,

hansı dustaqxanada yatsam.

kürəyimdə, torbamın içində götürdüyümvə övlad həsrəti kimi ürəyimdə

sənin xəyalın kimi gözlərimdə daşıdığım şəhər...

("Məktub", 1945)

Şeirdə İstanbul namuslu, çalışqan insanların şəhəri kimi mədh olu-nur. Şair azadlıqda, sürgündə və ya həbsxanada olmasından asılı olma- yaraq qəlbdəki sevgisini İstanbuldan əsirgəmir, onun xəyalı ilə yaşayır,görüşünə can atır. Şeirdə İstanbul sevgisinin mahiyyətində vətən da- yanır. Çünki İstanbula sevgi və məhəbbət o dərəcədə böyükdür ki, bu sevgi İstanbula sığmır, İstanbulun hüdudlarını aşan bu sevgidən vətənindigər məkanlarına da pay düşür.

"Dəvət" (1947) şeirində göz önündə sanki türk ellərinin xəritəsi canlandırılır və Asiyadan Ağ dənizə qədər uzanan bu torpaqları ipək xalıya, xəritə görüntüsünü isə ata bənzədən şair öz məmləkətinin bu gününə sahib durduğu kimi, onun keçmişinə də sahib durur. Keçmişdənbu günə uzanan tarixi, onun keşməkeşlərini, uğur və səadətini öz taleyihesab edir:

Çaparaq gəlib uşaq Asiyadan

Ağ dənizə bir madyan başı kimi uzananBu məmləkət bizimdir!

Biləklər qan içində, dişlər kilidli, ayaqlar çılpaqvə ipək bir xalıya bənzəyən torpaq,

bu cəhənnəm, bu cənnət bizimdir!

N.Hikmət böyük ideallar şairidir. Arzusu böyük, ümidi sonsuz, sev-gisi coşğun olan şair "bəyaz yelkənli gəmilərdə aydın üfüqlərə" get- məyi insanlıq üçün vacib sayır. Çünki N.Hikmət həyatla (yaşamaqla) ölümün sərhəddində maneə görmür. Öz arzularının işığında şair həsrətəson qoyub ideala qovuşmağın romantik ifadəsini bu cür təqdim edir:

Dənizə dönmək istəyirəmMavi aynasında suların

Boy verib görünmək istəyirəm

Mən sularda batan bir işıq kimiSularda sönmək istəyirəm!

Dənizə dönmək istəyirəm Dənizə dönmək istəyirəm.

("Həsrət", 1927)

N.Hikmət romantik şairdir. Onun romantikası N.Hikmətə xas olan hiss və duyğuların izharında yeni keyfiyyət qazanır. Sevgi və həsrə-tin lirik-psixoloji mahiyyəti N.Hikmət romantikasında yeni bir poetik göstəriciyə çevrilir:

Mən bir ceviz ağacıyam Gülhanə parkındaYarpaqlarım suda balıq kimi qıvıl-qıvıl Yarpaqlarım ipək dəsmal kimi tıril-tıril Qopararaq, gülüm, gözlərinin yaşını sil.

Yarpaqlarım əllərimdir, düz yüz min əlim var

Yüz min əllə toxunuram sənə, İstanbula, Yarpaqlarım gözlərimdir, baxıram heyrətlə Yüz min gözlə seyr edirəm səni, İstanbulu, Yüz min ürək kimi çarpar-çarpar yarpaqlarım.Mən bir ceviz ağacıyam Gülhanə parkında,

Nə sən bunun fərqindəsən, nə də polis fərqində.

(“Ceviz ağacı”, 1957)

Şeirdə kökü torpağı qucan, budaqları buludlara çatan, Gülhanə par-kında əzəməti ilə seçilən, lakin heç kimin fərqində olmadığı qocaman Ceviz ağacı vətənpərvər insanın – şairin, İstanbul isə həsrətin, sevgi-nin, vətənin simvoludur. Şeir N.Hikmətin Türkiyə həsrətini ifadə etməkbaxımından xarakterikdir, Şair 7 il əvvəl ayrıldığı, bir daha görə bil- məyəcəyi Vətəninə İstanbulun simasında tamaşa edir. Lakin şair buradaümumiləşdirmə apararaq özü ilə yanaşı, yüz minlərlə insanın həsrətivə sevgisini ifadə etmişdir. Şeirdə təsvir olunan ağac adi ağac deyildir.Bu ağac yarpaqlarının sayı qədər -yüz min əli, yüz min gözü, yüz min ürəyi olan ağacdır (insandır). Bu ağac (insan) yüz min əli ilə İstanbulatoxunur, yüz min gözü ilə İstanbula tamaşa edir, yüz min ürəklə İstan- bul üçün döyünür. Bu yolla o,həsrət yaralarına məlhəm qoyur, vüsalınaqovuşur, “sevgilisinin” göz yaşlarını silir, qollarını onun boynuna ke- çirir. Amma bunu elə sakit tərzdə icra edir ki, heç kim bunu hiss etmir,“fərqində ola bilmir”. Çünki burada şair qalib obraz rolunda çıxış edir.Mövcud rejim onun arzuları qarsısında(reallaşma anlamında) sədlər çəksə də, şairin vətənlə bağlı sevgi hisslərini cilovlaya bilmir.

N.Hikmət yaradıcılığında məhəbbət tərənnümlü şeirlərin özünəməx-

sus yeri vardır. Onun poeziyasında məhəbbətin mahiyyəti bəşəriyyətə,insana, qadına, təbiətə və s. olan həssas duyğuların ifadəsində açılır. N.Hikmət “enini, uzununu santimetrinə qədər sevdiyi” dünyanın bütünxalqlarına məhəbbətlə yanaşır. N.Hikmət heç bir dini və irqi ayrı-seçki-liyə yol vermədən bəşər övladına qəlbinin hərarətindən pay ayıra bilir.“Dünya, dostlarım, düşmənlərim, sən və torpaq”, “Asiya-Afrika yazıçı-larına”, “İsveçrə dağları”, “Praqada Bir may” və s. şeirlərində N.Hikmətdünyaya, bəşər övladına olan məhəbbətini nümayiş etdirir. Təbii olaraqşairin vətəninə olan məhəbbəti bu sırada xüsusi yer tutur. N.Hikmət qəlbində səngər qazıb müdafiə etdiyi, bağrından qoparıb ata bilmədiyi məmləkətinə sonsuz məhəbbət ifadə edir. Maraqlıdır ki, şairin doğma vətəni ilə bağlı yazdıqlarını ümumiləşdirsək, vətəni özünün taleyi, tər- cümeyi-halı, qüruru və s. hesab etdiyinin şahidi olarıq. Məmləkətini ömür yolu, saçlarının ağ rəngi, alnının qırışı, ürəyinin infarktı kimi sə-ciyyələndirərkən şairin sadəlik və səmimiliyi şübhə doğurmur:

Sən indi qalmısan ancaqSaçlarımın ağında, ürəyimin infarktında.

Alnımın qırışlarındasan, məmləkətim!Məmləkətim, məmləkətim!

N.Hikmətin şeirlərindəki sevdiyi qadınlara məhəbbəti şairin pak duyğularının, səmimi hiss və etiraflarının göstəricisidir. Bu şeirləri oxu- duqca insan gözləri önündə sanki dünyanın ən gözəl mənzərəsini görür,ən həzin musiqisini eşidir.

Sən ey, dildarım mənim, təmiz ürəkli,qızıl rəngli.

Gözləri baldan dadlı arım mənim.

(“Arvadıma məktub”, 1933)

Bu şeirin 1933-cü ildə Bursa həbsxanasında olarkən həyat yoldaşı-na yazıldığını nəzərə alsaq, şairin ən çətin şəraitdə, psixoloji gərginlik-də belə ruhunda gəzdirdiyi ecazkar sevgi duyğularının şahidi oluruq. “Sənsiz Paris” (1958) şeirində sənsizliyin doğurduğu assosiativ duy- ğuların maraqlı təsiri ilə üzləşirik. Cəmi 7 misradan ibarət olan şeirdə biz Parisi gəzən şairin keçirdiyi hisslərlə tanış oluruq. Şair üçün sevdiyiinsan müqayisədə hamıdan gözəldir. Buna görə də gözəlliklər şəhəri Parisdə şairin diqqətini heç nə cəlb etmir. Əksinə, onu narahat edir, qəl-bində kədər hissi oyadır:

Sənsiz Paris, gülüm,Bir hava fişəngidir. bir quru gurultu

kədərli bir bulaq. Yaxdı, məhv etdi məni

Parisdə dayanıb, dincimi almadanSəni çağırmaq.

N.Hikmət lirikasında qeyri-adi poetik həssaslıq müşahidə olunur. Onun "mən"i daxilən narahatdır. Bu narahatçılığı doğuran səbəblər olduqca müxtəlifdir. "Qəlbim" (1948), "Dünyanın ən yazıq məxluqu" (1949), "Vəsiyyət" (1953), "Məmədə son məktubum" (1954), "Məməd"(1957), "Son avtobus" (1957), "Münəvvərə məktun yazdım, dedim ki:"(1957) və s. şeirlərində bu səbəblər oxucu üçün aydınlaşır. Oxucu onun şeirlərindəki emosional "yükün" mənbəyini müəyyənləşdirməkdə çə- tinlik çəkmir. N.Hikmət həyatda olduğu kimi şeirlərində də nə qədər narahatdırsa, idealına bir o qədər sədaqətlidir. "Röyalarının ölkəsində ölməyi" özünə şərəf bilən şairin aşağıdakı misralarında bu fikir öz təs-diqini belə tapır:

Mən məni bir daha ələ keçirsəm

...Mən bu xanəyə bir daha girsəm Yaşardım yenə belə qorxu, dəhşət içində.

("Mən məni", 1949)

N.Hikmətdə gerçəkliyi yeni poetik təfəkkürlə qavramaq imkanı bö-yükdür. Onun şeirlərində poetik görkəmi yeni olan obrazlar və assosia-siyalar çoxluq təşkil edir. Ona görə də N.Hikmətdə mənanın özünəməx-sus forma və söz-ifadə imkanlarında verilməsi ardıcıl səciyyə daşıyır:

Mən dostların gözündə özümüOlduğum kimi görürəm... ("Vida", 1931)

Güldün,

Güllər açıldı pəncərəmin dəmirlərində,Ağladın,

Ovuclarıma töküldü incilər.

("Xoş gəldin", 1949)Və ya

Təpədəyəm

Uşaqlaşır ucsuz-bucaqsız ayrılıqdaBir sal kimi ürəyim.

Gedər xatirələrin gerisinə, Ulduzsuz, ağır dənizə qədərZil qaranlıqda.

("Gecə vaxtı Bakı", 1960)

Nazim Hikmət harada yaşamasından asılı olmayaraq Azərbaycana böyük məhəbbət bəsləmiş, ona ürəkdən bağlı olmuşdur. Bu da səbəbsizdeyildir. Hər şeydən əvvəl Azərbaycan Nazim Hikmət üçün qədim türkyurdu və türk ruhunu qoruyan insanların yaşadığı müqəddəs bir məkanidi. Şair "Bakıya gedirəm" şeirində Azərbaycana səmimi duyğularını aşağıdakı kimi ifadə edir:

Bakıya gedirəm, ay balam,Bakı-Əsli, mən-Kərəm.

Bakı gəncliyim demək,

Dost əlinə əmanət etdiyim ürək.

Nazim Hikmətin "Neftə doğru" adlı şeirinin mövzusu da Azərbay-canla bağlıdır. Şeirdə bir sıra təbiət lövhələri ilə yanaşı, əsasən Bakı mənzərələri timsalında Bakının obrazı əksini tapmışdır:

Düşünen beyni Moskovaysa ülkemizin,Taze kan dağıtan kalbidir Bakü!..

İlık ve aydınlık bir güney gecesi... Havalarda iri taşlı billur avizeler yanıyor...Her tanesi içinden aydınlanan,

Şeffaf üzüm salkımları sallanıyor havalardan...

N.Hikmətin epik poeziyası daha çox ictimai-siyasi səciyyə daşıyır. “Cakonda və Si-ya-u”, “İnsan mənzərələri”, “Qurtuluş davası dastanın- dan”, “Moskva simfoniyası”, “Zoya” və s. poemalarda problemə obyektiv baxış və münasibət insanı hadisələrindən düzgün nəticə çıxar- mağa sövq edir, geniş poetik lövhələrdə həyatın ictimai-siyasi mənzərə-si əksini tapır.

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FROM OOCYTE TO IMPLANTATION IN ASSISTED REPRODUCTIVE TECHNOLOGIES: A STRUCTURED SYNTHESIS OF CURRENT INTERNATIONAL GUIDELINES IN TERMS OF EMBRYOLOGICAL DECISION POINTS

YARDIMCI ÜREME TEKNİKLERİNDE OOSİTTEN İMPLANTASYONA: GÜNCEL ULUSLARARASI REHBERLERİN EMBRİYOLOJİK KARAR NOKTALARI AÇISINDAN YAPILANDIRILMIŞ SENTEZİ

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ÖZET

Amaç: Yardımcı üreme tekniklerinde başarı, tek bir laboratuvar işleminden çok başlangıç değerlendirmesi, ovaryan stimülasyon, fertilizasyon yöntemi, embriyo kültürü ve seçimi, transfer ve luteal desteğin birbiriyle uyumlu yürütülmesine bağlıdır. Bu çalışmanın amacı, güncel uluslararası rehberlerde yer alan önerileri in vitro fertilizasyon (IVF) sürecinin temel basamakları boyunca bütüncül biçimde değerlendirmek ve klinik karar noktalarını görünür kılan pratik bir çerçeve sunmaktır.

Yöntem: 2023–2026 yılları arasında yayımlanan WHO, ESHRE ve ASRM'ye ait dokuz rehber, konsensüs ve komite görüşü incelendi. Belgeler; infertilite değerlendirmesi, ovaryan stimülasyon, oosit ve embriyo morfolojisi, embriyo transferi ve transfer edilecek embriyo sayısı, add-on uygulamaları, intrasitoplazmik sperm enjeksiyonu, anöploidi için preimplantasyon genetik test (PGT-A) ve IVF laboratuvarında yapay zeka başlıklarını kapsıyordu. Öneriler; ilgili IVF basamağı, uygulamadaki konumu, hasta seçimi, güvenlik, kanıt düzeyi ve canlı doğumla ilişkili klinik yarar dikkate alınarak "yerleşik yaklaşım", "seçilmiş olguda kullanım" ve "rutin önerilmeyen yaklaşım" kategorileri altında yapılandırılmış olarak sentezlendi.

Bulgular: Güncel belgeler, kadın ve erkek faktörlerinin birlikte değerlendirilmesini, stimülasyonun over rezervi ve ovaryan hiperstimülasyon sendromu riskine göre bireyselleştirilmesini ve erkek faktörü bulunmayan olgularda intrasitoplazmik sperm enjeksiyonunun rutin yöntem olarak kullanılmamasını öne çıkarmaktadır. Morfolojik değerlendirme embriyo seçiminin temelini korurken, time-lapse görüntüleme ve yapay zeka destekli sistemlerin yardımcı araçlar olarak ele alınması, PGT-A'nın ise seçilmiş olgularda hasta yaşı, prognoz ve hedeflenen sonlanıma göre tartışılması önerilmektedir. Transfer aşamasında uygun embriyo sayısı, atraumatik teknik ve embriyo-endometrium zamanlama uyumu; add-on uygulamalarında ise etkinlik, güvenlik, maliyet ve şeffaf hasta bilgilendirmesi belirleyici görünmektedir.

Sonuç: IVF başarısı, tek bir teknolojiye değil, ardışık basamaklarda doğru endikasyon, bireyselleştirme, laboratuvar kalite güvencesi ve kanıta dayalı kararların uyumuna dayanmaktadır. Önerilen çerçeve, güncel rehberleri klinik ve embriyolojik karar zincirine dönüştürerek eğitim ve uygulamaya yönelik bütüncül bir yol haritası sunmaktadır.

Anahtar Kelimeler: İn vitro fertilizasyon, yardımcı üreme teknikleri, embriyo seçimi, klinik rehberler, kanıta dayalı karar

ABSTRACT

Objective: Success in assisted reproductive technologies depends not on a single laboratory procedure, but on the coordinated implementation of initial assessment, ovarian stimulation, fertilization method, embryo culture and selection, transfer, and luteal support. This study aimed to evaluate recommendations in current international guidelines across the main stages of in vitro fertilization (IVF) and to present a practical framework that makes clinical decision points explicit.

Methods: Nine guidelines, consensus statements, and committee opinions published by WHO, ESHRE, and ASRM between 2023 and 2026 were reviewed, covering infertility assessment, ovarian stimulation, oocyte and embryo morphology, embryo transfer and embryo number, add-on interventions, intracytoplasmic sperm injection, preimplantation genetic testing for aneuploidy, and artificial intelligence in the IVF laboratory. Recommendations were synthesized under the categories "established approach," "use in selected cases," and "not recommended for routine use," considering the relevant IVF stage, clinical position, patient selection, safety, level of evidence, and clinical benefit associated with live birth.

Results: Current documents emphasize joint evaluation of female and male factors, individualization of stimulation according to ovarian reserve and ovarian hyperstimulation syndrome risk, and avoidance of routine intracytoplasmic sperm injection without male-factor infertility. Morphological assessment remains the basis of embryo selection, whereas time-lapse imaging and artificial intelligence-supported systems are considered supportive tools. Preimplantation genetic testing for aneuploidy should be discussed in selected cases according to patient age, prognosis, and intended outcome. During transfer, appropriate embryo number, atraumatic technique, and embryo-endometrium timing concordance are important; for add-ons, effectiveness, safety, cost, and transparent patient information are key.

Conclusion: IVF success relies not on a single technology, but on the alignment of correct indications, individualization, laboratory quality assurance, and evidence-based decisions across consecutive stages. The proposed framework translates current guidelines into a clinical and embryological decision chain and provides an integrated roadmap for education and practice.

Keywords: In vitro fertilization, assisted reproductive technologies, embryo selection, clinical guidelines, evidence-based decision-making

PRELIMINARY GEOLOGICAL AND MINERALOGICAL FINDINGS FROM THE EASTERN EXTENSION OF THE KARAMADAZI Fe-SKARN SYSTEM (YAHYALI, KAYSERİ, CENTRAL TÜRKİYE)

KARAMADAZI FE-SKARN SİSTEMİNİN DOĞU UZANIMINA İLİŞKİN ÖN JEOLOJİK VE MİNERALOJİK BULGULAR (YAHYALI, KAYSERİ, ORTA TÜRKİYE)

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ABSTRACT

The eastern extension of the Karamadazı iron skarn system was investigated through detailed geological mapping and field observations to evaluate the continuity of skarn mineralization and its host lithologies. The study area, located east of the well-known Karamadazı Fe-skarn deposit near Yahyalı (Kayseri, Central Türkiye), is characterized by intrusive rocks belonging to the Karamadazı granitoid and an overlying carbonate sequence that has undergone extensive contact metamorphism and metasomatism. The intrusive suite is dominated by porphyritic granodiorite and is locally represented by granite and hydrothermally altered tonalite. The carbonate succession consists predominantly of marbleized limestones with subordinate calc-schist horizons and is unconformably overlain by a thin basaltic volcanic cover. Field observations reveal a well-developed skarn zone along the granitoid-carbonate contact. Prograde skarn assemblages are represented mainly by garnet and epidote, whereas widespread oxidation zones indicate intense supergene alteration. Magnetite constitutes the dominant ore mineral and occurs as massive to semi-massive bodies accompanied by hematite, limonite, chalcopyrite and pyrite. The ore-bearing zones are spatially associated with intense hydrothermal alteration, pervasive fracturing and iron oxide enrichment. Extensive limonitization and hematitization observed at the surface suggest prolonged oxidation of primary sulphide-bearing assemblages. The observed lithological relationships, alteration characteristics and ore mineral assemblages are consistent with the genetic framework previously proposed for the Karamadazı Fe-skarn system, while new field evidence indicates that economically significant skarn mineralization extends farther east than previously

documented. These preliminary observations demonstrate that the eastern sector of the Karamadazı system represents a promising target for detailed petrographic, mineral chemical, whole-rock geochemical and geochronological investigations aimed at constraining the evolution of the magmatic-hydrothermal system and its metallogenic significance.

Keywords: Karamadazı Fe-skarn, magnetite, granitoid, contact metasomatism, Yahyalı, Central Türkiye

ÖZET

Karamadazı demir skarn sisteminin doğu uzanımı, skarn cevherleşmesinin sürekliliğini ve ana kayaç ilişkilerini ortaya koymak amacıyla ayrıntılı jeolojik haritalama ve arazi gözlemleri ile incelenmiştir. Çalışma alanı, Kayseri ili Yahyalı ilçesi yakınlarında yer alan Karamadazı demir skarn yatağının doğusunda konumlanmakta olup Karamadazı granitoyidi ile karbonatlı kayaçların dokanağında gelişmiş kontakt metasomatik cevherleşmeleri kapsamaktadır. Magmatik kayaçlar başlıca porfirik granodiyorit bileşiminde olup yer yer granit ve hidrotermal alterasyona uğramış tonalitlerle temsil edilmektedir. Karbonatlı istif ise yoğun mermerleşmeye uğramış kireçtaşlarından oluşmakta, yer yer kalkşist seviyeleri içermekte ve uyumsuz olarak ince bazaltik volkanik örtü tarafından üzerlenmektedir. Arazi gözlemleri granitoyid-karbonat dokanağı boyunca iyi gelişmiş skarn zonlarının varlığını ortaya koymaktadır. Prograd evreyi temsil eden granat ve epidot mineralleri yaygın olarak gözlenirken, yüzeyde gelişmiş yoğun demir oksit alterasyonu belirgin hematitleşme ve limonitleşme zonları oluşturmaktadır. Cevherleşmenin ana minerali masif ve yarı masif manyetit olup buna hematit, limonit, kalkopirit ve pirit eşlik etmektedir. Cevher zonları kuvvetli hidrotermal alterasyon, kırıklı yapı ve demir oksit zenginleşmesi ile yakın ilişki göstermektedir. Arazi gözlemleri, litolojik ilişkiler ve mineral birliktelikleri Karamadazı demir skarn yatağı için daha önce önerilen oluşum modeliyle büyük ölçüde uyumlu olmakla birlikte, skarn sisteminin doğuya doğru devam ettiğine ilişkin yeni kanıtlar sunmaktadır. Elde edilen ön bulgular, çalışma alanının petrografi, mineral kimyası, tüm kaya jeokimyası ve jeokronoloji verileri ile desteklenecek ayrıntılı çalışmalar açısından önemli bir potansiyel taşıdığını göstermektedir.

Anahtar Kelimeler: Karamadazı demir skarnı, manyetit, granitoyid, kontakt metasomatizma, Yahyalı, Orta Türkiye

Introduction

Skarns are among the most important hydrothermal mineral deposits worldwide and constitute significant resources of Fe, Cu, Zn, W, Sn, Mo and Au. They form through metasomatic interaction between magmatic-hydrothermal fluids and chemically reactive carbonate rocks, producing characteristic coarse-grained calc-silicate mineral assemblages dominated by garnet and pyroxene, together with epidote, amphibole, magnetite and sulfide minerals (Einaudi et al., 1981; Einaudi and Burt, 1982; Meinert, 1992; Meinert et al., 2005). In Türkiye, skarn deposits have been exploited since ancient times and represent one of the country's most important metallogenic systems, particularly for Fe and Pb-Zn mineralization, with numerous abandoned smelters, slag accumulations and historical mine workings preserved throughout central and western Anatolia (Kuşcu, 2019, Kuşçu et al., 2019) (Fig. 1). The Central Taurides preserve numerous Late Cretaceous granitoids and associated skarn systems related to the tectono-magmatic evolution of the Neotethyan realm. Previous studies have emphasized the granitoid magmatism of the Central Anatolian Crystalline Complex and its significance for the Alpine evolution of central Anatolia, where both magmatic-arc and post-collisional tectonic models have been proposed (Akıman et al., 1993; Göncüoğlu and Türeli, 1994; Boztuğ, 2000).

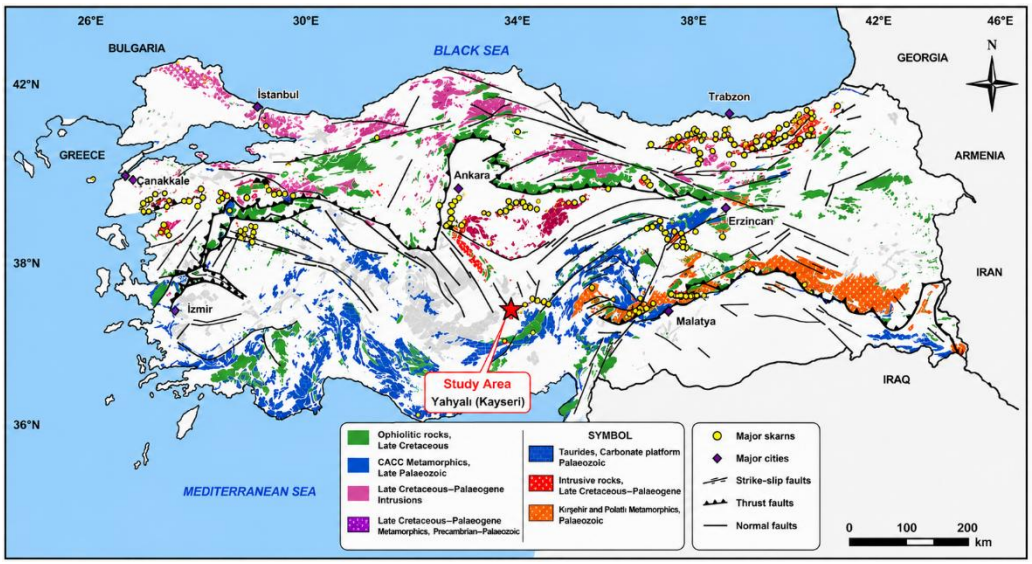

Figure 1. Simplified geological and metallogenic map of Türkiye illustrating the distribution of major skarn deposits, host rock assemblages, causative plutons and principal tectonic structures. The location of the present study (Yahyalı, Kayseri) is indicated by the red star. Modified after Kuşcu (2019)

Against this regional geological framework, the present study provides preliminary geological and mineralogical observations from the eastern extension of the Karamadazı Fe-skarn system, with the aim of improving the current understanding of its lithological relationships, skarn mineralization, and eastern continuity.

Geological Setting

Along the northern margin of the Taurides, granitoid intrusions and related skarn mineralization provide important constraints on regional magmatism and metallogeny, although these systems remain considerably less investigated. The Karamadazı Fe-skarn deposit, located approximately 25 km northwest of Yahyalı (Kayseri), represents one of the best-known magnetite skarn occurrences in the Central Taurides (Fig. 2). The deposit developed along the contact between the Karamadazı granitoid and the carbonate rocks of the Yahyalı succession and is characterized by well-developed skarn zonation and economically significant iron mineralization. Previous investigations mainly focused on the geology and petrogenesis of the Karamadazı granitoid and the mineralogical characteristics of the main skarn deposit, whereas the eastern continuation of the mineralized system has received little attention. This contribution presents preliminary geological and mineralogical observations from the eastern extension of the Karamadazı Fe-skarn system. Field investigations document the lithological relationships between granitoids and carbonate rocks, characterize the principal skarn and ore mineral assemblages, and provide new evidence for the eastward continuation of the mineralized system. These preliminary observations establish the geological framework for ongoing petrographic, mineral chemical and geochemical investigations.

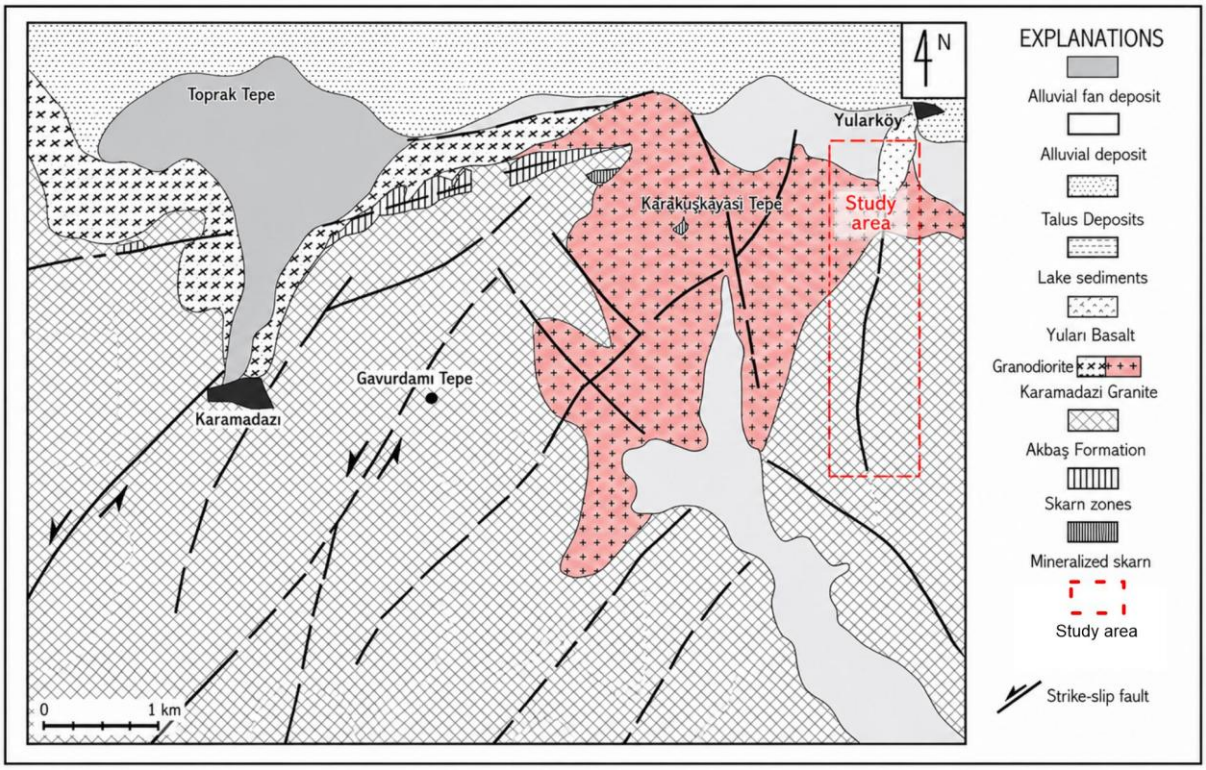

Figure 2. Simplified geological map of the eastern extension of the Karamadazı Fe-skarn system, illustrating the distribution of the Karamadazı Granitoid, the Akbaş Formation, the Yuları Basalt, skarn zones and the study area. Modified after Gençalıoğlu-Kuşcu et al. (2001).

The geological map (Fig. 2) summarizes the preliminary field observations from the eastern extension of the Karamadazı Fe-skarn system. The intrusive body is dominated by granodiorite and is locally represented by granitic rocks, altered granitoids and rare tonalite. The intrusion is emplaced into the carbonate-dominated Akbaş formation and is unconformably overlain by the Yuları basalt in the northern part of the study area. Skarn mineralization is confined to the intrusive contact with the Akbaş formation, where discontinuous mineralized zones are developed along the granitoid-carbonate interface. The Karamadazı area has been the subject of numerous geological investigations since the early twentieth century. Early studies primarily focused on the regional stratigraphy and tectonic evolution of the Yahyalı region (Blumenthal, 1941, 1944; Baykal, 1944; Okay, 1954; Abdüsselamoğlu, 1962; Özgül, 1976; Göncüoğlu et al., 1991), whereas subsequent investigations concentrated mainly on the economic geology, skarn mineralization and mining potential associated with the Karamadazı granitoid (Oygür et al., 1978; Ulakoğlu, 1983; Oygür, 1986; Kuşcu et al., 2000b). Although these studies documented the geology of the principal skarn bodies and iron mineralization, detailed information on the eastern continuation of the mineralized system remains limited (Fig. 3).



Figure 3**.** Field photographs from the eastern extension of the Karamadazı Fe-skarn system, Yahyalı, Kayseri, Central Türkiye. (a) Iron-oxide-rich and intensely altered skarn exposure developed within carbonate host rocks. (b) Magnetite-rich skarn sample observed in the field. (c) Panoramic view of the Yahyalı area and the surrounding landscape, with Mount Erciyes in the background

Karamadazı Granitoid and Host Rocks

The study area is located southwest of Yuları village and is dominated by intrusive rocks belonging to the Karamadazı granitoid. Granodiorite is the predominant lithology throughout the area, whereas locally developed highly altered granitic rocks exhibiting intense arenization were also observed. Some granodioritic bodies display a distinct porphyritic texture, suggesting emplacement at shallow crustal levels and representing hypabyssal intrusive phases. Tonalite is relatively rare and is mainly exposed on the western slope of Karakuşkayası hill. The granitoid is locally overlain by basaltic volcanic rocks with a very limited areal distribution. In addition, intrusive contacts between the granitoid and the carbonate succession assigned to the Akbaş formation are well exposed in several locations. The carbonate sequence consists predominantly of limestone and calcareous schist, locally recrystallized into marble adjacent to the intrusive contact, reflecting contact metamorphism associated with granitoid emplacement.

Preliminary Mineralization and Skarn Alteration

Field observations indicate that mineralization is principally developed along the contact between the Karamadazı granitoid and the carbonate rocks of the Akbaş formation. Iron mineralization occurs discontinuously along the intrusive contact, forming lenses and irregular bodies generally ranging from approximately 2 to 5 m in thickness. Magnetite is the dominant ore mineral, whereas hematite and limonite occur locally as minor constituents, most likely reflecting supergene oxidation of primary iron mineralization. Skarn alteration is relatively limited within the investigated area and is mainly

represented by localized garnet-epidote assemblages developed along the granitoid-carbonate contact. These calc-silicate assemblages indicate metasomatic alteration associated with emplacement of the granitoid and subsequent hydrothermal fluid circulation. In the southern part of Yuları village, magnetite mineralization is locally accompanied by chalcopyrite, suggesting a transition from iron-dominated to locally Cu-bearing skarn mineralization. Pyrite is commonly observed as coarse euhedral crystals hosted by marble and calcareous schist, where it is locally associated with coarse-grained calcite and quartz veins. Chalcopyrite commonly accompanies pyrite within these vein systems, indicating a later stage of hydrothermal sulfide deposition. Representative hand specimens illustrating the principal mineral assemblages identified during the field investigation are presented in Fig. 3, including magnetite-, garnet-, epidote-, pyrite- and chalcopyrite-bearing lithologies.

Petrography

Petrographic investigations indicate that the study area comprises granitoid, volcanic, sedimentary and hydrothermal vein lithologies associated with the Karamadazı Fe-skarn system. The granitoid is represented predominantly by granodiorite, whereas mafic rocks include dolerite and olivine-bearing basalt belonging to the Yuları basalt. Hydrothermal alteration is characterized by quartz- and calcite-rich veins locally containing abundant opaque ore minerals (Fig. 4).

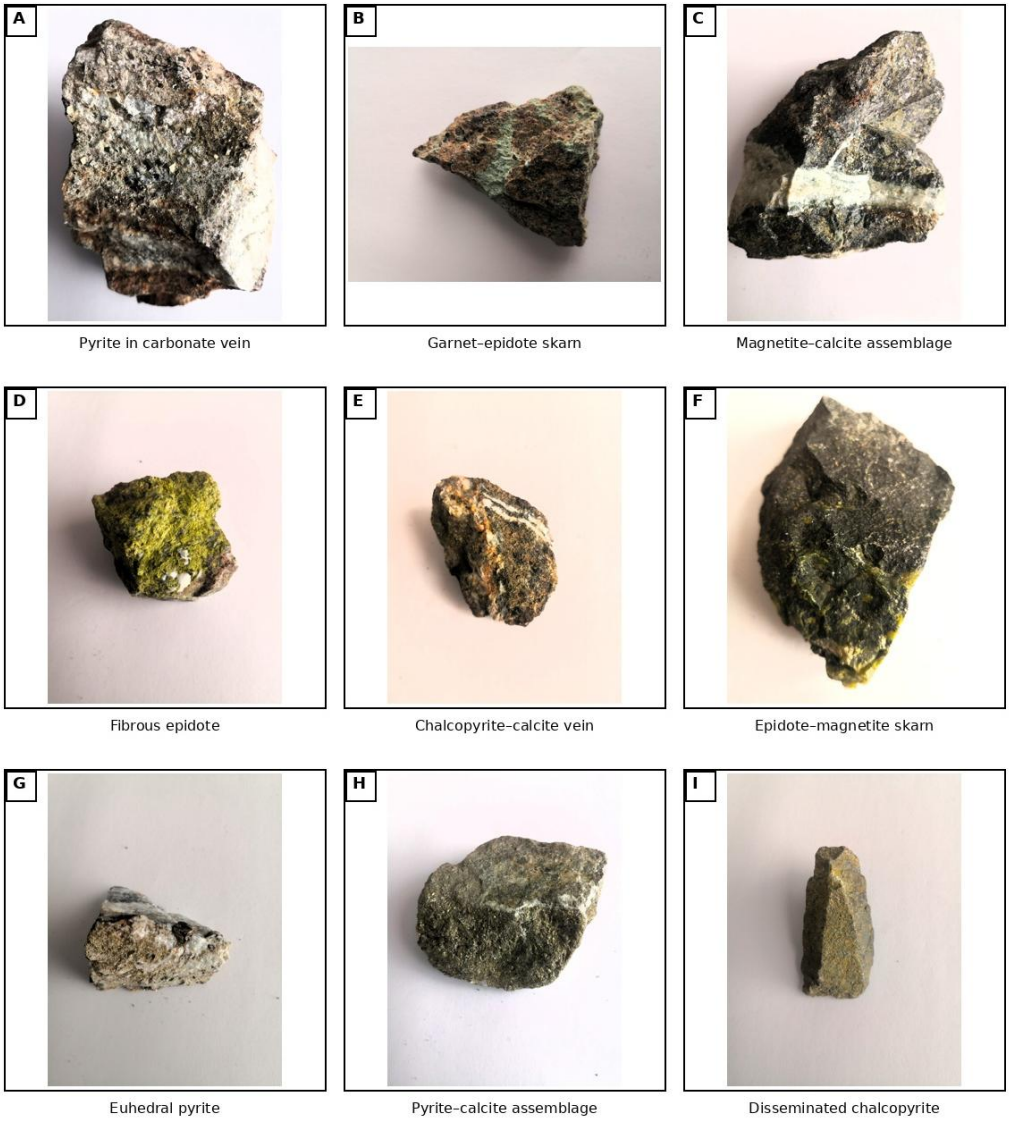

Figure 4. Representative hand specimens from the eastern extension of the Karamadazı Fe-skarn system. (a) Pyrite in carbonate vein, (b) Garnet-epidote skarn, (c) Magnetite-calcite assemblage, (d) Fibrous

epidote, (e) Chalcopyrite-calcite vein, (f) Epidote-magnetite skarn, (g) Euhedral pyrite, (h) Pyrite-calcite assemblage, and (ı) Disseminated chalcopyrite.

The granodiorite (sample YK-9) exhibits a holocrystalline, medium-grained hypidiomorphic granular texture composed mainly of quartz and feldspar with subordinate mafic minerals. Local alteration of feldspars and the development of secondary minerals are common. The dolerite (sample YK-2) displays a fine- to medium-grained crystalline texture with plagioclase laths and mafic minerals typical of subvolcanic mafic intrusions. The olivine-bearing basalt (sample YK-5) is characterized by a porphyritic texture in which olivine phenocrysts are set within a fine-grained groundmass. Quartz-rich hydrothermal veins (samples YK-7 and YK-10) are composed predominantly of coarse-grained quartz with subordinate calcite filling fractures within the host rocks. Locally, these veins are accompanied by opaque ore minerals. Samples YDH-2 and YDH-3 are dominated by coarse quartz and calcite accompanied by abundant opaque ore minerals. Graphitic material is locally observed in sample YDH-2, indicating mineralization within carbonaceous host rocks. Sample YK-3 consists of a siltstone cut by quartz veins and contains abundant opaque ore minerals concentrated along fractures and vein margins, reflecting structurally controlled hydrothermal mineralization. Overall, the petrographic observations are consistent with field evidence indicating hydrothermal alteration and Fe-dominated skarn mineralization developed along the contact between the Karamadazı granitoid and the carbonate rocks of the Akbaş formation (Fig. 5).

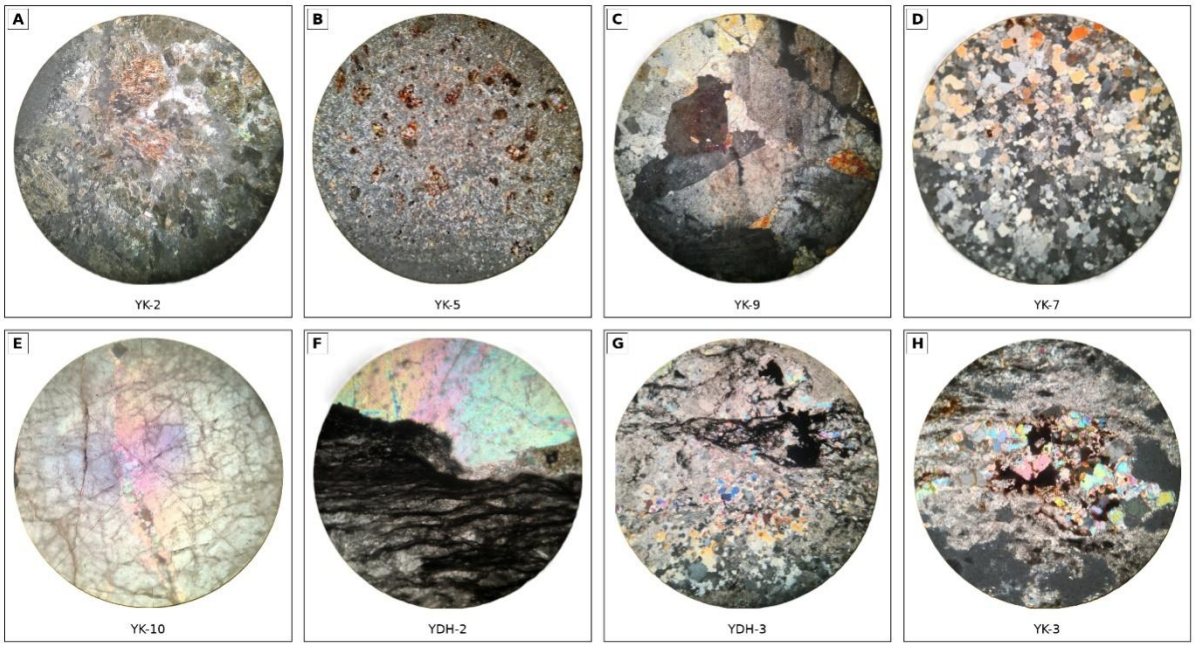

Figure 5. Representative photomicrographs of the rock units collected from the eastern extension of the Karamadazı Fe-skarn system, Yahyalı (Kayseri), Central Türkiye. (a) Dolerite (YK-2), (b) Olivine basalt (YK-5), (c) Granodiorite of the Karamadazı Granitoid (YK-9), (d) Quartzite vein (YK-7), (e) Quartz vein (YK-10), (f) Quartz-calcite-graphitic schist with ore minerals (YDH-2), (g) Quartz-calcite-bearing ore zone (YDH-3), and (h) Ore-bearing quartz-veined siltstone (YK-3).

Discussion

The preliminary field observations indicate that iron mineralization in the eastern extension of the Karamadazı Fe-skarn system is spatially controlled by the intrusive contact between the Karamadazı granitoid and the carbonate-dominated rocks of the Akbaş formation (Fig 6). Magnetite constitutes the dominant ore mineral and generally forms discontinuous lenses and massive bodies reaching several metres in thickness along the granitoid-carbonate contact. Although the mineralized zones are locally discontinuous, their distribution consistently follows the intrusive contact, indicating a strong lithological control on mineralization. The observed mineral assemblages further support the

interpretation of a contact metasomatic origin typical of calcic Fe-skarn systems (Einaudi and Burt, 1982; Meinert et al., 2005).

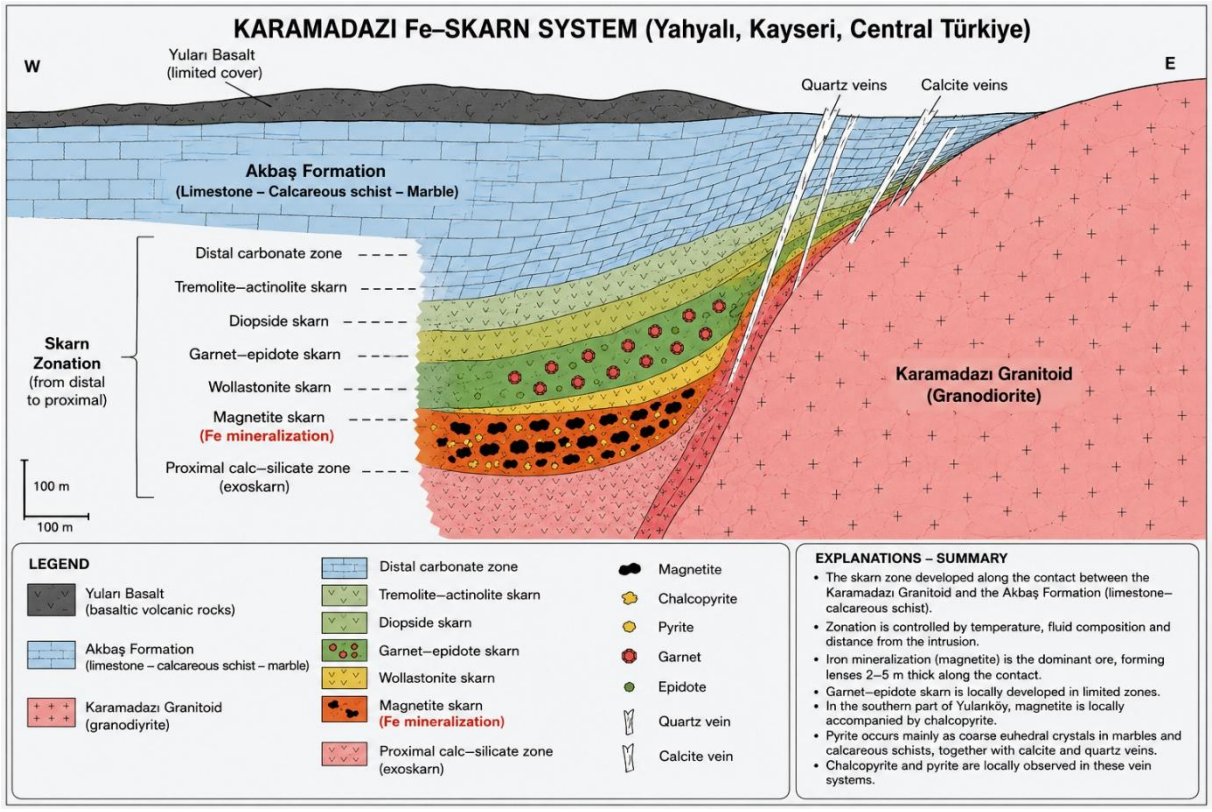

Figure 6. Conceptual model illustrating the geological setting and skarn zonation of the eastern extension of the Karamadazı Fe-skarn system, Yahyalı (Kayseri), Central Türkiye.

Garnet-epidote assemblages are locally developed along the contact zone, whereas magnetite-rich horizons are accompanied by subordinate hematite and limonite produced during supergene oxidation. Chalcopyrite is locally associated with magnetite, particularly in the southern part of Yuları village, suggesting that Cu-bearing hydrothermal fluids locally accompanied the Fe mineralizing event. In contrast, pyrite commonly occurs as coarse euhedral crystals within marbles and calcareous schists, frequently associated with calcite and quartz veins. These textural relationships suggest that sulfide mineralization probably represents a relatively late hydrothermal stage that postdates the main magnetite-forming event, as commonly reported from calcic skarn systems (Meinert, 1992; Meinert et al., 2005). Petrographic observations are consistent with the field relationships. Granodiorite represents the dominant intrusive lithology, whereas porphyritic granodiorite and locally altered granitic rocks indicate multiple intrusive phases and variable degrees of hydrothermal alteration. Quartz and calcite veins cutting both the granitoid and carbonate host rocks demonstrate continued fluid circulation following granitoid emplacement. The occurrence of sulfide-bearing quartz veins further suggests that hydrothermal activity persisted beyond the principal skarn-forming stage. Although the present study is based primarily on field observations and petrographic investigations, the observed lithological relationships, mineral assemblages and inferred skarn zonation closely resemble those documented from calcic Fe-skarn systems developed along granitoid-carbonate contacts worldwide (Einaudi et al., 1981; Einaudi and Burt, 1982; Meinert, 1992; Meinert et al., 2005). The conceptual geological model proposed herein therefore provides a preliminary framework for understanding the eastern continuation of the Karamadazı Fe-skarn system. Future mineral chemistry, whole-rock geochemistry and geochronological investigations will be essential to constrain the physicochemical conditions of skarn formation, the evolution of hydrothermal fluids and the metallogenic significance of this previously unexplored eastern extension.

Conclusions

The principal conclusions of this preliminary study are summarized as follows:

- The eastern extension of the Karamadazı Fe-skarn system is controlled by the intrusive contact between the Karamadazı granitoid and the carbonate-dominated rocks of the Akbaş formation. The observed geological relationships indicate that the contact zone represents the principal locus of hydrothermal alteration and Fe mineralization.
- Granodiorite is the dominant intrusive lithology in the study area, locally accompanied by porphyritic granodiorite, altered granitic rocks and rare tonalite. Thin basaltic volcanic rocks of the Yuları basalt unconformably overlie the carbonate succession.
- Iron mineralization is dominated by magnetite, which forms discontinuous lenses and massive bodies generally reaching 2-5 m in thickness along the granitoid-carbonate contact. Garnet-epidote skarn is locally developed, whereas chalcopyrite occurs in limited zones associated with magnetite. Pyrite is mainly observed as coarse euhedral crystals within marbles and calcareous schists and is commonly accompanied by calcite and quartz veins.
- Field observations and petrographic data indicate a mineral assemblage and zonation consistent with a typical calcic Fe-skarn system. The occurrence of quartz-calcite veins and late sulfide mineralization suggests that hydrothermal activity continued after the principal magnetite-forming stage.
- The conceptual geological model proposed in this study provides the first preliminary description of the eastern continuation of the Karamadazı Fe-skarn system. Although the mineralized zones appear more limited than those of the main Karamadazı deposit, they demonstrate that skarn-related hydrothermal processes extended farther east than previously documented.
- Future mineral chemistry, whole-rock geochemistry and geochronological studies will be essential to constrain the evolution of the causative magmatism, the physicochemical conditions of skarn formation and the metallogenic potential of this previously unexplored sector.

Acknowledgements

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NUTRITION AND COLORECTAL CANCER: CURRENT EVIDENCE ON RISK, PREVENTION, AND MANAGEMENT

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ABSTRACT

Colorectal cancer (CRC) is one of the most widespread and high-mortality cancer types across the globe. It usually originates from molecular changes in the normal intestinal mucosa. Over time, molecular changes lead to the formation of polyps in the mucosa. Although colorectal polyps are classified as adenocarcinomas, hyperplastic polyps, or dysplasia, adenocarcinoma histology is seen in most cases. While molecular pathways explain the underlying mechanisms of CRC development, factors such as dietary habits, alcohol consumption, gut microbiota, and inflammation have been implicated in influencing the disease process as well. The aim of the present study is to examine the effects of nutritional interventions in CRC disease In the present literature review was performed by searching the databases PubMed, Google Scholar, and ScienceDirect during the period from 2020 to 2025 using the following terms: “colorectal cancer,” “nutrition,” “red meat,” “processed meat,” and “alcohol”. Studies conducted on patients with CRC have shown that excessive consumption of red meat is associated with an increased risk of developing CRC. In addition to red meat consumption, it has been reported that alcohol consumption may also play a role in the development of colorectal cancer; even alcohol consumption ranging from 0.01 to 12.4 g per day has been found to be associated with a significant increase in CRC risk. Along with alcohol, studies have indicated a link between gut microbiome and colorectal cancer. It has been suggested that individuals with significant dysbiosis have a higher likelihood of developing CRC. The findings highlight the significance of dietary patterns in CRC. In particular, numerous factors—such as the type of meat consumed and the amount of alcohol consumed—are associated with an increased risk of the disease. A well-planned dietary intervention might be key part in managing the progress of CRC.

Key Words: Alcohol, Colorectal cancer, Nutrition, Processed meat, Red meat

INTRODUCTION

Colorectal cancer (CRC) is one of the most common and deadliest types of cancer worldwide and is becoming an increasingly significant public health problem[1]. It generally arises from molecular changes in the normal intestinal mucosa. These polyps, which develop by detaching from the normal mucosa, are mostly adenocarcinoma histology. Adenomatous polyps are defined as precancerous polyps that may progress to cancer, while hyperplastic polyps are classified as inflammatory polyps[2]. Hyperplastic polyps are the most frequently encountered type of polyp in the colorectal region; adenomatous polyps, on the other hand, are the type of polyps that precedes cancer[2,3]. Three main mechanisms are involved in the development of these polyp types. The adenoma-carcinoma sequence is the most classic and

common pathway of CRC development[4]. This pathway initiates tumor formation by inactivating the Adenomatous Polyposis Coli (APC) gene—which suppresses tumor growth—thereby activating the Wnt/β-catenin pathway. The subsequent KRAS mutation leads to uncontrolled cell division[5].

Another mechanism that leads to impairment is the Microsatellite Instability (MSI) Pathway[6]. As a result of the disruption of DNA repair systems such as MLH1, MSH2, and MSH6, DNA damage becomes irreparable. The high mutation load resulting from unrepaired damage leads to the production of many neo-antigens. The Serrated (CIMP-associated) pathway, which differs from other pathogenic pathways, results from a mutation in BRAF V600E3 arising from epigenetic changes[7]. The mutation in the gene activates the MAPK signaling pathway, thereby increasing cell proliferation.

Risk factors include family history, sex, age and several inflammatory bowel diseases such as ulcerative colitis and Crohn's disease. In addition to this, particularly among individuals diagnosed with CRC, those in both genders are older than those without diagnosis[8]. Also, it indicates that height is a risk factor for both men and women as well. Treatment methods may vary based on the tumor's location and stage. Treatment options are presented in Table 1.

Table 1. Treatment Modalities Used in CRC

Treatment Modality	Indication	Objective
Surgery	Stage 0-I localized tumor	Total removal of the tumor
Neoadjuvant Chemotherapy	Preoperative	Shrinking the tumor
Adjuvant Chemotherapy	Post-surgery	Reducing recurrence
Immunotherapy	Advanced stage	Activating the immune system
Radiation Therapy	Local control	Reducing tumor size

Diet-related risk factors include high consumption of red meat, processed meat, and alcohol; and low intake of fiber and whole grains[9]. Red meat contains considerable amounts of iron which gives it its color; it can also trigger the Fenton reaction, contributing to reactive oxygen species (ROS) production. These products attack DNA bases, thereby causing mutagenic effects in cells[10]. ROS not only attack DNA bases but also increase cell proliferation, altering the balance of the microbiota. Furthermore, alcohol follows several distinct pathways in CRC metabolism: acetaldehyde formation, oxidative stress (OS), and solvent effects[11]. While acetaldehyde exhibits a carcinogenic effect in colonocytes, OS produces the same effect by increasing ROS. The solvent effect of alcohol can accelerate the entry of carcinogens into cells by increasing the permeability of cell membranes[11]. All these factors disrupt the balance of cellular and molecular pathways thereby setting the stage for the process. The objective of the present study is to examine the effects of nutritional interventions in CRC disease. The dietary mechanisms involved in the development of colorectal cancer are illustrated in Figure 1.

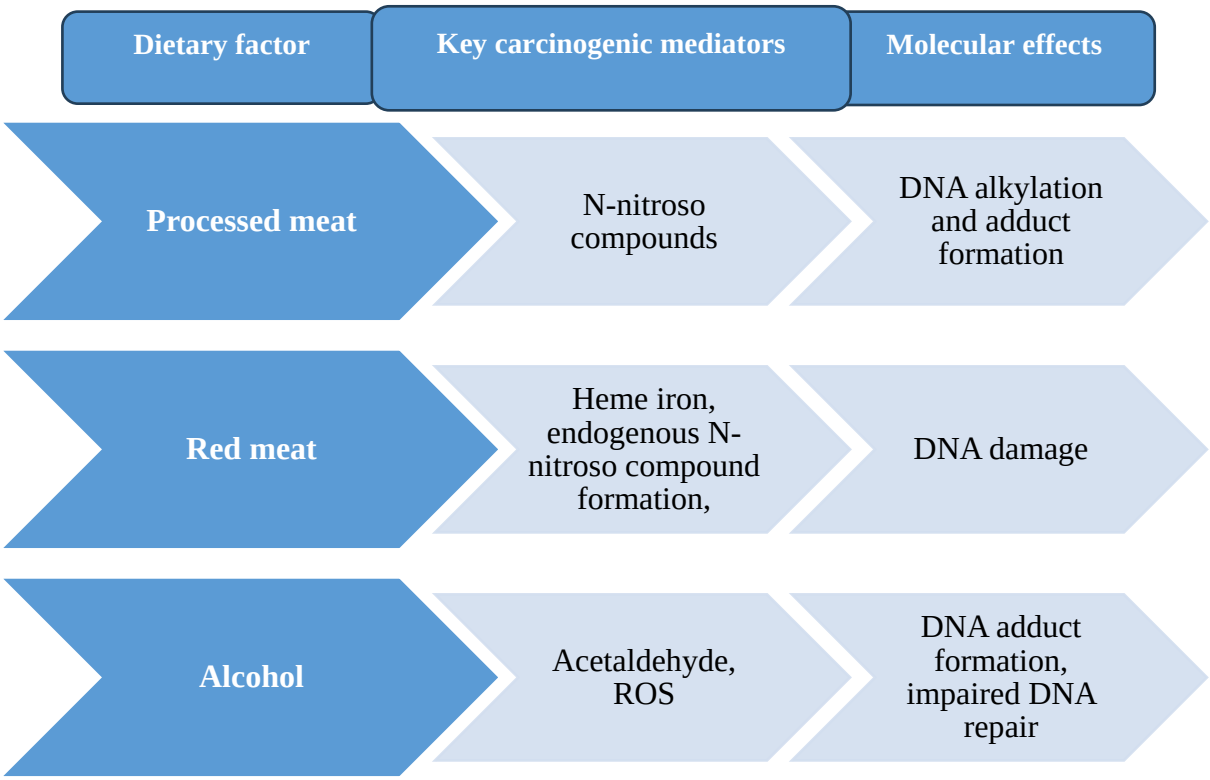

Fig. 1. Summary of dietary mechanisms in colorectal carcinogenesis

METHOD

In the present study, a literature search was conducted for systematic reviews and meta-analyses published between 2020 and 2025 in the PubMed, Google Scholar, and ScienceDirect databases using the terms “colorectal cancer,” “nutrition,” “red meat,” “processed meat,” and “alcohol.”

FINDINGS

A 20-year cohort study investigated the association between the consumption of red, white, and processed meat and the incidence of colorectal cancer (CRC). In this study, which recorded 9,461 cases of CRC during 6,896,619 person-years of follow-up, meat consumption was assessed using a food frequency questionnaire. The results showed that every 50 g/1,000 kcal of red meat consumption was associated with a higher incidence of CRC in the proximal colon (11%), the distal colon (22%), and the rectum (19%)[12].

In a systematic review and meta-analysis that included 139 cohort studies examining the association between different levels of alcohol consumption and various types of cancer, alcohol consumption levels were categorized: light (0.01–12.4 g/day); light-to-moderate (12.5–24.9 g/day); moderate-to-high (25.0–49.9 g/day); high (≥50.0 g/day)[13]. Results showed that individuals who consumed light amounts of alcohol were at a higher risk of having esophageal cancer with an increased risk of 39%. Also, the risk of having CRC is 4% higher. However, while the risk of having CRC was 16% for men, no such risk was identified among women.

In a study, 20-year follow-up study involved 88,092 participants to understand the link between lifetime alcohol consumption since age 18 and CRC risk[14]. Lifetime alcohol consumption was categorized based on weekly consumption of participants: 1-<7; 7-<14; and ≥14. Consumption of beer, wine, and spirits was estimated using the Dietary History Questionnaire for different age intervals: 18-24, 25-39, 40-54, and ≥55 years. Results of the study showed that among the current drinkers, no association between lifetime consumption and adenoma development risk was found; however, in the case of former

drinkers, a significantly lower risk of non-advanced adenomas was identified as compared with current drinkers who consumed <1 drink/week.

A prospective cohort study involving 866.535 female participants that examined the association between 97 different foods, beverages, and nutrients and the risk of CRC a 40% reduction in CRC was observed among those who consumed more than 200 g/day of dairy products [15]. Conversely, among those who consumed 30 g/day or more of processed and red meat, the risk of developing CRC increased by 8%.

In a multicenter cohort study to evaluate the link between dietary consumption of fatty fish and the risk of CRC, considering long-chain n-3 polyunsaturated fatty acids (LC-PUFAs), and n-6: n-3 ratio of long-chain PUFAs in the diet[16]. It was observed that people consuming high quantities of fatty fish had a 10% reduced risk of developing CRC than the people consuming low quantities. In individuals with high n-3 LC-PUFA consumption, the risk of developing CRC was 14% less than the people with low consumption.

CONCLUSIONS AND RECOMMENDATIONS

From the extant literature, it can be concluded that dietary approaches contribute to managing the risks associated with CRC. By decreasing the levels of alcohol consumption, processed meat, red meat, and many other environmental factors, it is possible to prevent CRC or slow down the progress of the disease. Larger, well-designed studies are still needed to develop and standardize dietary protocols for this type of cancer.

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IN VITRO ANTAGONISTIC EFFECT OF *TRICHODERMA HARZIANUM* AGAINST THE PEA WILT PATHOGEN *FUSARIUM OXYSPORUM* F. SP. *PISI* AT DIFFERENT SALINITY LEVELS

FARKLI TUZLULUK DÜZEYLERİNDE *TRICHODERMA HARZIANUM*'UN BEZELYE SOLGUNLUK ETMENİ *FUSARIUM OXYSPORUM* F. SP. *PISI*'YE KARŞI *IN VITRO* ANTAGONİSTİK ETKİSİ

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ABSTRACT

Soil salinity is an important abiotic stress factor that not only restricts plant growth but may also affect pathogen–antagonist–host interactions and the success of biological control. *Fusarium oxysporum f. sp. pisi (Fop), the causal agent of pea wilt, is one of the important soil-borne fungal pathogens that adversely affect yield.* This study aimed to determine the antagonistic activity of *Trichoderma harzianum* against the *Fop* B74 isolate belonging to race 6, a widespread race in Türkiye, and its effect on pathogen development around pea seeds at different salinity levels. In dual culture, Potato Dextrose Agar was supplemented with 0, 50, 100, or 150 mM NaCl, and mycelial discs from seven-day-old cultures of *Fop* and *T. harzianum* were placed opposite each other. In seed colonization assays, seeds of the susceptible cultivar Little Marvel were treated with equal volumes of *Fop* and *T. harzianum* conidial suspensions (1×10^6 conidia/ml) and placed on media containing 0, 50, or 100 mM NaCl. Dual culture and seed colonization assays were conducted with four and five replicates, respectively. Colony growth inhibition was calculated, and the data were analyzed by one-way analysis of variance. *T. harzianum* inhibited *Fop* colony growth in dual culture by 60.62%, 60.00%, 58.75%, and 58.12% at 0, 50, 100, and 150 mM NaCl, respectively, with no significant differences among these values. In the seed colonization assay, inhibition was 81.24% in the non-saline medium but decreased to 52.28% and 46.31% at 50 and 100 mM NaCl, respectively. The findings showed *T. harzianum* suppressed the *Fop* B74 isolate under saline conditions, although its efficacy, particularly around the seed, declined with increasing salinity. It was concluded that the biocontrol potential of *T. harzianum* against *Fop* under salinity-prone conditions should be evaluated in both pot and field experiments.

Keywords: Pea, *Fusarium oxysporum* f. sp. *pisi*, race 6, *Trichoderma harzianum*, salinity, seed colonization.

ÖZET

Toprak tuzluluğu, bitki gelişimini sınırlandırmasının yanı sıra patojen–antagonist–konukçu etkileşimlerini ve biyolojik mücadelenin başarısını etkileyebilen önemli bir abiyotik stres faktörüdür. Bezelyede solgunluğa neden olan *Fusarium oxysporum* f. sp. *pisi* (*Fop*), verimi olumsuz etkileyen önemli toprak kökenli fungal patojenlerden biridir. Bu çalışmada, farklı tuzluluk düzeylerinde *Trichoderma harzianum*'un, Türkiye'de yaygın olarak görülen 6 no'lu ırkı temsil eden *Fop* B74

izolatına karşı antagonistik aktivitesinin ve patojenin bezelye tohumu çevresindeki gelişimi üzerine etkisinin belirlenmesi amaçlanmıştır. İkili kültürde Patates Dekstroz Agar ortamına 0, 50, 100 ve 150 mM NaCl ilave edilmiş; yedi günlük *Fop* ve *T. harzianum* kültürlerinden alınan miseliyal diskler karşılıklı olarak yerleştirilmiştir. Tohum kolonizasyonu denemelerinde, duyarlı Little Marvel çeşidine ait tohumlar, eşit hacimlerde karıştırılan 1×10^6 konidi/ml yoğunluğundaki *Fop* ve *T. harzianum* konidi süspansiyonlarıyla muamele edilerek 0, 50 ve 100 mM NaCl içeren ortamlara yerleştirilmiştir. İkili kültür ve tohum kolonizasyonu denemeleri sırasıyla dört ve beş tekerrürlü yürütülmüştür. Koloni gelişimini engelleme oranları hesaplanmış ve veriler tek yönlü varyans analizi ile değerlendirilmiştir. İkili kültürde *T. harzianum, Fop*'un miseliyal koloni gelişimini 0, 50, 100 ve 150 mM NaCl düzeylerinde sırasıyla %60.62, %60.00, %58.75 ve %58.12 oranında engellemiş; bu değerler arasındaki farklılık istatistiksel olarak önemli bulunmamıştır. Tohum kolonizasyonu denemesinde ise engelleme oranı tuzsuz ortamda %81.24 olarak belirlenmiş, 50 ve 100 mM NaCl düzeylerinde sırasıyla %52.28 ve %46.31'e düşmüştür. Bulgular, *T. harzianum*'un *Fop* B74 izolatını tuzlu koşullarda da baskılayabildiğini, ancak etkinliğin özellikle tohum çevresinde tuzluluk düzeyine bağlı olarak azaldığını göstermiştir. *T. harzianum*'un tuzluluk riski bulunan koşullarda *Fop*'a karşı biyolojik mücadele potansiyelinin hem saksı hem de tarla denemelerinde değerlendirilmesi gerektiği sonucuna varılmıştır.

Anahtar kelimeler: Bezelye, *Fusarium oxysporum* f. sp. *pisi*, ırk 6, *Trichoderma harzianum*, tuzluluk, tohum kolonizasyonu.

GİRİŞ

Toprak tuzluluğu, bitkilerde su alımı, besin dengesi, çimlenme ve fide gelişimini olumsuz etkileyen önemli abiyotik stres faktörlerinden biridir. Tuz konsantrasyonundaki artış yalnızca bitki büyümesini sınırlandırmakla kalmamakta, aynı zamanda bitki-patojen-mikroorganizma etkileşimlerini de değiştirerek hastalık gelişimi ve biyolojik mücadele uygulamalarının başarısı üzerinde etkili olabilmektedir (Dikilitas & Karakas, 2014; Shahid vd., 2018; Otlewska vd., 2020; Li vd., 2024). Bu nedenle, tuzlu koşullarda hem patojenlerin gelişme yeteneklerinin hem de biyolojik mücadele etmenlerinin baskılayıcı etkilerinin değerlendirilmesi önem taşımaktadır.

Trichoderma harzianum, fungal bitki patojenlerine karşı rekabet, mikoparazitizm, antibiyozis ve bitkide savunma mekanizmalarını uyarma gibi özellikleriyle biyolojik mücadelede yaygın olarak kullanılan antagonistlerden biridir (Harman vd., 2004; Tyśkiewicz vd., 2022). Ancak tuzluluk, *T. harzianum* izolatlarının miseliyal gelişimi, sporulasyon kapasitesi ve antagonistik etkinliği üzerinde değişken etkiler oluşturabilmektedir (Kredics vd., 2000; Mohamed & Haggag, 2006; Yiğit, 2011; Rawat vd., 2013; Poosapati vd., 2014; Mbarki vd., 2017; Abu-Shanab vd., 2022; Abdelrhim vd., 2024; Okçu & Özer, 2025a). Tuz stresi karşısında *T. harzianum*'un farklı *Fusarium* türleri üzerine etkileri kapsamında yapılan çalışmalarda, domateste *F. oxysporum* f. sp. *lycopersici* (Mohamed & Haggag, 2006), nohutta *F. oxysporum* f. sp. *ciceri* (Rawat vd., 2013), güvercin bezelyesinde *F. udum* (Mishra vd., 2024), çerezlik kabakta *F. proliferatum* (Okçu & Özer 2025b), buğdayda *F. culmorum* (Okçu & Özer, 2025c) üzerine etkileri incelenmiştir. Bu çalışmalarda söz konusu antagonistin tuz stresine maruz kalmış bitkilerin farklı *Fusarium* türleri tarafından oluşturulan enfeksiyona karşı sağlığını korumada etkili olduğu belirtilmiştir.

Bezelye (*Pisum sativum* L.), insan beslenmesinde protein ve karbonhidrat kaynağı olarak değerlendirilen ve ekim nöbeti sistemlerinde önemli yeri olan serin iklim baklagillerinden biridir. Bununla birlikte bezelye, tuzluluk stresine duyarlı bitkiler arasında yer almakta ve tuzlu toprak koşulları çimlenme, fide gelişimi ve bitki büyümesini olumsuz yönde etkileyebilmektedir (Gupta, 2020; Tracy, 2020). Bezelyede verim ve kaliteyi sınırlandıran önemli biyotik stres etmenlerinden biri de *F. oxysporum* f. sp. *pisi* (*Fop*)'nin neden olduğu Fusarium solgunluğudur. Etmen, yapraklarda sararma ve solgunluk, iletim dokularında kahverengileşme, bitki gelişiminde gerileme ve ileri dönemlerde bitki ölümü gibi simptomlara neden olabilmektedir (Kraft, 1994; Neumann & Xue, 2003; Deng vd., 2022; Kotera vd., 2022). Ayrıca *Fop*'un klamidospor oluşumunun bazı steril tuz çözeltilerinden etkilenebildiği bildirilmiştir (Hsu & Lockwood, 1973). Bu nedenle, tuzluluk koşullarında bezelye– *Fop* etkileşiminin ve bu etkene karşı uygulanabilecek biyolojik mücadele olanaklarının değerlendirilmesi önem taşımaktadır. Bununla birlikte, tuzluluk koşullarında *T. harzianum*'un *Fop*'a karşı biyokontrol etkinliği ve patojenin bezelye tohumu çevresindeki gelişimi üzerine etkisine dair bir çalışmaya rastlanmamıştır.

Bu çalışmada, farklı tuzluluk seviyeleri altında *T. harzianum*'un *Fop*'a karşı antagonistik aktivitesinin ve patojenin bezelye tohumu çevresindeki kolonizasyonu üzerindeki etkisinin belirlenmesi amaçlanmıştır.

MATERYAL VE YÖNTEM

Materyal

Çalışmada antagonist fungus olarak, daha önce Tekirdağ ili soğan ekili alanlarından izole edilen ve farklı fungal etmenlere karşı antagonistik özelliği bilinen *T. harzianum* TRIC8 izolatı (GenBank Erişim No: MH351669) kullanılmıştır. Patojen fungus olarak ise bezelyede solgunluk etmeni *Fop*'un B74 izolatı seçilmiştir. Bu izolat, Türkiye'de en yaygın ırk olarak belirlenen 6 no'lu ırkı temsil eden ve önceki patojenisite çalışmalarında yüksek hastalık şiddeti oluşturan izolatlar arasında yer alan bir izolat olarak değerlendirilmiştir (Gültekin vd., 2025; Gültekin & Özer, 2026). Tohum kolonizasyonu denemelerinde, *Fop*'a duyarlı genotip olarak yaygın şekilde kullanılan ve ırk 6'ya karşı duyarlı kontrol olarak değerlendirilen bezelye çeşidi Little Marvel tercih edilmiştir (Haglund, 1984, 1989; Kraft, 1994; Merzoug vd., 2014).

Farklı tuzluluk düzeylerinde ikili kültür denemesi

T. harzianum'un *Fop* üzerindeki antagonistik etkisini belirlemek amacıyla Patates Dekstroz Agar (PDA-Merck) besi ortamına 0, 50, 100 ve 150 mM NaCl ilave edilmiştir. Hazırlanan ortamlar 121°C'de 20 dakika otoklavlandıktan sonra 8.5 cm çapındaki steril petri kaplarına dökülmüştür. Besi yeri katılaştıktan sonra, yedi gün süreyle PDA'da geliştirilen patojen ve antagonist kültürlerinden 5 mm çapında miseliyal diskler alınmıştır. Diskler, petri kabının karşılıklı kenarlarına ve kenardan yaklaşık 1 cm içeride olacak şekilde yerleştirilmiştir. Patojen kontrolünde ise tuz içermeyen PDA ortamının merkezine yalnızca *Fop* diski konulmuştur. Petri kapları 23±1 °C'de inkübe edilmiş ve kontrol grubunda patojen kolonisinin petri kabını doldurmaya yaklaştığı dönemde ölçümler yapılmıştır. Her uygulamada *Fop* koloni yarıçapı ölçülmüş ve *T. harzianum* tarafından sağlanan engelleme oranı [(*Fop*K − *Fop*Th) / *Fop*K × 100] formülüne göre hesaplanmıştır. Formülde *Fop*K, tuz içermeyen PDA ortamında tek başına geliştirilen *Fop* koloni yarıçapını; *Fop*Th ise ilgili tuzluluk düzeyinde *T. harzianum* ile ikili kültürde gelişen *Fop* koloni yarıçapını ifade etmektedir. Deneme her uygulama için dört tekerrürlü olarak yürütülmüş ve her petri kabı bir tekerrür kabul edilmiştir.

Farklı tuzluluk düzeylerinde tohum kolonizasyonu denemesi

T. harzianum'un bezelye tohumu çevresinde *Fop* gelişimi üzerine etkisini belirlemek amacıyla 0, 50 ve 100 mM NaCl içeren PDA ortamları kullanılmıştır. Little Marvel çeşidine ait bezelye tohumları yüzey dezenfeksiyonu amacıyla %2'lik sodyum hipoklorit çözeltisinde 7 dakika bekletilmiş, ardından steril saf su ile üç kez durulanmış ve steril filtre kağıdı üzerinde kurumaya bırakılmıştır. Patojen ve antagonist fungusların konidi süspansiyonları, yedi günlük kültürlerden steril saf su ve Tween 20 yardımıyla hazırlanmış ve yoğunlukları hemasitometre ile 1 × 10^6 konidi/ml olacak şekilde ayarlanmıştır. Tohumlar, eşit hacimlerde karıştırılan *Fop* ve *T. harzianum* konidi süspansiyonunda çalkalanarak muamele edilmiş, ardından farklı tuzluluk düzeylerini içeren PDA ortamlarına yerleştirilmiştir. Patojen kontrolünde ise tohumlar yalnızca *Fop* konidi süspansiyonu ile muamele edilmiş ve tuz içermeyen PDA ortamına yerleştirilmiştir. Petri kapları 23±1 °C'de inkübe edilmiş ve inkübasyon sonunda tohum çevresinde gelişen *Fop* koloni çapı ölçülmüştür. *T. harzianum* uygulamasının patojenin tohum çevresindeki gelişimini engelleme oranı [(*Fop*K − *Fop*Th) / *Fop*K × 100] formülüne göre hesaplanmıştır. Formülde *Fop*K, tuz içermeyen PDA ortamında yalnızca *Fop* ile muamele edilen tohumların çevresinde gelişen patojen koloni çapını; *Fop*Th ise ilgili tuzluluk düzeyinde *Fop* + *T. harzianum* ile muamele edilen tohumların çevresinde gelişen *Fop* koloni çapını ifade etmektedir. Deneme her uygulama için beş tekerrürlü olarak kurulmuş ve her petri kabı bir tekerrür kabul edilmiştir.

İstatistik analizi

Elde edilen veriler öncelikle varyansların homojenliği ve normal dağılım varsayımları bakımından değerlendirilmiştir. Bu amaçla Levene testi ve Shapiro-Wilk testi uygulanmıştır. Verilerin parametrik test varsayımlarını karşılaması durumunda uygulamalar arasındaki farklılıklar tek yönlü varyans analizi

ile belirlenmiş, ortalamalar arasındaki karşılaştırmalar Tukey HSD testi kullanılarak yapılmıştır. İstatistik analizlerde SPSS version 23 (IBM SPSS Statistics for Windows, IBM Corp., Armonk, NY, ABD) ve JMP Pro version 17 (SAS Institute Inc., Cary, NC, ABD) yazılımlarından yararlanılmıştır. Tüm değerlendirmeler p=0.05 önem düzeyinde yapılmıştır.

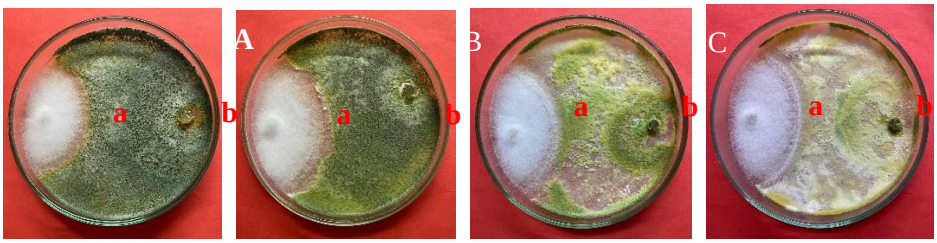
ARAŞTIRMA BULGULARI VE TARTIŞMA

İkili kültür denemelerinde, tuz içermeyen patojen kontrolünde (*Fop*K) *Fop*'un koloni yarıçapı 4.00 cm olarak belirlenmiştir. *T. harzianum* ile birlikte geliştirilen uygulamalarda *Fop* koloni yarıçapı tüm tuzluluk düzeylerinde önemli ölçüde azalmış ve 1.57–1.67 cm arasında değişmiştir (Çizelge 1). Tuzsuz ortamda *T. harzianum* uygulaması patojen gelişimini %60.62 oranında engellemiştir. Tuz konsantrasyonunun 50, 100 ve 150 mM NaCl'ye yükselmesiyle engelleme oranları sırasıyla %60.00, %58.75 ve %58.12 olarak belirlenmiş; ancak bu değerler arasındaki farklılık istatistiksel olarak önemli bulunmamıştır. İkili kültürlerde tuz düzeyleri arttıkça *T. harzianum* ve *Fop* kolonilerinin gelişim alanlarında kısmi değişiklikler görülmekle birlikte, antagonist fungusun patojenle temas bölgesinde gelişimini sürdürdüğü gözlenmiştir (Şekil 1).

Çizelge 1. Farklı tuzluluk düzeylerinde *Trichoderma harzianum*'un *Fusarium oxysporum* f. sp. *pisi*'nin miseliyal koloni gelişimi üzerine etkisi

Tuzluluk/Uygulama	Miseliyal koloni yarıçapı (cm)*	Miseliyal koloni gelişimini engelleme oranı (%)*
*Fop*K	4.00±0.00 a	-
0 (*Fop*+Th)	1.57±0.06 b	60.62±1.57 a
50 (*Fop*+Th)	1.60±0.04 b	60.00±1.02 a
100 (*Fop*+Th)	1.65±0.06 b	58.75±1.61 a
150 (*Fop*+Th)	1.67±0.05 b	58.12±1.20 a

*Her bir değer 4 tekerrürün ortalamasıdır. Aynı sütunda aynı harflerle gösterilen ortalamalar arasındaki farklılıklar Tukey HSD testine göre önemli değildir. [Miseliyal koloni yarıçapı ve koloni gelişimini engelleme oranı için sırasıyla, $F_{4,15}$= 467.4569 (P<0.0001), $F_{3,12}$= 0.6897 (P=0.5756)]. *Fop*K: Patojen (*Fusarium oxysporum* f. sp. *pisi*) kontrol, *Fop*: *Fusarium oxysporum* f. sp. *pisi*, Th: *Trichoderma harzianum*



Şekil 1. Farklı tuzluluk düzeylerinde ikili kültürde *Fusarium oxysporum* f. sp. *pisi* ve *Trichoderma harzianum* gelişimi. A: 0 mM *Fop*+Th, B: 50 mM *Fop*+Th, C: 100 mM *Fop*+Th, D: 150 mM *Fop*+Th. a: *Fusarium oxysporum* f. sp. *pisi*, b: *Trichoderma harzianum*.

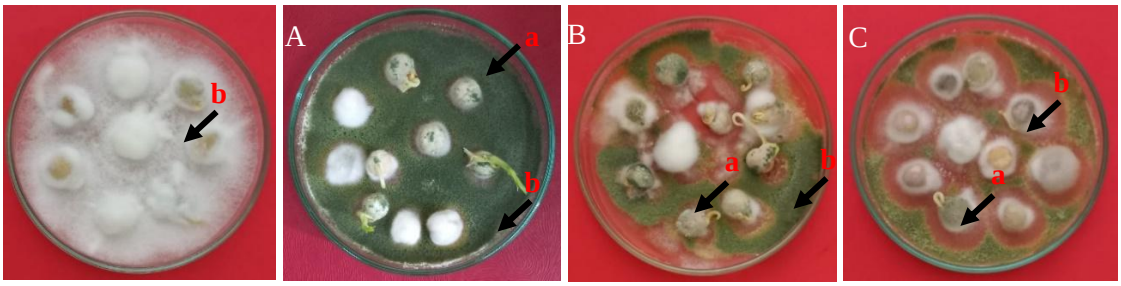
Tohum kolonizasyonu denemesinde, yalnızca *Fop* ile muamele edilen bezelye tohumlarının çevresinde gelişen patojen koloni çapı 2.08 cm olarak ölçülmüştür. *T. harzianum* uygulaması, tuz bulunmayan ortamda *Fop*'un tohum çevresindeki gelişimini belirgin şekilde sınırlandırmış ve koloni çapını 0.39 cm'ye düşürmüştür (Çizelge 2). Bu uygulamada engelleme oranı %81.24 ile en yüksek değere ulaşmıştır. Buna karşılık, 50 ve 100 mM NaCl içeren ortamlarda *Fop* koloni çapı sırasıyla 0.99 ve 1.12 cm'ye yükselmiş, engelleme oranları ise %52.28 ve %46.31'e gerilemiştir. Tuzlu ortamlarda *T. harzianum*'un patojen gelişimini baskılayıcı etkisi devam etmekle birlikte, özellikle tohum çevresindeki etki düzeyinin tuz konsantrasyonuna bağlı olarak azaldığı belirlenmiştir. Görsel değerlendirmelerde, tuzsuz ortamda *T. harzianum*'un tohum çevresinde daha yoğun geliştiği, tuzlu ortamlarda ise *Fop* gelişiminin kısmen arttığı görülmüştür (Şekil 2).

Daha önce yapılan *in vitro* çalışmalarda, *T. harzianum*'un *Fop* üzerine farklı düzeylerde antagonistik etki gösterdiği bildirilmiştir. Bu çalışmalarda kullanılan antagonist izolatların kaynağı bezelye tarlası rizosferi, bezelye tarlası toprağı, bezelye baklası veya hazır kültür koleksiyonları olarak değişmiş; bildirilen koloni gelişimini engelleme oranları yaklaşık %34.55 ile %83.00 arasında yer almıştır (Verma & Dohroo, 2005a, b; Kapoor vd., 2006; Abo Dakika & Zen-El-Dein, 2007; Kapoor vd., 2012; Hamid vd., 2012; Ali vd., 2014; Kumari, 2016; Nigam vd., 2020; El-Sharkawy vd., 2021; Yousuf, 2021; Kurmi vd., 2023; El-Sayed & Al-Oufi, 2025). Benzer şekilde, Checa Coral vd. (2017) da bezelye rizosferinden elde edilen *Trichoderma* izolatlarının *Fop*'a karşı inhibisyon zonu oluşturduğunu bildirmiştir. Mevcut çalışmada tuz içermeyen ortamda *T. harzianum*'un B74 izolatına karşı %60.62 oranında koloni gelişimi engellemesi sağlaması, bu antagonistin *Fop* üzerindeki baskılayıcı etkisinin önceki *in vitro* bulgularla uyumlu olduğunu göstermektedir. Bununla birlikte, önceki çalışmaların çoğunda patojen izolatlarının ırk durumu belirtilmemiştir. Bu yönüyle çalışmamızda Türkiye'de yaygın ırklardan biri olan 6 no'lu ırkı temsil eden B74 izolatının kullanılması, elde edilen bulgulara ayrı bir önem kazandırmaktadır.

Çizelge 2. Farklı tuzluluk düzeylerinde *Trichoderma harzianum*'un bezelye tohumu çevresindeki *Fusarium oxysporum* f. sp. *pisi* gelişimi üzerine etkisi

Tuzluluk/Uygulama	Miseliyal koloni çapı (cm) *	Miseliyal koloni gelişimini engelleme oranı (%)*
*Fop*K	2.08±0.09 a	
0 (*Fop*+Th)	0.39±0.03 c	81.24±1.24 a
50 (*Fop*+Th)	0.99±0.02 b	52.28±0.74 b
100 (*Fop*+Th)	1.12±0.01 b	46.31±0.33 c

*Her bir değer 5 tekerrürün ortalamasıdır. Aynı sütunda aynı harflerle gösterilen ortalamalar arasındaki farklılıklar Tukey HSD testine göre önemli değildir. [Miseliyal koloni çapı ve koloni gelişimini engelleme oranı için sırasıyla, $F_{3,16}$= 260.5445 (P<0.0001), $F_{2,12}$= 480.6852 (P<0.0001)]. *Fop*K: Patojen (*Fusarium oxysporum* f. sp. *pisi*) tohum kontrol, *Fop*: *Fusarium oxysporum* f. sp. *pisi*, Th: *Trichoderma harzianum*



Şekil 2. *Fusarium oxysporum f. sp. pisi'nin* bezelye tohumu çevresindeki gelişimi ve farklı tuzluluk düzeylerinde *Trichoderma harzianum* varlığındaki gelişimi. A: Patojen kontrol; B: 0 mM *Fop*+Th; C: 50 mM *Fop*+Th; D: 100 mM *Fop*+Th; a: *Trichoderma harzianum*, b: *Fusarium oxysporum* f. sp. *pisi*

Farklı *Fusarium* türlerinin tuzluluğa karşı gösterdiği toleransın aynı düzeyde olmadığı çeşitli çalışmalarda ortaya konulmuştur (Mandeel, 2006; Shoaib vd., 2018; Maharshi vd., 2021; Tiwari vd., 2024). Bu farklılık, tuz stresi altında *T. harzianum*'un antagonistik performansının da patojen türüne göre değişmesine yol açabilmektedir. Bu kapsamda, *F. oxysporum* f. sp. *lycopersici*'de *T. harzianum* tarafından sağlanan en yüksek koloni gelişimi engellemesi 69 mM NaCl'de %40.4 olarak bildirilirken, *F. oxysporum* f. sp. *ciceri*'de 70 mM NaCl'de %93.66 ve *F. udum*'da 684.46 mM NaCl'de %60 düzeyinde engelleme elde edilmiştir (Mohamed & Haggag, 2006; Rawat vd., 2013; Mishra vd., 2024). Diğer taraftan, *F. proliferatum*'un 342.3–1171 mM NaCl aralığında tuz düzeyi yükseldikçe daha sınırlı miseliyal gelişim gösterdiği belirtilmiştir (Deepthi vd., 2022). Bu çalışmada kullanılan *T. harzianum* izolatıyla yürütülen önceki çalışmalarda da tuzluluk altındaki etkinliğin hedef patojene göre farklılaştığı görülmüş, *F. proliferatum*'a karşı en yüksek engelleme oranı 50 mM NaCl'de %52.50 olarak belirlenmiştir (Okçu & Özer, 2025b). Buna karşılık *F. culmorum*'da tuz bulunmayan ortamda %65.00 olan engelleme oranı, 50, 100 ve 150 mM NaCl'de sırasıyla %40.62, %40.00 ve %38.75'e gerilemiştir (Okçu & Özer, 2025c). Bu çalışmada ise *Fop* B74 izolatı için 50, 100 ve 150 mM NaCl uygulamalarında

sırasıyla %60.00, %58.75 ve %58.12 oranında engelleme belirlenmiştir. Bu değerler, ikili kültür koşullarında *Fop*'a karşı antagonist etkinin artan NaCl düzeylerine rağmen birbirine oldukça yakın kaldığını göstermektedir.

Çalışmamızda tuz içermeyen ortamda tohum etrafındaki *Fop* gelişiminin %81.24 oranında engellenmesi, antagonist etkinin tohum çevresinde ikili kültüre göre daha yüksek düzeye çıkabildiğini göstermiştir. Bu durumun, tohum çevresinin yalnızca patojen ve antagonistin karşılaştığı fiziksel bir alan olmaktan öte, bitki kaynaklı bileşiklerin de etkili olduğu özel bir mikroçevre olmasından kaynaklandığı düşünülmektedir. Bitki dokuları çevresinde gelişen patojen–antagonist ilişkilerinde mikroorganizmaların bitkiden salınan besin maddeleri için rekabete girdiği ve *T. harzianum*'un bu rekabette avantaj sağlayabildiği bildirilmektedir (Tyśkiewicz vd., 2022). Ayrıca *T. harzianum*'un tohum yüzeyini saprofitik olarak kolonize edebilmesi, rekabet ve mikoparazitizm gibi mekanizmalarının ortaya çıkmasında önemli görülmektedir (Brozova, 2004; Güçlü & Özer, 2022). Bu nedenle, çalışmamızda tuzsuz ortamda çimlenmenin başlamasıyla birlikte tohumdan çevreye geçen besin maddeleri ve düşük molekül ağırlıklı metabolitlerin, *T. harzianum* gelişimini destekleyerek *Fop'*un tohum çevresindeki yayılımını azalttığı kanaatine varılmıştır.

Tuzluluk altında *T. harzianum–Fusarium* spp.–bitki ilişkisini doğrudan ele alan çalışma sayısı sınırlıdır. Domates–*F. oxysporum* f. sp. *lycopersici* sisteminde, 4 mM NaCl varlığında *T. harzianum* uygulaması enfeksiyonu %56.48 oranında azaltmıştır (Mohamed & Haggag, 2006). Güvercin bezelyesi–*F. udum* sisteminde ise 48 mM NaCl koşulunda *T. harzianum* uygulamasının enfeksiyonu istatistiksel olarak önemli düzeyde baskıladığı bildirilmiştir (Mishra vd., 2024). Canlı bitki çalışmalarından farklı olarak, bu çalışmada kullanılan *T. harzianum* izolatıyla yürütülen önceki tohum kolonizasyonu denemelerinde de tuzlu koşullarda patojen gelişiminin baskılandığı belirlenmiştir; buğdayda *F. culmorum*'a karşı yapılan çalışmada tohum çevresindeki patojen gelişimi 50 mM NaCl'de %70.64, 100 mM NaCl'de ise %45.16 oranında engellenmiştir (Okçu & Özer, 2025c). Çerezlik kabakta *F. proliferatum*'a karşı yapılan çalışmada ise engelleme oranları 50 ve 100 mM NaCl düzeylerinde sırasıyla %52.83 ve %39.81 olarak bulunmuştur (Okçu & Özer, 2025b). Mevcut çalışmada NaCl içeren ortamlarda *T. harzianum* tarafından tohum çevresindeki *Fop* gelişiminin engellenme oranı tuzsuz ortama göre daha düşük bulunmuş, patojenin gelişimi 50 mM NaCl'de %52.28, 100 mM NaCl'de ise %46.31 oranında engellenmiştir. Bezelyenin tuzluluğa duyarlı bir bitki olması ve tuz stresinin çimlenme ile erken fide gelişimini olumsuz etkileyebilmesi, bu azalmanın değerlendirilmesinde dikkate alınmalıdır (Tracy, 2020; Gupta, 2024). Tuzluluğun, tohumun su alımını ve tohum çevresine salınan bileşiklerin miktarını veya bileşimini değiştirdiği ve buna bağlı olarak *T. harzianum*'un tohum çevresindeki kolonizasyon başarısı ile *Fop*'la rekabet ilişkisini tuzsuz ortama göre farklılaştırdığı öngörülmektedir. Bununla birlikte, 50 ve 100 mM NaCl koşullarında da belirgin düzeyde engelleme elde edilmesi, antagonist etkinin tuz varlığında tamamen kaybolmadığını göstermektedir.

SONUÇ

Bu çalışmada, *T. harzianum*'un *Fop* B74 izolatına karşı antagonistik etkinliğinin tuzluluk koşullarında da devam ettiği belirlenmiştir. İkili kültür denemelerinde antagonist fungusun patojen gelişimini tüm NaCl düzeylerinde benzer oranlarda engellemesi, miseliyal gelişim düzeyindeki etkinin artan tuzluluktan önemli ölçüde etkilenmediğini göstermiştir. Tohum kolonizasyonu denemesinde ise tuzsuz ortamda daha yüksek olan engelleme oranı NaCl varlığında azalmış, ancak 50 mM NaCl düzeyinde *T. harzianum* patojenin tohum çevresindeki gelişimini %52.28 oranında baskılamıştır. Bu bulgular, *T. harzianum*'un özellikle orta düzey tuzluluk koşullarında *Fop* gelişimini sınırlandırma potansiyelini koruyabildiğini göstermektedir. Bununla birlikte, tohum çevresindeki etkinin tuzluluk düzeyine bağlı olarak değişmesi, bu antagonistin bezelyede *Fop*'a karşı biyolojik mücadele potansiyelinin saksı ve tarla koşullarında da test edilmesi gerektiğini ortaya koymaktadır.

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EFFECTS OF ALTERNATIVE TREATMENTS AGAINST GRAPEVINE DOWNY MILDEW DISEASE ON THE ACCUMULATION OF STILBENE PHYTOALEXINS

BAĞ MİLDİYÖSÜ HASTALIĞINA KARŞI ALTERNATİF UYGULAMALARIN STİLBEN GRUBU FİTOALEKSİNLERİN BİRİKİMİ ÜZERİNE ETKİLERİ

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ABSTRACT

Grapevine downy mildew, caused by *Plasmopara viticola*, is a major disease responsible for substantial yield and quality losses in grape production worldwide. Although chemical fungicides are widely used, concerns about their environmental effects, fungicide resistance, and the need for sustainable viticulture have increased interest in alternative management strategies. Induction of stilbene phytoalexins represents a promising approach because these compounds contribute to grapevine defence against *P. viticola*. This review evaluated the effects of chitosan and other defence-inducing agents, plant extracts and other natural products, and microbial applications on stilbene phytoalexin accumulation and disease development in grapevine. Scientific studies on plant defence responses, stilbene phytoalexin accumulation, and alternative control methods in the *P. viticola*–grapevine interaction were reviewed. Treatments were compared according to the stilbene compounds affected and their effects on sporulation, zoospore motility, infection development, and disease severity. Studies reporting only total stilbene content without identifying individual compounds were excluded. The reviewed studies showed that chitosan and other defence-inducing agents, plant extracts and other natural products, and some microbial applications increased the accumulation of resveratrol, piceid, pterostilbene, and viniferin derivatives to varying degrees. Some treatments directly stimulated phytoalexin synthesis, whereas others primed grapevine tissues against the infection, leading to faster and greater stilbene accumulation after pathogen inoculation. Increased levels of toxic stilbene derivatives were generally associated with reduced *P. viticola* sporulation, zoospore motility, infection development, and disease severity. However, phytoalexin profiles and protective efficacy varied with treatment type, dose, timing, formulation, grapevine genotype, and environmental conditions. These findings indicate that treatments promoting stilbene phytoalexin accumulation may complement chemical control, reduce fungicide dependence, and contribute to sustainable grapevine downy mildew management.

Keywords: *Plasmopara viticola*, grapevine downy mildew, stilbene phytoalexins, plant defence responses, alternative disease management

ÖZET

Bağ mildiyösü etmeni *Plasmopara viticola*, dünya genelinde üzüm üretiminde önemli verim ve kalite kayıplarına neden olan başlıca hastalık etmenlerinden biridir. Kimyasal fungisitler hastalığın kontrolünde yaygın olarak kullanılmakla birlikte, çevresel etkileri, fungisit dayanıklılığı riski ve sürdürülebilir bağcılık gereksinimleri alternatif mücadele yaklaşımlarına ilgiyi artırmıştır. Stilben fitoaleksinlerinin uyarılması, bu bileşiklerin asmanın *P. viticola*'ya karşı savunmasına katkıda bulunması nedeniyle ümitvar bir yaklaşım oluşturmaktadır Bu derlemede, kitosan ve diğer savunma uyarıcıları, bitki ekstraktları ve diğer doğal ürünler ile mikrobiyal uygulamaların asmada stilben fitoaleksinlerinin birikimi ve hastalık gelişimi üzerindeki etkileri değerlendirilmiştir. *P. viticola*–asma etkileşiminde bitki savunma tepkileri, stilben fitoaleksinlerinin birikimi ve alternatif mücadele yöntemlerini ele alan bilimsel çalışmalar incelenmiştir. Uygulamalar, etkiledikleri stilben bileşikleri ile

sporulasyon, zoospor hareketliliği, enfeksiyon gelişimi ve hastalık şiddeti üzerindeki etkileri bakımından karşılaştırılmıştır. Stilben bileşiklerinin ayrı ayrı tanımlanmadığı ve yalnızca toplam stilben miktarının bildirildiği çalışmalar değerlendirmeye alınmamıştır. İncelenen çalışmalar, kitosan ve diğer savunma uyarıcıları, bitki ekstraktları ve diğer doğal ürünler ile bazı mikrobiyal uygulamaların asmada resveratrol, piceid, pterostilben ve viniferin türevlerinin birikimini farklı düzeylerde artırdığını göstermiştir. Bazı uygulamalar fitoaleksin sentezini doğrudan uyarırken, bazıları asma dokularını enfeksiyona karşı hazırlayarak patojen inokulasyonundan sonra stilbenlerin daha hızlı ve yüksek düzeyde birikmesini sağlamıştır. Toksik stilben türevlerindeki artışın genellikle *P. viticola*'nın sporulasyonu, zoospor hareketliliği, enfeksiyon gelişimi ve hastalık şiddetindeki azalma ile ilişkili olduğu görülmüştür. Bununla birlikte, fitoaleksin profili ve koruyucu etkinlik; uygulamanın türü, dozu, zamanı ve formülasyonu ile asma genotipi ve çevre koşullarına bağlı olarak değişmiştir. Bulgular, stilben fitoaleksinlerinin birikimini artıran uygulamaların kimyasal mücadeleyi tamamlayabileceğini, fungisitlere bağımlılığı azaltabileceğini ve bağ mildiyösünün sürdürülebilir yönetimine katkı sağlayabileceğini göstermektedir.

Anahtar kelimeler: *Plasmopara viticola,* bağ mildiyösü, stilben grubu fitoaleksinler, bitki savunma tepkileri, alternatif mücadele

GİRİŞ

Asma (*Vitis vinifera* L.), sofralık üzüm, kuru üzüm, meyve suyu ve şarap üretiminde kullanılan, ekonomik açıdan önemli bir kültür bitkisidir (Brilli vd., 2018; Nascimento vd., 2019; Xiang vd., 2021). Bununla birlikte üzüm üretimi, çok sayıda hastalık etmeninin baskısı altındadır. Bağ mildiyösü etmeni *Plasmopara viticola* (Berk. & M.A. Curtis) Berl. & De Toni, Oomycota grubunda yer alan obligat biyotrof bir patojen olup dünya bağcılığının en önemli hastalık etmenlerinden biri olarak kabul edilmektedir (Gessler vd., 2011; Fontaine vd., 2021).

Patojen asmanın fotosentetik olarak aktif yaprak, genç sürgün, çiçek salkımı ve gelişmekte olan meyve gibi yeşil organlarını enfekte etmektedir (Moriondo vd., 2005; Gessler vd., 2011; Blasi vd., 2011; Yu vd., 2012). Hastalığın ilk belirtileri genellikle yaprakların üst yüzeyinde yağ lekesi görünümündeki sarımsı alanlar, alt yüzeyinde ise yüksek nem koşullarında oluşan beyaz sporulasyon şeklinde ortaya çıkmaktadır (Musetti vd., 2005). Şiddetli enfeksiyonlarda yaprak ve sürgünlerde nekroz, erken yaprak dökümü, salkımlarda buruşma ve meyve kayıpları meydana gelmekte; fotosentetik yaprak alanının azalmasına bağlı olarak verim ve ürün kalitesi önemli ölçüde düşmektedir (Moriondo vd., 2005; Blasi vd., 2011; Yu vd., 2012; Sun vd., 2024; Gouveia vd., 2024; Zhang vd., 2025). Uygun sıcaklık ve yüksek nem koşullarında patojenin zoosporları stomalardan bitkiye girerek sezon boyunca tekrarlanan enfeksiyonlara neden olabilmektedir (Wong vd., 2001; Perazzolli vd., 2020).

Bağ mildiyösünün kontrolünde kimyasal fungisitler yaygın olarak kullanılmasına rağmen, yoğun ve tekrarlanan uygulamalar fungisitlere dayanıklılık, çevresel kirlilik, ürünlerde kalıntı ve özellikle bakırlı preparatların kullanımına bağlı olarak toprakta bakır birikimi gibi sorunlara yol açmaktadır. Bu nedenle son yıllarda bitkinin doğal savunma mekanizmalarını harekete geçiren çevre dostu ve sürdürülebilir alternatif mücadele yaklaşımlarına yönelik çalışmalar artmıştır (Gessler vd., 2011; Fontaine vd., 2021).

Asmanın *P. viticola*'ya karşı savunmasında fenilpropanoid yolu üzerinden sentezlenen stilben fitoaleksinleri önemli rol oynamaktadır. Resveratrol, piceid, pterostilben ile ε- ve δ-viniferin gibi stilbenlerin birikmesi, patojen gelişiminin sınırlandırılması ve dayanıklılık yanıtının güçlenmesiyle ilişkilendirilmektedir. Etmene karşı kullanılan bazı alternatif uygulamaların hastalığın kontrolünün yanı sıra stilben fitoaleksinlerinin sentezini veya enfeksiyon sonrasındaki birikimini de artırabildiği belirlenmiştir (Aziz vd., 2006; Gindro vd., 2007; Godard vd., 2009; Krzyzaniak vd., 2018; Lakkis vd., 2019; Burdziej vd., 2021; Mijailović vd., 2022; Taillis vd., 2022; Brulé vd., 2024; Raveau vd., 2024; Rappo vd., 2026).

Bu derlemede, *P. viticola*'ya karşı uygulanan alternatif mücadele yöntemleri arasından asmada stilben fitoaleksinlerinin birikimi üzerindeki etkilerinin araştırıldığı çalışmalar güncel literatür ışığında değerlendirilmiştir. İncelenen çalışmalarda kullanılan uygulamaların kitosan ve diğer savunma uyarıcıları, bitki ekstraktları ve diğer doğal ürünler ile mikrobiyal uygulamalar başlıkları altında

toplandığı görülmüştür. Bu kapsamda, söz konusu uygulamaların resveratrol, piceid, viniferin türevleri ve pterostilben gibi başlıca stilben fitoaleksinlerinin birikimini ne ölçüde ve hangi mekanizmalarla etkilediğinin ortaya konulması ve bu yanıtların bağ mildiyösünün sürdürülebilir yönetimindeki öneminin değerlendirilmesi amaçlanmıştır.

KİTOSAN VE DİĞER SAVUNMA UYARICILARININ STİLBEN FİTOALEKSİN BİRİKİMİNE ETKİSİ

Aziz vd. (2006), farklı molekül ağırlığı ve asetilasyon derecesine sahip kitosan oligomerlerinin asmada stilben fitoaleksini birikimi ve ***P. viticola***'ya karşı koruyucu etkisini araştırmışlardır. Çalışmada, 1500 Da molekül ağırlığına ve %20 asetilasyon derecesine sahip kitosan oligomeri (CHN1.5/20), 200 µg/ml konsantrasyonda uygulandığında trans-resveratrol, cis-resveratrol, ε-viniferin ve piceid birikimini belirgin biçimde artırmıştır. Bu uygulama hastalıkla kaplı yaprak alanını %42'den %12'ye düşürerek yaklaşık %71 koruma sağlamıştır. Kitosanın 50 µg/ml $CuSO_4$ ile birlikte uygulanması ise stilben fitoaleksini birikimini daha güçlü biçimde uyarmış ve koruma oranını yaklaşık %85'e yükseltmiştir. Araştırmacılar kitosanın bağ mildiyösüne karşı etkisinin büyük ölçüde stilben fitoaleksinlerinin birikiminin uyarılmasıyla ilişkili olduğunu ileri sürmüşlerdir.

Burdziej vd. (2021), metil jasmonat (MeJA), benzotiyadiazol (BTH) ve fosfonat (PHOS) uygulamalarının asmada stilben fitoaleksini birikimi ve *P. viticola* gelişimi üzerindeki etkilerini incelemişlerdir. Uyarıcılar inokulasyondan 6 gün önce yapraklara uygulanmış; BTH, PHOS ve MeJA patojen gelişimini sırasıyla %98.5, %97.3 ve %85.8 oranında baskılamıştır. İnokulasyon öncesinde MeJA, trans-resveratrol, cis- ve trans-piceid ile ε-viniferin birikimini artırırken, BTH ve PHOS uygulamalarında toplam stilben miktarı azalmıştır. MeJA ile ön işlem görmüş yapraklarda inokulasyondan 2 gün sonra toplam stilben miktarı yaklaşık 1.9 kat yükselmiştir. Aynı yapraklarda piceid miktarı, MeJA uygulanmış fakat inokule edilmemiş yapraklara göre 1.8 kat, inokule edilmiş işlem görmemiş kontrole göre ise 7.2 kat daha yüksek bulunmuştur. ε-Viniferin düzeyi de aynı uygulamanın inokule edilmemiş yapraklarına göre 2.8 kat artmıştır. Pterostilben miktarı PHOS uygulanan yapraklarda hem inokulasyon öncesinde hem de sonrasında karşılık gelen kontrollere göre yaklaşık 2.4 kat yüksek bulunurken, BTH uygulanmış yapraklarda belirgin artış yalnızca inokulasyondan sonra ortaya çıkmış ve inokule edilmemiş BTH yapraklarına göre 2.7 kat yükselmiştir. Bu sonuçlar, MeJA'nın daha çok piceid ve ε-viniferin birikimini teşvik ettiğini, BTH ve PHOS'un ise özellikle pterostilben oluşumunu desteklediğini göstermiştir.

Brulé vd. (2024), farklı polimerizasyon derecelerine sahip kitosanların *P. viticola*'ya karşı doğrudan etkilerini, asmada stilben fitoaleksini birikimini ve hastalık kontrolündeki etkinliklerini karşılaştırmışlardır. Zoospor denemelerinde, 5 mg/L gibi düşük bir konsantrasyonda DP12, DP25, DP33 ve DP470 uygulamaları zoospor hareketliliğini tamamen engellerken, DP44 ve DP100 uygulamalarında sırasıyla %19 ve %29 oranında hareketli zoospor kalmıştır. Metabolomik analizlerde resveratrol, α-viniferin, ε-viniferin, miyabenol C ve daha düşük düzeyde piceid birikimindeki en belirgin artışlar DP12, DP25 ve DP33 uygulamalarında görülmüş; DP44 ve DP100 orta, DP470 ise zayıf elisitör olarak değerlendirilmiştir. Sera koşullarında inokulasyondan 48 saat önce 30 mg/L dozunda uygulanan DP12, DP25 ve DP33 sırasıyla %95, %91 ve %89 koruma sağlarken, DP44, DP100 ve DP470'in koruma oranları %45, %47 ve %35 düzeyinde kalmıştır. Bağda uygulanan DP12, daha sonra laboratuvarda inokule edilen yapraklarda hastalık şiddetini %21.9'dan %4.4'e düşürerek %80 koruma sağlamış; DP470 uygulamasında ise koruma yalnızca %8 olmuştur. Üç farklı bağ lokasyonunda DP12 uygulaması yapraklarda ortalama %52, salkımlarda %54 koruma sağlamıştır. Ayrıca DP12'nin sezon boyunca yalnızca iki bakır uygulamasıyla birlikte kullanılması, yıllık bakır miktarını yaklaşık %70 azaltırken yaprak ve salkımlarda sırasıyla %58 ve %48 koruma sağlamıştır. Çalışma, düşük polimerizasyon derecesine sahip kitosanların, özellikle DP12'nin, stilben fitoaleksini birikimini uyarmanın yanı sıra düşük konsantrasyonlarda zoospor hareketliliğini baskılayarak sera ve bağ koşullarında etkili koruma oluşturduğunu göstermiştir.

BİTKİ EKSTRAKTLARI VE DİĞER DOĞAL ÜRÜNLERİN STİLBEN FİTOALEKSİN BİRİKİMİNE ETKİSİ

Gindro vd. (2007), farklı doğal kökenli preparatları asmada stilben fitoaleksini sentezini uyarma kapasiteleri bakımından karşılaştırmışlardır. İncelenen uygulamalar arasında *Rheum palmatum* kök ekstraktı ile *Frangula* alnus kabuk ekstraktının, özellikle δ-viniferin olmak üzere stilben fitoaleksinlerinin uzun süreli birikimini teşvik ettiği belirlenmiştir. Buna karşılık gallik asidin yalnızca kısa süreli bir stilben artışı oluşturduğu bildirilmiştir.

Godard vd. (2009), *Rheum palmatum* kök ekstraktı (RPRE), *Frangula alnus* kabuk ekstraktı (FABE) ve bu ekstraktların bileşenlerinden biri olan emodin uygulamalarının duyarlı *Vitis vinifera* cv. Chasselas yapraklarında oluşturduğu fitoaleksin yanıtını ve *P. viticola*'ya karşı sağladığı korumayı değerlendirmişlerdir. Her iki bitki ekstraktı da resveratrol, ε-viniferin, δ-viniferin ve pterostilben birikimini artırmış, ancak RPRE daha güçlü bir uyarıcı etki göstermiştir. RPRE enfeksiyon olmadan da yoğun fitoaleksin üretimini teşvik ederken, FABE ve emodinin etkisi özellikle patojen inokulasyonundan sonra belirginleşmiştir. Enfeksiyon sonrasında oluşan resveratrol ve viniferin düzeylerinin dirençli asma çeşitlerinde görülen değerlere yaklaştığı bildirilmiştir. Ekstraktlar ayrıca zoospor hareketliliğini önemli ölçüde azaltmış; hareketli zoospor sayısı su kontrolünde 63.3 iken RPRE ve FABE uygulamalarında sırasıyla 3.0 ve 5.7'ye düşmüş, emodin uygulamasında ise 39.0 olarak belirlenmiştir. Kontrolde 7. günde inokulasyon alanlarının %89'unda sporulasyon görülürken bu oran RPRE ve FABE uygulamalarında sırasıyla %16 ve %25'e gerilemiştir. Böylece bu ekstraktların bağ mildiyösünü hem stilben fitoaleksinlerinin birikimini uyararak hem de zoosporlar üzerinde doğrudan baskılayıcı etki göstererek sınırlandırdığı ortaya konulmuştur.

Krzyzaniak vd. (2018), bitkisel kökenli bir ekstraktın asma savunmasını uyarma kapasitesini ve *P. viticola*'ya karşı doğrudan etkisini birlikte incelemişlerdir. Hücre süspansiyonlarında trans-resveratrol miktarı uygulamadan sonra hızla artarak 12. saatte yaklaşık 160 µg/g taze hücre ağırlığı düzeyine ulaşmış, daha sonra başlangıç düzeyine gerilemiştir. Yaprak dokularında ise analiz edilen stilbenler arasında yalnızca piceidin anlamlı biçimde biriktiği ve ekstrakt uygulanan, inokule edilmemiş yapraklarda kontrolün yaklaşık iki katına ulaştığı belirlenmiştir. İnokulasyondan 48 saat önce 5 g/L dozunda uygulanan ekstrakt, mildiyö sporulasyonunu su kontrolüne göre %67, formülasyondaki koruyucu maddelere göre %74 azaltmıştır. Bunun yanında 0.5–2.5 g/L konsantrasyonlarında zoospor salınımını tamamen engellemiş, 0.5 g/L'de önceden salınmış zoosporların hareketliliğini durdurmuştur. Uygulamadan yalnızca 2 saat sonra yapılan inokulasyonlarda enfeksiyon noktalarının azaldığı ve hif kolonizasyonunun yaklaşık 10 kat düştüğü de gösterilmiştir. Bu çok yönlü etki; stilben metabolizmasının uyarılması, zoosporların doğrudan baskılanması ve yaprak yüzeyinde oluşan kalıntıların stomalara ulaşmayı sınırlandırmasıyla ilişkilendirilmiştir.

Mijailović vd. (2022), D-tagatoz içeren IFP48 formülasyonunun bağ mildiyösüne karşı koruyucu etkisini ve stilben fitoaleksini birikimine katkısını değerlendirmişlerdir. Yaprak uygulamasının kök uygulamasından daha etkili bulunduğu ve yüksek etkinlik gösteren en düşük konsantrasyonun 5 g/L olduğu belirlenmiştir. Doğrudan etki denemelerinde 5 ve 10 g/L IFP48 sporulasyonu tamamen engellerken, 5 g/L saf D-tagatoz sporangiyum yoğunluğunu yaklaşık %90 azaltmıştır. IFP48 uygulaması resveratrol, trans-piceid, ε-viniferin ve δ-viniferin miktarlarını uygulamadan sonraki 1., 2. ve 3. günlerde artırmış; bu bileşiklerin düzeyleri *P. viticola* inokulasyonundan sonraki 1. ve 2. günlerde de yüksek kalmıştır. Resveratrol ilk gün en yüksek düzeye ulaşırken, trans-piceid ve viniferinlerin sonraki günlerde artmayı sürdürmesi, resveratrolün türevlerine dönüştürüldüğünü düşündürmüştür. Saf D-tagatozun stilben fitoaleksini birikimi ve savunma yanıtları üzerindeki etkisi ise daha sınırlı kalmıştır. Fitoaleksin analizlerinin yapıldığı denemede ürün kalıntıları inokulasyondan önce yapraklardan uzaklaştırıldığından, gözlenen koruyucu etkinin doğrudan antioomiset etkiden bağımsız olarak bitki savunmasının uyarılmasıyla ilişkili olduğu gösterilmiştir.

Taillis vd. (2022), asma gövdesi ve köklerinden elde edilen oligomerleşmiş stilbenlerce zengin ekstraktın (OSE), *P. viticola*'ya karşı doğrudan ve bitki aracılı etkilerini incelemişlerdir. Ekstrakt, zoospor hareketliliğini doza bağlı biçimde azaltmış; 25 mg/L'de zoosporların kısa sürede hareketlerini kaybetmesine ve parçalanmasına neden olmuştur. Yaprak diski denemelerinde 200 mg/L OSE sporulasyonu yaklaşık %88 azaltırken, 300 mg/L'de tamamen engellemiştir. Yapraklardan ekstrakt

kalıntıları uzaklaştırıldıktan sonra yapılan analizlerde, endojen trans-piceid miktarının uygulamadan 1 gün sonra kontrolün yaklaşık 1.5 katına çıktığı belirlenmiştir. Bitki savunmasının uyarılmasına bağlı koruma 1. günde %36, 2. günde %59 ve 3. günde %31 olarak gerçekleşmiş, 6. günde ise ortadan kalkmıştır. Yarı kontrollü koşullarda formüle edilmiş OSE, ilk enfeksiyon döneminde hastalık şiddetini %70 azaltarak Bordeaux bulamacından (%51) daha yüksek koruma sağlamış; ancak sonraki enfeksiyon dönemlerinde Bordeaux bulamacının etkinliği daha yüksek ve daha kalıcı olmuştur. Bu sonuçlar, OSE'nin zoosporlar üzerindeki doğrudan etkisinin yanı sıra asmanın kendi stilben savunmasını da geçici olarak uyardığını göstermiştir.

MİKROBİYAL UYGULAMALARIN STİLBEN FİTOALEKSİN BİRİKİMİNE ETKİSİ

Lakkis vd. (2019), köklere uygulanan *Pseudomonas fluorescens* PTA-CT2'nin, bağ mildiyösüne duyarlı Pinot noir ve kısmen dayanıklı Solaris çeşitlerinde sistemik savunmanın çeşitlere göre nasıl değiştiğini belirlemişlerdir. Bakteri uygulaması *P. viticola* gelişimini Pinot noir'da yaklaşık %80, Solaris'te ise %55 azaltmış; 2017 yılı hastalık sınıflandırmasına göre her iki çeşitte de hastalık şiddetinde yaklaşık %40 azalma sağlamıştır. PTA-CT2 tek başına, patojen bulunmadığında resveratrol, ε-viniferin ve δ-viniferin miktarlarında anlamlı bir artış oluşturmamıştır. Buna karşılık patojenin inokulasyonundan sonra Pinot noir'da ε- ve δ-viniferin, Solaris'te ise resveratrol ve δ-viniferin birikimini artırarak fitoaleksin yanıtını hazırlamıştır. PTA-CT2'nin patojenle birlikte doğrudan uygulanması sporulasyonu azaltmadığından, korumanın bakterinin doğrudan antioomiset etkisinden değil, köklerde oluşturduğu sistemik savunma uyarımından kaynaklandığı sonucuna varılmıştır.

Raveau vd. (2024), *Bacillus velezensis* Buz14 ve *B. ginsengihumi* S38 kültür süpernatantlarının bağ mildiyösüne karşı koruyucu, doğrudan antioomiset ve savunma uyarıcı etkilerini yarı kontrollü koşullarda değerlendirmişlerdir. İnokulasyondan 48 saat önce uygulanan %10'luk süpernatantlar sporulasyonu anlamlı biçimde azaltmış; %25'lik Buz14 ve S38 uygulamalarında sporulasyon alanı sırasıyla yalnızca %0.3 ve %0.6 düzeyinde kalmıştır. Aynı konsantrasyonda her iki süpernatant zoospor hareketliliğini tamamen engellemiş ve zoospor salınımını güçlü biçimde baskılamıştır. Uygulamadan 24 saat sonra Buz14, trans-ε-viniferin ve trans-ω-viniferin miktarlarını sırasıyla 13.6 ve 11.2 kat, S38 ise isorhapontini 13.3 kat artırmıştır. Cis-piceid miktarı S38 uygulamasında yaklaşık 1.5 kat yükselmiştir. Bununla birlikte, bakterilerin üretiminde kullanılan Luria–Bertani (LB) besiyerinin de bazı stilbenlerin birikimini ve zoospor salınımını etkilediği belirlenmiş; bu nedenle gözlenen etkinliğin yalnızca bakteriyel metabolitlerden değil, kısmen besiyeri bileşenlerinden de kaynaklanabileceği belirtilmiştir.

Rappo vd. (2026), asma fillosferinden elde edilen 46 bakteriyel izolatın ***P. viticola***'ya karşı doğrudan etkilerini, hastalık baskılama kapasitelerini ve stilben savunmasını uyarma özelliklerini taramışlardır. Yaprak diski denemelerinde 14 izolat hastalık belirtilerini %24–59 arasında azaltmış; bunların 11'i en az üç savunma geninin ifadesini artırmıştır. Etkili izolatların çoğu piceid, resveratrol ve farklı viniferinlerin birikimini yükseltmiş; özellikle *Micrococcus yunnanensis*, *Bacillus xylanexedens*, *Cupriavidus metallidurans* ve bazı ***B. cereus*** izolatları en az iki viniferin formunun üretimini güçlü biçimde uyarmıştır. Buna karşılık pterostilben hiçbir örnekte belirlenmemiştir. Saksı koşullarında yürütülen denemelerde seçilen izolatların oluşturduğu üçlü konsorsiyumlar, tek tek uygulanan izolatlara göre daha yüksek ve daha kararlı koruma sağlamıştır. *C. metallidurans–B. cereus–Herbaspirillum huttiense* kombinasyonu hastalık belirtilerini bakteri uygulanan yapraklarda %94.2, uygulama yapılmamış yapraklarda ise %94.0 azaltmıştır. Diğer iki etkili konsorsiyum da yerel ve sistemik olarak yaklaşık %85–90 koruma sağlamış, böylece stilben birikimiyle ilişkili savunma yanıtının bitkinin uzak dokularında da ortaya çıkabildiği gösterilmiştir.

SONUÇ

Bu derlemede değerlendirilen çalışmalar, bağ mildiyösüne karşı kullanılan alternatif uygulamaların asmada stilben fitoaleksini metabolizmasını farklı biçimlerde etkileyebildiğini göstermiştir. Kitosan ve diğer savunma uyarıcıları, bitki ekstraktları ve doğal elisitörler ile mikrobiyal uygulamalar; resveratrol, piceid, pterostilben, ε-viniferin, δ-viniferin ve diğer stilben türevlerinin birikimini artırmış veya

enfeksiyon sonrasında daha hızlı birikmelerini sağlayarak bitki savunmasını güçlendirmiştir. Bu artışların birçok çalışmada sporulasyonun, zoospor hareketliliğinin ve hastalık şiddetinin azalmasıyla birlikte gerçekleşmesi, stilben fitoaleksinlerinin *P. viticola*'ya karşı savunmadaki önemini desteklemektedir.

Bununla birlikte, tüm uygulamalar aynı fitoaleksin profilini oluşturmamıştır. Metil jasmonat daha çok piceid ve ε-viniferin birikimini artırırken, benzotiyadiazol ve fosfonat uygulamaları özellikle pterostilben birikimiyle ilişkilendirilmiş; bazı mikrobiyal uygulamalar ise enfeksiyon sonrasında viniferin türevlerinin daha hızlı ve yüksek düzeyde birikmesini sağlamıştır. Kitosanların etkisinin polimerizasyon derecesine, bitki ekstraktlarının etkinliğinin ise bileşim, doz ve formülasyona bağlı olarak değişmesi, uygulama özelliklerinin fitoaleksin yanıtı üzerinde belirleyici olduğunu göstermektedir. Ayrıca bazı uygulamaların stilben birikimini uyarmanın yanında zoosporlara doğrudan etki göstermesi, hastalık kontrolünün birden fazla mekanizmanın birlikte çalışmasıyla gerçekleşebileceğini ortaya koymaktadır.

Sonuç olarak, stilben fitoaleksinlerinin birikimini uyaran doğal ve biyolojik kökenli uygulamalar, bağ mildiyösüne karşı kimyasal fungisit kullanımını azaltabilecek tamamlayıcı araçlar olarak değerlendirilebilir. Ancak bu uygulamaların bağ koşullarındaki etkinliğinin artırılması için uygun doz, uygulama zamanı, formülasyon ve genotip etkileşimlerinin ayrıntılı olarak belirlenmesi gerekmektedir. Gelecekte yapılacak çalışmaların, fitoaleksin birikimi ile hastalık azalması arasındaki ilişkiyi doğrudan ortaya koyan metabolomik ve bağ denemelerine ağırlık vermesi, bu yaklaşımların sürdürülebilir bağ mildiyösü yönetimindeki kullanımını güçlendirecektir.

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ASSESSMENT OF ANTIMICROBIAL ACTIVITY OF SELECTED EDIBLE MUSHROOMS EXTRACT AGAINST FOODBORNE PATHOGENS

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ABSTRACT

Foodborne diseases remain a significant public health concern worldwide and are responsible for considerable morbidity, mortality, and economic losses. The increasing emergence of antimicrobial-resistant foodborne pathogens has reduced the effectiveness of conventional antibiotics and created an urgent need for alternative antimicrobial agents from natural sources. Edible mushrooms are increasingly recognized as sources of bioactive compounds with potential therapeutic applications. This study assessed the antimicrobial activity of extracts obtained from selected edible mushrooms. Fresh samples of *Lentinula edodes* (Shiitake),*Cordyceps* spp and *Calocybe indica (*Milky oyster) were collected from local mushroom farmers in Ilorin and extracted using ethanol, cold aqueous, and hot aqueous extraction methods. The antimicrobial activity of the extracts was tested against selected foodborne microorganisms, including *Staphylococcus aureus, Escherichia coli, Pseudomonas aeruginosa, and Aspergillus niger,* using the agar well diffusion method. The results showed that the Milky Oyster extract exhibited limited antimicrobial activity, with only the ethanol extract inhibiting *Staphylococcus aureus* (11.50 ± 3.54 mm). Cordyceps extract demonstrated the highest antimicrobial activity, producing inhibition zones of 12.50 ± 2.12 mm against *Escherichia coli*, 23.50 ± 14.14 mm against *Aspergillus flavus,* and 18.25 ± 11.67 mm against *Aspergillus niger*. Shiitake extract showed appreciable activity against *Staphylococcus aureus* with an inhibition zone of 20.75 ± 13.79 mm, while the cold extract inhibited *Aspergillus niger* with a zone of 10.00 ± 2.83 mm. The lowest MIC value recorded was 3.00 mg/mL against *Aspergillus flavus*, whereas MIC values of 10.00, 30.00, and 50.00 mg/mL were obtained for other susceptible microorganisms. No bactericidal or fungicidal concentrations (MBC/MFC) were observed for the extracts. It can be concluded that the mushroom extracts exhibited significant antimicrobial activity, with the highest activity observed against *Aspergillus flavus* and *Staphylococcus aureus* with the least activity against *Pseudomonas aeruginosa*. The findings suggest that edible mushroom extracts possess significant antimicrobial potential and could serve as natural antimicrobials amid rising antibiotic resistance.

Keywords: Edible mushrooms, *Calocybe indica, Lentinula edodes, Cordyceps* spp, natural antimicrobial

ENERGY DIVERSIFICATION: AN ENHANCEMENT OF TEACHING AND LEARNING PROCESS IN NIGERIA INSTITUTION OF HIGHER LEARNING

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ABSTRACT

The study examined the effects of energy diversification of teaching and learning process in Nigeria institutions of higher learning. The study employed survey research design. The research instrument adapted for the study was titled, Energy Diversification: Enhancement of Teaching and Learning Process in Nigeria Institution of Higher Learning (EDETLPNIHL). The population for the study sample comprises of 2347 respondents out of which purposive sampling techniques were used to select 181 respondents across various Universities, Polytechnics and Colleges of Education in southwest Nigeria. The instrument was subjected to face and content validity and Cronbach Alpha reliability of r=.973. Three research hypotheses were postulated and tested on 0.05 significant level. Data were analysed using ANCOVA. The study revealed that there was a significant main effect of energy diversification on academic sustainability in institution of higher learning. ($F_{(1,1)} = 52.171$; $p>0.05$, partial $\eta^2 = .228$). Also, the outcome of the result shown that it was revealed that energy diversification was significantly predict achievement of students in institution of higher learning. ($F_{(1, 2)} = .705.$; $p<0.05$, partial $\eta^2 = .004$). And finally, it was revealed that energy diversification predicts enhancement of staff retention and teacher training in institution of higher learning ($F_{(1, 3)} = 32.546$; $p>0.05$, partial $\eta^2 = .155$). Based on these results it was concluded that energy diversification is a foundational investment in the quality, equity and future readiness of higher education.

Keywords: Energy Diversification, Enhancement, Teaching and Learning

ECONOMIC FACTORS INFLUENCING STUDENT ACADEMIC DROPOUT IN NORTHWEST IRANIAN UNIVERSITIES: A SYSTEMATIC LITERATURE REVIEW

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ABSTRACT

Academic decline among university students represents a significant structural challenge in higher education systems, particularly in developing countries facing prolonged economic pressures. This narrative literature review aims to identify, categorize, and synthesize existing theoretical and empirical literature on economic factors associated with academic decline, with particular attention to public universities in northwest Iran (University of Tabriz, Urmia University, and University of Mohaghegh Ardabili). Drawing on Becker's human capital theory, opportunity cost theory, Roemer's equality of opportunity framework, and Tinto's student integration model, economic factors are examined at three interrelated levels: individual (micro) economy, macroeconomic conditions, and technology-related economic constraints. A review of domestic and international studies indicates that individual-level economic constraints are most consistently linked to reduced academic performance, motivation, and persistence, while macroeconomic instability and digital access barriers appear to amplify these effects. The key regional qualitative study by Ostadi, Ranjpour, and Nobahar (2026) provides the most focused empirical insight into this three-level framework within the northwest Iranian context. Findings highlight the need for multi-level interventions and offer a conceptual framework to guide future empirical research and policy design in the region. Limitations arising from the scarcity of quantitative and longitudinal studies specific to northwest Iran are explicitly acknowledged.

Keywords: academic decline, economic factors, individual economy, macroeconomy, digital divide, literature review, northwest Iran, university students

Introduction

Higher education is widely recognized as one of the primary drivers of sustainable economic development, social mobility, innovation, and human capital formation. Universities not only produce skilled labor but also foster scientific advancement, technological innovation, and social cohesion. Consequently, academic success among university students has become a strategic concern for governments, higher education institutions, and policymakers worldwide. Conversely, academic decline—including declining grade point average (GPA), academic probation, delayed graduation, repeated course failure, and student dropout—represents a significant loss of educational investment and threatens both individual welfare and national economic development (Becker, 1964; Tinto, 1993).

Academic decline has traditionally been explained through psychological, educational, social, and institutional perspectives. Previous studies have examined factors such as learning motivation, academic self-efficacy, teaching quality, family support, mental health, and university environment as major determinants of students' academic performance (Tinto, 1975, 1993). Although these factors remain important, recent international evidence suggests that economic conditions have become increasingly influential, particularly following the global financial crises, the COVID-19 pandemic, rapid inflationary pressures, and growing inequalities in access to educational resources (Aina et al., 2021).

Economic influences on academic outcomes extend beyond students' financial resources alone. Contemporary research indicates that economic hardship affects academic performance through multiple interconnected mechanisms, including financial stress, increased employment during study,

reduced study time, psychological distress, weakened academic engagement, food and housing insecurity, and unequal access to digital learning resources. Consequently, economic disadvantage should be viewed as a multidimensional phenomenon operating simultaneously at individual, household, institutional, and societal levels rather than merely as low household income (Aina et al., 2021; Nurmalitasari et al., 2023).

The importance of economic determinants is particularly evident in developing countries experiencing prolonged macroeconomic instability. Persistent inflation, declining purchasing power, labor-market uncertainty, high graduate unemployment, and economic sanctions may substantially reduce students' expectations regarding the future returns to higher education. Under such conditions, students may increasingly perceive higher education as a risky investment, resulting in declining academic motivation, greater psychological pressure, and a higher likelihood of academic underachievement or withdrawal from university (Blanchard, 2021).

In recent years, another dimension of economic inequality has attracted growing scholarly attention: digital economic deprivation. The expansion of online and technology-enhanced learning has increased students' dependence on reliable internet access, digital devices, licensed software, and online academic resources. Consequently, unequal access to digital infrastructure has become an additional mechanism through which economic inequality contributes to educational disparities. Rather than representing a purely technological issue, the digital divide has increasingly been conceptualized as an extension of socio-economic inequality affecting students' learning opportunities and academic persistence.

Within Iran, the economic context presents additional challenges. During the past decade, universities have operated under conditions characterized by persistent inflation, exchange-rate volatility, declining household purchasing power, international sanctions, and increasing uncertainty regarding graduate employment. Several Iranian studies have identified financial hardship, compulsory student employment, and limited economic opportunities as important contributors to academic decline (Fadavi Roodsari et al., 2020; Mirzaeikhah et al., 2021; Pahlavan et al., 2019). Nevertheless, these studies have generally examined economic variables alongside broader psychological or educational factors, without developing an integrated conceptual understanding of how different dimensions of economic conditions jointly influence academic outcomes.

Furthermore, despite the growing body of international literature on student persistence and educational inequality, relatively little attention has been devoted to the interaction between microeconomic conditions (student and family finances), macroeconomic instability (inflation, unemployment, and economic uncertainty), and technology-related economic barriers (digital inequality) within a unified analytical framework. This limitation is particularly evident in studies conducted in Iran and, more specifically, in public universities located in northwest Iran.

Accordingly, the present literature review seeks to synthesize theoretical and empirical evidence regarding the economic determinants of academic decline by integrating three complementary dimensions of economic influence: individual economic conditions, macroeconomic environment, and technology-related economic constraints. Unlike previous reviews that primarily summarize isolated economic variables, this study develops a multi-level conceptual framework that explains how these economic dimensions interact to influence students' academic performance, psychological well-being, behavioral engagement, and risk of dropout. By focusing on universities in northwest Iran while simultaneously drawing upon contemporary international evidence, this review aims to bridge the gap between global theoretical developments and the specific socio-economic realities of the Iranian higher education system.

Methodology of the Review

This study employed a structured narrative literature review to synthesize theoretical and empirical evidence on the economic determinants of academic decline among university students. A structured narrative approach was selected because the existing literature is characterized by substantial methodological heterogeneity, encompassing quantitative, qualitative, mixed-methods, and review studies conducted across diverse educational and socio-economic contexts. Unlike a formal systematic

review or meta-analysis, the primary objective of this study was to develop an integrated conceptual understanding of the economic mechanisms contributing to academic decline rather than to estimate pooled effect sizes.

To enhance transparency and reduce selection bias, the review followed a predefined search strategy. Relevant studies published primarily between 2015 and March 2026 were identified through comprehensive searches of major international databases, including Scopus, Web of Science, Google Scholar, ScienceDirect, SpringerLink, Taylor & Francis Online, and Wiley Online Library. To ensure adequate coverage of Iranian research, complementary searches were conducted in SID, Magiran, Noormags, and ISC.

The search strategy combined controlled vocabulary and free-text keywords related to academic decline and economic determinants. English search terms included academic decline, academic underachievement, academic failure, student dropout, student attrition, higher education, financial stress, economic hardship, student poverty, digital divide, economic inequality, higher education finance, and Iran. Equivalent Persian keywords, including « افت تحصیلی»، «ترک تحصیل»، «عوامل اقتصادی»، «نابرابری آموزشی»، «فشار مالی»» and «دانشجویان», were also employed. Boolean operators (AND, OR) were used to maximize retrieval.

Studies were included if they met the following criteria:

- Examined university or higher education students.
- Investigated one or more economic determinants of academic performance, academic decline, or student dropout.
- Employed quantitative, qualitative, mixed-methods, or review methodologies.
- Were published in peer-reviewed journals.
- Were available in English or Persian.
- Studies were excluded if they:
- focused exclusively on primary or secondary education;
- investigated only psychological or educational variables without considering economic factors;
- consisted solely of conference ABSTRACTs, editorials, dissertations, or unpublished reports;
- lacked sufficient methodological information.

Following the initial database search, duplicate records were removed. Titles and ABSTRACTs were then screened for relevance. Full texts of potentially eligible studies were subsequently assessed according to the predefined inclusion criteria. Additional influential publications cited within the selected articles were identified through backward citation tracking to ensure comprehensive coverage of the literature.

Rather than organizing the literature chronologically, the synthesis adopted a thematic analytical approach. Evidence was classified into three complementary dimensions of economic influence:

- Individual (microeconomic) factors, including household income, financial stress, student employment, and educational expenses;
- Macroeconomic factors, including inflation, unemployment, economic instability, sanctions, and expected returns to education;
- Technology-related economic factors, including digital inequality, internet accessibility, availability of digital devices, and access to online educational resources.

Within each dimension, similarities, inconsistencies, methodological differences, and remaining research gaps were critically compared across international and Iranian studies. Particular attention was

devoted to evidence concerning public universities in northwest Iran, while broader international findings were used to contextualize regional evidence and strengthen conceptual interpretation.

Finally, based on the synthesis of theoretical perspectives and empirical findings, an integrated conceptual framework was developed to illustrate the interrelationships among multiple dimensions of economic conditions and the major components of academic decline.

Theoretical Foundations

Conceptualizing Academic Decline

Academic decline is a multidimensional phenomenon that extends beyond declining academic performance. Contemporary higher education research conceptualizes academic decline as a gradual deterioration in students' academic functioning, psychological well-being, behavioral engagement, and educational persistence. Rather than representing a single event, academic decline is increasingly understood as a dynamic process through which cumulative academic, psychological, social, and economic pressures progressively reduce students' capacity to succeed in higher education (Tinto, 1993).

Drawing upon previous conceptualizations (Esmaeilpour et al., 2015; Ostadi et al., 2026), academic decline can be classified into four interrelated dimensions:

- **Academic deterioration**, including declining GPA, academic probation, repeated course failure, delayed graduation, and reduced learning achievement.
- **Psychological deterioration**, reflected in academic stress, emotional exhaustion, reduced motivation, academic burnout, declining self-efficacy, and feelings of hopelessness.
- **Behavioral and social disengagement**, including absenteeism, reduced classroom participation, limited interaction with faculty and peers, and withdrawal from extracurricular activities.
- **Educational withdrawal**, represented by increased intentions to discontinue higher education, temporary interruption of studies, or permanent dropout.

These dimensions rarely occur independently. Instead, empirical evidence suggests that they reinforce one another through cumulative feedback mechanisms, whereby declining academic performance increases psychological distress, which subsequently reduces academic engagement and ultimately increases the probability of dropout.

Economic Perspectives on Academic Decline

Economic explanations of academic decline have undergone substantial theoretical development over the past two decades. Earlier research primarily viewed financial conditions as direct determinants of educational outcomes, emphasizing variables such as household income, tuition fees, and educational expenditures. Within this perspective, students from economically disadvantaged families were assumed to experience lower academic achievement because of limited financial resources and restricted access to educational opportunities. However, contemporary research suggests that the relationship between economic conditions and academic decline is considerably more complex. Economic disadvantage is now understood as a multidimensional construct operating through a network of interconnected mechanisms that influence students' psychological well-being, academic engagement, educational expectations, and institutional integration (Aina et al., 2022).

At the **microeconomic level**, students' financial resources directly influence their ability to participate effectively in higher education. Household income, parental financial support, scholarships, educational expenditures, and financial stress determine not only students' capacity to meet educational expenses but also their allocation of time and cognitive resources. Students experiencing financial hardship are considerably more likely to engage in paid employment while studying, thereby reducing the time available for learning, increasing psychological stress, and weakening academic engagement. Consequently, financial stress should not be interpreted merely as a consequence of insufficient income but rather as a multidimensional condition that affects students' educational experiences through multiple behavioural and psychological pathways (Aina et al., 2022; Goldrick-Rab et al., 2019).

Beyond individual financial circumstances, **macroeconomic conditions** increasingly shape educational decisions and academic outcomes. Persistent inflation, declining purchasing power, labour-market uncertainty, rising graduate unemployment, and economic recession alter students' perceptions of the expected returns to higher education. According to human capital theory, individuals invest in education when expected long-term benefits exceed immediate costs (Becker, 1964). During periods of economic instability, however, uncertainty regarding future employment opportunities may reduce students' motivation to invest sustained effort in academic achievement. Macroeconomic instability therefore affects academic persistence indirectly by modifying students' expectations, increasing opportunity costs, and intensifying financial insecurity rather than through direct financial deprivation alone (Mankiw, 2021).

Recent developments in higher education have also introduced **technology-related economic inequality** as a third dimension of academic disadvantage. The rapid expansion of digital and hybrid learning environments has fundamentally transformed access to educational opportunities. Reliable internet connectivity, personal computers, licensed software, online databases, and digital learning platforms have become essential educational resources rather than optional technological facilities. Students lacking these resources face disadvantages that extend beyond technical limitations. Digital exclusion reduces participation in online learning, limits access to educational materials, weakens communication with instructors, and ultimately contributes to unequal academic outcomes. Consequently, contemporary scholarship increasingly conceptualizes digital inequality as an extension of socio-economic inequality rather than merely a technological issue (Van Deursen, 2020; UNESCO, 2023).

These three dimensions of economic conditions should not be viewed as independent determinants. Instead, they interact continuously throughout students' educational experiences. For example, macroeconomic instability may reduce household purchasing power, thereby intensifying students' financial stress at the microeconomic level. Financial hardship, in turn, may limit access to digital technologies, further restricting participation in contemporary learning environments. Such interactions illustrate that academic decline is better explained through an integrated economic framework than through isolated financial indicators. This multidimensional perspective provides the theoretical foundation for understanding why similar levels of household income may lead to different educational outcomes depending on broader economic conditions, institutional support, and access to digital resources.

Empirical Background

Empirical research consistently demonstrates that economic factors constitute one of the principal determinants of academic decline in higher education. However, contemporary evidence suggests that economic conditions rarely influence students' academic outcomes directly. Instead, their effects operate through multiple pathways, including financial stress, employment during study, academic engagement, institutional support, and access to educational resources. Accordingly, recent research has shifted from examining isolated economic variables toward investigating the complex interactions among individual financial circumstances, macroeconomic conditions, and technology-related economic inequalities.

International Evidence

International research has increasingly demonstrated that academic decline and student dropout are multidimensional phenomena resulting from the interaction of economic, academic, institutional, and psychosocial factors rather than the influence of a single determinant. Earlier studies frequently emphasized students' financial circumstances as isolated predictors of educational outcomes; however, more recent investigations have adopted integrated theoretical frameworks explaining how economic disadvantage interacts with academic engagement, institutional support, and psychological well-being throughout students' educational trajectories (Aina et al., 2022).

One of the most comprehensive reviews of the socio-economic determinants of university dropout was conducted by **Aina, Baici, Casalone, and Pastore (2022)**. Synthesizing evidence from numerous empirical studies, the authors concluded that students' decisions to persist or withdraw from higher education are jointly shaped by individual characteristics, institutional environments, and broader economic conditions. Their review further argued that economic constraints rarely influence dropout

directly; rather, their effects are mediated through students' academic and social integration within the university environment, thereby extending Tinto's student integration theory through an economic perspective.

Recent systematic reviews reinforce this multidimensional interpretation. A review of the contemporary literature indicates that although academic performance remains one of the strongest predictors of student attrition, financial hardship consistently emerges as a major structural determinant of academic decline. Importantly, financial difficulties rarely operate independently. Instead, financial stress increases students' employment obligations, reduces study time, intensifies emotional strain, weakens academic engagement, and ultimately increases the probability of university withdrawal (Aina et al., 2022; Alrashidi et al., 2025).

The international literature has also expanded its conceptualization of economic disadvantage beyond household income. Contemporary studies increasingly emphasize financial stress, food insecurity, housing insecurity, and educational affordability as distinct yet interrelated dimensions of students' economic experiences. This broader perspective recognizes that students with similar income levels may experience substantially different educational outcomes depending on their debt burden, employment intensity, access to financial aid, and institutional support mechanisms. Consequently, financial hardship should be regarded as a multidimensional construct rather than a single economic indicator (Aina et al., 2022).

Evidence from European higher education systems likewise indicates that economic conditions continue to shape academic achievement even in countries characterized by relatively generous welfare systems. **Wiborg and Grätz (2022)** demonstrated that parental income and accumulated household wealth remain significant predictors of students' academic performance despite extensive public investment in higher education. Their findings suggest that economic inequality influences educational outcomes through differences in learning opportunities, educational resources, and family support rather than tuition costs alone.

Another important development in recent scholarship concerns the growing role of **digital inequality**. The expansion of online learning environments has transformed access to digital technologies into an essential educational resource. Students lacking reliable internet connectivity, appropriate digital devices, licensed software, or access to electronic learning materials encounter disadvantages that extend well beyond technological inconvenience. Digital exclusion increasingly represents an economic mechanism through which socio-economic inequalities translate into educational disparities, particularly among disadvantaged populations (UNESCO, 2023; Van Deursen, 2020).

Furthermore, recent evidence has highlighted the mediating role of students' psychological well-being in the relationship between economic adversity and academic persistence. Studies have consistently shown that prolonged financial stress contributes to emotional exhaustion, reduced academic self-efficacy, lower educational engagement, and stronger intentions to discontinue higher education. These findings reinforce the need to conceptualize psychological processes as mediating mechanisms linking economic hardship to academic decline (Madigan & Curran, 2026).

Collectively, the contemporary international literature reveals a significant theoretical shift from viewing economic variables as isolated predictors toward recognizing them as components of interconnected educational systems. Financial hardship interacts with institutional support, academic engagement, psychological resilience, and digital resources to shape students' educational trajectories. Nevertheless, important gaps remain. Most empirical evidence originates from developed economies characterized by relatively stable institutional structures and established student-support systems. Consequently, considerably less attention has been devoted to contexts experiencing persistent inflation, macroeconomic instability, international sanctions, and limited educational resources. The interaction between microeconomic constraints, macroeconomic pressures, and technology-related economic barriers therefore remains insufficiently understood in developing countries, particularly within higher education systems such as Iran.

Evidence from Iran

Research conducted in Iran confirms that economic factors play a substantial role in shaping students' academic performance and persistence in higher education. However, compared with the international literature, Iranian studies have generally examined economic variables as one component among broader educational, psychological, and social determinants of academic decline. Consequently, the specific mechanisms through which economic conditions influence students' academic outcomes remain insufficiently explored.

Existing evidence suggests that household income, family financial status, educational expenditures, and students' employment during study are among the most frequently investigated economic variables. Several studies have reported that financial difficulties increase students' psychological stress, reduce the time available for academic activities, and negatively affect educational achievement. Economic hardship has also been associated with lower academic motivation, reduced classroom participation, and an increased probability of academic probation and delayed graduation (Pahlavan et al., 2019; Fadavi Roodsari et al., 2020).

Recent Iranian studies further indicate that prolonged economic instability has intensified these challenges. Persistent inflation, declining household purchasing power, rising educational expenses, and limited employment opportunities for graduates have increased financial pressure on university students. Under such circumstances, many students are compelled to engage in part-time or full-time employment while studying, often at the expense of academic engagement and learning outcomes (Mirzaeikhah et al., 2021).

Although these findings emphasize the importance of economic conditions, most Iranian studies have focused primarily on **microeconomic variables**, such as family income, scholarships, or students' employment. Comparatively little attention has been devoted to the influence of **macroeconomic conditions**, including inflation, unemployment, exchange-rate instability, and economic uncertainty, despite their substantial effects on students' educational expectations and future career prospects.

Similarly, the rapidly growing importance of **digital inequality** has received limited attention within Iranian higher education research. While access to digital technologies became essential following the expansion of online education, relatively few studies have examined how unequal access to internet services, digital devices, online learning platforms, and electronic educational resources contributes to academic inequality among university students.

Another limitation of the Iranian literature concerns its theoretical orientation. Most empirical studies identify statistically significant relationships between economic variables and academic performance but provide limited theoretical explanation regarding the mechanisms through which these relationships operate. Consequently, the indirect roles of psychological well-being, academic engagement, institutional integration, and educational expectations have received comparatively little empirical attention.

Furthermore, existing Iranian research has largely examined individual determinants of academic decline in isolation. Few studies have simultaneously considered the interaction between students' financial circumstances, macroeconomic instability, and technology-related economic barriers within a unified analytical framework. This fragmented approach restricts a comprehensive understanding of how multiple dimensions of economic conditions jointly influence academic decline.

Overall, the available evidence indicates that economic conditions constitute an important determinant of academic decline in Iranian universities. Nevertheless, significant gaps remain regarding the integration of microeconomic, macroeconomic, and technology-related perspectives. Addressing these gaps requires a more comprehensive conceptual framework capable of explaining both the direct and indirect pathways through which economic conditions affect students' academic performance and educational persistence. Such a framework is particularly relevant for public universities in northwest Iran, where prolonged economic challenges may intensify students' academic vulnerability.

Comparative Analysis of Previous Studies

A critical examination of the existing literature reveals several important patterns regarding the relationship between economic conditions and academic decline. Although previous studies consistently acknowledge the importance of economic factors, considerable differences exist in their theoretical perspectives, methodological approaches, and analytical scope.

First, the majority of international studies have investigated **microeconomic determinants**, particularly household income, financial stress, tuition costs, and students' employment during study. These studies generally conclude that financial hardship adversely affects academic performance by increasing psychological stress, reducing study time, and weakening students' academic engagement (Aina et al., 2022; Nurmalitasari et al., 2023). However, relatively few studies simultaneously consider broader macroeconomic conditions such as inflation, unemployment, and economic uncertainty.

Second, recent international research demonstrates a gradual transition from single-factor explanations toward multidimensional conceptual models. Contemporary studies increasingly recognize that economic conditions influence academic outcomes indirectly through mediating variables, including academic engagement, institutional integration, psychological well-being, and learning opportunities. This shift reflects the growing acceptance that academic decline is the result of cumulative interactions among economic, educational, and social factors rather than direct financial deprivation alone.

Third, empirical evidence from developed countries has increasingly incorporated **digital inequality** into the analysis of educational outcomes. Access to internet services, digital devices, online learning platforms, and electronic educational resources has become an essential component of educational opportunity. Nevertheless, this dimension remains largely unexplored in developing countries despite the rapid expansion of technology-enhanced learning.

The review of Iranian studies reveals a different pattern. Existing research has primarily focused on identifying statistically significant relationships between selected economic variables and academic performance. Household income, educational expenses, scholarships, and students' employment constitute the most frequently examined variables. Although these studies confirm the importance of economic conditions, they generally investigate these variables independently rather than within an integrated theoretical framework.

Another notable limitation concerns the neglect of macroeconomic influences. Persistent inflation, exchange-rate fluctuations, declining purchasing power, labor-market uncertainty, and international sanctions have fundamentally transformed the economic environment of Iranian higher education during the past decade. Despite their potential influence on students' educational expectations and academic behavior, these macroeconomic factors have received only limited empirical attention.

Furthermore, neither the international nor the Iranian literature has adequately examined the interaction among **microeconomic conditions, macroeconomic instability, and technology-related economic inequality** within a unified analytical framework. Existing studies typically investigate one or two dimensions independently, making it difficult to understand how multiple economic pressures jointly influence students' academic performance and educational persistence.

Table 1 summarizes the principal characteristics of representative studies reviewed in the present research. The comparison highlights substantial differences in geographical context, methodological design, economic variables, and theoretical perspectives while simultaneously identifying the major research gaps addressed by the present study.

Table 1. Representative Studies on the Economic Determinants of Academic Decline in Higher Education

Authors	**Year**	**Journal**	**Country**	**Research Design**	**Economic Variables**	**Main Findings**	**Research Gap**
Becker	1964	*Human Capital*	USA	Theoretical	Human capital investment	Education is an investment	Does not explain institutional

						that increases productivity and lifetime earnings.	and psychological mechanisms of academic persistence.
Tinto	1975, 1993	*Review/Theoretical*	USA	Theoretical	Student integration	Academic and social integration are fundamental to student persistence.	Economic factors are only indirectly addressed.
Bourdieu	1986	*The Forms of Capital*	France	Theoretical	Economic and cultural capital	Family resources shape educational opportunities and academic success.	Limited attention to macroeconomic conditions and digital inequality.
Roemer	2000	*Equality of Opportunity*	International	Theoretical	Equality of opportunity	Educational outcomes are strongly influenced by socio-economic circumstances beyond individual control.	Behavioural mechanisms are not fully explained.
Goldrick-Rab et al.	2019	*The Hope Center Report*	USA	Quantitative	Food insecurity, housing insecurity, financial stress	Basic-needs insecurity significantly reduces academic success and persistence.	Macroeconomic influences are not examined.
Van Deursen	2020	*Journal of Medical Internet Research*	Netherlands	Quantitative	Digital inequality	Digital inequality constitutes an important dimension of socio-economic inequality affecting educational participation.	Does not specifically analyse academic decline.
Aina, Baici, Casalone, & Pastore	2022	*Socio-Economic Planning Sciences*	International	Systematic Literature Review	Financial stress, socio-economic status	Economic conditions influence persistence mainly through indirect mechanism	Limited empirical evidence from developing countries.

						s, including academic and social integration.	
Wiborg & Grätz	2022	*Research in Social Stratification and Mobility*	Norway	Quantitative	Household income, parental wealth	Family wealth remains a significant predictor of academic achievement despite welfare-state support.	Institutional and macroeconomic factors are not jointly analysed.
Nurmalitasari et al.	2023	*Education Research International*	Indonesia	Mixed Methods	Family income, employment, financial status	Economic hardship, academic performance, and academic satisfaction jointly explain student dropout.	Digital inequality is not incorporated.
De Cnudde et al.	2021	*Decision Support Systems*	Belgium	Machine Learning	Student financial and academic characteristics	Early prediction models improve identification of at-risk students.	Economic mechanisms are not theoretically explained.
Orellana Correa et al.	2024	*LATAM Revista Latinoamericana de Ciencias Sociales y Humanidades*	Ecuador	Quantitative	Household income, financial hardship	Financial constraints significantly increase the probability of university dropout.	Institutional support and digital factors are overlooked.
Madigan & Curran	2021	*Educational Psychology Review*	International	Systematic Review & Meta-analysis	Academic burnout	Academic burnout strongly predicts dropout intentions and educational withdrawal.	Economic antecedents of burnout require further investigation.
Esmaeilpour et al.	2015	*Iran*	Iran	Quantitative	Socio-economic status	Economic difficulties negatively affect students' academic achievement.	Macroeconomic conditions are ignored.

Pahlavan et al.	2019	*Iran*	Iran	Quantitative	Household income, educational expenditure	Financial problems reduce academic motivation and educational performance.	Limited theoretical integration.
Fadavi Roodsari et al.	2020	*Iran*	Iran	Survey	Financial stress	Financial stress is negatively associated with educational performance.	Psychological mediators are not examined.
Mirzaeikhah et al.	2021	*Iran*	Iran	Quantitative	Student employment, household income	Employment during study negatively influences academic achievement.	Macroeconomic and digital dimensions are neglected.

Research Gap and Proposed Conceptual Framework

Although the existing literature provides valuable insights into the relationship between economic conditions and academic decline, several important theoretical and empirical gaps remain unresolved.

First, previous studies have predominantly examined **individual economic variables**, such as household income, tuition costs, financial stress, scholarships, or student employment. While these variables have consistently been identified as important predictors of academic performance, they have generally been investigated in isolation. Consequently, the cumulative and interactive effects of multiple economic dimensions have received limited scholarly attention.

Second, the majority of empirical studies have concentrated on **microeconomic factors**, whereas the broader macroeconomic environment has been largely overlooked. Variables such as inflation, unemployment, exchange-rate volatility, economic uncertainty, and declining purchasing power fundamentally shape students' educational decisions by influencing both household financial capacity and expectations regarding future returns to higher education. Despite their importance, these macroeconomic conditions have rarely been incorporated into conceptual models explaining academic decline.

Third, the rapid digital transformation of higher education has introduced a new dimension of educational inequality. Although recent international studies increasingly recognize the importance of digital access, most previous research continues to treat digital resources as technological variables rather than economic assets. Access to reliable internet services, digital devices, licensed software, and online learning platforms has become an essential prerequisite for successful participation in higher education. Nevertheless, the interaction between digital inequality and traditional economic disadvantage remains insufficiently investigated.

Another limitation concerns the theoretical fragmentation of the existing literature. Most studies rely on a single theoretical perspective, including human capital theory, student integration theory, or socio-economic inequality, without integrating these complementary approaches into a unified explanatory framework. Consequently, current knowledge remains fragmented and provides only a partial

understanding of the complex mechanisms through which economic conditions influence academic decline.

Methodological limitations also remain evident. The majority of empirical studies employ cross-sectional research designs and primarily focus on direct statistical relationships between economic variables and academic performance. Comparatively few studies investigate indirect pathways involving psychological well-being, academic engagement, institutional integration, or educational expectations as mediating mechanisms. As a result, the causal processes linking economic hardship to academic decline remain insufficiently understood.

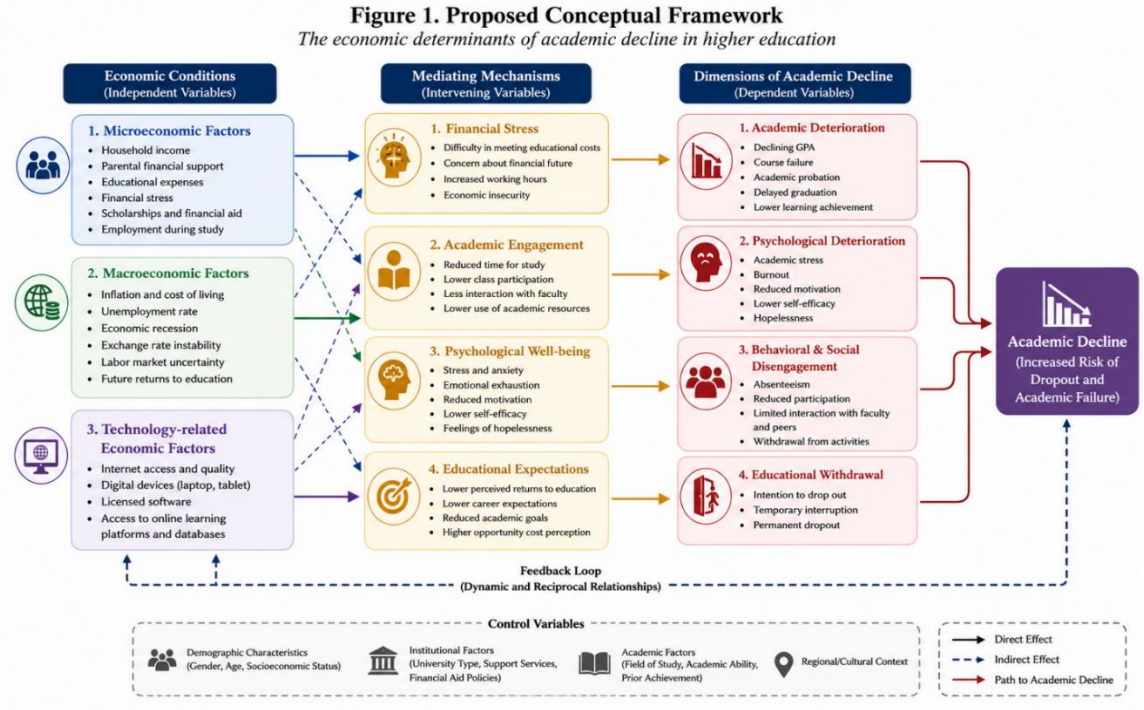
The review of Iranian studies reveals additional gaps. Existing research has primarily examined financial difficulties at the individual or household level while giving limited attention to the effects of prolonged inflation, labor-market uncertainty, international sanctions, and regional disparities. Moreover, empirical evidence from public universities located in northwest Iran remains particularly scarce despite the unique socio-economic conditions of this region.

Based on these observations, the present review proposes an integrated conceptual framework in which academic decline is viewed as the outcome of interactions among three complementary dimensions of economic conditions: (1) microeconomic factors, (2) macroeconomic conditions, and (3) technology-related economic resources. Rather than exerting independent effects, these dimensions influence students' academic outcomes through multiple mediating processes, including financial stress, academic engagement, psychological well-being, institutional integration, and educational expectations. This integrated perspective extends previous literature by providing a comprehensive explanation of both the direct and indirect mechanisms linking economic conditions to academic decline.

The proposed framework also contributes to the literature by adapting international theoretical developments to the socio-economic realities of Iranian higher education. By incorporating structural economic instability alongside individual financial conditions and digital inequality, the framework offers a more comprehensive basis for future empirical research and educational policymaking. Figure 1 (Conceptual model of economic factors associated with student academic decline) illustrates the proposed relationships. The model depicts three levels of economic factors feeding into the four components of academic decline, with arrows indicating hypothesized direct and amplifying pathways.

Figure 1. Proposed Conceptual Framework

The economic determinants of academic decline in higher education



Discussion

The present review demonstrates that economic conditions constitute a fundamental determinant of academic decline in higher education. However, unlike earlier studies that primarily associated academic performance with household income or educational expenses, the contemporary literature suggests that economic influences are considerably more complex and multidimensional. Academic decline should therefore be understood as the outcome of interactions among individual financial conditions, macroeconomic environments, institutional characteristics, and technology-related educational opportunities.

One of the most important findings emerging from the reviewed literature is the transition from direct to indirect explanations of economic effects. Rather than reducing academic achievement through financial deprivation alone, economic hardship appears to influence students through several interconnected mechanisms, including financial stress, increased employment during study, reduced academic engagement, psychological distress, and weaker integration into university life. This finding supports multidimensional theoretical perspectives, particularly Tinto's Student Integration Theory and Human Capital Theory, while also extending these frameworks by emphasizing the importance of broader economic contexts.

Another important observation concerns the growing significance of macroeconomic conditions. Although individual financial circumstances remain important, prolonged inflation, unemployment, economic uncertainty, and declining purchasing power increasingly shape students' educational decisions by influencing both family resources and expectations regarding future labour-market outcomes. In developing economies, where macroeconomic instability is often persistent, these structural conditions may exert stronger influences on academic persistence than traditional indicators of household income alone.

The review also identifies digital inequality as an emerging dimension of economic disadvantage. The expansion of online and technology-supported learning has transformed access to digital infrastructure into an essential educational resource. Students lacking adequate internet access, digital devices, or electronic learning resources face disadvantages that extend beyond technology itself, reflecting broader socio-economic inequalities. Consequently, digital inclusion should be considered an integral component of educational equity and student success strategies.

Despite these advances, significant gaps remain within the existing literature. Most previous studies have examined isolated economic variables rather than adopting comprehensive frameworks capable of integrating microeconomic conditions, macroeconomic environments, and digital economic resources. Furthermore, empirical research has largely concentrated on developed countries, while evidence from developing economies remains comparatively limited. This imbalance restricts the generalizability of existing theoretical models to countries experiencing persistent inflation, economic sanctions, labour-market uncertainty, and regional disparities.

The review further indicates that research on Iranian higher education has focused predominantly on identifying statistical relationships between selected economic variables and academic performance. Comparatively little attention has been devoted to understanding the mechanisms through which economic pressures influence students' psychological well-being, academic engagement, educational expectations, and institutional integration. Addressing these mechanisms would provide a more comprehensive understanding of academic decline and improve the design of evidence-based educational interventions.

Overall, the proposed conceptual framework contributes to the literature by integrating three complementary dimensions of economic influence—microeconomic conditions, macroeconomic environments, and technology-related economic resources—within a single analytical perspective. This framework provides a more comprehensive explanation of the pathways through which economic conditions affect academic decline and establishes a foundation for future empirical studies in both developed and developing countries.

From a policy perspective, the findings suggest that reducing academic decline requires more than conventional financial assistance. Universities and policymakers should adopt comprehensive strategies

that combine targeted financial support, affordable digital infrastructure, psychological counselling services, academic mentoring, and policies aimed at reducing the adverse educational consequences of economic instability. Such integrated interventions are likely to be more effective than isolated financial assistance programs in promoting student persistence and academic success.

Conclusion, Policy Implications, Limitations, and Future Research

This literature review has synthesized theoretical perspectives and empirical findings on economic factors associated with academic decline among university students, with special reference to the public universities of northwest Iran. Individual economic constraints emerge as the most direct and frequently documented correlates, while macroeconomic instability and technology-related barriers function as important amplifying conditions. The focused qualitative study by Ostadi et al. (2026) provides the most detailed regional insight into this multi-level structure.

Policy implications include the design of targeted financial support (need-based scholarships, low-interest student loans, and installment tuition arrangements), creation of suitable on-campus or flexible part-time employment opportunities, systematic reduction of the digital divide through provision of devices and affordable connectivity, strengthening of university–labor market linkages and skills-oriented curricula to sustain career hope, and integration of financial literacy and counseling services with academic support.

Limitations of the present review must be acknowledged. The Iranian literature is dominated by cross-sectional and qualitative designs; large-scale quantitative, mixed-methods, and especially longitudinal studies focused on northwest Iranian universities remain scarce. Causal claims cannot be firmly established on the basis of the available evidence. The review itself is narrative rather than fully systematic, and the possibility of incomplete coverage of Persian-language sources cannot be excluded.

Future research should prioritize quantitative testing of the proposed three-level framework, examination of mediating and moderating variables (social capital, psychological resilience, institutional support structures), expansion of the geographical scope to other Iranian regions for comparative analysis, and the use of longitudinal designs capable of tracing pathways from economic pressure to academic outcomes over time. Mixed-methods designs that combine the depth of qualitative insight with the generalizability of quantitative measurement would be particularly valuable.

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PREVALENCE AND PRE-HARVEST FRUIT INFECTION STATUS OF GRAY MOLD DISEASE AGENT (*BOTRYTIS* SP.) IN KIWIFRUIT ORCHARDS OF THE MARMARA REGION IN TÜRKİYE

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ABSTRACT

Introduction and Purpose: *Botrytis sp*. is commonly acknowledged as one of the major fungal pathogens causing severe post-harvest problems, leading to significant product losses during the preservation and storage processes in kiwifruit production. Therefore, the objective of the present study was to determine the prevalence and pre-harvest fruit infection status of *Botrytis* sp. across major kiwifruit cultivation areas in the Marmara region and emphasize the necessity of holistic management strategies.

Materials and Methods: Extensive field survey studies were conducted in a total of 35 commercial kiwifruit orchards across Yalova, Bursa, Kocaeli, and Sakarya provinces between 2022 and 2025 to determine the overall presence rate of the pathogen. To further examine the specific pre-harvest fruit infection rates, comprehensive laboratory and field analyses were performed in five focus orchards selected from high-production districts, namely Orhangazi (Bursa), Altınova (Yalova), and Çınarcık (Yalova).

Results: As a result of the regional survey studies, the overall presence rate of *Botrytis* sp. in the examined orchards was determined to be remarkably high at 91.2%, establishing it as the most common agent in the region. Depending on the specific locations of the focus orchards, pre-harvest fruit infection rates varying between 20% and 50% were detected in three out of the five selected focus areas. The current study has demonstrated that the primary source of gray mold disease, which triggers destructive product and quality losses during the kiwifruit preservation and storage phases, is the active infections occurring in the orchard during the pre-harvest period. In conclusion, to effectively reduce both orchard and cold storage losses in regional kiwifruit cultivation, it is of great importance to plan integrated pest management (IPM) strategies and protective applications with a holistic approach.

Key Words: Kiwifruit, *Botrytis* sp., Survey, Pre-harvest infection, Storage rot.

BIO-WASTE MATERIALS FOR WASTEWATER TREATMENT: A SUSTAINABLE SOLUTION

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ABSTRACT

Wastewater is a global concern nowadays. Less than 1% water is available as fresh water. However, by releasing untreated residential and industrial effluents, fast urbanization and industrialization have contaminated freshwater quality. Several highly toxic chemicals and other substances that seriously endanger living things can be found in untreated wastewater. As a result, the production of economical and sustainable materials and technology for wastewater remediation has attracted global prominence. Adsorption has grown in popularity and is currently one of the most commonly employed techniques for treating wastewater due to its ease of use and operational flexibility. Another appealing, readily available, and ecologically sound adsorb for wastewater treatment is biomaterials made from plants. This study aims to fully evaluate the potential of agricultural waste materials as sustainable adsorbent substances for the removal of emerging contaminants from wastewater, with an emphasis on hazardous metals and other developing pollutants. It also emphasizes their potential for significant applications in the environment in sustainable wastewater treatment in the future, as well as their capacity for adsorption, regeneration, and underlying removal mechanisms.

Keywords: Bio-waste, hazardous chemicals, SDG-6, toxic pollutants, wastewater treatment

READING DIVINE WILL: *SORTES BIBLICAE* IN HAGIOGRAPHIC NARRATIVE

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ABSTRACT

This paper examines the Sortes Biblicae motif in the Life of Theodora of Alexandria (BHG 1727–1730) as a distinctive hermeneutical model through which Scripture functions as a medium for discerning divine will. In early Christian spiritual culture, the practice of Sortes Biblicae – the random opening of Scripture in search of divine guidance – reflects the understanding of the Bible not merely as a repository of theological doctrine but as a performative text capable of directly addressing the believer and shaping existential decisions. Drawing on Paul Ricoeur's concept of the performative nature of sacred texts, the study argues that biblical passages in such contexts function as signa, requiring interpretation within a concrete spiritual situation.

The central case study is the episode in the Life of Theodora of Alexandria in which the heroine, overwhelmed by repentance after her fall into sin, requests that the Gospel be opened at random. The verse revealed – John 19:22 ("What I have written, I have written") – is interpreted as God's response to her spiritual crisis and becomes the decisive turning point leading to her ascetic transformation. The paper compares this episode with analogous narratives in Augustine's Confessions, the Life of Anthony the Great, and the Life of Mary of Egypt, demonstrating that each presents a different manifestation of the same narrative pattern: divine guidance communicated through Scripture, sacred space, or inspired speech at moments of existential crisis.

The study further explores the reception of this motif in the Georgian hagiographical tradition. Unlike Byzantine hagiography, original Georgian hagiographical works do not depict the practice of Sortes Biblicae. Instead, divine will is typically revealed through visions, miracles, angelic interventions, or the authority of a spiritual father. Particular attention is devoted to an unpublished commentary preserved in the Metaphrastic manuscript KSHM, K-3, which explains the procedure of casting lots and suggests that such practices required interpretation within the Georgian monastic milieu. This evidence indicates a conscious cultural and theological preference for mediated forms of revelation over random consultation of Scripture.

By comparing Byzantine and Georgian narrative models, the paper demonstrates how differing conceptions of scriptural authority shaped the representation of divine communication in medieval Christian hagiography and contributes to a broader understanding of the cultural adaptation of Late Antique spiritual practices.

Keywords: Sortes Biblicae; hagiography; Theodora of Alexandria; Byzantine literature; Georgian hagiography; hermeneutics; performative Scripture; divine revelation; monastic culture.

INTRODUCTION

In early Christian spiritual culture, Holy Scripture was understood not merely as a source of theological teaching but also as the living word of God, capable of addressing individuals directly and guiding the course of their lives. This understanding gave rise to the practice known as *Sortes Biblicae*. The term refers to the random opening of the Bible, whereby the verse encountered is interpreted as a divine response to a particular spiritual question or existential dilemma.

Sortes Biblicae (from the Latin *sortes*, “lot,” and *biblicae*, “biblical”) was a widespread practice in early Christianity. A person facing a spiritual crisis or an important decision would open the Scriptures at random and interpret the first verse that came into view as an expression of God's will or an answer to their particular situation. The practice was grounded in the belief that God could communicate directly with believers through the words of Scripture.

CONCEPTUAL FRAMEWORK

Sortes Biblicae may therefore be understood as a distinctive hermeneutical model of engaging with sacred texts. It is based on the concept of the performative nature of Scripture – that is, its capacity not merely to convey theological doctrine but to reshape the reader's existential self-understanding and reinterpret lived experience (Ricoeur 1995, 57-65). In this context, the biblical text functions as more than a repository of revealed truth: it becomes an active medium through which the divine will is disclosed to a particular individual within a concrete spiritual situation.

In this context, the biblical text functions as a *signum* – a sign that requires interpretation, whose meaning is determined by the believer's particular spiritual situation. Within hagiographic narrative, such episodes often serve as moments of decisive transformation: a biblical verse encountered by chance becomes the guiding principle of the protagonist's subsequent life, while the authority of Scripture is transformed into personal religious experience.

Examples of *Sortes Biblicae* occur repeatedly in early Christian literature. Among them, one of the most remarkable is found in the *Life of Theodora of Alexandria (BHG* 1727–1730), a fifth-century Alexandrian saint, where the random opening of the Gospel marks the decisive turning point in the heroine's spiritual crisis.

METHODOLOGY

This paper argues that Byzantine and Georgian hagiography preserve two distinct narrative models of divine revelation. It explores the role of *Sortes Biblicae* in Byzantine tradition and explains why this motif is virtually absent from original Georgian hagiography.

The Life of Theodora of Alexandria contains a particularly illuminating example of Sortes Biblicae. Theodora, a young woman of noble birth renowned for her virtue and piety, is deceived into committing adultery through the schemes of a young man aided by a cunning woman. Overwhelmed by remorse, she realizes the gravity of her sin but is unable to confess it to her husband. Seeking divine guidance, she goes to a women's monastery and asks the abbess to open the Gospel at random and read aloud the first passage that appears. Through this act, Theodora hopes to discover whether God knows of the sin she committed under the cover of night. The Gospel is opened to John 19:22: "What I have written, I have written." For Theodora, these words become God's direct answer to her spiritual crisis.

This episode marks the narrative turning point of Theodora's life. Having fallen into sin, she finds herself in a profound spiritual crisis, which is resolved through the scriptural response received by means of *Sortes Biblicae*. The verse encountered by chance is interpreted as confirmation of the divine will, legitimizing her decision to embrace repentance and an ascetic life. From this moment onward, Theodora abandons her former way of life and embarks upon the path of spiritual renewal.

Thus, this scene represents the decisive transition from sin to repentance within the narrative structure. The scriptural response legitimizes Theodora's inner decision and redirects the course of her life. The episode of *Sortes Biblicae* therefore functions as the pivotal moment of the narrative, establishing the ascetic model that defines the remainder of the saint's life.

More broadly, this episode illustrates a characteristic feature of early Christian spirituality, in which Scripture functions not merely as a source of doctrinal instruction but as a means of revealing the divine will. The biblical text becomes a divine sign, guiding the believer through a moment of existential crisis. Although *Sortes Biblicae* was widespread in early Christian and monastic practice, it later came under criticism in some ecclesiastical circles because of its perceived resemblance to divinatory practices (*sortilegium*).

The episode in the *Life of Theodora of Alexandria* also finds important parallels in other works of early Christian literature. The best-known example appears in Augustine's *Confessions*, where, in the midst of a profound spiritual crisis, Augustine hears the child's voice repeating *tolle lege* ("take up and read"). He opens the Epistles of Paul at random and encounters Romans 13:13–14, a passage that ultimately leads to his conversion. This episode has long been regarded as the classical example of *Sortes Biblicae* in Christian tradition.

Augustine's *Confessions* are particularly significant not only because they present one of the best-known examples of *Sortes Biblicae*, but also because Augustine himself recalls a similar experience in the *Life of Antony*, where the Gospel is likewise received as a direct call from God.

The episode in the *Life of Theodora of Alexandria* can also be viewed alongside the conversion narratives characteristic of Byzantine hagiography, in which either a sacred text or a sacred space becomes the catalyst for spiritual transformation. A particularly illuminating parallel is found in the *Life of Mary of Egypt*. Burdened by sin, Mary is prevented from entering the Church of the Holy Sepulchre. This invisible barrier becomes a divine sign that leads her to recognize her sin and begin a life of repentance. Similarly, in Theodora's life, the random opening of the Gospel and the verse that is revealed are interpreted as God's answer, marking the decisive turning point of her spiritual journey.

Despite their different forms, these narratives perform the same function within the hagiographic tradition. Each depicts a decisive moment of spiritual conversion in which a divine sign determines the protagonist's future course of life. In Theodora's case, God's will is revealed through Scripture; in the *Life of Mary of Egypt*, it is disclosed through sacred space. Yet in both narratives, the divine sign inaugurates the saint's life of repentance and asceticism.

Thus, the episode in the *Life of Theodora of Alexandria* should be understood not merely as a narrative motif but as an expression of monastic spiritual culture, in which Scripture is perceived as the living word of God, capable of speaking directly to the individual believer.

The picture changes, however, when we turn to original Georgian hagiography. Although Georgian authors frequently adopted Byzantine hagiographical models and narrative patterns, they never describe the practice of *Sortes Biblicae* explicitly. In original Georgian hagiographical texts, the divine will is not revealed through the random opening of Scripture. Instead, it is disclosed through more conventional hagiographical forms of revelation.

The most common of these are visions and the authority of the spiritual father. Saints receive divine guidance through visions granted during prayer, while crucial decisions are entrusted to the discernment of an experienced spiritual guide, whose words are understood as the authentic interpretation of God's will. An illustrative example is found in the Life of Gregory of Khandzta, where divine revelation is communicated through a visionary experience, while throughout the work the authority of the spiritual father is presented as the indispensable foundation of monastic life.

Thus, in Georgian hagiography, the revelation of God's will is associated primarily with visions, divine revelations, and the mediation of spiritual authority rather than with the random opening of Scripture. In other words, Georgian hagiographical tradition gives preference to narrative forms of revelation instead of the practice of *Sortes Biblicae*.

Why, then, is *Sortes Biblicae* absent from original Georgian hagiography? One possible explanation is that, although widespread in early Christian tradition, the practice was viewed with increasing suspicion because of its close association with divination. Indeed, *Sortes Biblicae* bears certain formal similarities to the Roman practice of *Sortes Virgilianae*, in which passages from Virgil were consulted for oracular guidance. For this reason, some ecclesiastical authors regarded the practice with caution, fearing that it might be confused with *sortilegium*. Within the rigorous context of Georgian monastic culture, hagiographers may therefore have deliberately avoided a practice that could be associated with divination.

A second, and perhaps even more significant, explanation lies in the exceptional authority of the spiritual father within Georgian monastic tradition. One of the fundamental principles of monastic life is unquestioning obedience to one's spiritual guide. Had *Sortes Biblicae* become an accepted means of discerning God's will, important decisions might have been made through the random opening of Scripture rather than through the guidance of a spiritual father. Consequently, within the Georgian Christian tradition, Scripture was understood primarily as a text to be read, interpreted, and explained – through biblical exegesis and catenae – rather than as an instrument for obtaining direct divine guidance.

It should also be noted that, in Georgian hagiography – as in most Byzantine hagiographical literature – the primary means of revealing God's will are visions, angelic apparitions, miracles, and the guidance of a spiritual father.

Further evidence of this cautious attitude toward decision-making based on chance is found in an unpublished commentary preserved in the Gelatian Metaphrastic collection for June and July (K-3), housed in the Kutaisi State Historical Museum. The note accompanies the reading for 31 July, the *Life of Symeon the Fool for Christ and John, His Companion* (BHG 1677), and explains both the meaning of the expression "to cast lots" and the procedure itself. Rather than offering a simple lexical gloss, the commentator carefully explains a practice that apparently required clarification for Georgian readers.

Particularly revealing is the description of lot-casting as "the custom of simple people." This characterization suggests a certain theological distance from decision-making based on chance, which may have been associated with divinatory practices rather than with accepted forms of monastic spirituality.

The commentary also provides an illuminating parallel to *Sortes Biblicae*. Although the latter specifically involves the random opening of Scripture, both practices share the same underlying principle: an apparently random act is interpreted as the manifestation of God's will. At the same time, the very need to explain the procedure suggests that such practices were not regarded as familiar within the Georgian monastic milieu. This observation may help explain why episodes resembling *Sortes Biblicae* are absent from original Georgian hagiography, where divine revelation is instead mediated through visions, miracles, and the authority of the spiritual father.

CONCLUSION

This study has demonstrated that the episode in the *Life of Theodora of Alexandria*, in which the heroine seeks an answer to her spiritual crisis through the random opening of the Gospel, represents a characteristic example of *Sortes Biblicae*. In this context, Scripture functions not merely as a source of theological instruction but as a performative text through which the divine will is disclosed to a particular individual. Within the hagiographic narrative, the randomly encountered biblical verse becomes the catalyst for spiritual transformation, marking the transition from sin to repentance and inaugurating the saint's ascetic life.

Comparison with other well-known examples from early Christian literature – including Augustine's *Confessions*, the *Life of Antony*, and the *Life of Mary of Egypt* – shows that Scripture, sacred space, and the spoken biblical word all function as media of divine revelation. Despite their different forms, these narratives share the same underlying structure: a divine sign initiates the protagonist's spiritual conversion and determines the course of a new ascetic life.

At the same time, the evidence examined here reveals a distinctive feature of the Georgian hagiographical tradition. Unlike Byzantine hagiography, original Georgian hagiographical works contain virtually no examples of *Sortes Biblicae*. Instead, the revelation of God's will is conveyed through visions, miracles, angelic manifestations, or the mediation of a spiritual father. This tendency is further supported by the unpublished commentary preserved in manuscript K-3, whose detailed explanation of the procedure of casting lots suggests that such practices required interpretation rather than being regarded as self-evident elements of monastic spirituality.

The analysis of *Sortes Biblicae* therefore highlights an important distinction between Byzantine and Georgian hagiographical narrative. Whereas Byzantine texts readily present the random opening of Scripture as a legitimate means of discerning God's will, Georgian authors consistently favor other narrative models of divine revelation, emphasizing visionary experience and spiritual authority over scriptural lot-casting. This difference offers new insight into the cultural adaptation of Byzantine hagiographical models and contributes to a better understanding of the distinctive character of the Georgian literary and monastic tradition.

Rather than simply translating Byzantine hagiographical models, Georgian authors reinterpreted them in accordance with the theological and monastic priorities of their own tradition. This comparison demonstrates that the transmission of Byzantine hagiography into medieval Georgia was not a process of simple translation but of theological and cultural reinterpretation.

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DIVERSITY AND CONSERVATION OF THE ORCHIDACEAE OF THE TAZEKKA NATIONAL PARK (EASTERN MIDDLE ATLAS, MOROCCO)

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ABSTRACT

The Tazekka National Park, located in the eastern part of the Moroccan Middle Atlas, represents a natural area of great ecological value, in particular for the conservation of wild flora. Among the plant groups present, the Orchidaceae occupy an important place because of their diversity, their sensitivity to environmental disturbances and their heritage interest. However, to date, the knowledge relating to the specific richness, the spatial distribution and the state of conservation of the Orchidaceae within this protected area still remain limited. The objectives of this work were to establish an inventory of the species of Orchidaceae present in the Tazekka National Park, to study their distribution according to the habitats surveyed and to highlight the threats that may compromise their maintenance. A total of 71

stations were surveyed during the favorable period for the vegetative development and flowering of orchids. This study made it possible to identify 15 species distributed in 8 genera of Orchidaceae. The genus Ophrys proved to be the most diverse among the inventoried taxa. Seven new taxa were reported for the first time in Morocco during this study: *Orchis langei* K. Richt., *Orchis mascula* (L.) L., *Limodorum abortivum* (L.) Sw., *Cephalanthera rubra* (L.) Rich., *Dactylorhiza elata* (Poir.) Soó, *Anacamptis coriophora* (L.) R. M. Bateman, Pridgeon & M. W. Chase and *Limodorum trabutianum* Batt. In the Tazekka National Park, the main threats to Orchidaceae species are overgrazing, fires, recreational use, anthropogenic developments, plant harvesting and the potential impacts of climate change. The results of this study confirm the major role of the Tazekka National Park as a refuge area for wild orchids of Morocco and provide recommendations for the in situ and ex situ conservation of Orchidaceae species on a national and regional scale.

Keywords: Orchidaceae, Tazekka National Park, floristic diversity, floristic inventory, conservation, Morocco.

FROM MAGICIAN TO DEVIL'S DEACON: THE LOGIC OF TEMPTATION IN THE GREEK PREMETAPHRASTIC *LIFE OF THEODORA OF ALEXANDRIA*

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ABSTRACT

Introduction: The Greek premetaphrastic tradition of the *Life of Theodora of Alexandria* constructs different accounts of how moral agency is weakened and redistributed under pressure. Building on Wessely's distinction between two principal recensions, this paper re-examines the temptation scene in Paris gr. 1454, Paris gr. 1468, and Paris gr. 1506.

Methods: The paper employs close textual and lexical comparison, focusing on the designation and narrative function of the female intermediary, the representation of Theodora's deliberation and consent, and the distribution of agency among Theodora, the intermediary, and the devil.

Results: In Paris gr. 1454, the intermediary appears directly as a "female magician" (γυνή τις μάγος). Paris gr. 1468 identifies her more gradually: first as "the woman who was with her" (τῇ οὔσῃ μετ' αὐτῆς γυναικί), and only later as "the magician" (ἡ μάγος). In both witnesses, prolonged pressure leads to deliberation, assent, and action. Paris gr. 1454 makes this sequence especially clear: Theodora considers adultery, questions the claim, accepts it, and summons the suitor herself. Temptation thus unfolds as a gradual process rather than an instantaneous fall.

Paris gr. 1506 recasts the sequence within a more explicit demonological and relational framework. The devil seeks to estrange Theodora and her husband from their love, while his "deacon" (ἡ διάκονος τοῦ διαβόλου) remains beside her to bring about the act. Theodora is "lured" (δελεασθεῖσα), consents, and leaves the practical arrangement to the intermediary. Her responsibility remains, but the emphasis shifts from self-persuasion to exhaustion, entrapment, and coordinated mediation.

Paris gr. 1468 complicates a simple opposition between folkloric magic and systematic demonology: a familiar female companion becomes identifiable as a magician through her actions. The movement from "magician" to "devil's deacon" therefore marks not only a lexical change but a redistribution of agency. Recensio I dramatises the self's gradual opening to false reasoning; Recensio II, the weakening of resistance under organised assault. Together, they construct sin as a process of pressure, imagination, consent, mediation, and action.

Keywords: *Life of Theodora of Alexandria*; Byzantine hagiography; premetaphrastic hagiography; temptation

THE ROLE OF INTEREST RATES ON ECONOMIC GROWTH IN TÜRKİYE

TÜRKİYE İÇİN FAİZ ORANLARININ EKONOMİK BÜYÜME ÜZERİNDEKİ ROLÜ

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ABSTRACT

Introduction and Purpose: The relationship between economic growth and interest rates has long been a central topic in macroeconomic research. In particular, it is widely argued that increases in interest rates raise the cost of capital, thereby dampening investment and, consequently, slowing economic growth. Within this context, the relationship between economic growth and interest rates in Turkey has been empirically investigated.

Materials and Methods: The study uses monthly data covering the period 2006:01-2026:02. Accordingly, the industrial production index was used as a proxy variable for economic growth, and the interest rate applied to deposits with maturities of up to one month was used as a proxy variable for the policy interest rate.

Results: Within the scope of the analysis, the stationarity properties of the variables are tested using the Augmented Dickey-Fuller (ADF) and Phillips-Perron (PP) unit root tests, and all series are found to be integrated of order one, I(1). Accordingly, the Granger causality test and impulse response functions are estimated within a Vector Autoregression (VAR) framework using first-differenced variables. The optimal lag length of the VAR model is determined as 12 based on standard information criteria.

Discussion and Conclusion: The empirical findings indicate that interest rates Granger-cause economic growth, in line with theoretical expectations. Furthermore, impulse response analysis reveals that shocks to interest rates exert delayed and negative effects on real economic activity, whereas their impact on inflation is relatively limited and short-lived. Overall, these results suggest that the monetary transmission mechanism in the Turkish economy operates indirectly and with a certain degree of lag.

Key Words: Economic Growth, Interest Rate, VAR, Granger Causality, Impulse Response

ÖZET

Amaç: Ekonomik büyüme ile faiz oranı arasındaki ilişki araştırmacıların yoğun olarak çalıştığı konulardan birisidir. Özellikle artan faiz oranının sermaye maliyetlerini artırarak yatırımları ve dolayısı ile ekonomik büyüme yavaşlatacağı yönünde görüşler mevcuttur. Bu kapsamda Türkiye'de ekonomik büyüme ve faiz oranı arasındaki ilişkiler ampirik olarak araştırılmıştır.

Materyal ve Yöntem: Çalışmada, 2006:01-2026:02 dönemini kapsayan aylık verileri kullanılmıştır. Bu doğrultuda, ekonomik büyümeye vekil değişken olarak sanayi üretim endeksi, politika faizi için bir aya kadar olan mevduatlara uygulanan faiz oranı değişkenleri kullanılmıştır.

Bulgular: Çalışmada, değişkenlerin durağanlıkları ADF ve PP Birim Kök Testleri ile sınanmış ve bütün değişkenlerin birinci derece fark durağan olduğu tespit edilmiştir. Bu itibarla, VAR analizi çatısı altında tahmin edilen Granger Nedensellik Testi ve Etki Tepki Fonksiyonları bir derece farklı alınan değişkenlerle gerçekleştirilmiştir. Tahmin edilen VAR modeline ilişkin uygun gecikme uzunluğu 12 olarak tespit edilmiştir.

Sonuç: Elde edilen bulgulara göre, faiz oranının beklentilerle tutarlı olarak ekonomik büyümenin Granger Nedeni olduğunu göstermektedir. Etki-tepki analizleri ise faiz şoklarının reel ekonomik faaliyetler üzerinde gecikmeli ve negatif etkiler yarattığını, enflasyon üzerindeki etkilerin ise daha sınırlı

ve kısa süreli kaldığını ortaya koymaktadır. Bu sonuçlar, para politikası aktarım mekanizmasının Türkiye ekonomisinde dolaylı ve gecikmeli işlediğine işaret etmektedir.

Anahtar Kelimeler: Ekonomik Büyüme, Faiz Oranı, VAR, Granger Nedensellik, Etki Tepki

DATA CAPITALIZATION ON *SCABIOSA ATROPURPUREA*: PHYTOCHEMICAL COMPOSITION AND BIOLOGICAL ACTIVITIES

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ABSTRACT

Scabiosa atropurpurea L., a member of the Caprifoliaceae family (formerly Dipsacaceae), is a perennial herb widely distributed in the Mediterranean region, Europe, Asia, and southern Africa. Traditionally, this plant has been used as herbal tea to treat hypoglycemia, as well as for acne, bronchitis, cold, cough, menstrual regulation, and as a veterinary diuretic. This study aims to systematically review and capitalize on reliable published data concerning the phytochemical composition and biological activities of *S. atropurpurea* stems.

According to published studies, the phytochemical investigation using GC-FID/MS, LC-PDA-ESI/MS, and LC-PDA-APCI/MS analyses led to the identification of 15 volatile compounds, 19 phenolic compounds, and 24 natural pigments. The most abundant volatile compounds were 1,8-cineole (8.1-33.5%), tetradecene (5.7-24.1%), and (E)-β-ionone (5.9-20.7%). Among phenolics, chlorogenic acid (6.08-657.78 µg/g) and cyanaroside (39.79-741.60 µg/g) were the most abundant, with the ethanol extract showing the highest phenolic content (2790.47 µg/g). The major carotenoid was lutein, reaching 447.74 µg/g in the dichloromethane extract. The antioxidant activity, evaluated by DPPH assay, revealed that the ethanol extract exhibited the highest capacity (IC_{50} = 0.138 mg/mL), followed by the ethyl acetate extract (IC_{50} = 0.480 mg/mL). The volatile fraction VF1 demonstrated significant antibacterial activity against *Escherichia coli* (MBC = 0.75 mg/mL) and antifungal activity against all tested *Candida* strains (MFC = 1 mg/mL). Allelopathic activity against *Brassica oleracea* and *Lens culinaris* was also observed, with complete germination inhibition at 20 mg/mL for chloroform and ethyl acetate extracts.

Scabiosa atropurpurea thus emerges as a promising source of bioactive compounds with significant antioxidant, antibacterial, and allelopathic potential. These findings provide a scientific basis for its traditional uses and suggest possible applications in food-related, agricultural, and pharmaceutical fields. However, further research is warranted, including the isolation of individual active constituents, detailed mechanistic studies, and comprehensive in vivo evaluations.

Keywords: *Scabiosa atropurpurea*, Caprifoliaceae, phenolic compounds, carotenoids, 1,8-cineole, chlorogenic acid, cyanaroside, lutein, antioxidant, antibacterial, allelopathic.

DIGITAL EDUCATION AND SUSTAINABLE DEVELOPMENT GOALS IN INDIA

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ABSTRACT

Technology-enabled learning is a remarkable innovation affecting educational practices in India, especially after the COVID-19 pandemic enforced online learning. The United Nations targets have set a goal to achieve SDGs by 2030 and this is where education is of prime importance in terms of making learning processes equitable, inclusive, and of high quality. As per Sustainable Development Goal 4, education must be inclusive and equitable and promote lifelong learning. Therefore, digital learning has become a major instrument of education in India as it helps broaden the access to education and improve learning outcomes. Apart from that, many projects aimed at enhancing online learning such as Digital India, PM eVIDYA, DIKSHA, SWAYAM project, and National Education Policy (NEP) are involved in providing necessary level of digital education infrastructure that significantly boosts the application of online learning. Nevertheless, the scope of digital education in India is still limited due to a number of difficulties connected with digital gap, access to the Internet, low level of digital education, and economic problems.

Keywords: Education, National Education Policy, Digital Education

Introduction

It is a known fact that education is an important human right and thus important for social, economic, and ecological development. Sustainable Development Goals were developed by the UN in 2015. Their aim was to address various problems including education. Among these 17 goals, Goal number 4 indicates the necessity of provision of quality education for everyone by the year 2030. Education in India has gone through a big transformation connected with technology progress and growth of internet use. Digital education has become part of education system providing education for everyone easily and at low price.

India has one of the largest education systems in the world with a huge number of students being part of schools and universities. Digital technology implementation in education gave possibility to eliminate the influence of geography on the process of education. The pandemic has brought digital education into broader use and increased the popularity of such methods of education. Now, as India is preparing for the implementation of SDG 4, digital education has been chosen as a means of making education constant, inclusive, and effective.

Digital Education in India

Digital education is defined as the use of internet technologies, web-based platforms, the use of mobile applications, virtual classes, and multimedia tools to support teaching and learning. It covers online education, e-learning platforms, educational TV, mobile learning, and educational technologies powered by artificial intelligence. The increased number of smartphones and cheap internet access has improved digital education in India.

In order to support digital education development, the Government of India has created and implemented several projects. The Digital India Project aims to make the country digitally empowered as well as a knowledge-based economy. The DIKSHA project creates digital resources for learning for teachers and students across the country and in different languages. The SWAYAM platform provides free online courses based on the program created by notable educational institutions and allows students across the country to access quality higher education from anywhere despite their geographical location. With the

help of PM eVIDYA, students are able to continue their education process using digital learning strategies combined with TV and radio. Finally, the National Education Policy 2020 emphasizes the importance of technology in education and the creation of digital environments to support online teaching and learning.

Digital Education and SDG 4

Digital education plays a critical role in achieving SDG 4, as it improves access to education, quality of teaching and supports lifelong learning. Online education eliminates geographical obstacles for students, who can obtain high-quality education without leaving remote areas. Digital technology provides various possibilities to study according to different needs and schedules.

Technology increases the effectiveness of teaching by providing multimedia, virtual labs and simulations. Teachers can evaluate student performance online and give them feedback, which is essential for the improvement of the educational process.

Also, digital education contributes to lifelong learning, as it enables people to acquire new knowledge and skills at any time of their lives.

Government Initiatives Supporting Digital Education

Several flagship programs have been implemented by the Government of India in a bid to improve digital education and move towards SDG 4. The Digital India program aims at improving digital infrastructure, improving internet connectivity, and promoting digital literacy in the country. BharatNet aims at providing high-speed internet connectivity to the rural sector to facilitate education online.

DIKSHA is a platform that provides access to digital textbooks, lesson plans, training for teachers, and educational videos in many Indian languages. The SWAYAM initiative helps the students access free online courses from various reputed universities and institutions.

The National Digital Library of India provides access to millions of books, journals, research papers, and educational materials to students. The National Policy on Education encourages the incorporation of technology in learning, teacher training, assessment, and education administration. The policy envisages setting up the National Educational Technology Forum for the promotion of innovations and research in educational technology.

Benefits of Digital Education

Many advantages of digital education promote sustainability. Digital education enhances educational access by catering to people with constraints related to distance, finances, and physical issues. Thanks to modern gadgets, such as computer, tablet, or smartphone, a person can get information about education at any time and practically anywhere. It contributes to broadened education coverage and lower dropout ratios.

Also, digital education promotes individualized education as students receive materials whenever they need them and can learn at their own pace. Special technologies provide opportunities for individualized learning as they reveal weaknesses and advantages of the individual. Various uses of visual materials, educational games, and virtual labs make the whole learning process interesting.

The next advantage of the educational process is that it is inexpensive. Digital learning allows avoiding wasting money on printed educational publications, transportation to classes, and conducting constructions works. Educational establishments are able to serve big groups of learners with minimum investments in the process.

Finally, digital education equips students with vital 21st-century skills, including digital literacy, critical thinking, good communication, creativity, and problem-solving abilities that help secure jobs and develop the economy.

Challenges of Digital Education in India

There are a number of challenges to the success of digital education, despite much progress being made. One of the most significant obstacles is the digital divide. Numerous students from rural areas or disadvantaged backgrounds have limited access to the internet, mobile phones, computers, and power

supply. Therefore, digital education has contributed to the magnification of educational discrepancies among marginalized groups.

Digital literacy is yet another important issue. Many students, teachers, and parents lack the required knowledge of technology to be able to apply digital learning. The inadequacy of teaching training leads to poor quality online teaching and lack of application of modern teaching methods.

Another issue is language diversity. In spite of the linguistic variety available in India, digital educational materials are produced predominantly in the English language and a few regional languages. Thus, people belonging to the vernacular community find it hard to get online educational content.

Finally, cybersecurity, data security, and too much screen time must be taken into account. Schools should implement appropriate measures aimed at the safeguarding of students' personal data.

Digital Education and Inclusive Development

Including education plays a key role in the Sustainable Development Goals. The benefits of digital technology in education can be seen in different settings due to assistive technologies like screen readers, voice recognition software and invoking captions. E-learning platforms give people flexible learning opportunities, thus allowing for different ways of gaining knowledge.

Women and girls benefit from online learning as they remain free of geographic limitations regarding their studies. The model of online education is especially supportive for women who have to deal with social and economic issues as well as family commitments which affect their educational choices. Online education is also a tool for achieving gender equality as it levels the information gap.

The potential of digital education in India can be regarded as bright. More and more digital tools such as AI, VR, AR, blockchain and learning analytics will revolutionize teaching and learning approaches. Adaptive learning systems will be introduced, which will provide personalized educational experience in accordance with the existing profiles of learners.

Conclusion

Digital education has played a significant role in achieving Sustainable Development Goals in India. In particular, SDG 4 promotes the concept of quality education for all. Several government programs including Digital India, DIKSHA, SWAYAM, PM eVIDYA, and the NEP 2020 have been implemented to advance access to education and technology. Despite persistent challenges, such as the digital divide, poor infrastructure, low digital literacy levels, and economic disparities, digital education remains an important component of innovative education in India. Therefore, India can achieve the benefits of digital education by investing in equitable digital infrastructure, improving teachers' skill levels, promoting inclusive educational content, and ensuring lifelong learning.

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MIDWIFE-LED BREASTFEEDING SUPPORT: CURRENT EVIDENCE ON EFFECTIVE INTERVENTIONS AND THEIR CLINICAL IMPLICATIONS (I)

EBE LİDERLİĞİNDE EMZİRMENİN DESTEKLENMESİ: GÜNCEL KANITLAR IŞIĞINDA ETKİLİ MÜDAHALELER VE KLİNİK UYGULAMAYA YANSIMALARI

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ÖZET

Giriş ve Amaç: Emzirme, anne ve bebek sağlığını kısa ve uzun dönemde olumlu etkileyen en önemli koruyucu sağlık uygulamalarından biridir. Buna karşın yalnızca anne sütü ile beslenme oranları dünya genelinde önerilen düzeylerin altında seyretmektedir. Bu derlemenin amacı, güncel bilimsel kanıtlar doğrultusunda ebe liderliğinde emzirmenin desteklenmesinde etkili müdahaleleri değerlendirmek ve klinik ebelik uygulamalarına yönelik öneriler sunmaktır.

Gereç ve Yöntem: Bu derleme, güncel uluslararası literatür doğrultusunda hazırlanmıştır. Emzirmenin desteklenmesine yönelik ebe liderliğinde uygulanan girişimleri değerlendiren sistematik derlemeler, meta-analizler, kapsam derlemeleri ve randomize kontrollü çalışmalar incelenerek mevcut kanıtlar bütüncül bir yaklaşımla sentezlenmiştir.

Bulgular: Kanıtlar; antenatal eğitim, erken emzirme ve ten tene temas uygulamaları, Bebek Dostu Hastane Girişimi, bireyselleştirilmiş danışmanlık, ev ziyaretleri, toplum temelli bakım, dijital sağlık uygulamaları, telelaktasyon ve psikoeğitim programlarının birlikte uygulanmasının emzirme öz yeterliliğini artırdığını, yalnızca anne sütü ile beslenme oranlarını yükselttiğini ve emzirmenin sürdürülmesini desteklediğini göstermektedir. Bu müdahalelerin özellikle primipar kadınlar, sezaryen doğum yapan anneler, çalışan kadınlar ve postpartum ruh sağlığı açısından risk taşıyan kadınlarda daha belirgin yarar sağladığı bildirilmektedir.

Tartışma ve Sonuç: Emzirmenin başarılı biçimde başlatılması ve sürdürülmesi, bakımın sürekliliğini esas alan kanıta dayalı, kadın merkezli ve bireyselleştirilmiş ebe liderliğinde bakım modelleriyle desteklenmelidir. Klinik uygulamalarda bu yaklaşımların yaygınlaştırılması, yalnızca anne sütü ile beslenme oranlarının artırılmasına, emzirmenin sürdürülmesine ve anne-bebek sağlığının iyileştirilmesine önemli katkılar sağlayacaktır.

Anahtar Kelimeler: Ebe; Ebelik Bakımı; Emzirme; Emzirme Desteği; Emzirme Özyeterliliği

ABSTRACT

Introduction and Purpose: Breastfeeding is one of the most important preventive health practices, providing substantial short- and long-term benefits for both maternal and infant health. Nevertheless, exclusive breastfeeding rates remain below recommended levels worldwide. This review aimed to evaluate effective midwife-led interventions supporting breastfeeding based on current scientific evidence and to provide recommendations for clinical midwifery practice.

Materials and Methods: This review was prepared based on the current international literature. Systematic reviews, meta-analyses, scoping reviews, and randomized controlled trials evaluating midwife-led breastfeeding support interventions were comprehensively reviewed, and the available evidence was synthesized.

Results: Current evidence demonstrates that combining antenatal education, early breastfeeding and skin-to-skin contact, the Baby-Friendly Hospital Initiative, individualized counseling, home visits, community-based care, digital health interventions, telelactation services, and psychoeducational programs improves breastfeeding self-efficacy, increases exclusive breastfeeding rates, and promotes breastfeeding continuation. These interventions appear to be particularly beneficial for primiparous women, mothers who have undergone cesarean birth, working mothers, and women at risk of postpartum mental health problems.

Discussion and Conclusion: Successful initiation and continuation of breastfeeding should be supported through evidence-based, woman-centered, individualized, and midwife-led models of care emphasizing continuity of care. The wider implementation of these approaches in clinical practice may substantially improve exclusive breastfeeding rates, support breastfeeding continuation, and enhance maternal and infant health outcomes.

Key Words: Breastfeeding; Midwife; Midwifery Care; Breastfeeding Support; Breastfeeding Self-Efficacy.

GİRİŞ

Anne sütü, yenidoğanın büyüme ve gelişmesi için gerekli tüm makro ve mikro besin ögelerini uygun biyoyararlanımla sağlayan, immünolojik, metabolik ve nörogelişimsel açıdan benzersiz özelliklere sahip fizyolojik bir besindir. Emzirme yalnızca optimal beslenmeyi sağlamakla kalmayıp enfeksiyonların önlenmesi, bağırsak mikrobiyotasının düzenlenmesi, bilişsel gelişimin desteklenmesi ve yaşamın ilerleyen dönemlerinde görülen birçok kronik hastalık riskinin azaltılması gibi uzun dönem sağlık yararları da sağlamaktadır.[1,2] Anne açısından ise postpartum uterin involüsyonun hızlanması, postpartum kanama riskinin azalması, metabolik iyileşmenin desteklenmesi ve meme ile over kanseri başta olmak üzere çeşitli kronik hastalık risklerinin azalması emzirmenin kanıtlanmış yararları arasındadır.[1,3] Buna karşın, yalnızca anne sütü ile beslenme oranları dünya genelinde hâlen önerilen düzeylerin altındadır.[4,5] Bu durum, emzirmenin biyolojik olarak doğal bir süreç olmasının tek başına başarılı ve sürdürülebilir emzirme davranışını garanti etmediğini; etkili bakım modellerine gereksinim duyulduğunu ortaya koymaktadır.

Sistematik derlemeler ve meta-analizler, emzirme başarısının yalnızca annenin motivasyonuna değil; gebelikten başlayıp doğum, erken postpartum dönem ve toplum temelli izlemleri kapsayan bakım sürekliliğine bağlı olduğunu göstermektedir.[6,7] Emzirme davranışı; annenin bilgi düzeyi, emzirme öz yeterliliği, psikolojik durumu, aile desteği, sağlık profesyonellerinin danışmanlığı, doğum şekli, hastane uygulamaları ve toplumsal çevre gibi biyopsikososyal belirleyicilerin etkileşimiyle şekillenmektedir.[8,5] Dolayısıyla emzirme başarısı yalnızca bireysel çabaların değil, kadın, aile ve sağlık sistemi arasındaki etkileşimin bir çıktısı olarak değerlendirilmelidir. Bu nedenle emzirmenin desteklenmesi, eğitimle sınırlı olmayan, bireyselleştirilmiş, kadın merkezli ve kanıta dayalı bakım modellerini gerektirmektedir.[6,2]

Güncel kanıtlar, antenatal eğitim, erken ten tene temas, emzirme danışmanlığı, ev ziyaretleri, telefon ve dijital destek sistemleri, psikoeğitim, akran desteği ve bakım sürekliliğini içeren çok bileşenli müdahalelerin emzirmenin başlatılması, yalnızca anne sütü ile beslenme oranları ve emzirmenin sürdürülmesinde tek bileşenli girişimlerden daha etkili olduğunu göstermektedir.[7,9,10] Ayrıca gebelikte başlayıp postpartum dönemde sürdürülen bakım modelleri, yalnızca doğum sonrasına odaklanan girişimlere göre daha başarılı sonuçlar sağlamaktadır.[2,11] Bu bulgular, emzirme bakımında müdahalenin türünden çok, bakımın doğru zamanda başlatılması ve sürekliliğinin sağlanmasının belirleyici olduğunu düşündürmektedir.

Bu süreçte ebeler, gebelik öncesinden postpartum döneme ve toplum temelli izlemlere kadar kadınlarla sürekli iletişim kurabilmeleri nedeniyle emzirmenin korunması, teşvik edilmesi ve sürdürülmesinde merkezi role sahiptir.[6] Emzirme tekniğinin öğretilmesinin yanı sıra annenin öz yeterliliğini güçlendirme,

emzirme sorunlarını erken tanılama, psikososyal gereksinimleri değerlendirme, aile katılımını destekleme ve bakım koordinasyonunu sağlama görevlerini üstlenmektedirler.[12,6] Şemsiye derlemeler ve sistematik incelemeler, ebe ve hemşire liderliğinde yürütülen müdahalelerin özellikle bireyselleştirilmiş danışmanlık ve bakım sürekliliği yoluyla emzirme sonuçlarını iyileştirdiğini göstermektedir.[6,10,11] Bu yönüyle ebe liderliğinde sunulan bakım, yalnızca emzirmenin başlatılmasını değil, emzirme davranışının uzun dönemde sürdürülebilirliğini destekleyen temel yaklaşımlardan biri olarak öne çıkmaktadır.

Bunun yanında dijital sağlık uygulamaları, telelaktasyon hizmetleri ve uzaktan danışmanlık modelleri ile psikoeğitim temelli programlar, özellikle çalışan anneler ve sağlık hizmetlerine erişimi sınırlı gruplarda emzirme bakımının önemli bileşenleri hâline gelmiştir.[3,13,14,9] Teknolojik ve psikososyal yaklaşımların giderek daha fazla bütünleşmesi, emzirme desteğinin yalnızca hastane ortamıyla sınırlı kalmayan, yaşam döngüsü boyunca sürdürülebilen bir bakım modeli olarak yeniden şekillendiğini göstermektedir. Bu derlemenin amacı, güncel bilimsel kanıtlar doğrultusunda ebe liderliğinde emzirmenin desteklenmesinde etkili müdahaleleri değerlendirmek, bu müdahalelerin emzirme sonuçları üzerindeki etkilerini sentezlemek ve elde edilen kanıtların klinik ebelik uygulamalarına yansımalarını tartışmaktır.

EMZİRMENİN GÜNCEL ÖNEMİ VE ANNE–BEBEK SAĞLIĞINA ETKİLERİ

Emzirme, yenidoğanın fizyolojik beslenme gereksinimini karşılamanın ötesinde, anne ve bebeğin kısa ve uzun dönem sağlık sonuçlarını iyileştiren önemli bir halk sağlığı müdahalesidir. Beslenme, enfeksiyon kontrolü, nörogelişim, kronik hastalıkların önlenmesi ve yaşam boyu sağlığın desteklenmesi açısından en maliyet etkin koruyucu sağlık uygulamalarından biri olarak kabul edilmektedir.[1,2] Buna rağmen, ilk altı ay yalnızca anne sütü ile beslenme ve emzirmenin tamamlayıcı beslenmeyle iki yaş ve ötesine kadar sürdürülmesine ilişkin önerilere birçok ülkede ulaşılamamaktadır.[4,5] Bu durum, emzirmenin kanıtlanmış yararlarına karşın uygulamadaki boşluğun sürdüğünü ve etkili destek stratejilerine gereksinim olduğunu göstermektedir.

Anne sütü, bebeğin gelişim dönemine göre içeriği değişen dinamik bir biyolojik sıvıdır. İçerdiği immünoglobulinler, büyüme faktörleri, hormonlar, canlı hücreler ve prebiyotik oligosakkaritler sayesinde immün sistemin olgunlaşmasını desteklemekte ve enfeksiyonlara karşı koruyucu etki göstermektedir.[1,3] Yaşamın ilk saatinde emzirmeye başlanması ve yalnızca anne sütü ile beslenmenin sürdürülmesi, neonatal morbidite ve mortalitenin azaltılmasında temel stratejiler arasında yer almaktadır.[4] Anne sütü ile beslenen bebeklerde nekrotizan enterokolit, sepsis, gastrointestinal ve solunum yolu enfeksiyonları daha düşük sıklıkta görülmekte; obezite, tip 2 diyabet ve bazı alerjik hastalıkların gelişme riski azalmakta, nörogelişim ve bilişsel performans olumlu etkilenmektedir.[1,2,3] Bu bulgular, anne sütünün yalnızca besleyici değil, yaşamın erken döneminden itibaren sağlığı şekillendiren biyolojik olarak aktif bir sistem olduğunu düşündürmektedir.

Anne açısından emzirme, postpartum iyileşmeyi hızlandırmakta, oksitosin salınımı yoluyla uterin involüsyonu desteklemekte ve postpartum kanama riskini azaltmaktadır. Ayrıca meme ve over kanseri, tip 2 diyabet, hipertansiyon, metabolik sendrom ve kardiyovasküler hastalık riskini azalttığına ilişkin güçlü epidemiyolojik kanıtlar bulunmaktadır.[1,3] Dolayısıyla emzirme, yalnızca yenidoğan sağlığını değil, kadın sağlığını da yaşam boyu destekleyen koruyucu bir sağlık davranışı olarak değerlendirilmelidir.

Bununla birlikte emzirmenin sürdürülmesi; yetersiz süt algısı, meme ağrısı, yanlış emzirme tekniği, bebeğin memeyi kavramasında güçlük, sezaryen doğum, yetersiz profesyonel destek, işe dönüş, aile baskısı ve erken formül mama kullanımı gibi biyolojik, psikolojik ve sosyal etmenlerden etkilenmektedir.[2,3,13] Bu durum, emzirme davranışının yalnızca fizyolojik değil, çevresel ve psikososyal koşullardan da güçlü biçimde etkilendiğini göstermektedir. Başarılı emzirmenin sürdürülebilmesi, laktasyon fizyolojisinin yanı sıra bakım ve destek sistemlerinin etkinliğine de bağlıdır.

Meta-analizler, annenin emzirme bilgi düzeyi, emzirme öz yeterliliği, erken emzirmeye başlama, sosyal destek, prenatal bakım, aile katılımı ve sağlık profesyonellerinin sürekli danışmanlığının yalnızca anne sütü ile beslenmenin temel belirleyicileri olduğunu göstermektedir.[5] Buna karşılık düşük öz yeterlilik,

bilgi eksikliği ve yetersiz profesyonel destek erken emzirmenin sonlandırılmasıyla ilişkilidir.[7,9] Bu belirleyicilerin önemli bölümünün değiştirilebilir olması, kanıta dayalı emzirme müdahalelerinin klinik etkisini artırmaktadır.

Psikososyal faktörler de emzirme davranışını önemli ölçüde etkilemektedir. Emzirme niyeti; bilgi, tutum, öz yeterlilik, algılanan sosyal normlar, aile desteği ve sağlık profesyonelleriyle kurulan iletişimden etkilenmektedir.[8] Ayrıca postpartum depresyon, emzirme öz yeterliliğini azaltmakta ve yalnızca anne sütü ile beslenmenin daha erken sonlanmasına neden olmaktadır.[15,16] Bu nedenle emzirme bakımının yalnızca teknik danışmanlığa odaklanması yeterli olmayıp, ruh sağlığı ve psikososyal gereksinimlerin sistematik biçimde değerlendirilmesini de içermesi gerekmektedir.

Bu bulgular birlikte değerlendirildiğinde, emzirmenin başarılı biçimde başlatılması ve sürdürülmesinin biyolojik yeterliliğin yanı sıra etkili danışmanlık, psikososyal destek, aile katılımı, bakım sürekliliği ve sağlık sistemi organizasyonuna bağlı olduğu görülmektedir. Emzirme başarısı tek bir belirleyiciyle açıklanamayacak kadar çok boyutlu olup, biyolojik, psikososyal ve sağlık sistemi bileşenlerinin bütüncül bir yaklaşımla ele alınmasını gerektirmektedir. Bu bağlamda emzirme başarısını belirleyen bireysel, psikososyal ve klinik faktörlerin ayrıntılı olarak incelenmesi, ebe liderliğinde geliştirilecek kanıta dayalı müdahalelerin planlanması açısından önem taşımaktadır.

EMZİRMENİN BAŞARISINI BELİRLEYEN BİREYSEL, PSİKOSOSYAL VE KLİNİK FAKTÖRLER

Emzirme fizyolojik bir süreç olmakla birlikte, başarılı biçimde başlatılması ve sürdürülmesi yalnızca laktasyon fizyolojisine bağlı değildir. Emzirme başarısı; annenin bilgi düzeyi, emzirme öz yeterliliği, ruh sağlığı, aile desteği, doğum deneyimi, bakım modeli ve sağlık profesyonelleriyle etkileşimi gibi biyolojik, psikolojik, sosyal ve sağlık sistemi kaynaklı belirleyicilerin etkileşimiyle şekillenmektedir.[8,5] Bu nedenle emzirme davranışı, tek bir risk veya koruyucu faktörle açıklanamayacak kadar çok boyutlu bir süreç olarak değerlendirilmelidir.

Yalnızca anne sütü ile beslenmenin en güçlü belirleyicilerinden biri annenin emzirme konusundaki bilgi ve farkındalık düzeyidir. Meta-analiz bulguları, emzirmenin yararlarına ilişkin yeterli bilgiye sahip olmanın yalnızca anne sütü ile beslenme olasılığını yaklaşık 2,7 kat artırdığını göstermektedir.[5] Prenatal dönemde verilen yapılandırılmış eğitimler emzirme davranışını olumlu yönde etkilerken doğum sonrasında karşılaşılan sorunlarla baş etme becerisini de güçlendirmektedir.[7,6] Ancak bilginin davranış değişikliğine dönüşebilmesi için sürekli profesyonel destekle bütünleştirilmesi gerekmektedir.[8] Bu bulgular, bilgi düzeyinin gerekli ancak tek başına yeterli olmadığını; bakım sürekliliğinin davranış değişikliğinin temel belirleyicilerinden biri olduğunu göstermektedir.

Emzirme öz yeterliliği, başarılı emzirmenin temel psikolojik belirleyicilerinden biridir ve annenin emzirme sürecini yönetebileceğine ilişkin inancını ifade eder. Eğitim, danışmanlık, psikoeğitim, ev ziyareti ve dijital destek programlarının emzirme öz yeterliliğini artırdığı, bunun da emzirme başarısı ve yalnızca anne sütü ile beslenme oranlarına olumlu yansıdığı gösterilmiştir.[9] Özellikle postpartum dönemde sürdürülen model temelli eğitim ve danışmanlık programlarının daha etkili olduğu bildirilmektedir.[7,9] Kanıtlar birlikte değerlendirildiğinde, öz yeterliliğin emzirme bakımında güçlendirilebilir temel belirleyicilerden biri olduğu anlaşılmaktadır.

Psikolojik iyilik hali de emzirmenin sürdürülmesinde kritik öneme sahiptir. Postpartum depresyon, emzirmenin daha erken sonlandırılması ve emzirme öz yeterliliğinin azalmasıyla ilişkilidir.[15,16] Buna karşılık psikoeğitim programlarının depresif belirtileri azaltırken emzirme öz yeterliliğini artırdığı gösterilmiştir.[14] Ruh sağlığı ile emzirme başarısı arasındaki bu çift yönlü ilişki, psikososyal değerlendirmenin emzirme bakımının ayrılmaz bir bileşeni olması gerektiğini göstermektedir.

Sosyal çevre ve aile desteği de emzirme davranışını önemli ölçüde etkilemektedir. Özellikle eş desteği ve aile bireylerinin olumlu tutumları annenin emzirme konusundaki güvenini artırmakta ve emzirmenin sürdürülmesini kolaylaştırmaktadır. Çocuk bakımında destek alan annelerde yalnızca anne sütü ile beslenme olasılığının yaklaşık 2,6 kat arttığı bildirilmektedir.[5] Ayrıca emzirme kararının algılanan sosyal normlar, aile beklentileri ve kültürel değerlerden de etkilendiği gösterilmiştir.[8] Bu bulgular, emzirme davranışının yalnızca bireysel değil, aile ve sosyal çevre tarafından şekillenen bir süreç

olduğunu göstermektedir. Bu nedenle emzirme danışmanlığının mümkün olduğunda eş ve aile bireylerini de kapsaması önerilmektedir.

Doğuma ilişkin klinik özellikler de erken emzirme başarısını etkileyebilmektedir. Vajinal doğum erken emzirmeyi desteklerken, sezaryen doğum emzirmenin başlatılmasını geciktirebilmektedir.[5] Ancak erken ten tene temas, etkili emzirme desteği ve uygun klinik organizasyon sayesinde bu olumsuz etkinin büyük ölçüde azaltılabildiği gösterilmiştir. Özellikle sezaryen sonrası erken ten tene temasın ilk emzirme süresini kısalttığı, ilk iki saatte emzirme oranlarını artırdığı ve taburculukta yalnızca anne sütü ile beslenmeyi desteklediği bildirilmektedir.[17] Kanıtlar, doğum şeklinin tek başına belirleyici olmadığını; uygun klinik uygulamalarla olumsuz etkilerin büyük ölçüde azaltılabileceğini göstermektedir.

Sağlık sistemi ve bakım modeli de emzirme başarısının önemli belirleyicileridir. Hastane uygulamaları, profesyonel danışmanlık, taburculuk sonrası izlem ve toplum temelli bakım hizmetleri emzirmenin sürdürülmesinde kritik rol oynamaktadır. Bebek Dostu Hastane Girişimi'nin tam olarak uygulandığı merkezlerde erken emzirmeye başlama ve yalnızca anne sütü ile beslenme oranları artmakta, toplum temelli Bebek Dostu girişimleri de bu etkinin altıncı aya kadar sürdürülmesine katkı sağlamaktadır.[4,10] Mevcut kanıtlar birlikte değerlendirildiğinde, emzirme başarısının bireysel özelliklerin yanı sıra sağlık sisteminin organizasyonu ve bakım sürekliliğinden de güçlü biçimde etkilendiği anlaşılmaktadır. Bu nedenle emzirmenin desteklenmesinde bireysel, psikososyal ve klinik belirleyicilerin birbirinden bağımsız değil, bütüncül bir bakım modeli içinde ele alınması gerekmektedir.

EBE LİDERLİĞİNDE EMZİRMENİN DESTEKLENMESİNDE ETKİLİ MÜDAHALELER

Güncel kanıtlar, emzirmenin desteklenmesinde tek bir müdahaleden çok, gebelikten postpartum döneme uzanan bakım sürekliliğini esas alan çok bileşenli yaklaşımların daha etkili olduğunu göstermektedir. Sistematik derlemeler ve meta-analizler; antenatal eğitim, erken emzirme uygulamaları, ten tene temas, bireyselleştirilmiş danışmanlık, ev ziyaretleri, telefon ve dijital danışmanlık, psikoeğitim, akran desteği ve toplum temelli bakım modellerinin emzirmenin başlatılması, yalnızca anne sütü ile beslenme oranları ve emzirmenin sürdürülmesi üzerinde olumlu etkiler sağladığını ortaya koymaktadır.[6,9,2] Kanıtlar birlikte değerlendirildiğinde, müdahalelerin başarısının uygulanan yöntemden çok, doğru zamanda başlatılmasına, bakım sürekliliğinin sağlanmasına ve bireysel gereksinimlere göre uyarlanmasına bağlı olduğu anlaşılmaktadır.[7,8] Bu durum, standart uygulamalar yerine bütünleşik ve bireyselleştirilmiş bakım modellerinin daha başarılı sonuçlar verdiğini düşündürmektedir.

Ebeler, gebelikten postpartum döneme kadar kadınlarla sürekli iletişim kurabilmeleri nedeniyle emzirme bakımının temel yürütücüleridir. Emzirme desteği; teknik danışmanlığın yanı sıra annenin öz yeterliliğinin güçlendirilmesi, psikososyal gereksinimlerin değerlendirilmesi, emzirme sorunlarının erken tanılanması, aile katılımının desteklenmesi ve gerektiğinde multidisipliner bakım koordinasyonunu kapsayan bütüncül bir süreçtir. Güncel kanıtlar, ebe liderliğinde ve bakım sürekliliği temelinde yürütülen programların emzirme sonuçlarını iyileştirdiğini göstermektedir.[6,12] Bu nedenle ebe liderliğinde sunulan bakım, tek bir danışmanlık oturumundan çok, gebelikten postpartum döneme uzanan koordineli ve süreklilik gösteren bir bakım modeli olarak değerlendirilmelidir.

Etkili müdahaleler, bakımın uygulandığı döneme göre sınıflandırılmaktadır. Gebelikte verilen eğitim ve danışmanlık emzirmeye hazırlığı güçlendirirken, doğum sırasındaki erken emzirme uygulamaları ve ten tene temas emzirmenin başarılı biçimde başlatılmasını desteklemektedir. Postpartum dönemde sürdürülen danışmanlık, ev ziyaretleri, dijital sağlık uygulamaları ve toplum temelli bakım ise emzirmenin sürdürülmesinde belirleyici rol oynamaktadır. Bu müdahaleler birbirinden bağımsız değil, bakım sürekliliğini sağlayan birbirini tamamlayıcı bileşenlerdir. Bu nedenle aşağıda ebe liderliğinde yürütülen emzirme müdahaleleri, gebelikten postpartum döneme uzanan bakım sürekliliği perspektifiyle ele alınmıştır.

Gebelik Döneminde Uygulanan Müdahaleler

Gebelik dönemi, emzirme davranışının şekillenmeye başladığı, annenin bilgi, tutum ve beklentilerinin oluştuğu kritik bir hazırlık sürecidir. Bu dönemde sunulan bakım yalnızca emzirme konusunda bilgi

vermeyi değil, annenin öz yeterliliğini güçlendirecek davranışsal ve psikososyal hazırlığı da kapsamalıdır. Güncel kanıtlar, antenatal dönemde başlayıp postpartum dönemde sürdürülen müdahalelerin emzirme başarısı üzerinde daha kalıcı etkiler oluşturduğunu göstermektedir.[7,2]

Prenatal eğitim programları, gebelik dönemindeki temel emzirme müdahaleleridir. Yapılandırılmış antenatal eğitimlerin emzirme bilgisini artırdığı, doğum sonrasında karşılaşılan sorunlarla baş etmeyi kolaylaştırdığı ve yalnızca anne sütü ile beslenme süresini uzattığı bildirilmektedir.[7] Ancak kanıtlar, yalnızca teorik bilgi aktarımına dayanan eğitimlerin sınırlı etkiye sahip olduğunu; uygulamalı eğitim, bireysel danışmanlık ve model temelli yaklaşımların daha başarılı sonuçlar verdiğini göstermektedir.[7] Bu bulgular, antenatal bakımda eğitimin varlığından çok içeriği ve uygulanış biçiminin belirleyici olduğunu düşündürmektedir.

Emzirme öz yeterliliğinin güçlendirilmesi antenatal bakımın temel hedeflerinden biridir. Öz yeterliliği yüksek kadınların emzirmeyi daha uzun süre sürdürdüğü ve karşılaştıkları güçlüklerle daha etkili baş ettiği bildirilmektedir.[9] Bu nedenle antenatal bakım yalnızca emzirmenin yararlarını aktarmakla sınırlı kalmamalı, annenin olası güçlüklerle baş etme becerilerini de geliştirmelidir. Böylece doğum sonrasında ortaya çıkabilecek sorunların önleyici bir yaklaşımla yönetilmesi mümkün olabilmektedir.

Meta-analizler; eğitim oturumları, danışmanlık programları, mobil uygulamalar, dijital eğitimler ve akran desteğinin emzirme sonuçlarını iyileştirdiğini, ancak tek seferlik eğitimlerin postpartum profesyonel destekle tamamlanmadığında etkisinin zamanla azaldığını göstermektedir.[9,3] Bu bulgular, antenatal eğitimin tek başına yeterli olmadığını ve bakımın postpartum dönemde de kesintisiz sürdürülmesi gerektiğini ortaya koymaktadır. Bu nedenle prenatal eğitim, postpartum bakımın sürekliliğiyle bütünleştirilmelidir.

Antenatal müdahalelerin önemi özellikle primipar kadınlarda daha belirgindir. Gebelikte başlayan eğitimlerin postpartum profesyonel destek ve akran danışmanlığıyla sürdürülmesi, altıncı aya kadar yalnızca anne sütü ile beslenme oranlarını artırmaktadır.[2] Ayrıca emzirme kararının yalnızca annenin bireysel tercihi olmadığı; eş desteği, aile beklentileri ve sosyal normlardan da etkilendiği gösterilmiştir.[8] Bu nedenle antenatal danışmanlığın mümkün olduğunda eş ve aile bireylerini de kapsayacak şekilde planlanması önerilmektedir.

Kanıtlar birlikte değerlendirildiğinde, antenatal dönemde yürütülen emzirme müdahalelerinin bilgi aktarımının ötesine geçerek öz yeterliliği güçlendiren, aile katılımını destekleyen ve postpartum bakım ile bütünleşen bir yaklaşımla planlanması gerektiği anlaşılmaktadır. Antenatal dönemde oluşturulan bu hazırlığın başarılı emzirme davranışına dönüşmesinde ise doğum sırasında ve erken postpartum dönemde uygulanacak girişimler belirleyici olmaktadır.

Doğum Sırasında ve Erken Postpartum Dönemde Uygulanan Müdahaleler

Doğumu izleyen ilk saatler, emzirmenin başarılı biçimde başlatılması açısından kritik bir dönemdir. Bu süreçte gerçekleştirilen uygulamalar yalnızca ilk emzirmeyi değil, uzun dönem yalnızca anne sütü ile beslenme oranlarını, emzirme süresini ve annenin emzirme öz yeterliliğini de etkilemektedir. Bu nedenle doğumun hemen ardından başlatılan emzirme destek uygulamaları, gebelik döneminde oluşturulan hazırlığın doğal devamı olarak değerlendirilmektedir.[4,5]

Erken emzirmeye başlanması doğum sonrası bakımın temel bileşenlerinden biridir. Kanıtlar, yaşamın ilk saatinde emzirmenin başlatılması ve Bebek Dostu Hastane Girişimi ilkelerinin eksiksiz uygulanmasının, yalnızca anne sütü ile beslenmenin sürdürülmesini desteklediğini göstermektedir.[5,4] Bu bulgular, doğum sonrası ilk saatlerde sunulan profesyonel desteğin uzun dönem emzirme sonuçlarını belirleyen temel bakım uygulamalarından biri olduğunu düşündürmektedir.

Erken postpartum dönemin en etkili uygulamalarından biri ten tene temastır. Doğumdan hemen sonra uygulanan ten tene temasın emzirme reflekslerini hızlandırdığı, başarılı meme kavramayı kolaylaştırdığı ve özellikle sezaryen doğum sonrasında ilk iki saat içinde emzirme ile taburculukta yalnızca anne sütü ile beslenme oranlarını artırdığı gösterilmiştir. Ayrıca maternal oksitosin salınımını destekleyerek süt salınımını kolaylaştırdığı ve anne-bebek bağlanmasını güçlendirdiği bildirilmektedir.[12]

Emzirmenin başarılı biçimde başlatılabilmesi için annenin doğru emzirme pozisyonu ve meme kavrama tekniği açısından değerlendirilmesi, olası sorunların erken dönemde belirlenmesi ve uygulamalı danışmanlık verilmesi gerekmektedir. Kanıtlar, bireyselleştirilmiş profesyonel danışmanlığın meme başı ağrısı, yanlış kavrama, yetersiz süt algısı ve gereksiz formül mama kullanımını azaltırken emzirme öz yeterliliğini ve yalnızca anne sütü ile beslenme oranlarını artırdığını göstermektedir.[9,6] Bu durum, erken danışmanlığın sorunları ortaya çıktıktan sonra yönetmekten çok önleyici bakım yaklaşımını güçlendirdiğini düşündürmektedir.

Doğum şekli de erken emzirme başarısını etkileyen önemli klinik faktörlerden biridir. Sezaryen doğum; ağrı, hareket kısıtlılığı, anestezi etkileri ve anne-bebek ayrılığı nedeniyle emzirmenin gecikmesine yol açabilmektedir. Bununla birlikte erken ten tene temas, anne-bebek birlikteliğinin korunması ve profesyonel emzirme desteği sayesinde bu olumsuz etkilerin büyük ölçüde azaltılabildiği gösterilmiştir.[12,4] Dolayısıyla doğum şeklinin tek başına belirleyici olmadığı, uygun klinik bakımın emzirme sonuçlarını önemli ölçüde iyileştirebildiği anlaşılmaktadır.

Emzirme desteğinin etkisi hastane yatışıyla sınırlı değildir. Taburculuk öncesinde emzirme becerisinin değerlendirilmesi, olası sorunlara yönelik danışmanlık verilmesi ve taburculuk sonrası profesyonel izlemin planlanması emzirmenin sürdürülmesini desteklemektedir.[2,6] Kanıtlar birlikte değerlendirildiğinde, doğum sırasında başlayan profesyonel desteğin postpartum dönemde kesintisiz sürdürülmesi, başarılı ve sürdürülebilir emzirmenin temel bileşenlerinden biri olarak öne çıkmaktadır.

Hastane Temelli Emzirme Destek Programları ve Bebek Dostu Hastane Girişimi

Emzirmenin başarılı biçimde başlatılması ve sürdürülmesinde doğumun gerçekleştiği sağlık kuruluşunun bakım anlayışı belirleyici rol oynamaktadır. Hastane ortamı, annenin emzirme deneyiminin şekillendiği ilk profesyonel bakım basamağı olduğundan, güncel politikalar bireysel danışmanlığın yanı sıra kurum kültürü, sağlık profesyonellerinin eğitimi ve standart bakım uygulamalarını kapsayan sistem düzeyindeki yaklaşımlara odaklanmaktadır.[4]

Bu kapsamda geliştirilen en önemli kurumsal model Bebek Dostu Hastane Girişimi (Baby-Friendly Hospital Initiative, BFHI)'dir. BFHI; erken emzirmenin desteklenmesi, gereksiz anne-bebek ayrılığının önlenmesi, yalnızca anne sütü ile beslenmenin teşvik edilmesi, standart emzirme danışmanlığı sunulması ve taburculuk sonrası bakım sürekliliğinin sağlanmasını amaçlayan bütüncül bir bakım modelidir. Kanıtlar, girişimin tüm bileşenleriyle uygulanmasının emzirme sonuçlarını anlamlı biçimde iyileştirdiğini göstermektedir.[4] Bu yönüyle BFHI, yalnızca belirli uygulamaları değil, emzirme bakımının tüm aşamalarını kapsayan sistematik bir kalite geliştirme modeli olarak değerlendirilebilir.

Meta-analiz bulguları, BFHI'nin erken emzirmeye başlamayı ve dördüncü ile altıncı aylarda yalnızca anne sütü ile beslenme oranlarını artırdığını ortaya koymaktadır. Bununla birlikte etkinliğin yalnızca "Bebek Dostu" unvanına değil, standartların eksiksiz ve sürdürülebilir biçimde uygulanmasına bağlı olduğu bildirilmektedir.[4] Bu durum, emzirme sonuçlarını iyileştiren temel unsurun standartların tanımlanmasından çok, uygulama sadakati olduğunu düşündürmektedir.

BFHI'nin başarısında sağlık profesyonellerinin bilgi ve beceri düzeyi kritik öneme sahiptir. Standart eğitim programları ve ortak bakım protokolleri emzirme danışmanlığının kalitesini artırırken, tutarsız uygulamalar ve emzirme sorunlarının geç fark edilmesi annenin emzirme güvenini azaltabilmekte ve erken formül mama kullanımına yol açabilmektedir.[9,6]

Başarılı hastane modellerinde antenatal danışmanlık, doğum salonu uygulamaları, postpartum servis izlemleri ve taburculuk sonrası yönlendirmeler tek bir bakım zinciri olarak planlanmaktadır. Kanıtlar, standart hastane uygulamalarının bireyselleştirilmiş emzirme danışmanlığıyla bütünleştirilmesinin emzirme tekniğini geliştirdiğini, meme başı sorunlarını azalttığını, emzirme öz yeterliliğini artırdığını ve yalnızca anne sütü ile beslenme süresini uzattığını göstermektedir.[4,7,9]

Hastanede başlayan desteğin taburculuk sonrasında da sürdürülmesi emzirmenin devamlılığı açısından önem taşımaktadır. Bu nedenle BFHI'nin yalnızca hastane ile sınırlı bir model olarak değil, aile sağlığı merkezleri, ev ziyaretleri ve dijital danışmanlık hizmetleriyle bütünleşik bir bakım yaklaşımı şeklinde uygulanması önerilmektedir.[2,4,6] Kanıtlar birlikte değerlendirildiğinde, başarılı emzirme sonuçlarının

yalnızca hastane temelli uygulamalara değil, hastane ve toplum temelli bakım hizmetlerinin kesintisiz entegrasyonuna bağlı olduğu anlaşılmaktadır.

Ev Ziyaretleri ve Toplum Temelli Emzirme Destek Hizmetleri

Emzirme ile ilgili güçlüklerin önemli bir bölümü hastaneden taburculuk sonrasında, özellikle postpartum ilk haftalarda ortaya çıkmaktadır. Hastanede başarılı biçimde başlatılan emzirme; meme ağrısı, memenin dolgunlaşması, bebeğin memeyi kavramasında güçlük, yetersiz süt algısı, aile baskısı ve profesyonel desteğe erişimde yaşanan sorunlar nedeniyle kesintiye uğrayabilmektedir. Bu nedenle güncel bakım modelleri, emzirme desteğinin taburculukla sonlandırılmayarak ev ziyaretleri, toplum temelli danışmanlık ve düzenli profesyonel izlemlerle sürdürülmesini önermektedir.[2,6]

Toplum temelli emzirme desteği, annenin günlük yaşamında karşılaştığı güçlüklerin erken dönemde belirlenmesini ve zamanında müdahale edilmesini amaçlamaktadır. Ev ziyaretleri sırasında emzirme tekniği, aile desteği, annenin psikolojik durumu ve çevresel koşullar birlikte değerlendirilerek biyopsikososyal gereksinimlere bütüncül yaklaşım sağlanabilmektedir.[8]

Kanıtlar, gebelikte başlayıp doğum sonrasında ev ziyaretleriyle sürdürülen bakım modellerinin yalnızca anne sütü ile beslenme oranlarını artırdığını göstermektedir. Özellikle profesyonel destek ile akran desteğinin birlikte sunulduğu ve en az altı ay sürdürülen programlar daha başarılı sonuçlar sağlamaktadır.[2] Ayrıca uygulamalı emzirme değerlendirmesi, problem çözme yaklaşımı, bireyselleştirilmiş danışmanlık ve psikososyal destek içeren ev ziyaretlerinin standart eğitim programlarından daha etkili olduğu bildirilmektedir.[9,7] Bu bulgular, toplum temelli bakımın etkinliğinin yalnızca ziyaret sıklığına değil, müdahalenin niteliği ve bireyselleştirilmesine de bağlı olduğunu göstermektedir.

Ev ziyaretleri, emzirme öz yeterliliğinin güçlendirilmesine de katkı sağlamaktadır. Emzirmenin doğrudan gözlenmesi, doğru uygulamaların pekiştirilmesi ve sorunlara yerinde müdahale edilmesi annenin güvenini artırırken, eş ve aile bireylerinin bakım sürecine katılımı emzirme desteğini güçlendirmektedir.[9,5,8] Böylece bakım yalnızca anneye değil, aileyi de kapsayan bütüncül bir yaklaşıma dönüşmektedir.

Toplum temelli bakımın etkinliği, hastane ile birinci basamak sağlık hizmetleri arasındaki koordinasyona da bağlıdır. Düzenli postpartum izlem, emzirme sorunlarının erken belirlenmesi ve gerektiğinde ileri danışmanlık hizmetlerine yönlendirme bakım sürekliliğini güçlendirmektedir. Bakım basamakları arasında etkin iletişim bulunan sağlık sistemlerinde yalnızca anne sütü ile beslenme oranlarının daha yüksek olduğu bildirilmektedir.[4,6] Bu durum, bakım basamakları arasındaki koordinasyonun toplum temelli emzirme desteğinin temel bileşenlerinden biri olduğunu düşündürmektedir.

Ev ziyaretlerinin düzenli yürütülemediği durumlarda dijital sağlık uygulamaları, telelaktasyon hizmetleri ve uzaktan emzirme danışmanlığı bakım sürekliliğini destekleyen önemli alternatifler sunmaktadır. Özellikle sağlık hizmetlerine erişimi sınırlı gruplarda ebe liderliğinde yürütülen bu modeller profesyonel desteğin devamlılığını sağlamaktadır. Kanıtlar birlikte değerlendirildiğinde, emzirmenin sürdürülebilirliğinde belirleyici olanın uygulamanın türünden çok, profesyonel desteğin kesintisiz, erişilebilir ve bireysel gereksinimlere uygun biçimde sunulması olduğu anlaşılmaktadır.

Dijital Sağlık Uygulamaları ve Telelaktasyon Hizmetleri

Sağlık hizmetlerinde dijital dönüşüm, emzirme danışmanlığı ve laktasyon desteğinin sunumunu önemli ölçüde değiştirmiştir. Özellikle sağlık hizmetlerine erişimin sınırlı olduğu bölgelerde yaşayan kadınlar, çalışan anneler ve postpartum dönemde sağlık kuruluşlarına yeniden başvurmakta güçlük yaşayan aileler için dijital sağlık uygulamaları bakım sürekliliğini destekleyen önemli araçlar hâline gelmiştir. Mobil uygulamalar, kısa mesaj sistemleri, telefon danışmanlığı, görüntülü görüşmeler, çevrim içi eğitim platformları ve telelaktasyon hizmetleri, ebe liderliğinde yürütülen emzirme bakımının tamamlayıcı bileşenleri olarak değerlendirilmektedir.[10,14] Bu gelişmeler, emzirme danışmanlığının zaman ve mekân kısıtlaması olmaksızın sürdürülebilmesine olanak sağlamaktadır.

Dijital müdahaleler, annelerin profesyonel desteğe kolay erişimini sağlayarak meme başı ağrısı, memenin dolgunlaşması, yanlış emzirme pozisyonu ve yetersiz süt algısı gibi sorunlara erken dönemde müdahale edilmesini kolaylaştırmaktadır.[14] Kanıtlar, dijital desteğin özellikle bakım sürekliliğini güçlendirmesi ve profesyonel danışmanlığa erişimi artırması bakımından önemli avantajlar sağladığını göstermektedir.

Ağ meta-analizi ve sistematik derleme bulguları, mobil uygulamalar, telefon danışmanlığı, kısa mesaj temelli destek sistemleri ve telelaktasyon hizmetlerinin yalnızca anne sütü ile beslenme oranlarını artırdığını ortaya koymaktadır. En yüksek etkinliğin planlanmış telefon görüşmeleri ile kısa mesaj desteğini birleştiren müdahalelerde, telelaktasyonda ise sağlık profesyonelleri tarafından yürütülen proaktif veya karma modellerde elde edildiği bildirilmektedir.[10,14] Bu bulgular, dijital müdahalelerin en etkili biçimde planlı profesyonel izlem ve düzenli iletişimle bütünleştirildiğinde sonuç verdiğini düşündürmektedir.

Bununla birlikte dijital uygulamaların başarısı yalnızca teknolojik altyapıya bağlı değildir. Danışmanlığın sağlık profesyonelleri tarafından yürütülmesi, içeriklerin kanıta dayalı hazırlanması, düzenli izlemin planlanması ve bireysel gereksinimlere göre uyarlanması gerekmektedir. Kanıtlar, otomatik bilgi paylaşımına dayanan pasif sistemlerden çok, ebe veya laktasyon danışmanıyla çift yönlü iletişim sağlayan etkileşimli modellerin daha başarılı olduğunu göstermektedir.[10,14]

Genel olarak mevcut kanıtlar, dijital sağlık uygulamaları ve telelaktasyon hizmetlerinin yüz yüze bakımın yerine geçen değil, bakım sürekliliğini güçlendiren tamamlayıcı müdahaleler olduğunu göstermektedir. Bu nedenle dijital ve yüz yüze danışmanlığı bütünleştiren hibrit bakım modelleri, ebe liderliğinde emzirme desteği açısından en uygun yaklaşım olarak öne çıkmaktadır. Emzirme başarısında psikolojik dayanıklılık ve öz yeterliliğin de belirleyici olması, psikoeğitim temelli müdahalelerin bu bütüncül bakım yaklaşımının önemli bir bileşeni olarak değerlendirilmesini gerektirmektedir.

Psikoeğitim ve Emzirme Öz Yeterliliğini Güçlendirmeye Yönelik Müdahaleler

Emzirmenin başarılı biçimde sürdürülmesinde teknik bilgi kadar annenin psikolojik hazırlığı, öz yeterlilik algısı ve karşılaştığı güçlüklerle baş edebilme becerisi de belirleyicidir. Bu nedenle güncel emzirme destek programları, emzirme tekniğinin yanı sıra annenin psikolojik dayanıklılığını ve emzirme öz yeterliliğini güçlendiren psikoeğitim temelli yaklaşımlara odaklanmaktadır.[15,8]

Psikoeğitim; annenin emzirme fizyolojisini anlamasını, olası güçlükleri önceden tanımasını ve emzirme sürecini güvenle yönetmesini amaçlayan yapılandırılmış eğitim ve danışmanlık programlarını kapsamaktadır. Bu programlarda stres yönetimi, problem çözme becerileri, anne-bebek bağlanmasının desteklenmesi ve sosyal destek kaynaklarının etkin kullanımı da ele alınmaktadır.[15]

Kanıtlar birlikte değerlendirildiğinde, psikoeğitim, uygulamalı eğitim, bireysel danışmanlık, ev ziyareti, telefon desteği ve dijital danışmanlığı içeren çok bileşenli müdahalelerin emzirme öz yeterliliğini artırdığı, postpartum depresyon belirtilerini azalttığı ve emzirmenin sürdürülmesini desteklediği görülmektedir. Özellikle postpartum dönemde sürdürülen müdahalelerin tek seferlik antenatal eğitimlerden daha etkili olduğu bildirilmektedir.[15,9,7] Bu bulgular, emzirme öz yeterliliğinin uygun bakım girişimleriyle güçlendirilebilen değiştirilebilir bir belirleyici olduğunu göstermektedir.

Psikoeğitim aynı zamanda emzirmeye ilişkin yanlış inanışların düzeltilmesine katkı sağlamaktadır. Özellikle ilk kez anne olan kadınlarda yetersiz süt algısı, bebeğin sık emmesini açlık belirtisi olarak yorumlama ve ilk günlerde yaşanan güçlükleri başarısızlık olarak değerlendirme gibi yanlış inanışların düzeltilmesi emzirme kaygısını azaltmakta ve gereksiz formül mama kullanımını önleyebilmektedir.[8] Düzenli psikoeğitim ve danışmanlık alan kadınlarda bakım deneyiminin iyileştiği ve postpartum depresyon belirtilerinin azaldığı da bildirilmektedir.[15,16]

Ebeler, gebelikten postpartum döneme kadar kadınlarla kurdukları sürekli iletişim sayesinde psikolojik gereksinimleri erken belirleyebilmekte ve danışmanlığı bireysel gereksinimlere göre uyarlayabilmektedir.[8,6] Bu yönüyle psikoeğitim, kadın merkezli ve bireyselleştirilmiş emzirme bakımının temel bileşenlerinden biri olarak değerlendirilmektedir.

Kanıtlar birlikte değerlendirildiğinde, psikoeğitim ve emzirme öz yeterliliğini güçlendirmeye yönelik müdahaleler teknik emzirme danışmanlığını tamamlayarak emzirme başarısını desteklemektedir. Bununla birlikte bazı kadın gruplarında standart bakımın ötesinde daha yoğun ve bireyselleştirilmiş desteğe gereksinim duyulmaktadır. Bu nedenle özel gereksinimi bulunan gruplara yönelik ebe liderliğinde yürütülen müdahalelerin ayrıca değerlendirilmesi gerekmektedir.

Özel Gereksinimi Olan Gruplarda Ebe Liderliğinde Emzirme Desteği

Her annenin emzirme süreci benzer fizyolojik mekanizmalara dayanmakla birlikte, emzirme başarısını etkileyen gereksinimler bireysel farklılık göstermektedir. Bu nedenle güncel bakım yaklaşımları, standart danışmanlık yerine risk faktörlerini ve bireysel gereksinimleri dikkate alan kişiselleştirilmiş bakım modellerini ön plana çıkarmaktadır. Özellikle primipar kadınlar, sezaryen doğum yapan anneler, çalışan kadınlar ve postpartum ruh sağlığı sorunu yaşayan bireyler daha yoğun ve süreklilik gösteren profesyonel desteğe gereksinim duymaktadır.[2,14]

Primipar Anneler

İlk kez anne olan kadınlarda bilgi eksikliği, kaygı ve düşük emzirme öz yeterliliği daha sık görülmektedir. Kanıtlar, gebelikte başlayan eğitimin doğum sonrası bireysel danışmanlık, profesyonel izlem ve akran desteğiyle sürdürülmesinin yalnızca anne sütü ile beslenme oranlarını artırdığını göstermektedir.[2] Özellikle emzirme kaygısı yüksek kadınlarda bireyselleştirilmiş bakım planlarının daha başarılı sonuçlar sağladığı bildirildiğinden, erken postpartum dönemde yakın izlem ve danışmanlık öncelikli olmalıdır.[9]

Sezaryen Doğum Yapan Anneler

Sezaryen doğum; ağrı, hareket kısıtlılığı, anestezi etkileri ve anne-bebek ayrılığı nedeniyle emzirmenin gecikmesine yol açabilmektedir. Bununla birlikte kanıtlar, erken ten tene temas, uygun ağrı kontrolü, erken emzirme desteği ve bireyselleştirilmiş danışmanlığın bu olumsuz etkileri önemli ölçüde azaltabildiğini göstermektedir.[12] Bu nedenle sezaryen doğum yapan kadınlarda emzirme desteğinin daha yakın ve planlı izlemle sürdürülmesi gerekmektedir.

Çalışan Anneler

İşe dönüş süreci; süt sağma olanaklarının yetersizliği, çalışma koşulları ve profesyonel desteğe erişimde yaşanan güçlükler nedeniyle emzirmenin sürdürülmesini olumsuz etkileyebilmektedir.[14] Kanıtlar, telelaktasyon ve dijital danışmanlık hizmetlerinin çalışan annelerde yalnızca anne sütü ile beslenme oranlarını artırdığını göstermektedir.[14] Bu nedenle ebe liderliğinde sunulan bakımın işe dönüş planlamasının yanı sıra süt sağma, saklama ve emzirmenin çalışma yaşamında sürdürülmesine yönelik danışmanlığı da kapsaması önem taşımaktadır.

Postpartum Depresyon Riski Taşıyan Anneler

Postpartum depresyon, emzirmenin erken sonlandırılmasıyla ilişkili önemli bir risk faktörüdür.[16] Kanıtlar, psikoeğitim, düzenli ebe izlemleri ve emzirme danışmanlığını bütünleştiren bakım modellerinin depresyon belirtilerini azaltırken emzirme öz yeterliliğini artırdığını göstermektedir.[15] Bu nedenle ruh sağlığının sistematik olarak değerlendirilmesi ve riskli kadınlara erken psikososyal destek sunulması emzirme bakımının temel bileşenleri arasında yer almalıdır.

Bireyselleştirilmiş Bakımın Önemi

Bu gruplara ilişkin kanıtlar birlikte değerlendirildiğinde, emzirme başarısının yalnızca risk faktörlerinin varlığına değil, bu risklerin bireysel gereksinimler doğrultusunda yönetilmesine bağlı olduğu görülmektedir.[8,6] Bu nedenle bakımın risk temelli, bireyselleştirilmiş ve bakım sürekliliğini esas alan modeller doğrultusunda planlanması önerilmektedir. Ebeler, gebelikten postpartum döneme kadar kadınlarla kurdukları sürekli iletişim sayesinde bu gereksinimleri erken belirleyebilmekte ve bakım planını bireysel gereksinimlere göre şekillendirebilmektedir. Bu yaklaşımın klinik uygulamalara sistematik biçimde entegre edilmesi, kanıta dayalı emzirme bakımının etkinliğini ve sürdürülebilirliğini güçlendirecektir.

KLİNİK UYGULAMAYA YANSIMALAR VE EBELİK BAKIMINA İLİŞKİN ÖNERİLER

Bu derlemede sentezlenen güncel kanıtlar, emzirmenin desteklenmesine yönelik klinik uygulamaların bakım sürekliliği, bireyselleştirilmiş danışmanlık ve çok bileşenli müdahaleler temelinde yeniden yapılandırılması gerektiğini göstermektedir. Antenatal eğitim, erken emzirme uygulamaları, Bebek Dostu Hastane standartları, bireysel danışmanlık, ev ziyaretleri, dijital sağlık uygulamaları, telelaktasyon ve psikoeğitim programlarının birlikte planlanması emzirme sonuçlarını anlamlı düzeyde iyileştirmektedir.[4,10,9,2]

Bu doğrultuda emzirme bakımının gebelikte başlaması, doğum sırasında kesintiye uğramaması ve postpartum dönemde düzenli izlemle sürdürülmesi gerekmektedir. Kanıtlar, özellikle emzirmenin ilk haftalarında ortaya çıkan sorunların zamanında profesyonel danışmanlıkla büyük ölçüde yönetilebildiğini ve bakım sürekliliğinin emzirme başarısının temel belirleyicilerinden biri olduğunu göstermektedir.[6,7]

Ebelerin klinik sorumlulukları; emzirme bilgi düzeyi ve öz yeterliliğinin değerlendirilmesi, risk faktörlerinin erken belirlenmesi, psikososyal gereksinimlerin izlenmesi, aile katılımının desteklenmesi ve bireyselleştirilmiş danışmanlığın sürdürülmesini kapsamaktadır.[8,5] Özellikle sezaryen doğum yapan kadınlar, primiparlar ve emzirme güçlüğü yaşayan annelerde risk temelli ve daha yakın izlemin planlanması, bakımın etkinliğini artırabilecek önemli uygulamalardan biridir.[12,2]

Kanıtlar, emzirme bakımında psikososyal değerlendirmenin rutin izlemin ayrılmaz bir bileşeni olması gerektiğini göstermektedir. Düşük emzirme öz yeterliliği, postpartum depresyon belirtileri ve yetersiz sosyal destek erken dönemde belirlenebilen ve uygun girişimlerle iyileştirilebilen değiştirilebilir faktörlerdir.[15,16] Ayrıca dijital sağlık uygulamaları ve telelaktasyon hizmetleri, özellikle çalışan anneler ve sağlık hizmetlerine erişimi sınırlı kadınlarda yüz yüze danışmanlığı tamamlayan etkili hibrit bakım modelleri olarak değerlendirilmelidir.[10,14]

Kurumsal düzeyde ise Bebek Dostu Hastane standartlarının klinik uygulamaya tam olarak entegre edilmesi, sağlık profesyonellerinin hizmet içi eğitimlerle desteklenmesi, ortak bakım protokollerinin uygulanması ve hastane ile birinci basamak sağlık hizmetleri arasındaki koordinasyonun güçlendirilmesi bakım sürekliliğinin sağlanması açısından önem taşımaktadır.[4]

Çalışmaların müdahale içerikleri, uygulama süreleri ve izlem dönemleri bakımından heterojen olması sonuçların doğrudan karşılaştırılmasını güçleştirmektedir. Buna karşın mevcut kanıtlar birlikte değerlendirildiğinde, farklı ülkelerde yürütülen araştırmalar bireyselleştirilmiş danışmanlık, bakım sürekliliği ve ebe liderliğinde yürütülen müdahalelerin emzirme sonuçlarını tutarlı biçimde iyileştirdiğini göstermektedir.

Bu doğrultuda klinik uygulamalarda bakımın gebelikten postpartum döneme kadar kesintisiz planlanması, emzirme desteğinin bireysel gereksinimlere göre uyarlanması, psikososyal değerlendirmenin rutin bakımın ayrılmaz bir bileşeni hâline getirilmesi ve hastane temelli hizmetlerin toplum temelli izlemlerle bütünleştirilmesi önerilmektedir. Bunun yanında dijital sağlık uygulamalarını yüz yüze danışmanlıkla bütünleştiren hibrit bakım modellerinin yaygınlaştırılması ve ebe liderliğinde yürütülen kanıta dayalı uygulamaların sağlık sisteminin tüm basamaklarında standartlaştırılması, emzirme bakımının etkinliğini artırabilecek temel stratejiler olarak değerlendirilmektedir.

SONUÇ

Emzirme, anne ve bebek sağlığını kısa ve uzun dönemde destekleyen en etkili koruyucu sağlık uygulamalarından biridir. Bu derlemede sentezlenen güncel kanıtlar, emzirme başarısının yalnızca biyolojik süreçlere değil; psikolojik, sosyal ve sağlık sistemiyle ilişkili çok boyutlu belirleyicilerin etkileşimine bağlı olduğunu göstermektedir. Bu nedenle emzirmenin korunması, teşvik edilmesi ve sürdürülmesinde bakım sürekliliğini esas alan, çok bileşenli ve kanıta dayalı müdahaleler en etkili yaklaşım olarak öne çıkmaktadır.

Gebelikte başlayan eğitim ve danışmanlığın doğum sonrası erken emzirme uygulamaları, bireyselleştirilmiş danışmanlık, hastane ve toplum temelli bakım, dijital sağlık uygulamaları ve psikososyal destekle bütünleştirilmesi; emzirme öz yeterliliğini güçlendirmekte, yalnızca anne sütü ile

beslenme oranlarını artırmakta ve emzirmenin sürdürülebilirliğini desteklemektedir. Özellikle primiparlar, sezaryen doğum yapan kadınlar, çalışan anneler ve postpartum ruh sağlığı açısından risk taşıyan kadınlarda gereksinime duyarlı bakım modelleri öncelikli olarak ele alınmalıdır.

Ebeler, gebelikten postpartum döneme kadar bakım sürekliliğini sağlayan temel sağlık profesyonelleri olarak emzirmenin korunması, teşvik edilmesi ve sürdürülmesinde stratejik bir konuma sahiptir. Kanıta dayalı, kadın merkezli ve bireyselleştirilmiş ebe liderliğinde bakım modellerinin rutin klinik uygulamalara ve sağlık politikalarına sistematik biçimde entegre edilmesi; emzirme sonuçlarının iyileştirilmesini destekleyecek, anne ve bebek sağlığının geliştirilmesine katkı sağlayacak ve sürdürülebilir anne-çocuk sağlığı hizmetlerinin güçlendirilmesinde önemli bir rol oynayacaktır.

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MIDWIFE-LED PREVENTION OF ALCOHOL USE DURING PREGNANCY: SCREENING, BRIEF INTERVENTION, AND EVIDENCE-BASED CLINICAL APPROACHES

GEBELİKTE ALKOL KULLANIMININ ÖNLENMESİNDE EBE LİDERLİĞİ: TARAMA, KISA MÜDAHALE VE KANITA DAYALI KLİNİK YAKLAŞIMLAR

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ÖZET

Giriş ve Amaç: Gebelikte alkol kullanımı, anne, fetüs ve yenidoğan sağlığını olumsuz etkileyen en önemli önlenebilir risk faktörlerinden biridir. Prenatal alkol maruziyeti, fetal alkol spektrum bozuklukları başta olmak üzere yaşam boyu sürebilen nörogelişimsel, bilişsel ve davranışsal sorunlara yol açabilmektedir. Bu derlemenin amacı, güncel kanıtlar doğrultusunda gebelikte alkol kullanımının önlenmesinde ebe liderliğinde yürütülen tarama, kısa müdahale, danışmanlık ve kanıta dayalı klinik yaklaşımları değerlendirmektir.

Gereç ve Yöntem: Bu derleme, 2025–2026 yıllarında yayımlanan güncel uluslararası literatür doğrultusunda hazırlanmıştır. Prenatal alkol maruziyeti, fetal alkol spektrum bozuklukları, alkol taraması, SBIRT yaklaşımı, ebelik bakımı ve eğitim uygulamalarına ilişkin araştırmalar, sistematik derlemeler ve güncel kanıtlar bütüncül olarak incelenmiştir.

Bulgular: Literatür, prenatal alkol maruziyetinin önlenmesinde evrensel tarama, SBIRT yaklaşımı, kadın merkezli danışmanlık ve uygun yönlendirmenin etkili olduğunu göstermektedir. Buna karşın damgalanma, alkol kullanımının gizlenmesi, sağlık profesyonellerinin bilgi ve beceri eksiklikleri ile sistem temelli engeller bu uygulamaların yaygınlaştırılmasını sınırlandırmaktadır. Yapılandırılmış eğitim programları ve ebe liderliğinde yürütülen kanıta dayalı bakım modellerinin klinik yeterliliği ve bakım kalitesini artırdığı bildirilmektedir.

Tartışma ve Sonuç: Prenatal alkol maruziyetinin önlenmesi; sistematik tarama, kısa müdahale, etkili danışmanlık, disiplinler arası iş birliği ve güçlü eğitim programlarını içeren bütüncül bir yaklaşım gerektirmektedir. Ebeler, gebelik öncesinden doğum sonrasına kadar kadınlarla kurdukları sürekli iletişim sayesinde bu sürecin temel yürütücüleridir. Kanıta dayalı uygulamaların rutin prenatal bakıma entegrasyonu, prenatal alkol maruziyetinin azaltılmasına ve anne ile çocuk sağlığının geliştirilmesine önemli katkılar sağlayacaktır.

Anahtar Kelimeler: Gebelik; Alkol Kullanımı; Prenatal Alkol Maruziyeti; Ebelik; SBIRT; Fetal Alkol Spektrum Bozuklukları.

ABSTRACT

Introduction and Purpose: Alcohol use during pregnancy is one of the most important preventable risk factors adversely affecting maternal, fetal, and neonatal health. Prenatal alcohol exposure can lead to lifelong neurodevelopmental, cognitive, and behavioral impairments, particularly fetal alcohol spectrum disorders (FASDs). This review aimed to evaluate midwife-led screening, brief intervention,

counseling, and evidence-based clinical approaches for preventing alcohol use during pregnancy in light of current evidence.

Materials and Methods: This review was prepared based on the current international literature published between 2025 and 2026. Studies, systematic reviews, and recent evidence addressing prenatal alcohol exposure, fetal alcohol spectrum disorders, alcohol screening, the SBIRT approach, midwifery care, and educational interventions were comprehensively reviewed.

Results: Current evidence indicates that universal screening, the SBIRT approach, woman-centered counseling, and timely referral are effective strategies for preventing prenatal alcohol exposure. However, stigma, concealment of alcohol use, insufficient knowledge and skills among healthcare professionals, and health system–related barriers limit the implementation of these interventions. Structured educational programs and evidence-based midwife-led care models have been shown to improve clinical competency and the quality of care.

Discussion and Conclusion: Preventing prenatal alcohol exposure requires a comprehensive approach that integrates systematic screening, brief intervention, effective counseling, interdisciplinary collaboration, and robust educational programs. Midwives play a pivotal role in this process through their continuous contact with women from the preconception period to the postpartum period. Integrating evidence-based practices into routine prenatal care may substantially reduce prenatal alcohol exposure and improve maternal and child health outcomes.

Key Words: Pregnancy; Alcohol Use; Prenatal Alcohol Exposure; Midwifery; SBIRT; Fetal Alcohol Spectrum Disorders.

GİRİŞ

Gebelikte alkol kullanımı, maternal, fetal ve yenidoğan sağlığını olumsuz etkileyen en önemli önlenebilir risk faktörlerinden biri olarak kabul edilmektedir. Prenatal alkol maruziyeti, fetal alkol spektrum bozukluklarının (Fetal Alcohol Spectrum Disorders, FASD) tek önlenebilir nedeni olması nedeniyle yalnızca gebelik ve doğum sürecini değil, çocukluk ve erişkin döneme uzanan nörogelişimsel, bilişsel ve davranışsal sonuçları da etkileyen önemli bir halk sağlığı sorunudur.[1] Prenatal alkol maruziyetine bağlı gelişebilen büyüme geriliği, doğumsal anomaliler, öğrenme güçlükleri, yürütücü işlev bozuklukları ve sosyal uyum sorunları birey, aile ve sağlık sistemi üzerinde uzun dönemli bir yük oluşturmaktadır.[2] Bu nedenle güncel uluslararası yaklaşımlar, gebelikte güvenli olduğu kanıtlanmış herhangi bir alkol tüketim düzeyinin bulunmadığını vurgulamakta ve gebelik planlayan ya da gebe olan kadınlarda alkol kullanımından tamamen kaçınılmasını önermektedir.[2]

Prenatal alkol maruziyetinin önlenmesine yönelik farkındalık son yıllarda artmış olmasına rağmen, alkol kullanımının erken tanılanması ve yönetimi klinik uygulamalarda hâlen önemli güçlükler içermektedir. Gebelikte alkol kullanımı; damgalanma korkusu, suçluluk duygusu ve olumsuz yargılanma endişesi nedeniyle çoğu zaman sağlık profesyonellerine eksik bildirilebilmekte, bu durum erken tanılama ve müdahale fırsatlarının kaçırılmasına neden olmaktadır.[3,4] Ayrıca kadınların, özellikle gebeliğin fark edilmediği erken dönemde gerçekleşen alkol tüketimine ilişkin bilgi arayışında sıklıkla çevrim içi platformlara yöneldikleri, ancak bu ortamlarda bilimsel kanıtlarla uyumlu olmayan bilgilerin yaygın olduğu bildirilmektedir.[5] Bu bulgular, prenatal alkol maruziyetinin önlenmesinde güvenilir sağlık danışmanlığının ve kanıta dayalı bilgilendirmenin önemini ortaya koymaktadır.

Güncel çalışmalar, gebelikte alkol kullanımının sağlık profesyonelleri tarafından yeterince sistematik biçimde ele alınmadığını göstermektedir. Almanya'da kadın doğum uzmanları, ebeler ve bağımlılık uzmanlarıyla yürütülen araştırmada kadın doğum uzmanlarının %14'ünün, ebelerin %28'inin ve bağımlılık uzmanlarının %15'inin gebelere rutin olarak alkol kullanımı hakkında soru sormadığı belirlenmiştir.[2] Aynı çalışmada obstetrik bakım profesyonellerinin prenatal alkol maruziyeti ve FASD konusunda bağımlılık uzmanlarına göre daha sınırlı düzeyde danışmanlık ve eğitim verdikleri gösterilmiştir.[2] Benzer şekilde doğum bakım profesyonelleriyle gerçekleştirilen ulusal bir araştırmada katılımcıların yarısından fazlası gebelikte sağlık davranışlarının yönetimi konusunda ek eğitime gereksinim duyduklarını ifade etmiş, zaman yetersizliğini etkili danışmanlığın önündeki temel engellerden biri olarak belirtmiştir.[6] Bu bulgular, prenatal alkol maruziyetinin önlenmesinde yalnızca

farkındalığın artırılmasının yeterli olmadığını; sağlık profesyonellerinin bilgi, beceri ve iletişim yetkinliklerinin de güçlendirilmesi gerektiğini göstermektedir.

Gebelikte alkol kullanımının önlenmesinde tarama ve kısa müdahale uygulamaları, riskli kadınların erken dönemde belirlenmesini ve davranış değişikliğinin desteklenmesini sağlayan temel girişimler arasında yer almaktadır. Kanıta dayalı çalışmalar, alkol taraması ve kısa müdahale uygulamalarının gebelik ve postpartum dönemde alkol kullanımını azaltabildiğini ve prenatal alkol maruziyetinin önlenmesine katkı sağlayabildiğini göstermektedir.[1] Buna karşın bu uygulamaların kadın sağlığı hizmetlerinde ve birinci basamak sağlık kuruluşlarında istenilen düzeyde yaygınlaştırılamadığı bildirilmektedir.[1] Bu doğrultuda geliştirilen Screening, Brief Intervention and Referral to Treatment (SBIRT) yaklaşımı, tarama, kısa müdahale ve uygun tedavi hizmetlerine yönlendirme basamaklarını standartlaştırarak prenatal bakımın rutin bir parçası hâline getirilebilecek yapılandırılmış bir model sunmaktadır.[7]

Ebeler, gebelik öncesi dönemden başlayarak doğum sonrasına kadar kadınlarla sürekli iletişim hâlinde bulunan sağlık profesyonelleri olmaları nedeniyle prenatal alkol maruziyetinin önlenmesinde stratejik bir role sahiptir. Düzenli prenatal izlemler sırasında riskli alkol kullanımını erken belirleyebilme, bireyselleştirilmiş danışmanlık sunabilme, davranış değişikliğini destekleyebilme ve gerektiğinde uygun tedavi hizmetlerine yönlendirebilme özellikleri, ebeleri koruyucu anne-bebek sağlığı hizmetlerinin temel paydaşlarından biri hâline getirmektedir.[6] Bu nedenle ebe liderliğinde yürütülen bakımın yalnızca bilgi aktarımına dayanmaması; kadının özerkliğini, kimliğini, psikososyal gereksinimlerini ve sosyal destek sistemlerini dikkate alan kadın merkezli ve kanıta dayalı bir yaklaşımla planlanması gerekmektedir. Bu derlemede, güncel kanıtlar doğrultusunda gebelikte alkol kullanımının önlenmesinde ebe liderliğinde yürütülen tarama, kısa müdahale ve kanıta dayalı klinik yaklaşımlar ele alınmıştır.

GEBELİKTE ALKOL KULLANIMININ MATERNAL, FETAL VE YENİDOĞAN SAĞLIĞI AÇISINDAN ÖNEMİ

Alkol, plasentayı kolaylıkla geçerek fetüsün dolaşımına ulaşabilen ve gelişmekte olan organ sistemleri üzerinde doğrudan toksik etki gösteren güçlü bir teratojendir. Fetal karaciğerin alkol metabolizma kapasitesinin yetersiz olması nedeniyle alkol ve metabolitleri fetüs dolaşımında daha uzun süre kalmakta; bu durum hücresel proliferasyon, migrasyon, farklılaşma ve apoptozis süreçlerini olumsuz etkileyerek organogenezden nörogelişime kadar uzanan geniş bir biyolojik süreçte kalıcı hasarlara neden olabilmektedir.[2] Güncel kanıtlar, gebelikte güvenli olduğu gösterilmiş herhangi bir alkol tüketim düzeyinin bulunmadığını ve gebelik planlayan ya da gebe olan kadınlar için en güvenli yaklaşımın alkol kullanımından tamamen kaçınmak olduğunu vurgulamaktadır.[5,8] Bu nedenle prenatal alkol maruziyetinin önlenmesi, günümüzde koruyucu anne ve çocuk sağlığı hizmetlerinin temel önceliklerinden biri olarak kabul edilmektedir.[1]

Prenatal alkol maruziyeti gebeliğin tüm dönemlerinde maternal, fetal ve yenidoğan sağlığını olumsuz etkileyebilmektedir. Alkol kullanımının spontan abortus, fetal büyüme geriliği, preterm doğum, düşük doğum ağırlığı ve ölü doğum riskini artırdığı; ayrıca plasental fonksiyon bozukluğu ve fetal gelişim kısıtlılığı ile ilişkili olduğu bildirilmektedir.[2] Bununla birlikte oluşabilecek olumsuz sonuçların yalnızca tüketilen alkol miktarına bağlı olmadığı; maruziyet zamanı, tüketim sıklığı, binge drinking davranışı, maternal metabolizma, genetik yatkınlık ve eşlik eden çevresel faktörlerden de etkilendiği belirtilmektedir.[8] Bu nedenle gebelik boyunca düşük düzeyde olduğu düşünülen alkol tüketiminin dahi tamamen güvenli olduğu söylenememektedir.[1]

Prenatal alkol maruziyetinin en önemli sonuçlarından biri fetal alkol spektrum bozukluklarıdır (FASD). FASD; fetal alkol sendromu, parsiyel fetal alkol sendromu, alkol ilişkili nörogelişimsel bozukluklar ve prenatal alkol maruziyetine bağlı diğer klinik tabloları kapsayan geniş bir hastalık spektrumunu ifade etmektedir.[8] Bu bozukluklar yalnızca karakteristik kraniyofasiyal anomaliler ve büyüme geriliğiyle sınırlı kalmamakta; bilişsel performansta azalma, dikkat eksikliği, öğrenme güçlükleri, yürütücü işlev bozuklukları, davranış problemleri ve sosyal uyum güçlükleri gibi yaşam boyu sürebilen nörogelişimsel etkilerle de karakterize olmaktadır.[2] FASD'nin bireylerde yaşam boyu sağlık, eğitim ve sosyal hizmet

gereksinimini artırması, prenatal alkol maruziyetinin önlenmesini yalnızca obstetrik bakımın değil, toplum sağlığının da öncelikli hedeflerinden biri hâline getirmektedir.[1]

Prenatal alkol maruziyetinin önlenmesini güçleştiren önemli nedenlerden biri, alkol tüketiminin çoğu zaman gebeliğin henüz fark edilmediği erken dönemde gerçekleşmesidir. Kadınların önemli bir kısmı gebelik tanısı almadan önce alkol tüketmeye devam etmekte ve bu durum istemeden prenatal alkol maruziyetine neden olabilmektedir.[5] Çevrim içi platformlarda gerçekleştirilen tematik analizler, kadınların bu süreçte yoğun kaygı yaşadıklarını ve bilgi edinmek amacıyla sosyal medya ile internet forumlarına yöneldiklerini göstermektedir.[5] Bununla birlikte bu platformlarda yer alan içeriklerin önemli bir bölümünün bilimsel kanıtlarla uyumlu olmadığı, bazı paylaşımların prenatal alkol maruziyetinin risklerini olduğundan düşük gösterdiği belirlenmiştir.[5] Bu durum, gebelik öncesi danışmanlık hizmetlerinin ve güvenilir sağlık bilgisinin erişilebilir olmasının önemini ortaya koymaktadır.

Prenatal alkol maruziyetinin değerlendirilmesinde öz bildirime dayalı yöntemler önemli sınırlılıklar taşımaktadır. Alkol kullanımının damgalanma korkusu, suçluluk duygusu ve sosyal kabul kaygısı nedeniyle eksik bildirilebilmesi, hem klinik değerlendirmeyi hem de riskli gebelerin belirlenmesini güçleştirmektedir.[3] İskoçya'da yürütülen prospektif kohort çalışmasında gebelikte bildirilen alkol kullanımının çocukların 30 aylık gelişim sonuçlarıyla ilişkili olduğu gösterilmiş; araştırmacılar yalnızca öz bildirime dayalı değerlendirmenin yüksek riskli gebeleri belirlemede yetersiz kalabileceğini ve biyobelirteçlerin gelecekte tarama süreçlerini destekleyebileceğini vurgulamıştır.[3] Bununla birlikte biyobelirteçlerin klinik değerlendirme ve güvene dayalı görüşmenin yerine geçmediği, bu yöntemlerin birbirini tamamlayan yaklaşımlar olarak değerlendirilmesi gerektiği belirtilmektedir.[3]

Prenatal alkol maruziyetinin etkileri yalnızca biyolojik sonuçlarla sınırlı değildir; aynı zamanda kadınların sağlık hizmetlerinden yararlanma davranışlarını ve bakım süreçlerini de doğrudan etkilemektedir. Alkol kullanan gebeler, damgalanma ve yargılanma korkusu nedeniyle sağlık profesyonellerine doğru bilgi vermekten kaçınabilmekte, bu durum erken tanılama ve müdahale fırsatlarının kaçırılmasına neden olabilmektedir.[4] Güncel çalışmalar, damgalanmayı azaltan, güvene dayalı ve kadın merkezli bakım yaklaşımlarının kadınların sağlık hizmetlerine katılımını artırdığını ve alkol kullanımının daha doğru değerlendirilmesine katkı sağladığını göstermektedir.[4,6] Bu nedenle prenatal alkol maruziyetinin önlenmesi yalnızca fetal risklerin anlatıldığı bir danışmanlık süreci olarak değil; biyopsikososyal gereksinimleri dikkate alan, kadın merkezli ve kanıta dayalı ebelik bakımının ayrılmaz bir bileşeni olarak ele alınmalıdır. Bu yaklaşım aynı zamanda prenatal alkol kullanımının erken dönemde belirlenmesine yönelik tarama stratejilerinin ve yapılandırılmış müdahalelerin gerekliliğini de ortaya koymaktadır.

GEBELİKTE ALKOL KULLANIMININ ERKEN TANILANMASI: TARAMA YAKLAŞIMLARI

Gebelikte alkol kullanımının önlenmesinde en kritik basamaklardan biri, riskli alkol kullanımının mümkün olan en erken dönemde belirlenmesidir. Prenatal alkol maruziyeti çoğu zaman gebeliğin erken haftalarında, hatta gebelik fark edilmeden önce gerçekleştiğinden, yalnızca gebelik sürecinde ortaya çıkan klinik bulguların değerlendirilmesi yeterli olmamaktadır.[5] Bu nedenle güncel kanıtlar ve klinik öneriler, gebelik planlayan kadınlardan başlayarak tüm gebelerin rutin prenatal bakım sürecinde alkol kullanımı açısından sistematik olarak değerlendirilmesini önermektedir.[1,2] Erken tanılama, yalnızca mevcut alkol kullanımını belirlemeyi değil, aynı zamanda prenatal alkol maruziyetinin sürmesini önleyerek maternal ve fetal komplikasyonların azaltılmasını hedeflemektedir.

Buna karşın güncel çalışmalar, alkol taramasının klinik uygulamalarda istenilen düzeyde standartlaştırılamadığını göstermektedir. Almanya'da gerçekleştirilen çok merkezli araştırmada kadın doğum uzmanlarının %14'ünün, ebelerin %28'inin ve bağımlılık uzmanlarının %15'inin gebelere rutin olarak alkol kullanımı hakkında soru sormadığı bildirilmiştir.[2] Ayrıca obstetrik bakım profesyonellerinin önemli bir bölümünün alkol kullanımının fetal etkileri konusunda ayrıntılı danışmanlık vermediği ve özellikle düşük riskli olarak değerlendirilen kadınlarda taramanın daha sınırlı kaldığı belirtilmiştir.[2] Bu durum, prenatal alkol maruziyetinin yalnızca yüksek riskli gruplara özgü bir sorun olarak değerlendirilmesinin önemli tanılama fırsatlarının kaçırılmasına neden olabileceğini göstermektedir.

Gebelikte alkol kullanımının değerlendirilmesinde evrensel tarama yaklaşımı giderek daha fazla önem kazanmaktadır. Risk temelli tarama stratejileri yalnızca belirli özelliklere sahip kadınların değerlendirilmesine odaklandığından, alkol kullanımını gizleyen veya risk grubunda görünmeyen kadınların gözden kaçmasına neden olabilmektedir. Bu nedenle güncel yaklaşım, tüm gebelerin sosyodemografik özelliklerinden bağımsız olarak prenatal bakımın rutin bir parçası olarak alkol kullanımı açısından değerlendirilmesini önermektedir.[1,2] Evrensel tarama aynı zamanda damgalanmayı azaltmakta, kadınların kendilerini hedef alınmış hissetmesini önlemekte ve sağlık profesyonelleri açısından standart bakım uygulamalarını kolaylaştırmaktadır.[1]

Taramanın etkinliği yalnızca kullanılan değerlendirme aracıyla değil, görüşmenin yürütülme biçimiyle de yakından ilişkilidir. Kadının yargılanmayacağına inanması, mahremiyetinin korunacağına güven duyması ve bakım veren sağlık profesyoneliyle güvene dayalı bir ilişki kurabilmesi doğru bilgi paylaşımını kolaylaştırmaktadır. Buna karşın suçlanma, çocuk koruma hizmetlerine bildirilme korkusu veya sağlık çalışanlarının olumsuz tutumları kadınların alkol kullanımını gizlemelerine neden olabilmektedir.[4] Nijerya'da yürütülen nitel araştırmada gebelerin alkol ve madde kullanımını sağlık profesyonellerinden saklamalarının temel nedenleri arasında damgalanma korkusu, suçlanma endişesi, olumsuz bakım deneyimleri ve sağlık çalışanlarının yargılayıcı tutumları öne çıkmıştır.[4] Bu bulgular, tarama sürecinin yalnızca soru sormaktan ibaret olmadığını; etkili iletişim becerileri, güven oluşturan bir bakım ortamı ve kadın merkezli yaklaşımın taramanın ayrılmaz bileşenleri olduğunu göstermektedir.[6]

Benzer şekilde çevrim içi platformlarda yürütülen çalışmalar da kadınların resmi sağlık hizmetleri yerine internet ortamında güven arayışına yöneldiğini göstermektedir. Gebelik fark edilmeden önce alkol tüketen kadınların çevrim içi forumlarda sıklıkla diğer kullanıcıların deneyimlerine başvurduğu, ancak paylaşılan bilgilerin önemli bir bölümünün bilimsel kanıtlarla uyumlu olmadığı belirlenmiştir.[5] Yanlış veya eksik bilgiler, kadınların gerçek riskleri olduğundan düşük algılamalarına ya da tam tersine gereksiz kaygı yaşamalarına neden olabilmektedir.[5] Bu nedenle prenatal bakım sürecinde ebelerin güvenilir bilgi kaynağı olarak aktif rol üstlenmeleri, yanlış bilgilerin düzeltilmesi ve kadınların kanıta dayalı danışmanlığa yönlendirilmesi açısından büyük önem taşımaktadır.[5]

Tarama sürecinde öz bildirime dayalı değerlendirmelerin önemli sınırlılıkları bulunmaktadır. Alkol kullanımı sosyal olarak damgalanan bir davranış olduğundan kadınlar gerçek tüketim miktarını olduğundan daha düşük bildirebilmekte veya tamamen inkâr edebilmektedir.[3] İskoçya'da gerçekleştirilen geniş ölçekli kohort çalışması, gebelikte öz bildirilen alkol kullanımının çocukların erken gelişim sonuçlarıyla ilişkili olduğunu göstermekle birlikte, yalnızca öz bildirime dayalı taramanın yüksek riskli gebeleri belirlemede yeterli olmayabileceğini ortaya koymuştur.[3] Araştırmacılar, gelecekte objektif biyobelirteçlerin uygun klinik değerlendirmelerle birlikte kullanılmasının prenatal alkol maruziyetinin daha doğru belirlenmesine katkı sağlayabileceğini belirtmiştir.[3] Bununla birlikte biyobelirteçler, kapsamlı klinik görüşmenin yerini alan yöntemler olarak değil, gerekli durumlarda klinik karar verme sürecini destekleyen tamamlayıcı araçlar olarak değerlendirilmelidir.

Günümüzde prenatal alkol kullanımının erken tanılanmasında en kapsamlı modellerden biri Screening, Brief Intervention, and Referral to Treatment (SBIRT) yaklaşımıdır. SBIRT, alkol kullanımının sistematik olarak sorgulanmasını, risk düzeyinin belirlenmesini, uygun kısa müdahalenin uygulanmasını ve gerekli durumlarda bağımlılık tedavi hizmetlerine yönlendirilmesini kapsayan yapılandırılmış bir bakım modelidir.[7] Kadın sağlığı hizmetlerine özgü geliştirilen algoritmalar, bu yaklaşımın rutin klinik uygulamalara entegrasyonunu kolaylaştırmayı ve uygulamalar arasındaki farklılıkları azaltmayı amaçlamaktadır.[7] Bu nedenle prenatal alkol maruziyetinin önlenmesinde yalnızca riskin belirlenmesi değil, tarama sonrasında kanıta dayalı kısa müdahale ve uygun yönlendirme süreçlerinin de etkin biçimde yürütülmesi gerekmektedir.[1] Bu yaklaşım, ebe liderliğinde sunulan koruyucu bakımın temel bileşenlerinden birini oluşturmaktadır.

KISA MÜDAHALE, DANIŞMANLIK VE YÖNLENDİRME

Gebelikte alkol kullanımının erken dönemde belirlenmesi, tek başına prenatal alkol maruziyetini önlemek için yeterli değildir. Tarama sonrasında kadının risk düzeyine uygun danışmanlık hizmeti alması, davranış değişikliğinin desteklenmesi ve gerektiğinde uzman tedavi hizmetlerine

yönlendirilmesi etkili bir bakım sürecinin temel bileşenlerini oluşturmaktadır. Bu doğrultuda son yıllarda en yaygın kabul gören yaklaşım Screening, Brief Intervention, and Referral to Treatment (SBIRT) modelidir. SBIRT; sistematik tarama, bireyselleştirilmiş kısa müdahale ve uygun tedavi hizmetlerine yönlendirme basamaklarını içeren bütüncül bir bakım modeli olup, kadın sağlığı hizmetlerinde prenatal alkol maruziyetinin azaltılmasına yönelik en güçlü kanıta dayalı yaklaşımlardan biri olarak değerlendirilmektedir.[1,7]

SBIRT yaklaşımının temel amacı yalnızca alkol kullanımını belirlemek değil, kadının değişime hazır oluş düzeyini değerlendirerek davranış değişikliğini desteklemektir. Risk düzeyi düşük olan kadınlarda kısa eğitim ve koruyucu danışmanlık yeterli olabilirken, riskli alkol kullanımı saptanan gebelerde motivasyonel görüşme teknikleriyle desteklenen kısa müdahaleler önerilmektedir. Alkol kullanım bozukluğu düşünülen olgularda ise bağımlılık tedavi hizmetlerine zamanında yönlendirme yapılması gerekmektedir.[7] Bu yapılandırılmış yaklaşım, farklı klinik ortamlarda bakım standardizasyonunu artırırken sağlık profesyonellerinin karar verme sürecini de kolaylaştırmaktadır.

Kısa müdahale uygulamaları, birkaç dakikalık görüşmelerden oluşmasına rağmen davranış değişikliği üzerinde anlamlı etkiler oluşturabilmektedir. Özellikle gebelik döneminin kadınların yaşam tarzı değişikliklerine daha açık olduğu bir dönem olması, bu müdahalelerin etkinliğini artırmaktadır. Prenatal alkol maruziyetinin önlenmesine yönelik güncel değerlendirmeler, kısa müdahale uygulamalarının gebelik ve postpartum dönemde alkol kullanımını azaltabildiğini ve bırakma oranlarını artırabildiğini göstermektedir.[1] Bununla birlikte etkili müdahalelerin ortak özelliklerinin tek seferlik bilgi vermekten ziyade tekrar eden görüşmeler, bireyselleştirilmiş danışmanlık ve bakımın sürekliliğini içermesi olduğu vurgulanmaktadır.[1]

Davranış değişikliğini destekleyen danışmanlık sürecinde iletişim biçimi, en az verilen bilginin içeriği kadar önemlidir. Gebelikte alkol kullanan kadınların önemli bir bölümü suçlanmaktan veya kötü anne olarak değerlendirilmekten çekindikleri için gerçek tüketim miktarını paylaşmamaktadır.[4,5] Bu nedenle kısa müdahalelerin yargılayıcı olmayan, empatik ve kadın merkezli bir iletişim anlayışıyla yürütülmesi önerilmektedir. Kadının mevcut yaşam koşullarını, sosyal desteğini ve bireysel gereksinimlerini dikkate alan görüşmelerin, yalnızca alkol kullanımını sorgulayan standart yaklaşımlara göre daha başarılı olduğu bildirilmektedir.[6] Ayrıca güvene dayalı terapötik ilişkinin kurulması, kadınların alkol kullanımını daha açık biçimde paylaşmalarını kolaylaştırarak müdahalenin etkinliğini artırmaktadır.[4]

Güncel kanıtlar, danışmanlığın yalnızca biyomedikal risklerin açıklanmasına odaklanmasının yeterli olmadığını göstermektedir. Kadının davranış değişikliğini sürdürebilmesi için özerkliğinin desteklenmesi, kendi kararlarını verebildiğini hissetmesi ve bakım sürecine aktif katılımının sağlanması gerekmektedir. Hollanda'da doğum bakım profesyonelleriyle gerçekleştirilen çalışmada katılımcıların büyük çoğunluğu, sağlık davranışlarının görüşülmesinde kadının özerkliğine (%91) ve bireysel kimliğine (%83) önem verilmesi gerektiğini belirtmiştir. Bununla birlikte zaman yetersizliği ve eğitim eksikliği, bu yaklaşımın klinik uygulamaya yansıtılmasındaki en önemli engeller arasında gösterilmiştir.[6] Bu bulgular, kısa müdahalenin yalnızca standart öneriler sunan bir uygulama değil, kadının yaşam bağlamını merkeze alan bireyselleştirilmiş bir danışmanlık süreci olması gerektiğini ortaya koymaktadır.

Danışmanlık sürecinde aile ve sosyal çevrenin de dikkate alınması önem taşımaktadır. Sağlık davranışlarının sürdürülmesinde partner desteği, aile içi iletişim ve sosyal destek sistemleri önemli belirleyiciler arasında yer almaktadır. Bununla birlikte doğum bakım profesyonellerinin partnerlerin sağlık davranışlarını değerlendirme ve danışmanlık verme oranlarının kadınlara göre daha düşük olduğu bildirilmektedir.[6] Benzer şekilde aile temelli bağımlılık hizmetlerinde yürütülen nitel araştırmalar, güvene dayalı destek ilişkilerinin yalnızca hizmet alan birey için değil, tüm aile sistemi açısından da iyileştirici etkiler oluşturduğunu göstermektedir.[9] Bu nedenle prenatal alkol maruziyetinin önlenmesine yönelik danışmanlık hizmetlerinin, uygun durumlarda partneri ve aileyi de kapsayan bütüncül bir yaklaşımla planlanması önerilmektedir.

Kısa müdahalenin başarısı, sağlık profesyonellerinin bilgi ve iletişim becerileriyle de yakından ilişkilidir. Prenatal alkol maruziyeti konusunda yeterli eğitim almayan sağlık çalışanlarının alkol kullanımını sorgulama, risk değerlendirmesi yapma ve danışmanlık verme konusunda daha çekingen davrandıkları bildirilmektedir.[2] Buna karşılık Healthcare Champion modeli, sağlık profesyonellerinin

eğitimini güçlendirerek tarama ve kısa müdahale uygulamalarının yaygınlaştırılabileceğini göstermiştir. Model kapsamında kadın hastalıkları ve doğum, pediatri, aile hekimliği, hemşirelik-ebelik ve diğer sağlık disiplinlerinden binlerce klinisyene eğitim verilmiş; prenatal alkol maruziyetinin önlenmesine yönelik bilgi, farkındalık ve klinik uygulama becerilerinin artırılabileceği ortaya konulmuştur.[1]

Tüm bu bulgular birlikte değerlendirildiğinde, gebelikte alkol kullanımının önlenmesinde kısa müdahale ve danışmanlık uygulamalarının yalnızca standart bilgi aktarımından ibaret olmadığı görülmektedir. Etkili bir müdahale; sistematik tarama ile başlayan, kadın merkezli iletişim teknikleriyle sürdürülen, davranış değişikliğini destekleyen, aile ve sosyal çevreyi dikkate alan ve gerektiğinde uygun sağlık hizmetlerine yönlendirmeyle tamamlanan bütüncül bir bakım sürecini gerektirmektedir. Bu sürecin en önemli yürütücülerinden biri ise gebelik boyunca kadınlarla sürekli iletişim kuran ve koruyucu sağlık hizmetlerinde aktif rol üstlenen ebelerdir. Bu nedenle prenatal alkol maruziyetinin önlenmesinde ebe liderliğinde yürütülen kanıta dayalı klinik uygulamaların yaygınlaştırılması, hem prenatal alkol maruziyetinin azaltılması hem de anne ve çocuk sağlığının geliştirilmesi açısından büyük önem taşımaktadır.

EBE LİDERLİĞİNDE KANITA DAYALI KLİNİK YAKLAŞIM

Ebeler, gebelik öncesi dönemden başlayarak doğum ve doğum sonrasına kadar kadınlarla sürekli iletişim kuran sağlık profesyonelleri olmaları nedeniyle gebelikte alkol kullanımının önlenmesinde stratejik bir konuma sahiptir. Kadın merkezli bakım anlayışı, süreklilik temelli izlem ve koruyucu sağlık hizmetlerini birlikte yürütebilmeleri, ebelerin prenatal alkol maruziyetinin önlenmesinde yalnızca risk belirleyen değil, aynı zamanda davranış değişikliğini destekleyen ve bakım koordinasyonunu sağlayan temel profesyonellerden biri olmasını sağlamaktadır.[6] Bu nedenle güncel yaklaşımlar, gebelikte alkol kullanımının yönetiminde ebelerin yalnızca danışmanlık veren sağlık çalışanları olarak değil, kanıta dayalı uygulamaların liderleri olarak değerlendirilmesi gerektiğini vurgulamaktadır.[1]

Ebe liderliğinde yürütülen bakımın temelini kadın merkezli yaklaşım oluşturmaktadır. Bu yaklaşım, kadının yalnızca biyolojik risklerini değerlendirmeyi değil; psikososyal özelliklerini, yaşam koşullarını, sosyal destek sistemlerini, kültürel değerlerini ve bireysel gereksinimlerini birlikte ele almayı gerektirmektedir. Özellikle kırılgan koşullarda yaşayan gebelerde sağlık davranışlarının sürdürülebilir biçimde değiştirilebilmesi için bakımın bireyselleştirilmesi büyük önem taşımaktadır. Hollanda'da doğum bakım profesyonelleriyle gerçekleştirilen araştırmada katılımcıların büyük çoğunluğu, gebelikte sağlık davranışlarını değerlendirirken kadının kimliğinin ve özerkliğinin mutlaka dikkate alınması gerektiğini belirtmiş; davranış değişikliğinin ancak kadının karar verme sürecine aktif katılımıyla kalıcı olabileceği ifade edilmiştir.[6] Bu yaklaşım, ebe liderliğinde sunulan danışmanlık hizmetlerinin temel felsefesiyle uyumludur.

Gebelikte alkol kullanımının önlenmesinde etkili bakımın önemli bileşenlerinden biri güvene dayalı terapötik ilişkinin kurulmasıdır. Damgalanma korkusu yaşayan kadınların önemli bir kısmı sağlık profesyonellerine gerçek alkol kullanım öyküsünü açıklamaktan kaçınmaktadır.[4] Bu nedenle ebelerin yargılayıcı olmayan, empatik ve destekleyici iletişim becerilerini kullanmaları, güven ilişkisinin oluşturulmasında belirleyici rol oynamaktadır. Nijerya'da yürütülen nitel çalışmada kadınlar, suçlanacaklarını düşündüklerinde sağlık çalışanlarından bilgi sakladıklarını; buna karşılık saygılı ve destekleyici iletişim kuran profesyonellere alkol kullanımlarını açıklamaya daha istekli olduklarını ifade etmişlerdir.[4] Bu bulgular, etkili danışmanlığın yalnızca bilimsel bilgiye değil, aynı zamanda iletişim kalitesine de bağlı olduğunu göstermektedir. Güvene dayalı iletişim, kadınların prenatal bakım sürecine katılımını güçlendirerek erken tanılama ve kısa müdahalenin etkinliğini artırmaktadır.[6]

Kadınların prenatal bakım sürecinde alkol kullanımını açıklama davranışını etkileyen faktörlerden biri de sağlık profesyonellerinin yaklaşımıdır. Almanya'da gerçekleştirilen çalışmada obstetrik bakım profesyonellerinin önemli bir bölümünün gebelikte alkol kullanımı konusunda ayrıntılı danışmanlık vermediği ve rutin tarama uygulamalarını yeterince gerçekleştirmediği gösterilmiştir.[2] Bu durum yalnızca bilgi eksikliğinden değil, aynı zamanda iletişim konusunda yaşanan çekingenlikten de kaynaklanabilmektedir. Bu nedenle ebe liderliğinde yürütülen bakımın önemli hedeflerinden biri, alkol kullanımını prenatal izlemin doğal bir bileşeni hâline getirmektir. Alkol kullanımının tüm gebelerde

standart olarak sorgulanması, kadınların kendilerini hedef alınmış hissetmelerini önlemekte, damgalanmayı azaltmakta ve evrensel tarama yaklaşımını desteklemektedir.[1,2]

Kanıta dayalı klinik yaklaşımın sürdürülebilir biçimde uygulanabilmesi için ebelerin bilgi ve klinik yeterliliklerinin sürekli güncellenmesi gerekmektedir. İran'da gerçekleştirilen randomize kontrollü çalışmada, madde bağımlısı gebelerin doğum ve postpartum bakımına yönelik dört haftalık e-öğrenme programına katılan ebelerin hem bilgi düzeylerinde hem de klinik becerilerinde anlamlı gelişme sağlandığı gösterilmiştir. Müdahale sonrasında elde edilen kazanımların bir ay sonra da büyük ölçüde korunduğu bildirilmiştir.[10] Bu sonuçlar, yapılandırılmış eğitim programlarının ebelerin kanıta dayalı bakım uygulamalarını güçlendirebileceğini göstermektedir.

Benzer şekilde Amerika Birleşik Devletleri'nde yürütülen çalışmalar, ebelik eğitim programlarında prenatal madde kullanımına ilişkin teorik eğitimin yaygın olmasına rağmen klinik uygulama fırsatlarının sınırlı olduğunu ortaya koymaktadır. Program yöneticileri özellikle bağımlılık alanında deneyimli klinik eğitici eksikliği, müfredat yoğunluğu ve klinik uygulama alanlarının yetersizliğini temel engeller olarak bildirmiştir.[11] Buna karşılık yenilikçi eğitim modelleri; çevrim içi öğrenme, toplum temelli klinik uygulamalar, disiplinler arası iş birlikleri ve deneyim temelli eğitim yöntemlerinin geleceğin ebelerini prenatal bağımlılık yönetimine daha iyi hazırlayabileceğini göstermektedir.[12] Bu bulgular, ebe liderliğinde sunulan bakımın niteliğinin yalnızca bireysel deneyime değil, güçlü lisans ve mezuniyet sonrası eğitim programlarına da bağlı olduğunu göstermektedir.

Gebelikte alkol kullanımının önlenmesinde sağlık sisteminin tüm bileşenlerinin birlikte çalışması gerekmektedir. Bu kapsamda geliştirilen Healthcare Champion modeli, farklı sağlık disiplinlerinde görev yapan profesyonellerin prenatal alkol maruziyetinin önlenmesi konusunda eğitilmesini ve kendi kurumlarında değişim lideri olarak görev almalarını amaçlamaktadır. Model kapsamında kadın hastalıkları ve doğum, pediatri, aile hekimliği, hemşirelik-ebelik, sosyal hizmet ve diğer sağlık alanlarında binlerce klinisyen eğitilmiş; alkol taraması ve kısa müdahale uygulamalarının yaygınlaştırılmasına önemli katkılar sağlanmıştır.[1] Ebelerin bu model içerisinde aktif rol almaları, hem klinik uygulamaların standartlaştırılması hem de disiplinler arası iş birliğinin güçlendirilmesi açısından önemli görülmektedir.

Ebe liderliğinde yürütülen kanıta dayalı klinik yaklaşım; evrensel tarama, kadın merkezli iletişim, bireyselleştirilmiş danışmanlık, davranış değişikliğinin desteklenmesi, aile katılımı, uygun yönlendirme ve bakım sürekliliğini bir araya getiren bütüncül bir bakım modelidir. Bu modelin etkin biçimde uygulanabilmesi ise yalnızca bireysel klinik deneyime değil, sağlık profesyonellerinin eğitimine, kurumsal desteğe ve damgalamayı azaltan sağlık sistemi politikalarına bağlıdır. Bununla birlikte prenatal alkol maruziyetinin önlenmesinde önemli güçlüklerden biri, kadınların alkol kullanımını açıklamalarını engelleyen damgalanma, yanlış bilgilendirme ve bakım süreçlerinde karşılaşılan yapısal engellerdir. Bu nedenle ebe liderliğinde sunulan bakımın bu engelleri de kapsayacak biçimde değerlendirilmesi gerekmektedir.

DAMGALANMA, GİZLEME DAVRANIŞI VE BAKIM ENGELLERİ

Gebelikte alkol kullanımının önlenmesine yönelik girişimlerin başarısı yalnızca etkili tarama ve danışmanlık uygulamalarına bağlı değildir. Kadınların sağlık hizmetlerine başvurma davranışları, alkol kullanımını açıklama istekleri ve önerilen müdahaleleri kabul etme düzeyleri; bireysel, toplumsal ve sağlık sistemi kaynaklı birçok faktörden etkilenmektedir. Bu faktörlerin başında damgalanma, suçlanma korkusu, yanlış bilgilendirme, sağlık profesyonellerinin tutumları ve sağlık hizmetlerine erişimde yaşanan güçlükler gelmektedir. Güncel kanıtlar, bu engellerin prenatal alkol maruziyetinin erken belirlenmesini geciktirdiğini ve koruyucu sağlık hizmetlerinin etkinliğini azalttığını göstermektedir.[3,4]

Damgalanma, gebelikte alkol kullanımının yönetiminde en önemli bakım engellerinden biri olarak kabul edilmektedir. Toplumsal beklentiler doğrultusunda gebelik döneminde alkol kullanan kadınların sıklıkla "kötü anne" olarak değerlendirilmesi, yoğun suçluluk ve utanç duygularına neden olabilmektedir. Bu durum kadınların sağlık profesyonelleriyle açık iletişim kurmalarını güçleştirmekte ve gerçek alkol kullanım öyküsünü gizlemelerine yol açmaktadır.[4] Nijerya'da yürütülen nitel araştırmada gebeler, alkol veya madde kullandıklarını açıklamaları hâlinde sağlık çalışanları tarafından yargılanacaklarını, sosyal

çevreleri tarafından dışlanacaklarını ve hatta çocuklarının ellerinden alınabileceğinden endişe duyduklarını ifade etmişlerdir.[4] Bu bulgular, damgalanmanın yalnızca psikolojik değil, bakım hizmetlerine erişimi doğrudan etkileyen önemli bir halk sağlığı sorunu olduğunu göstermektedir.

Damgalanmanın bir diğer sonucu, kadınların riskli davranışlarını sağlık profesyonellerinden gizlemeleridir. Klinik uygulamalarda alkol kullanımının değerlendirilmesi büyük ölçüde öz bildirime dayandığından, eksik veya yanlış bilgi verilmesi prenatal alkol maruziyetinin belirlenmesini güçleştirmektedir. İskoçya'da yürütülen prospektif kohort çalışmasında araştırmacılar, gebelikte öz bildirilen alkol kullanımının çocukların gelişimsel sonuçlarıyla ilişkili olduğunu göstermekle birlikte, gerçek tüketimin öz bildirimlerle tam olarak yansıtılamayabileceğini ve bu nedenle yüksek riskli gebelerin gözden kaçabileceğini belirtmişlerdir.[3] Bu durum, güvene dayalı iletişim kurulmadığı sürece yalnızca standart tarama uygulamalarının yeterli olmayacağını ortaya koymaktadır.

Sağlık profesyonellerinin iletişim biçimi de kadınların bakım sürecine katılımını önemli ölçüde etkilemektedir. Yargılayıcı ifadeler, korkutucu söylemler veya cezalandırıcı yaklaşımlar kadınların sağlık hizmetlerinden uzaklaşmasına neden olabilmektedir. Buna karşılık empati temelli, kadın merkezli ve destekleyici iletişim anlayışının hem doğru bilgi paylaşımını hem de davranış değişikliğini kolaylaştırdığı bildirilmektedir.[6] Bu nedenle ebelerin iletişim becerileri yalnızca danışmanlığın kalitesini değil, prenatal alkol maruziyetinin erken tanılanmasını da doğrudan etkileyen önemli bir klinik yeterlilik alanıdır.[4]

Damgalanmayı güçlendiren faktörlerden biri de toplumda ve dijital ortamlarda dolaşan yanlış bilgilerdir. Gebelik fark edilmeden önce alkol tüketen kadınların önemli bir kısmının sağlık kuruluşlarına başvurmak yerine internet forumlarından bilgi edinmeye çalıştığı gösterilmiştir.[5] Ancak bu platformlarda yer alan içeriklerin önemli bir bölümünün bilimsel kanıtlarla uyumlu olmadığı, bazı paylaşımların düşük düzeyde alkol kullanımının güvenli olduğu yönünde yanlış mesajlar içerdiği, bazılarının ise gerçek risk düzeyini olduğundan fazla göstererek gereksiz kaygıya neden olduğu belirlenmiştir.[5] Bilimsel doğruluğu olmayan bu bilgilerin yaygınlaşması, kadınların sağlık profesyonellerinden danışmanlık alma davranışını olumsuz etkileyebilmekte ve kanıta dayalı bakımın etkinliğini azaltabilmektedir. Bu durum, prenatal bakım sürecinde güvenilir ve kanıta dayalı bilgilendirmenin önemini artırmaktadır.[5]

Bakım sürecindeki önemli engellerden biri de sağlık profesyonellerinin bilgi ve özgüven eksikliğidir. Almanya'da yürütülen araştırmada bazı kadın doğum uzmanları ve ebelerin prenatal alkol maruziyeti konusunda rutin tarama yapmadıkları, ayrıntılı danışmanlık vermedikleri ve FASD hakkında yeterli bilgiye sahip olmadıkları gösterilmiştir.[2] Benzer şekilde Hollanda'da doğum bakım profesyonellerinin yarısından fazlası gebelikte sağlık davranışlarının yönetimi konusunda ek eğitime gereksinim duyduklarını ifade etmiş, önemli bir bölümü ise mevcut eğitimlerinin yetersiz olduğunu belirtmiştir.[6] Bu bulgular, bakım engellerinin yalnızca kadınlardan değil, sağlık sisteminin eğitim ve organizasyon yapısından da kaynaklandığını göstermektedir.

Kurumsal ve örgütsel faktörler de bakımın niteliğini etkileyen önemli belirleyiciler arasındadır. Sağlık profesyonellerinin yoğun iş yükü, zaman kısıtlılığı, standart bakım protokollerinin bulunmaması ve disiplinler arası koordinasyon eksikliği, prenatal alkol maruziyetine yönelik müdahalelerin sürekliliğini olumsuz etkileyebilmektedir.[6] Buna ek olarak sağlık çalışanlarında iş stresi, tükenmişlik ve travmatik deneyimlerin riskli alkol kullanımıyla ilişkili olduğu; güçlü örgütsel desteğin ise profesyonel işlevselliği olumlu yönde etkilediği bildirilmektedir.[13,14] Dolayısıyla prenatal alkol maruziyetinin önlenmesine yönelik etkili bir sistem oluşturulabilmesi için yalnızca gebelerin değil, bakım veren sağlık profesyonellerinin de desteklenmesi gerekmektedir.

Bu sorunların çözümünde disiplinler arası iş birliği ve aile merkezli bakım anlayışı önemli bir yer tutmaktadır. Aile destek modellerini inceleyen çalışmalar, güvene dayalı profesyonel ilişkilerin yalnızca hizmet alan bireyin değil, tüm aile sisteminin iyilik hâlini güçlendirdiğini göstermektedir.[9] Benzer şekilde Healthcare Champion modeli, damgalanmayı azaltan eğitimlerin, sağlık profesyonellerinin bilgi düzeyini artırmanın ve kurumlar arası iş birliğini güçlendirmenin prenatal alkol maruziyetinin önlenmesinde önemli katkılar sağlayabileceğini ortaya koymuştur.[1] Bu nedenle ebe liderliğinde yürütülen bakımın yalnızca bireysel danışmanlıkla sınırlı kalmaması; eğitim, kurumsal politika, ekip iş

birliği ve toplum temelli farkındalık çalışmalarını kapsayan çok düzeyli bir yaklaşımla planlanması gerekmektedir.

Prenatal alkol maruziyetinin önlenmesinde damgalanmanın azaltılması, güvene dayalı bakım ilişkilerinin geliştirilmesi ve sistem kaynaklı engellerin ortadan kaldırılması, tarama ve danışmanlık uygulamalarının etkinliğini artıracak temel unsurlar arasındadır. Bu doğrultuda ebe liderliğinde sunulan bakımın sürdürülebilirliğinin sağlanabilmesi için sağlık profesyonellerinin bilgi ve becerilerinin güçlendirilmesi, eğitim programlarının güncellenmesi ve sağlık sistemi düzeyinde destekleyici politikaların geliştirilmesi gerekmektedir. Bu gereksinimler, prenatal alkol kullanımının önlenmesine yönelik gelecekteki uygulama ve politika önerilerine yön verecek temel bileşenleri oluşturmaktadır.

EĞİTİM, KLİNİK YETERLİLİK VE SİSTEM TEMELLİ GEREKSİNİMLER

Gebelikte alkol kullanımının önlenmesine yönelik kanıta dayalı uygulamaların sürdürülebilirliği, sağlık profesyonellerinin bireysel bilgi ve becerilerinin yanı sıra bu uygulamaları destekleyen eğitim sistemleri, kurumsal politikalar ve sağlık hizmeti organizasyonuyla doğrudan ilişkilidir. Prenatal alkol maruziyetinin önlenmesi yalnızca riskli gebelerin belirlenmesini değil; tarama, kısa müdahale, etkili danışmanlık, uygun yönlendirme ve bakımın sürekliliğini içeren çok bileşenli bir yaklaşımı gerektirmektedir. Bu nedenle ebe liderliğinde sunulan bakımın etkinliği, mezuniyet öncesinden başlayarak yaşam boyu öğrenme anlayışıyla desteklenen kapsamlı eğitim programlarının varlığına bağlıdır.[10,1]

Güncel çalışmalar, birçok ebe ve diğer doğum bakım profesyonelinin prenatal alkol maruziyeti konusunda eğitim gereksinimi duyduğunu göstermektedir. Hollanda'da gerçekleştirilen ulusal araştırmada doğum bakım profesyonellerinin %57'si gebelikte sağlık davranışlarının yönetimi konusunda ek bilgiye ihtiyaç duyduğunu, %53'ü ise mevcut eğitimlerinin bu alanda yeterli olmadığını ifade etmiştir.[6] Katılımcılar özellikle kronik stres, davranış değişikliği danışmanlığı ve kırılgan koşullarda yaşayan gebelerle etkili iletişim konularında kendilerini yetersiz hissettiklerini bildirmiştir.[6] Bu bulgular, yalnızca prenatal alkol maruziyetine ilişkin bilgi aktarımının değil, davranış değişikliği danışmanlığı ve iletişim becerilerinin de eğitim programlarının ayrılmaz bir parçası olması gerektiğini göstermektedir.

Ebelerin klinik yeterliliklerinin geliştirilmesinde yapılandırılmış eğitim programlarının etkili olduğu gösterilmiştir. Heidarian ve arkadaşlarının gerçekleştirdiği randomize kontrollü çalışmada, madde bağımlılığı bulunan gebelerin intrapartum ve postpartum bakımına yönelik dört haftalık e-öğrenme programına katılan ebelerin bilgi düzeylerinde ve klinik beceri performanslarında kontrol grubuna göre anlamlı artış sağlanmıştır. Müdahale sonrasında bilgi düzeyinde zamanla sınırlı bir azalma görülmesine rağmen klinik becerilerin büyük ölçüde korunduğu bildirilmiştir.[10] Bu sonuçlar, dijital eğitim modellerinin yalnızca teorik bilgi kazandırmakla kalmayıp klinik karar verme süreçlerini de güçlendirebildiğini göstermektedir.

Prenatal alkol maruziyetinin önlenmesine yönelik eğitim gereksinimi yalnızca hizmet sunan profesyonellerle sınırlı değildir. Amerika Birleşik Devletleri'nde ebelik eğitim programları üzerinde gerçekleştirilen değerlendirmelerde, müfredatlarda madde kullanımıyla ilişkili temel kavramlara yer verilmesine rağmen uygulamalı eğitim olanaklarının yetersiz olduğu belirlenmiştir. Program yöneticileri; klinik uygulama alanlarının sınırlı olması, bağımlılık konusunda deneyimli eğiticilerin azlığı ve yoğun müfredat nedeniyle öğrencilerin bu alanda yeterli deneyim kazanamadıklarını ifade etmiştir.[12] Bu nedenle prenatal alkol maruziyetinin önlenmesine yönelik eğitimlerin yalnızca teorik derslerden oluşmaması; simülasyon uygulamaları, vaka temelli öğrenme, disiplinler arası eğitim ve toplum temelli klinik deneyimlerle desteklenmesi önerilmektedir.[12] Bu yaklaşımın mezuniyet sonrası sürekli mesleki gelişim programlarıyla desteklenmesi de kanıta dayalı bakımın sürdürülebilirliği açısından önem taşımaktadır.[10]

Eğitim süreçlerinin yanı sıra sağlık sisteminin organizasyonu da prenatal alkol kullanımının önlenmesinde belirleyici bir rol üstlenmektedir. Tarama uygulamalarının standart bakım protokollerine entegre edilmesi, kayıt sistemlerinin güçlendirilmesi, yönlendirme mekanizmalarının açık biçimde tanımlanması ve disiplinler arası iletişimin güçlendirilmesi bakımın sürekliliğini artırmaktadır.[7] Buna

karşın standart uygulamaların bulunmadığı sağlık sistemlerinde tarama sıklığının azaldığı, kısa müdahalelerin düzensiz uygulandığı ve yüksek riskli gebelerin uygun hizmetlere yönlendirilmesinde gecikmeler yaşanabildiği bildirilmektedir.[2] Bu bulgular, kurumsal standartların geliştirilmesinin klinik uygulamaların başarısı açısından kritik olduğunu göstermektedir.

Bu kapsamda geliştirilen Healthcare Champion modeli, prenatal alkol maruziyetinin önlenmesinde sistem temelli yaklaşımın başarılı örneklerinden biridir. Model, kadın hastalıkları ve doğum, pediatri, aile hekimliği, hemşirelik-ebelik, sosyal hizmet ve diğer sağlık disiplinlerinde görev yapan profesyonellerin kendi kurumlarında değişim lideri olarak yetiştirilmesini hedeflemektedir. Program kapsamında 2018-2022 yılları arasında 7800'den fazla klinisyen ve sağlık profesyoneli adayına prenatal alkol maruziyeti, FASD, alkol taraması ve kısa müdahale konusunda eğitim verilmiş; farklı sağlık sektörlerinde ortak bir önleme yaklaşımının geliştirilmesine katkı sağlanmıştır.[1] Model, yalnızca bireysel bilgi düzeyini artırmayı değil, aynı zamanda kurumsal kültürün ve sağlık politikalarının güçlendirilmesini de amaçlamaktadır.

Prenatal alkol maruziyetinin önlenmesinde sağlık profesyonellerinin çalışma koşulları da göz ardı edilmemesi gereken bir diğer sistem bileşenidir. Yoğun iş yükü, zaman baskısı, tükenmişlik ve psikososyal stres, koruyucu sağlık hizmetlerinin niteliğini olumsuz etkileyebilmektedir. Sağlık çalışanlarında iş stresi ve travmatik yaşantılar ile riskli alkol kullanımı arasındaki ilişkiyi inceleyen sistematik derleme, özellikle tükenmişlik düzeyindeki artışın riskli alkol kullanımını artırabildiğini ve bunun mesleki performansı olumsuz etkileyebildiğini göstermektedir.[13] Benzer şekilde Polonya'da sağlık çalışanları üzerinde gerçekleştirilen araştırmada, yönetsel destek ve güçlü örgütsel iletişimin çalışanların alkolle ilişkili sorunlara daha etkili müdahale etmelerini kolaylaştırdığı bildirilmiştir.[14] Bu bulgular, prenatal alkol maruziyetinin önlenmesine yönelik etkili bakımın yalnızca kadınların değil, bakım veren sağlık profesyonellerinin de desteklenmesini gerektirdiğini ortaya koymaktadır.

Bu bulgular, prenatal alkol maruziyetinin önlenmesinde sürdürülebilir başarının güçlü eğitim programları, güncel klinik rehberler, standart bakım algoritmaları, disiplinler arası iş birliği ve destekleyici sağlık politikalarının birlikte uygulanmasına bağlı olduğunu göstermektedir. Ebelerin bu sistem içerisindeki liderlik rolü yalnızca bireysel danışmanlık hizmetleriyle sınırlı olmayıp eğitim faaliyetlerinin yürütülmesi, kalite geliştirme çalışmalarına katkı sağlanması, kurumlar arası koordinasyonun desteklenmesi ve kanıta dayalı uygulamaların yaygınlaştırılmasını da kapsamaktadır. Bu nedenle ebe liderliğinde yürütülen tarama, kısa müdahale ve kanıta dayalı klinik yaklaşımların etkili biçimde uygulanabilmesi için eğitim, sağlık sistemi ve politika düzeyindeki iyileştirmelerin eş zamanlı olarak hayata geçirilmesi gerekmektedir.

SONUÇ

Gebelikte alkol kullanımı, anne, fetüs ve yenidoğan sağlığı üzerinde kısa ve uzun dönemli olumsuz etkileri bulunan, büyük ölçüde önlenebilir önemli bir halk sağlığı sorunudur. Prenatal alkol maruziyetinin önlenmesi; fetal alkol spektrum bozukluklarının azaltılmasının yanı sıra anne ve çocuk sağlığının korunması, yaşam boyu sağlık yükünün azaltılması ve koruyucu sağlık hizmetlerinin güçlendirilmesi açısından stratejik önem taşımaktadır. Bununla birlikte mevcut kanıtlar, gebelikte alkol kullanımının erken tanılanması, sistematik olarak değerlendirilmesi ve etkili müdahale süreçlerinin sağlık hizmetlerine tam olarak entegre edilemediğini göstermektedir.

Bu derlemede değerlendirilen güncel kanıtlar, prenatal alkol maruziyetinin önlenmesinde evrensel tarama, yapılandırılmış kısa müdahale, kadın merkezli danışmanlık, uygun yönlendirme ve bakımın sürekliliğini temel alan bütüncül bir yaklaşımın gerekliliğini ortaya koymaktadır. Bu yaklaşımın başarısı yalnızca kullanılan tarama araçlarına değil; güvene dayalı iletişime, damgalanmanın azaltılmasına, sağlık profesyonellerinin klinik yeterliliklerinin güçlendirilmesine ve disiplinler arası iş birliğine de bağlıdır.

Ebeler, gebelik öncesi dönemden başlayarak doğum sonrasına kadar kadınlarla kurdukları sürekli iletişim sayesinde riskli alkol kullanımının erken belirlenmesi, davranış değişikliğinin desteklenmesi, bireyselleştirilmiş danışmanlık sunulması, gerekli durumlarda uygun tedavi hizmetlerine yönlendirme yapılması ve bakımın sürekliliğinin sağlanmasında kritik bir role sahiptir. Bu nedenle prenatal bakım

hizmetlerinde evrensel tarama yaklaşımının benimsenmesi, SBIRT modelinin rutin uygulamalara entegre edilmesi, ebelik eğitim programlarının güncel kanıtlar doğrultusunda güçlendirilmesi, mezuniyet sonrası sürekli mesleki gelişimin desteklenmesi, standart bakım algoritmalarının oluşturulması ve damgalamayı azaltan sağlık politikalarının yaygınlaştırılması öncelikli uygulamalar arasında yer almalıdır.

Sonuç olarak, gebelikte alkol kullanımının önlenmesi yalnızca prenatal alkol maruziyetinin azaltılmasına yönelik bir girişim değil; anne, fetüs ve yenidoğan sağlığını koruyan, yaşam boyu sağlık kazanımlarını destekleyen ve toplum sağlığını güçlendiren kapsamlı bir koruyucu sağlık stratejisidir. Ebe liderliğinde yürütülen kanıta dayalı tarama, kısa müdahale ve danışmanlık uygulamalarının prenatal bakımın standart bir bileşeni hâline getirilmesi, önlenebilir sağlık yükünün azaltılmasına ve daha sağlıklı nesillerin yetişmesine önemli katkılar sağlayacaktır.

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THE SCOPE OF MAQBUL AND SHÂDHQİRÂʾAT ACCORDİNG TO SAYYİD RİZQ AL-TAWİL: A STUDY OF A MODERN SCHOLAR

MODERN DÖNEM ÂLİMLERİNDEN SEYYİD RIZK ET-TAVİL'E GÖRE MAKBUL VE ŞAZ KIRÂATLERİN KAPSAMI

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ÖZET

Seyyid Rızk et-Tavîl, kırâatlerin kabul veya reddedilmesi meselesini klasik kırâat eserleri çerçevesinde ele almakta ve bu konuda belirlenen ilmî ölçütleri ayrıntılı biçimde açıklamaktadır. Ona göre bir okuyuşun Kur'ân'dan sayılabilmesi için üç temel şartın birlikte bulunması gerekmektedir: rivayetin tevâtür derecesinde sahih olarak gelmesi, Arapçanın yerleşik ve bilinen bir dil yapısına uygunluk göstermesi ve Mushaf-ı Osmân'nın hattıyla uyum sağlaması. Bu üç şartı taşıyan kırâatler makbul kabul edilirken, bunlardan herhangi birini taşımayan okuyuşlar şâz veya merdûd kırâat olarak belirtilmektedir. Müellif, bu kriterlerin kırâat farklılıklarının şahsî tercihlere değil, sağlam rivayet geleneğine ve ilmî esaslara dayandığını açıkça ortaya koyduğunu vurgulamaktadır. Tavîl, bu yönüyle tevâtürü, yalnızca rivayetin güvenilirliğini gösteren bir unsur olmadığını, aynı zamanda bir okuyuşun Kur'ân olarak kabul edilmesini sağlayan temel ölçütlerden biri olarak değerlendirilmektedir.

Tavîl'e göre kırâat imamlarının farklı okuyuşlar arasında yaptıkları tercihler, yeni bir kırâat ortaya koydukları anlamına gelmemektedir. Kırâat İmamları, kendilerine güvenilir rivayet yollarıyla ulaşan farklı okuyuşları karşılaştırmış, daha güçlü ve sağlam buldukları rivayetleri tercih ederek bunları okumaya devam etmiş ve talebelerine öğretmişlerdir. Bu sebeple bir kırâatin belirli bir imama nispet etmek, o okuyuşun imam tarafından ortaya konulduğunu değil; sahih rivayetler arasından seçilip benimsenerek sonraki nesillere aktarılmış olduğunu göstermektedir. Tavîl, şâz kırâatleri ise makbul kırâat için gerekli şartlardan birini veya birkaçını taşımayan okuyuşlar olarak değerlendirmektedir. Bu nedenle şâz kırâatlerin Kur'ân tilavetinde okunmasını doğru bulmadığını, ancak bazı fıkhî meselelerin açıklanmasında veya Arap diliyle ilgili çalışmalarda delil olarak kullanılabileceğini ifade etmektedir.

Sonuç olarak Tavîl, kırâat farklılıklarının rastgele ortaya çıkmadığını; sağlam rivayet, Arap dili kuralları ve Mushaf-ı Osmân yazımı esas alınarak oluştuğunu vurgulamaktadır. Böylece makbul ve merdud kırâatler arasındaki ayrımın belirli ilmî esaslara dayandığını açık bir şekilde ortaya koymaktadır.

Anahtar kelimeler: Şâz, Kırâat, Makbul, Sahih, Merdud

ABSTRACT

Sayyid Rizq al-Tawîl examines the issue of the acceptance or rejection of *qirâʾat* within the framework of the classical literature on Qurʾânic recitations and provides a detailed explanation of the scholarly criteria established in this regard. According to him, for a recitation to be recognized as part of the Qurʾân, three essential conditions must be fulfilled simultaneously: the transmission must be authentically established through *tawâtur* (mass transmission), it must conform to the established rules

and recognized linguistic usage of Arabic, and it must be compatible with the consonantal script (*rasm*) of the ʿUthmânic Muṣḥaf. Recitations that satisfy all three conditions are regarded as accepted (*maqbul*), whereas those lacking any one of them are classified as anomalous (*shadh*) or rejected (*mardud*). Al-Tawîl emphasizes that these criteria clearly demonstrate that the differences among the *qirâʾat* are based not on personal preference but on a sound transmission tradition and established scholarly principles. In this respect, he considers *tawâtur* not merely as an indicator of the reliability of transmission but also as one of the fundamental criteria for recognizing a recitation as part of the Qurʾân.

According to al-Tawîl, the preferences made by the imams of *qirâʾat* among different recitations do not signify that they introduced new recitations. Rather, they compared the various recitations transmitted to them through reliable chains of transmission, preferred those they deemed stronger and more authentic, continued to recite them, and transmitted them to their students. Therefore, attributing a particular recitation to a specific imam does not imply that the imam originated it; instead, it indicates that the recitation was selected from among authentic transmitted readings, adopted, and passed on to subsequent generations. Al-Tawîl defines anomalous (*shadh*) recitations as those that fail to satisfy one or more of the conditions required for an accepted recitation. Accordingly, he maintains that *shadh* recitations should not be used in Qurʾânic recitation (*tilâwah*), although they may serve as supporting evidence in the explanation of certain juristic issues and in studies related to the Arabic language.

In conclusion, al-Tawîl argues that the differences among the *qirâʾat* did not emerge arbitrarily but were established on the basis of sound transmission, the rules of the Arabic language, and conformity with the script of the ʿUthmânic Mushaf. Thus, he demonstrates that the distinction between accepted (*maqbul*) and rejected (*mardud*) recitations rests upon well-defined scholarly principles.

Keywords: Shadh, Qirâʾat, Maqbul, Sahîh, Mardud

Giriş

Kırâat ilmi, Kur'ân'ın farklı okuyuşlarını belirli ilmî ölçütlere göre değerlendiren önemli ilim dallarından biridir. Bir okuyuşun kabul edilmesi veya reddedilmesi kişisel görüşlere göre değil, İslâm âlimlerinin belirlediği esaslara göre yapılmaktadır. Seyyid Rızk et-Tavîl de eserinde bu esasları ayrıntılı şekilde ele almakta ve sahih bir kırâatin hangi şartları taşıması gerektiğini açıklamaktadır. Ona göre gerekli şartları taşıyan okuyuşlar makbul kırâat, bu şartları taşımayanlar ise şâz kırâat olarak değerlendirilmektedir. Böylece kırâatlerin doğruluğu belirli ilmî kurallar çerçevesinde tespit edilmektedir.

Müellife göre kırâat farklılıkları Hz. Osman döneminde ortaya çıkmış değildir. Bu farklılıklar daha önce de güvenilir rivayetler yoluyla bilinmekteydi. Hz. Osman'ın Mushaf'ı çoğaltıp İslâm beldelerine göndermesiyle birlikte bu okuyuşlar belli sınırlar içinde korunmuş, ancak tamamen ortadan kalkmamıştır. Ayrıca ilk dönem Arap yazısında nokta ve hareke işaretlerinin bulunmaması, bazı kelimelerin birden fazla şekilde okunmasına imkân vermiştir. Bu durum, yedi ve on kırâat imamından nakledilen sahih okuyuşların Mushaf'ın yazısına uygun olarak günümüze kadar ulaşmasını sağlamıştır. Dolayısıyla kırâatlar arasındaki farklılıklar şahsî tercihlerden değil, güvenilir rivayetlere ve ilmî esaslara dayanmaktadır.

Tavîl, kırâat imamlarının okuyuş tercihlerini de bu anlayış doğrultusunda açıklamaktadır. Nitekim Nâfi' (ö. 169/785), birçok tâbiîden kırâat öğrenmiş, üzerinde görüş birliği bulunmayan veya güven vermeyen rivayetleri tercih etmemiştir. Bu durum, tercihlerin kişisel düşüncelere değil, rivayetlerin karşılaştırılması sonucu yapıldığını göstermektedir. Benzer şekilde Kisâî (ö. 189/805) de Hamza'dan rivayette bulunmasına rağmen bazı okuyuşlarda farklı tercihler yapmıştır. Bunun sebebi, farklı hocalardan aldığı rivayetleri karşılaştırarak daha güçlü gördüğü okuyuşları benimsemesidir. Aynı yöntem Ebû Amr (ö. 154/771) tarafından da uygulanmış, İbn Kesîr' (ö. 120/738) den aldığı bütün rivayetleri değil, daha sağlam bulduğu okuyuşları tercih etmiştir. Bu örnekler, kırâat imamlarının tercihlerini senedin güvenilirliği, rivayetlerin sağlamlığı ve Arap diline uygunluk gibi ilmî ölçütlere göre yaptıklarını göstermektedir.[1]

[1] Seyyid Rızk et-Tavîl, *Fî Ulûmi-l-Kıraât Medhal ve Dirâse ve Tahkîk* , (Mekke: el-Mektebetü'l-faysaliyye,1985), 48.

Bu açıklamalardan sonra Tavîl, kırâatleri makbul ve şâz olmak üzere iki ana gruba ayırmakta; her iki grubu kabul şartları, rivayet değeri ve ilmî özellikleri bakımından ayrıntılı şekilde incelemektedir.

1. Makbul ve merdûd kırâat kavramı

Seyyid Rızk et-Tavîl, makbul kırâat kavramını klasik kırâat literatürünü esas alarak değerlendirmektedir. Müellife göre bir kırâatin sahih ve makbul kabul edilebilmesi, belirli ilmî ölçütleri taşıması gerekmektedir. Bu ölçütler, kırâatin güvenilirliğini ortaya koyan temel esaslar olarak kabul edilmektedir. Tavîl, klasik kırâat âlimlerinin benimsediği yaklaşımı takip ederek, bir okuyuşun makbul sayılabilmesi için üç temel şartın birlikte bulunması gerektiğini vurgulamaktadır. Bu şartlardan herhangi birinin eksik olması hâlinde ilgili okuyuş makbul kırâat kapsamında değerlendirilmiyeceği vurgulanmaktadır. Üç temel şart ise şunlardır:

- Güvenilir râviler vasıtasıyla Hz. Peygamber'e (s.a.s.) ulaşması,
- Kur'ân'ın nâzil olduğu fasih Arapça içerisinde yerleşik ve geçerli bir lehçeye uygun olması,
- Osman Mushafı'nın hattına uygunluk göstermesi.[2]

Müellif, makbul (kabul edilen) kırâat şartlarını her birini müstakil başlıklar altında incelemiştir.

Birici Şart: Mütevatir Sened

İslâm ilim geleneğinde kırâatlerin sıhhat meselesinin özellikle usûl, hadis, fıkıh ve kırâat âlimleri tarafından büyük ölçüde "tevatür" ilkesi çerçevesinde değerlendirildiği belirtilmektedir. Bu bağlamda müellif, öncelikle Kur'ân'ın tanımına temas eder. *"Kur'ân: Âlimlerin çoğunluğuna göre nesilden nesile tevatür yoluyla rivayet edilen ilâhî vahiydir*." Bu tanım özellikle Kur'ân'ın mahiyetini belirleyen temel unsurlardan biri olduğunu vurgulamaktadır. Dolayısıyla sened bakımından sahih kabul edilen bir rivayet, tevatür derecesine ulaşmadığı sürece Kur'ân kırâati olarak değerlendirilemez ve tilavet için yeterli görülemez.[3]

Müellif'in tevatür tanımı ise şu şekildedir: "*Bir topluluğun diğer bir topluluktan aktarmasıdır; bu toplulukların senedin başından sonuna kadar yalan söylemeye ortak olmaları âdetle mümkün değildir*."[4] Bu tanım, Kur'ân'ın sübûtunda kesinlik ifade eden nakil biçiminin esas alındığını göstermektir.

Tavîl, konuya ilişkin temel kavramları açıkladıktan sonra Nüveyrî'nin (ö. 733/1333) görüşünü aktarmaktadır. Nüveyrî'ye göre, Mekkî b. Ebî Tâlib (ö. 437/1045) ve onu takip eden bazı âlimler, kırâatlerin kabulünde tevâtürün zorunlu bir şart olmadığını kabul etmişlerdir. Ancak Tavîl, bu değerlendirmeyi İslâm ilim geleneğinde yerleşmiş genel anlayışla bağdaşmayan bir yaklaşım olarak değerlendirmektedir. Ona göre başta dört mezhep imamı olmak üzere birçok âlim, mushafın iki kapağı arasında yer alan bir metnin Kur'ân olarak kabul edilebilmesi için tevâtür yoluyla nakledilmiş olmasını gerekli görmüştür. Bu sebeple tevâtür, Kur'ân'ın sübûtunda vazgeçilmez bir ölçüt olarak kabul edilmiştir.

Nitekim İbn Abdilberr (ö. 463/1071), İbn Atıyye (ö. 541/1147), Nevevî (ö. 676/1277), Sübkî (ö. 756/1355) ve Zerkâşî (ö. 794/1392) gibi birçok âlim de eserlerinde bu anlayışı benimsemiş ve Kur'ân'ın ancak tevâtür yoluyla sabit olacağını açıkça ifade etmiştir. Bu durum, söz konusu görüşün İslâm ilim geleneğinde geniş kabul gördüğünü göstermektedir.

Bununla birlikte, bazı kaynaklarda ve Nüveyrî'nin ifadelerinde Mekkî b. Ebî Tâlib ile onu takip eden bazı âlimlerin tevâtürü şart koşmadıkları yönünde değerlendirmelere yer verilmiştir. Ancak bu nispetlerin tarihî arka planı ve ilmî dayanakları tartışmalıdır. Nitekim Tavîl, bu görüşün Mekkî'ye nispet edilmesini ve onun bu sebeple "son dönem âlimleri" arasında değerlendirilmesini isabetli bulmamaktadır. Çünkü klasik kaynaklar dikkatle incelendiğinde, Mekkî'nin kırâat anlayışının belirli

[2] Tavîl, *fî ulûmi'l-kırâat,* 48; Ebû Hafs Sirâceddîn Ömer bin Zeyneddîn Kâsım bin Muhammed bin Alî el-Ensârî, *el-Büdûrü'zZâhire fi'l-Kıraati'l-Aşri'l-Mütevâtira*, thk. Ahmed İsâ el-M'isrâvî, (Katar: Vezâratü'l-Evkâf ve'şŞüûni'l-İslâmiyye, 2011), 1/26; Mustafa Atilla Kandemir, *Kırâat İlmi Eğitim ve Öğretim Metodları*, (İstanbul: İFAV Yayınları, 2015), 59; Abdulhamid Birışık, *Kıraat İlmi ve Tarihi*, (Bursa: Emin Yayınları, 2024), 24.

[3] Tavîl, *fî ulûmi'l-kırâat,* 49. Mehmet Emin Maşalı, *Tarihi ve Temel Meseleleriyle Kırâat İlmi* (Ankara: OTTO Yayınları, 2022), 98.

[4] Tavîl, *fî ulûmi'l-kırâat,* 49.

ölçü ve esaslara dayandığı görülmektedir. O, makbul bir kırâatin kabul edilebilmesi için birtakım şartlar ileri sürmüş ve bu şartlar çerçevesinde sahih kırâatleri belirlemeye çalışmıştır.[5] Bu çerçevede Mekkî'nin benimsediği bu şartlar şu şekilde sıralanabilir:

- Üç şartı taşıyan kırâatler hem sahih kabul edilir hem de tilavet bakımından geçerlidir.
- Rivayet yönüyle sahih olmakla birlikte âhâd yolla rivayet edilen ve Mushaf-ı osman hattına aykırılık içeren kırâatler tamamen reddedilmez; ancak Kur'ân olarak okunmaları uygun görülmez.
- Güvenilir rivayete dayanmayan veya Arap diline uygunluk atfetmeyen rivayetler ise Mushaf hattına uygunluk gösterseler dahi kabul edilmez.[6]

Bu değerlendirmeler, Mekkî'nin Kur'ân'ın tespitinde âhâd rivayetleri yeterli görmediğini ve kırâatlerin kabulünde sağlam rivayeti esas aldığını göstermektedir. Mekkî, eserlerinde tevatür kavramını açıkça kullanmasa da sahih kırâatin kabulü için belirlediği şartlar, onun tevatürü gerekli gördüğünü ortaya koymaktadır. Çünkü ona göre bir kırâatin sahih kabul edilebilmesi, yalnızca Arap diline ve resmü'l-mushafa uygun olmasına değil, aynı zamanda güvenilir ve yaygın bir rivayet yoluyla nakledilmiş olmasına da bağlıdır. Bu yaklaşım, Mekkî'nin tevatürü kırâatin kabulünde temel ölçütlerden biri olarak değerlendirdiğini göstermektedir.

Benzer şekilde, İbnü'l-Cezerî'ye (ö. 833/1429) de sahih kırâatlerin kabulünde tevatürü şart koşmadığı yönünde bazı görüşler nispet edilmiştir. Ancak bu değerlendirmeler daha çok onun manzum eserlerinde yer alan ifadeler esas alınarak yapılmıştır. Buna karşılık, İbnü'l-Cezerî'nin *Müncidü'l-Mukriîn* ve *Mürşidü't-Tâlibîn* adlı eserleri incelendiğinde, sahih kırâatlerin kabulünde tevatürü açıkça benimsediği görülmektedir. Bu nedenle, onun tevatürü gerekli görmediği yönündeki değerlendirmelerin bütün eserleri dikkate alındığında tam olarak doğru olmadığı anlaşılmaktadır. Aksine, eserlerinde yaptığı açıklamalar birlikte değerlendirildiğinde, İbnü'l-Cezerî'nin sahih kırâatlerin kabulünde tevatürü temel şartlardan biri olarak kabul ettiği söylenebilir.[7]

İkinci Şart: Okuyuşun Arapçada yaygın bilinen bir dil yönüne uygun olması

Kırâatin kabul şartlarından biri, Arap dili açısından bilinen ve güvenilir bir kullanım şekline dayanmasıdır. Müellife göre bu şart, okuyuşun Arap dilinde yerleşmiş ve tanınan bir kullanım biçimiyle uyumlu olması anlamına gelir. Ancak bir kırâat sahih rivayetle sabit olmuşsa, onun dil kurallarına uygunluğu ayrıca tartışılmaz. Aksine, böyle bir durumda nahiv kuralları kırâati değerlendiren bir ölçü değil, kırâat nahiv kurallarına delil kabul edilir. [8]

Bu durum, Kûfe ve Basra dil ekolleri arasındaki görüş ayrılıklarında açıkça görülmektedir. Kûfeli dil âlimleri, Hamza'nın "وَاتَّقُوا اللَّهَ الَّذِي تَسَاءَلُونَ بِهِ وَالْأَرْحَامِ" ayetindeki "الأرحامِ" kelimesini mecrûr okumasını delil göstererek, cer edatının tekrar edilmesine gerek kalmadan mecrûr bir kelimeye atıf yapılabileceğini savunmuşlardır. Buna karşılık Basralı dil âlimleri, bu okuyuşun nahiv kuralından değil, yemin anlamı taşıması ve akrabalık bağlarının önemini vurgulaması sebebiyle bu şekilde okunduğunu ileri sürmüşlerdir. Bu tartışmalar, kırâatin dil kurallarına göre değil, rivayete dayalı olarak değerlendirildiğini göstermektedir. Nitekim Zeyd b. Sâbit'ten nakledilen rivayette kırâatin uyulması gereken bir sünnet olduğu ifade edilmiştir. Beyhakî (ö. 458/1066) de bu sözü, harflerin telaffuzu ve okuyuş şekillerinde önceki nesillerden aktarılan uygulamaya bağlı kalınması gerektiği şeklinde açıklamıştır.

Müellif, imam mushafı'nın yazımına aykırı bir okuyuşa cevaz verilemeyeceği gibi, Arap dilinde yaygın olmasa bile meşhur kırâatlere muhalefet de söz konusu olamaz. Kûfe ve Basra dil ekolleri arasında bazı kırâatlerin dilsel temellendirilmesi konusunda ihtilaf bulunduğu örnek üzerinden gösterilmiş, Zeyd b. Sâbit ve Ebû Amr ed-Dânî gibi otoriteler, kırâatin rivayet temelli ve bağlayıcı bir sünnet olduğunu, dil kıyasıyla reddedilemeyeceğini savunurlar. Buna karşılık bazı âlimler, kırâatin Arapçada yaygın bir

[5] Tavîl, *fî ulûmi'l-kırâat,* 49.
[6] Tavîl, *fî ulûmi'l-kırâat,* 49; Abdulhakim Ağırbaş, *Kıraât Eğitim-Öğretim Geleneği ve Günümüzdeki uygulamaları,* (Ankara*:* Diyanet İşleri Başkanlığı Yayınları, 2022), 63.
[7] Tavîl, *fî ulûmi'l-kırâat,*49-51.
[8] Tavîl, *fî ulûmi'l-kırâat,* 52; Ramazan Pakdil, *Talim Tecvit ve Kırâat,* (İstanbul: Marmara Üniversitesi İlahiyat Fakültesi Yayınları,2014) 363.

veçhe dayanmasını zorunlu görerek, dilde karşılığı olmayan bir okuyuşun kabul edilemeyeceğini ileri sürmüşlerdir.[9]

Üçüncü Şart Mushaf Hattına Uygunluk

kırâatin sahih kabul edilmesindeki üçüncü şart, imam mushafının hattına uygun olmasıdır. Kırâat âlimlerinin büyük çoğunluğu bu şart üzerinde görüş birliği sağlamıştır. Bunun temel sebebi ise Hz. Osman döneminde çoğaltılan Mushafların sahâbe icmâı ile kabul edilmiş olmasındandır. Bu sebepten dolayı Mushaf hattına uymayan bir kırâati kabul etmek dolaylı biçimde bu icmâya muhalefet anlamına gelmektedir.[10] Mekkî'nin, İsmail el-Kâdî (ö. 282/895)'den aktardığı görüş de bu çerçeveyi destekler nitelikte:*"Mushaf hattına aykırı bir kırâati tercih etmek, cemaatin cemaatten naklettiği tevatürlü rivayeti terk ederek, âhâd bir habere dayanmak demektir."*[11] Oysa bağlayıcı ve delil olan, topluluk tarafından topluluğa aktarılan rivayettir. Bu nedenle mushaf hattına aykırılık, kırâatin tevatür niteliğini zedeler niteliktedir.

Kırâatler hakkında şu sonuç çıkmaktadır. Mushaf hattına uygun olan kırâatler, daha önce belirtildiği üzere yedi harf kapsamındadır. Mushaf hattına aykırı olan kırâatler ise rivayeti sahih, Arapça bakımından geçerli bir veçhe uygunluk arz etse, mana bakımında problemli olmasa bile yalnızca ahâd rivayet yoluyla nakledildikleri için o kırâatin tevatür özelliğini kaybettiğini gösterir. Tevatür özeliğini kaybeden bir rivayet de Kur'an olarak kabul edilmez ve kırâat olarak okunamaz.

Sened Bakımından Kırâatler

Önceki açıklamalarda da anlaşılacağı üzere tevatür, kırâatin kabulü için kesinlikle şarttır. Çünkü sahih ve makbul kırâat tevatür yoluyla ancak kur'an'a dayandırılabilir. Âlimler kırâatleri üç kısma ayırmışlardır:

- Tevatürü üzerinde ittifak edilen kısım**:** Bu hususta âlimler arasında herhangi bir ihtilaf yoktur. Bu grup, yedi imamın kırâatleridir.
- Hakkında ihtilaf edilen kısım: Sahih ve meşhur olan görüşe göre bu da mütevatirdir. Bu kısım, ilave üç imamın kırâatleridir: Ebû Ca'fer el-Medenî, Ya'kûb b. İshak el-Hadramî ve Halef b. Hişâm.
- Şâz olduğu üzerinde ittifak edilen kısım: Bu da on kırâatin dışında kalan rivayetlerdir.[12]

Müellif, kırâatlerin sened bakımından daha iyi anlaşılabilmesi amacıyla bu alanda otorite kabul edilen âlimlerin görüşlerine yer vermektedir. Bu çerçevede İbnü'l-Cezerî, İmam Abdülvehhâb es-Sübkî'ye (ö. 756/1355) yöneltilen bir fetvayı nakletmektedir. Fetvada şu sorular sorulmaktadır: Günümüzde okunan on kırâatin hükmü nedir? Bu kırâatler mütevatir kabul edilir mi? On imamdan birinin yalnız başına rivayet ettiği bir vecih de mütevatir sayılır mı? Eğer bunlar mütevatir ise, söz konusu kırâatleri inkâr eden veya tahrif eden kimsenin hükmü nedir?

İbnü'l-Cezerî, bu soruyu bizzat kendisinin yönelttiğini ve cevabı İmam es-Sübkî'nin kendi el yazısından naklettiğini belirtmektedir.

"Hamd Allah'a mahsustur. Şâtıbî'nin zikretmekle yetindiği yedi kırâat ile Ebû Ca'fer, Ya'kûb ve Halef'in kırâatlerinden oluşan üç kırâat mütevatirdir ve dinden zarurî olarak bilinmektedir. On imamdan birinin tek başına rivayet ettiği her bir harf de dinden zarurî olarak bilinir ki Resûlullah'a indirilmiştir. Bunu inkâr eden ancak cahildir.

Bu kırâatlerin tevatürü, yalnızca rivayet zincirleriyle okuyanlara mahsus değildir; bilakis 'Allah'tan başka ilah olmadığına ve Muhammed'in Allah'ın Resûlü olduğuna şehadet eden her Müslüman nezdinde mütevatirdir; hatta Kur'an'dan bir harf ezberlememiş sıradan bir kimse bile bu hükme dâhildir.

[9] Tavîl, *fî ulûmi'l-kırâat,* 52.
[10] Tavîl, *fî ulûmi'l-kırâat,* 53.
[11] Tavîl, *fî ulûmi'l-kırâat,* 53.
[12] Tavîl, *fî ulûmi'l-kırâat,* 54.

Bu hususun uzun bir izahı ve geniş bir delillendirmesi vardır; bu sayfada açıklanması mümkün değildir. Her Müslümanın payı ve görevi, zikredilenlerin mütevatir olduğuna, kesin bilgi ifade ettiğine, bunlara zan ve şüphe karışmayacağına kalben kesin olarak inanmasıdır. Allah en doğrusunu bilir."[13]

Bu konuda Kurtubî(ö. 671/1273)'de şöyle demiştir. "*Müslümanlar tüm beldelerde, on imamın sahih rivayetlerine dayanma konusunda icmâ etmiştir; bu bağlamda eserler yazılmış, icmâ süreklilik kazanmış ve Kur'an'ın korunması ilahî vaadinin gerçekleştiği kabul edilmiştir."* Bu görüş, İbn Cerîr et-Taberî (ö. 310/923) ve Kadı Ebû Bekir b. et-Tayyib el-Bâkıllânî (ö. 403/1013) gibi önde gelen âlimler tarafından da benimsenmiştir.[14]

Bu örneklerde anlaşılıyor ki on kırâat imamın sahih rivayetleri sadece rivayet zincirini bilenler için değil tüm Müslümanlar için mütevatirdir. Ancak inkâr etmek cehalet olarak kabul edilmektedir. Bu durum kırâatlerin hem ilmî bağlamda hem de ibadet bağlamında Kur'an'ın korunması ilahî vaadinin gerçekleştiği anlayışını teyit eder niteliktedir.

Kırâatlerde "İhtiyâr" Kavramı

Sözlükte " Tercih etmek, seçmek, üstün tutmak, seçip ayırmak"[15] anlamlarına gelen ihtiyar kırâat ilminde ise bir kırâat imamının kendisine sahih yollarla ulaşan farklı okuyuş vecihleri arasından birini tercih etmek, öne çıkartmak[16] benimsemek, o vecih üzere talebe yetiştirmek anlamlarına gelir.[17]

Harflerin ve kırâatlerin kırâat imamlarına ve onların râvilerine nispet edilmesi şu şekilde açıklanabilir: Bir kırâat imamı, dili belirli bir vecih üzere nasıl öğrenmişse o okuyuşu tercih etmiş, bu okuyuşu kendi nezdinde sahih kabul etmiş, diğer vecihlere üstün tutmuş ve ona devam ederek bağlılık göstermiştir. Zamanla bu tercih ettiği okuyuşla meşhur olmuş ve o vecihle tanınmıştır. İnsanlar da bu kırâatin ondan almış ve onu diğer kurrâya tercih etmiştir. Bununla birlikte, bir kırâatin belirli bir imama nispet edilmesi, o okuyuşun imam tarafından icat edildiği anlamına gelmez. İmam, sadece kendisine sahih yollarla ulaşan vecihlerden birini sahih kabul etmiş, onu diğer vecihlere tercih etmiş, bu okuyuş üzere devam etmiş ve talebelerini bu vecih üzere yetiştirmiştir. Buna benzer örnekler sahabe döneminde de görmek mümkündür. İbn Abbâs genellikle kırâatini Zeyd b. Sabit'ten almış ama bazen de İbn Mes'ûd'un kırâatini tercih etmiştir.[18]

Müellifin Bu konudaki görüşü bir kırâatin yedi veya on kırâat imamından birine yahut başkasına nispet edilmesinin temelinde üç şart olduğu ifade etmiştir. Bunlar: ihtiyâr (seçim), müdavemet (süreklilik) ve lüzûm (bağlılık) dur.[19]

Şaz Kırâatler

Şâz sözlükte, "ş-z-z" kökünden türemiş "ayrılan, tek kalan, çoğunluktan uzaklaşan," benzerlerinden farklı olan gibi anlamlara gelir.[20] Kırâat terminolojisinde ise sahih kırâatlerin kabulünde aranan şartlardan birini veya birkaçını taşımayan, bu sebeple yaygın ve geçerli kırâatler arasında değerlendirilmeyen okuyuş şekilleridir.[21]

Tavîl, klasik kırâat kaynaklarında ortaya koyduğu makbul ve sahih bir kırâatin taşıması gereken temel şartları ele almakta; bu şartlardan birini veya birkaçını karşılamayan okuyuşların ise makbul kırâat

[13] Tavîl, *fî ulûmi'l-kırâat,* 55.
[14] Tavîl, *fî ulûmi'l-kırâat,* 54.
[15] Ebü'l-Feyz Muhammed el-Murtazâ b. Muhammed b. Muhammed b. Abdirrezzâk el-Bilgrâmî elHüseynî ez-Zebîdî, *Tâcü'l-arûs min cevâhiri'l-kâmûs*, Heyet (Kuveyt: Dâru'l-hidâye, 1965-2001), 11/243; İbn Manzûr, Ebü'l-Fazl Muhammed b. Mükerrem b. Ali el- Ensârî, *Lisânu'l-Arab*, (Beyrur: Dâru Sâdır, 1993), 4/265; H.Yunus Apaydın, "İhtiyar", *Türkiye diyanet vakfı İslâm Ansiklopedisi* (İstanbul: TDV Yayınları, 2000), 21/575.
[16] Maşalı, *Tarihi ve Temel Meseleleriyle Kırâat İlmi,* 32.
[17] Tavîl, *fî ulûmi'l-kırâat,* 55.
[18] Tavîl, *fî ulûmi'l-kırâat,* 56; Muhsin Demirci, *Kur'ân Tarihi,* (İstanbul: Marmara Üniversitesi İlahiyat Fakültesi Yayınları,2024), 229.
[19] Tavîl, *fî ulûmi'l-kırâat,* 56.
[20] Zebîdî, *Tâcü'l-arûs min cevâhiri'l-kâmûs,* 9 /423; İbn Manzûr, *Lisânu'l-Arab*, 3/494.
[21] Ebû Tâhir Abdülkayyûm Abdülğafûr es-Sindî, *Safahât fî ulûmi'l-kırâât* (Medine: el-Mektebetü'l Emdâdiyye, 1415/1994), 80; Tavîl, *fî ulûmi'l-kırâat,* 57; Mehmet Maşuk Acar, *Kıraat İlminde Şâz Meselesi,* (Ankara: İlahiyat yayınları, 2025),43.

kapsamında değerlendirilemeyeceğini ifade etmektedir. Bu çerçevede, makbul kırâatlerin sahip olması gereken üç temel şartı şu şekilde sıralamaktadır:

- Tevâtür şartı: Kırâat güvenilir zincirlerle nakledilmiş olmalı.
- Mushaf hattına uygunluk: Okuyuş, Osman Mushaf'ı ile uyumlu olmalı.
- Arap dili kurallarına uygunluk: Okunuş Arapça dili kaidelerine uygun olmalı.

Şâz kırâatler, bu şartlardan herhangi birini yerine getirmediğinde Kur'ân olarak kabul edilmez ve tilavet edilmez. Müellif, şâz kırâat türlerini kısa başlıklar altında ve örneklerle açıklamaktadır.

- Güvenilir olmayan ravilerin, rivayet ettikleri fakat Osman Mushafı'na ve Arapçaya uygun kıraatlerdir. Burada rivayetçi güvenilir değildir, ancak metin ve Arapça doğrudur.

Örnek: İbnü's-Sümeyfa (ö. 215/830) ve Ebû's-Semâl (ö. 160/776):[22]"فاليوننجيك ببدنك لتكون لمن خلفك آية" "خلفك" (ح) hâ *noktasız* (ل) *lâm ise fethalı okunur.* Bir diğer örnek ise Ebû Hanîfe'ye nispet edilen ancak gerçekte ona ait olmadığı belirtilen bir okuyuş gösterilebilir. Bazı müfessirler bu kırâati Ebû Hanîfe'ye ait kabul ederek açıklamaya çalışmışlardır. Bu okuyuşta [23]**إنما يخشى اللهَ من عباده العلماءُ** ayeti, lafzatullah (**الله**) merfû, **(العلماء)** kelimesi ise mansûb olacak şekilde **إنما يخشى اللهُ من عباده العلماءَ** biçiminde okunmaktadır.

- Güvenilir ravinin rivayet ettiği, fakat Arapça bakımından uygun olmayan kırâatler:

Rivayet güvenilir, ancak Arap dili kurallarına uygun değildir. Genellikle dalgınlık, hata veya eksik zabt sonucu ortaya çıkar ve çok nadirdir.

Örnek: Nâfi', Hârice b. Zeyd(ö. 100/718-719)'den gelen rivayette:"وجعلنا لكم فيها معاءش" *Hemze ile okunması Arapçaya aykırıdır.* Mekkî b. Ebû Tâlib: Bu tür kırâatler Mushaf hattına uyumlu olsa bile kabul edilmez demiştir. Çünkü: Mekki b. ebû Tâlip şaz kırâat kavramını yedi kırâatın dışında kalanlar diye tanımlamamış, dilbilim açısında zayıf oldukları için şâz kırâatler ifadesini kullanmaktadır.[24]

- Âhâd yolla sahih rivayetle gelmiş, Arapça bakımından mümkün, fakat Mushaf hattına aykırı olan kıraatlerdir. Rivayet güvenilir, Arapça kurallarına uygun; ancak Osman Mushaf'ına uymayan kırâatler şeklinde ifade edilmiştir. Bu örnek olarak şu rivayetler verilebilir:

1. Sa'd b. Ebî Vakkas (ö. 55/675): [25]"وله اخ او اجة" ayetini şöyle okumuştur "وله أخ أو أخت من أمه" (*fazlalık: "من أمه"*)
2. İbn Şenebûz (ö. 328/939): [26] "يأخذ كل سفينة غصبًا" "يأخذ كل سفينة صالحة غصبًا" (*fazlalık: "صالحة"*)
3. İbn Mes'ûd (ö. 32/652-53): [27] "فسعوا إلى ذكرالله" "فامضوا إلى ذكر الله" (*"فاسعوا" yerine okunmuş*)
4. İbn Mes'ûd ve Ebû'd-Derdâ (ö. 32/652): [28] "وما خلقوالذكر والأنثي" "والذكر والأنثى" (*"ما خلق" hazfedilmiş*)

- Nakledilmemiş, Arapça ve Mushaf'a uygun okunuşlar

İbnü'l-Cezerî'ye göre, bu tür okuyuşlar Arapçaya ve Mushaf hattına uygun olsa bile, sahih nakille aktarılmadıkları için kabul edilemez ve bunların önüne geçilmelidir. Tavîl de bu konuda İbnü'l-Cezerî ile aynı görüşü benimsediğini belirtmektedir. Hicrî III. asırdan sonra yaşayan İbn Miksem el-Bağdâdî (ö. 354/965) de bu görüşü savunmuş; ancak Bağdat âlimleri onun yaklaşımını reddetmiş ve kendisini bu

[22] Yunus, 10/92.
[23] Fatır, 35/28.
[24] Tavîl, *fî ulûmi'l-kırâat,* 57; Mehmet Dağ, "Tarihten günümüze Kırâat İlmi", *Uluslararası Kıraat Sempozyumu*, ed. Yüksel Selman,(Ankara: DİB Yayınları, 2015), 96.
[25] Nisa, 4/12
[26] Kahf,18/79.
[27] Cuma,62/9.
[28] Leyl, 92/3.

görüşünden vaz geçirerek tövbe ettirmişlerdir. Tavîl, bu olayın Hatîb el-Bağdâdî'(ö. 463/1071)nin Târîhu Bağdâd ile İbnü'l-Cezerî'nin Tabakât ve en-Neşr adlı eserlerinde yer aldığını ifade etmektedir.[29]

Şâz Kıraâtlerin Hükmünün Başlangıcı

Müellif, şâz kırâatlerin tespiti, Mushaf-ı Osmanî'nin hazırlanması ve Müslüman beldelere dağıtılması ile başladığını ifade etmiştir. Bu dönemde, kırâatlerin doğruluk ölçütleri ortaya çıkmış ve Mushaf ile uyumsuz kırâatler şâz olarak kabul edilmiştir. Başlangıçta şâz kırâatler mevcut olsa da, bu terim henüz o dönemde kullanılmamaktaydı. Mushaf hattına uyumlu olmayan okuyuşlar, sahabelerin icmaî dikkate alınarak şâz kabul edilmiştir. Şâz kırâatlerle hükmetme alanı ise Arapça gramer ve çekim kuralları netleştikten sonra, yani hicrî birinci asrın ikinci yarısından itibaren ortaya çıktığını vurgulamaktadır.[30] Şâz kavramının ikinci asırda dilbilim ve hadis alanında ortaya çıkmış fakat kırâat alanına Taberi ile başladığını ifade etmiştir.[31]

Bazı araştırmacılar, Hz. Osman döneminde şâz kırâatlerin mevcut olduğunu, ancak bu şekilde isimlendirilmediğini ileri sürmektedir. Hatta bazı sahâbîlerin kendi mushaflarını muhafaza ettikleri veya Hz. Osman'ın bazı farklı okunuşlara müsaade ettiği de iddia edilmektedir. Ancak bu görüşler tarihî verilerle tam anlamıyla örtüşmemektedir. Zira sahâbîlerin kendi mushaflarını Hz. Osman'dan gizlemeleri düşünülemeyeceği gibi, Hz. Osman'ın da mushafların cem'i sürecinde benimsediği esaslara aykırı okunuşlara izin vermeside tutarlı görünmemektedir.

Nitekim İbn Zübeyr'e nispet edilen Fâtiha sûresindeki "صراط من أنعمت عليهم" kıraati buna örnek olarak gösterilmektedir. Ancak söz konusu okunuşun, Osman mushaflarının çoğaltılıp İslâm beldelerine gönderilmesinden önceki döneme ait olduğu anlaşılmaktadır. Bu kıraat rivayet yoluyla nakledilmiş olsa da, cem edilen Mushaf'ın resmine uygun düşmediği için Müslümanların genel kabulüne mazhar olmamış ve uygulamada yer bulmamıştır. Bu yönüyle Mushaf-ı Osman, sahih kabul edilen kırâatlerle şâz kırâatleri birbirinden ayıran temel ölçüt olarak kabul edilmektedir.[32]

Namazda şâz kırâat ile okumak

Müellif, Ebû Hanîfe ve Şâfiî mezhebine mensup bazı âlimler, İmamı Mâlik ve Ahmed b. Hambel'den gelen birer rivayetle de namazda **şâz kırâatle okumanın caiz olduğunu** söylemiştir. Bunun iki sebebe bağladığını ifade etmiştir. Birincisi**:** Sahâbe ve tâbiîn, bu harflerle (şâz kıraâatlerle) namazda okuyorlardı. **İkincisi:** Eğer şâz kırâatle okumanın câiz olmadığı söylenirse, bu durumda sahâbe ile onları takip eden tâbiîn âlimlerinden bazılarının bu şekilde okuyarak haram işlemiş oldukları kabul edilmiş olur. Tavîl, bu iki görüşü söyledikten sonra âlimlerin çoğunluğuna göre şâz kırâatle namaz kılmanın caiz olmadığını, sebebinin ise nakille gelmiş olsa bile mütevatir olmadığı ve Mushaf-ı Osman'a aykırı olduğundandır.[33] Tavîl, bu konuda İmam Nevevî(ö. 676/1277)'nin şu görüşüne yer vermektedir:

"*Şâz kırâatleri ne namazda ne de namaz dışında okumak câiz değildir. Çünkü bu, Kur'an değildir. Zira Kur'an ancak tevâtür yoluyla sabit olur; şâz kırâat ise mütevâtir değildir. Bunun aksini söyleyen kimse ya hataya düşmüştür ya da cahildir. Eğer bir kimse buna muhalefet eder ve şâz kırâatle okursa, gerek namazda gerek namaz dışında onun bu okuyuşu reddedilir. Bağdat fakihleri, şâz kırâatle okuyan kimsenin bundan vazgeçirilmesi gerektiği hususunda ittifak etmişlerdir ve bu şekilde okuyan kimsenin arkasında namaz kılınmaz*." Bakıldığında imam Nevevî'nin bu sözleri yukardaki açıklamayı destekler niteliktedir.[34]

Şâz kırâatle istişhâd

Müellif, çoğu İslâm âliminin şâz kırâatler üzerinden hüküm çıkarılmasının veya bunlardan şer'i hükümlerde delil olarak kullanmanın caiz olduğunu ifade etmektedir. Âlimler, ahad haberleri şer'i hükümlerde delil olarak kullanmakta ihtilaf etmemiş ve bu tür şâz kırâatlerle pek çok şer'i hükümlerde delil olarak kullanmışlardır. Tavîl, bu meseleyi örnekler vererek değerlendirmiştir. Birinci örnek: Hırsız

[29] Tavîl, *fî ulûmi'l-kırâat,* 58.
[30] Tavîl, *fî ulûmi'l-kırâat,* 59.
[31] Dağ, *Tarihten günümüze Kırâat İlmi*, 92.
[32] Tavîl, *fî ulûmi'l-kırâat,* 60.
[33] Tavîl, *fî ulûmi'l-kırâat,* 63.
[34] Tavîl, *fî ulûmi'l-kırâat,*63-64.

erkek ve kadının sağ elinin kesilmesi: والسارق والسارقة فاقطعوا أيمانهما İbn Mes'ud'un okumasına dayanarak denilmiştir. Bilinen meşhur kırâatte ise ayet, Kur'an'da **"**فاقطعوا أيديهما" şeklindedir ve anlamı:

"Erkek hırsızın ve kadın hırsızın ellerini kesin." Şeklindedir. Şâz okuyuşta "ellerini" yerine özellikle "sâğ ellerini" ifadesi yer aldığı için Âlimler, hırsızın sağ elinin kesileceğine bu kırâati de delil olarak göstermişlerdir

İkinci örnek**:** Hanafîler, yemin kefaretinin oruçlarının peş peşe tutulmasının farz olduğunu İbn Mes'ud'un okumasındaki فصيام ثلاثة أيام متتابعات "Üç gün peş peşe oruç tutun" ayetinden delil olarak getirmişler, oysa bilinen meşhur kırâatte ise ayet, فَصِيَامُ ثَلَاثَةِ أَيَّامٍ **"Üç gün oruç tutmak" şeklindedir.** [35]

Şâz kırâatlerle dil ve nahiv meselelerinde delil getirme

Şaz Kırâatler, Kur'an metni olarak kabul edilmeseler de, Arap dili ve grameri açısından önemli bir başvuru kaynağı sayılmaktadır. Müellif, mütevâtir olmamaları ya da Mushaf-ı Osman yazımına uymamaları, onların dil bakımından değerini düşürmez. Nitekim nahiv'te bu tür kırâatlere sıkça rastlanır ve dil meselelerinde delil olarak kullanılmıştır. Hatta rivayet zincirlerinin sağlamlığı sebebiyle, bazı şiir örneklerinden daha güvenilir görülmüşlerdir. Bununla birlikte, şâz bir kırâat yerleşik dil kurallarıyla çelişir gibi göründüğünde, özellikle Basra ekolüne mensup dilciler ya onu kabul etmemiş ya da kendi sistemlerine uygun şekilde yorumlama yoluna gitmiştir.

Buna karşılık bazı âlimler, mevcut kuralları esas almak yerine, kırâatlerin bizzat dilin bir kullanım biçimini yansıttığını ve bu sebeple dil kaidelerinin kırâatler doğrultusunda gözden geçirilmesi gerektiğini ileri sürmüştür. Müellifin görüşü ise şâz kırâatler kurallara aykırı görünse bile, Arapçanın bir kullanım biçimini temsil eder. Bu yüzden dil açısından yine de delil olabilir. Ve çoğunluk âlimlerin görüşü de bu yönde olduğu belirtmektedir.[36]

SONUÇ

Seyyid Rızk et-Tavîl'in makbul ve şâz kırâatlere dair ortaya koyduğu yaklaşım, kırâat ilmini belli kaide ve kurallara dayanan ciddi bir ilmi disiplin olarak ele aldığını göstermektedir. Tavil, bir kırâatin Kur'an kapsamında kabul edilebilmesi için üç temel şartı taşıması gerektiğini ifade etmiştir. Birincisi, güvenilir ve yaygın bir rivayet zinciriyle Hz. Peygamber'e kadar ulaşmış olmasıdır. Bu, kırâatin sağlam bir nakle dayanmasını ifade eder. İkincisi, okuyuşun Arap dilinin bilinen ve doğru kullanımına uygun olmasıdır. Çünkü Kur'an Arapça indirilmiştir ve dil yapısına aykırı bir okuyuş kabul edilemez. Üçüncüsü ise kırâatin Mushaf-ı Osman'ın yazım şekliyle uyumlu olmasıdır. Sahâbenin üzerinde ittifak ettiği bu yazım biçimi, kırâatler için önemli bir ölçü olarak kabul edilmiştir. Müellif, bu üç şartın birlikte bulunmasının kırâatin sahihliğini garanti altına aldığını vurgular.

On kırâat imamına nispet edilen okuyuşlar bu şartları taşıdığı için makbul kabul edilir. Buna karşılık bu şartlardan birini eksik taşıyan kırâatler ise şâz olarak değerlendirilir. Ancak Tavîl, şâz kırâatleri tamamen değersiz görmez. Onların Kur'an olarak okunamayacağını açıkça ifade etmekle birlikte, ilmî açıdan önemli bir yere sahip olduklarını belirtir. Özellikle tefsir çalışmalarında ayetlerin anlamını açıklamada, fıkıh alanında bazı hükümlerin çıkarılmasından ve nahiv meselelerinde dil kurallarını desteklemede şâz kırâatlerden yararlanılabileceğini vurgular.

Müellif, namazda şâz kırâat okuma meselesinde ise çoğunluk âlimlerin görüşünü benimser ve bunun câiz olmadığını ifade eder. Çünkü ibadetlerde kesinlik ve birlik esastır. Tevâtür derecesine ulaşmamış bir okuyuşun namazda okunması, Kur'an tilaveti açısından yeterli görülmemiştir.

Sonuç olarak Tavîl'in yaklaşımı, hem rivayet merkezli geleneğe bağlı hem de dil ve usûl açısından dengeli bir tutum sergilemektedir. O, Kur'an kırâatlerinin gelişigüzel değil, sağlam rivayet zincirleri ve belirli esaslar çerçevesinde şekillendiğini ortaya koymaktadır. Bu yönüyle çalışması, kırâat ilmi açısından hem klasik mirası yansıtan hem de akademik disiplin içinde değerlendirme sunan önemli bir katkı niteliğindedir.

[35] Tavîl, *fî ulûmi'l-kırâat,* 64.
[36] Tavîl, *fî ulûmi'l-kırâat,* 66.

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MEASURING THE PERFORMANCE AND EFFECTIVENESS OF CLOUD-BASED HRM SYSTEMS WITHIN ENTERPRISE RESOURCE PLANNING FRAMEWORKS

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ABSTRACT

Introduction and Purpose: The integration of cloud-based Human Resource Management Systems (HRMS) into Enterprise Resource Planning (ERP) environments has become a key component of digital transformation strategies in modern organizations. Despite the growing adoption of cloud technologies, there is limited empirical evidence regarding their long-term impact on HR performance and organizational efficiency. This study aims to examine the effectiveness of cloud-based HRMS solutions integrated with ERP systems, identify critical success factors, and evaluate challenges encountered during implementation processes.

Materials and Methods: A mixed-methods research design was employed, combining quantitative and qualitative approaches. Data were collected from 120 organizations that had implemented cloud-based HRMS solutions within ERP platforms. In addition, five in-depth case studies were conducted to gain a comprehensive understanding of implementation experiences, organizational outcomes, and user adoption patterns. The Technology Acceptance Model (TAM) was utilized as a theoretical framework for analyzing enterprise software adoption.

Results: The findings indicate that cloud-based HRMS implementations significantly improve organizational performance by reducing HR operational costs by an average of 32% and increasing process accuracy by 28%. However, several implementation challenges were identified, particularly related to system integration complexities and data security concerns, which accounted for 42% of project delays. Furthermore, user resistance emerged as a major barrier, affecting approximately 68% of first-year deployments. The results suggest that phased implementation strategies, enhanced security measures, and employee-centered system design contribute substantially to successful adoption and long-term effectiveness of cloud-based HRMS solutions.

Discussion and Conclusion: The findings indicate that cloud-based HRMS integration within ERP systems significantly improves operational efficiency and process accuracy while reducing HR-related costs. However, challenges related to system integration, data security, and user resistance remain critical factors affecting implementation success. Therefore, organizations should adopt phased implementation strategies and prioritize employee engagement to achieve sustainable digital transformation outcomes.

Key Words: Tam Theory, Digital Transformation, Cloud Hrms, Erp İntegration, İmplementation Metrics

PROTECTIVE EFFECT OF THYMOQUINONE AGAINST 2,3,7,8-TETRACHLORODIBENZO-p-DIOXIN-INDUCED PANCREATIC INJURY

2,3,7,8-TETRAKLORODİBENZO-p-DİOKSİN İLE İNDÜKLENEN PANKREAS HASARINA KARŞI TİMOKİNONUN KORUYUCU ETKİSİ

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ABSTRACT

Purpose: 2,3,7,8-Tetrachlorodibenzo-p-dioxin (TCDD) is a persistent environmental pollutant associated with multiorgan toxicity. This study assessed TCDD-induced pancreatic histopathology and active caspase-3 immunoreactivity and the potential protective effect of thymoquinone.

Materials and Methods: This evaluator-blinded secondary analysis included archival pancreatic tissues from 32 adult male Wistar albino rats (250–350 g) in control, thymoquinone, TCDD, and TCDD+thymoquinone groups (n=8/group). TCDD (1 µg/kg/day) and thymoquinone (50 mg/kg/day) were administered by oral gavage once daily for 30 days. Acinar degeneration and necrosis, vacuolization, inflammatory infiltration, and islet damage were semiquantitatively scored in hematoxylin-eosin-stained sections. Active caspase-3 immunoreactivity was assessed using the H-score method by a histologist blinded to group allocation. Archival tissue use was approved by the İnönü University Faculty of Medicine Local Ethics Committee for Animal Experiments (July 6, 2026; decision no. 2026/7-16). Data were expressed as median (minimum–maximum) and analyzed using the Kruskal–Wallis and Conover post hoc tests.

Results: Total histological damage scores were 0 (0–0), 0 (0–0), 5 (4–6), and 1 (1–2) in the control, thymoquinone, TCDD, and TCDD+thymoquinone groups, respectively ($p<0.001$). Acinar active caspase-3 H-scores were 10 (1–20), 10 (1–10), 210 (180–270), and 100 (80–120), whereas islet scores were 1 (1–10), 1 (1–10), 95 (80–140), and 50 (20–120), respectively (both $p<0.001$). Histological damage and active caspase-3 H-scores were lower in the TCDD+thymoquinone group than in the TCDD group ($p<0.05$).

Conclusion: TCDD caused marked exocrine and endocrine pancreatic injury and increased active caspase-3 immunoreactivity. Thymoquinone attenuated these changes, indicating protection against TCDD-associated pancreatic injury.

Key Words: TCDD; thymoquinone; pancreas; active caspase-3; apoptosis; histopathology

ÖZET

Amaç: 2,3,7,8-Tetraklorodibenzo-p-dioksin (TCDD), çoklu organ toksisitesiyle ilişkili kalıcı bir çevresel kirleticidir. Bu çalışmada, TCDD'nin pankreasta oluşturduğu histopatolojik değişiklikler ve aktif kaspaz-3 immünreaktivitesi ile timokinonun olası koruyucu etkisi değerlendirildi.

Gereç ve Yöntem: Bu değerlendirici-kör sekonder analize, kontrol, timokinon, TCDD ve TCDD+timokinon gruplarındaki 32 erişkin erkek Wistar albino sıçana ait arşiv pankreas dokuları dahil edildi (250–350 g; n=8/grup). TCDD (1 µg/kg/gün) ve timokinon (50 mg/kg/gün), 30 gün boyunca günde bir kez oral gavaj yoluyla uygulandı. Hematoksilen-eozin boyalı kesitlerde asiner dejenerasyon ve nekroz, vakuolizasyon, inflamatuvar infiltrasyon ve adacık hasarı yarı nicel olarak skorlandı. Aktif kaspaz-3 immünreaktivitesi, grup bilgisine kör bir histolog tarafından H-skor yöntemiyle değerlendirildi. Arşiv dokularının kullanımı, İnönü Üniversitesi Tıp Fakültesi Hayvan Deneyleri Yerel Etik Kurulunun 06.07.2026 tarihli ve 2026/7-16 sayılı kararıyla uygun bulundu. Veriler medyan (minimum–maksimum) olarak sunuldu ve Kruskal–Wallis ile Conover post hoc testleri kullanılarak analiz edildi.

Bulgular: Toplam histolojik hasar skorları kontrol, timokinon, TCDD ve TCDD+timokinon gruplarında sırasıyla 0 (0–0), 0 (0–0), 5 (4–6) ve 1 (1–2) idi ($p<0,001$). Asiner hücrelerde aktif kaspaz-3 H-skorları sırasıyla 10 (1–20), 10 (1–10), 210 (180–270) ve 100 (80–120); adacıklardaki skorlar ise 1 (1–10), 1 (1–10), 95 (80–140) ve 50 (20–120) idi (her iki parametre için $p<0,001$). Histolojik hasar ve aktif kaspaz-3 H-skorları, TCDD+timokinon grubunda TCDD grubundan daha düşüktü ($p<0,05$).

Sonuç: TCDD, pankreasın ekzokrin ve endokrin bölümlerinde belirgin hasara ve artmış aktif kaspaz-3 immünreaktivitesine yol açtı. Timokinon bu değişiklikleri azaltarak TCDD ile ilişkili pankreas hasarına karşı koruyucu etki gösterdi.

Anahtar Kelimeler: TCDD; timokinon; pankreas; aktif kaspaz-3; apoptoz; histopatoloji

THE EVOLUTION OF THE CIRCUMGALACTIC MEDIUM ACROSS COSMIC TIME

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ABSTRACT

We present a comparative study of neutral hydrogen (H I) and triply ionized carbon (C IV) in the circumgalactic medium (CGM) across cosmic time, using samples at median redshifts of $z \approx 3.3$ and $z \approx 0.06$. Our results reveal a striking evolution in the spatial extent and ionization structure of the CGM from the early universe to the present epoch. At high redshift, the CGM shows nearly unity H I covering fractions extending to 200 pkpc and relatively flat C IV distributions, indicating an extended, multiphase medium sustained by active gas accretion and efficient metal transport. At low redshift, both H I and C IV exhibit strong radial declines, with metal absorption increasingly confined to the inner halo. Stacking 33 low-redshift systems yields no significant C IV detection, placing a 3σ upper limit of $\log N(\text{C IV}) \leq 12.1$ cm^{-2} on diffuse metal-bearing gas. Photoionization modeling supports a transition from a denser, more extended neutral phase at high redshift to a more ionized, centrally concentrated CGM at low redshift. These findings indicate the CGM evolves from a dynamically active, extended gas reservoir into a virialized, compact, highly ionized environment, underscoring its critical role in governing gas and metal exchange that drives galaxy evolution.

Keywords: Circumgalactic Medium (CGM), Cosmic Evolution, Quasar Absorption Spectroscopy.

THE PLACE OF WATER KEFIR AMONG FERMENTED BEVERAGES, ITS PRODUCTION AND THERAPEUTIC PROPERTIES

FERMENTE İÇECEKLER ARASINDA SU KEFİRİNİN YERİ, ÜRETİMİ VE TERAPÖTİK ÖZELLİKLERİ

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ÖZET

Fermente içecekler, mikroorganizmaların (özellikle maya ve laktik asit bakterilerinin) şekerleri metabolize ederek organik asit, alkol, gaz ve aromatik bileşikler üretmesiyle ortaya çıkan ürünlerdir ve üretimleri insanlık tarihiyle eşdeğer bir geçmişe uzanmaktadır. Şarap ve bira gibi alkol, kefir gibi laktik asit fermantasyonuna dayalı içecekler ve sirke gibi asetik asit fermantasyonuna dayalı ürünler bu içeceklerin başlıca temsilcileridir. Su kefiri, su kefiri tanelerinin su, şeker, kuru meyve ve limon gibi katkılarla birlikte oda sıcaklığında 2-4 gün süren anaerobik fermantasyonuyla üretilen; meyvemsi, hafif asidik, hafif tatlı, gazlı ve hafif alkol içeren bir içecektir. Standart bir üretim yöntemi bulunmaması nedeniyle mikroflorası kullanılan hammaddelere ve fermantasyon koşullarına göre değişkenlik gösterir. Temel bileşenleri arasında karbonhidratlar, laktik asit ve asetik asit gibi organik asitler, etanol, karbon dioksit ve aromatik bileşikler yer alır. Süt kefirinden farklı olarak su kefiri, şekerli su ortamında fermente edilir ve protein içeriği, viskozitesi daha düşüktür. pH değeri fermantasyon süresince düşerek asiditeyi artırır. Su kefiri taneleri, LAB, mayalar ve zaman zaman asetik asit bakterilerinden oluşan simbiyotik bir topluluktur. Süt kefiri tanelerinde *Lactobacillus kefiranofaciens* gibi süt kaynaklı laktobasiller baskınken, su kefiri tanelerinde *Lactobacillus ruminis*, *Bacillus methanolicus* ve *Gluconobacter* gibi bakteriler ile *Pichia kudriavzevii* ve *Saccharomyces cerevisiae* gibi mayalar öne çıkar. Su kefiri tanelerinde *Gluconobacter* türleri levansucrase enzimleri aracılığıyla prebiyotik özellikte fruktanlar üretirken, süt kefirinde *Lactobacillus kefiranofaciens* kefiran polisakkaritini oluşturur. Su kefiri, probiyotik özellikleriyle bağırsak mikrobiyotasını olumlu etkileyebilecek, anti-inflamatuar, antioksidan ve antimikrobiyal etkiler gösterebilecek, kan şekeri kontrolü sağlayabilecek, kolesterol düşürücü etki ve yara iyileştirici özellikler taşıyan bir içecek olarak değerlendirilmektedir. Bağırsak-mikrobiyota-beyin ekseni çerçevesinde su kefiri tüketiminin irritabl bağırsak sendromu semptomlarını ve mental sağlığı olumlu etkileyebileceği yönünde çalışmalar sürmektedir. Bu derlemede, su kefirinin üretimi, özellikleri ve sağlık üzerine etkileri incelenmektedir. Ancak su kefirinin sağlık etkilerine ilişkin doğrudan çalışmalar sınırlıdır ve daha fazla *in vitro* ve *in vivo* araştırmaya ihtiyaç duyulmaktadır.

Anahtar sözcük: Su kefiri, fermente içecek, Terapötik Etki

ABSTRACT

Fermented beverages are products that arise when microorganisms (particularly yeasts and lactic acid bacteria) metabolize sugars to produce organic acids, alcohol, gas, and aromatic compounds, and their production dates back as far as human history itself. Alcoholic beverages such as wine and beer, drinks based on lactic acid fermentation such as kefir, and products based on acetic acid fermentation such as vinegar are the main representatives of these beverages. Water kefir is a fruity, mildly acidic, mildly sweet, carbonated beverage containing a small amount of alcohol, produced through the anaerobic fermentation of water kefir grains together with water, sugar, dried fruit, and additions such as lemon, at room temperature for 2-4 days. Since there is no standard production method, its microflora varies

depending on the raw materials used and the fermentation conditions. Its main components include carbohydrates, organic acids such as lactic acid and acetic acid, ethanol, carbon dioxide, and aromatic compounds. Unlike milk kefir, water kefir is fermented in a sugary water medium and has lower protein content and viscosity. The pH value decreases over the course of fermentation, increasing acidity. Water kefir grains are a symbiotic community composed of LAB, yeasts, and occasionally acetic acid bacteria. While milk-derived lactobacilli such as *Lactobacillus kefiranofaciens* dominate in milk kefir grains, bacteria such as *Lactobacillus ruminis*, *Bacillus methanolicus*, and *Gluconobacter*, along with yeasts such as *Pichia kudriavzevii* and *Saccharomyces cerevisiae*, are prominent in water kefir grains. In water kefir grains, *Gluconobacter* species produce prebiotic fructans via levansucrase enzymes, while in milk kefir, *Lactobacillus kefiranofaciens* forms the kefiran polysaccharide. Water kefir is regarded as a beverage with probiotic properties that may positively affect the gut microbiota, exhibit anti-inflammatory, antioxidant, and antimicrobial effects, help control blood sugar, have cholesterol-lowering effects, and possess wound-healing properties. Within the framework of the gut-microbiota-brain axis, studies are ongoing regarding the potential positive effects of water kefir consumption on irritable bowel syndrome symptoms and mental health. This review examines the production, properties, and health effects of water kefir. However, direct studies on the health effects of water kefir are limited, and further *in vitro and in vivo* research is needed.

Key Words: Water Kefir, Fermented Beverage, Therapeutic Effect

GİRİŞ

Farklı kıtalarda yaşayan farklı topluluk ve bölgenin, kendine özgü kültürlerine ve bitkisel/hayvansal kaynaklı yenilebilir ham maddelere erişimlerine bağlı olarak benzersiz ve farklı yiyecek ve beslenme alışkanlıkları vardır. Özellikle dinler, ırklar ve etnik kökenler, yiyecek alışkanlıkları üzerinde güçlü bir etkiye sahiptir. Bu nedenle, domuz eti ve diğer etler, hayvansal süt ve alkol de dahil olmak üzere çok çeşitli yiyecek ve içeceklere tabular ve diğer kısıtlamalar uygulanmaktadır. Genel olarak, yiyecek alışkanlıkları, bu bölgelerde tüketilen baskın tahıl bazlı yiyecek türüne göre dünyada üç ana beslenme kültürüne ayrılabilir: (a) Doğu Asya'da ana besin maddesi olarak buharda pişirilmiş pirinç, (b) Batı Asya, Avrupa, Kuzey Amerika ve Avustralya'da buğday veya arpa bazlı ekmekler ve (c) Afrika ve Güney Amerika'da sorgum veya mısırdan hazırlanan lapalar ve Afrika'da manyok ve kök/yumru bazlı temel besinler. Alternatif olarak, hayvansal süt tüketimi de kültürel farklılıkları ayırt edebilir. Dolayısıyla, süt ve süt ürünleri tüketimi Avrupalılar, Hintliler, Semitler ve Kuzey Orta Asyalılar arasında yaygınken, Moğol kökenli ve diğer uzak doğu Asya topluluklarının çoğunluğu tarafından hayvansal süt nadiren tüketilmektedir. Özellikle fermente gıdalar için, fermantasyonun nasıl başlatıldığı, farklı kültürler arasında ayrım yapmanın bir başka yolunu sunmaktadır. İnsanlık tarihinin büyük bir bölümünde, fermente gıdalar ve alkollü içecekler, geleneksel fermantasyon yoluyla bitkisel veya hayvansal kaynaklardan üretilmiştir. Fermantasyon, doğal veya kendiliğinden fermantasyona veya daha önce fermente edilmiş bir ürünün parçalarının taze bir substrata eklendiği geri besleme yöntemine dayanmıştır. Geleneksel fermente gıdaların ve alkollü içeceklerin çoğunun hala evde üretildiği ve bu geleneksel fermantasyon yöntemlerine dayandığı tahmin edilmektedir. Ancak, 20. yüzyılda başlangıç kültürleri kullanılabilir hale gelmiş, günümüzde özellikle Batı'da şarap, süt ürünleri ve et dahil olmak üzere endüstriyel fermantasyonlarda yaygın olarak kullanılmaktadır (Tamang vd., 2020).

Fermente içecekler, temel olarak mikroorganizmaların (özellikle maya ve laktik asit bakterilerinin) şekerleri metabolize ederek organik asit, alkol, gaz ve çeşitli aromatik bileşikler üretmesiyle ortaya çıkan ürünlerdir. Bu süreç hem içeceğin korunmasını sağlar hem de lezzet ve aroma profiline katkıda bulunur (Pereira vd., 2024). Fermente içecek üretiminin kökeni insanlık tarihiyle eşdeğer bir geçmişe uzanmakta olup, farklı coğrafyalarda farklı hammaddeler kullanılarak geliştirilmiştir. Üzümden elde edilen şarap ile arpa kaynaklı bira bu duruma verilebilecek en bilinen örnekler arasındadır ve binlerce yıldır hem kültürel hem de ekonomik açıdan değer taşımaktadır (Schifferdecker vd., 2014). Bu süreçte *Saccharomyces cerevisiae* türü mayalar alkolik fermentasyonun temel aktörleri olarak bilinirken, laktik asit bakterileri (LAB) özellikle süt ürünleri ve bazı alkolsüz fermente içeceklerde önemli rol oynamaktadır (Abiola vd., 2022).

Fermente ürün üretimi sürecinde rol alan mikroorganizma türü ve kompozisyonu, kullanılan hammaddeye ve fermantasyon koşullarına göre farklılık göstermekte, bu durum da her bir fermente içeceğin kendine özgü duyusal, kimyasal ve fonksiyonel özelliklerini belirlemektedir (Değirmencioğlu, 2020). Bu fermente içecekler arasında su kefiri, standart bir üretim yönteminin bulunmaması nedeniyle mikroflorası kullanılan hammaddelere ve fermantasyon koşullarına bağlı olarak değişkenlik gösteren, meyvemsi, hafif asidik, hafif tatlı, gazlı ve düşük oranda alkol içeren bir içecek olarak öne çıkmaktadır. Su kefiri taneleri; laktik asit bakterileri, mayalar ve zaman zaman asetik asit bakterilerinden oluşan simbiyotik bir mikrobiyal topluluktur (Garofalo vd., 2015). Süt kefirinden farklı olarak su kefiri, şekerli su ortamında fermente edilmekte ve daha düşük protein içeriği ile viskoziteye sahip olmaktadır (Değirmencioğlu, 2020). Su kefirinin; probiyotik özellikleri sayesinde bağırsak mikrobiyotasını olumlu etkileyebileceği, anti-inflamatuar, antioksidan ve antimikrobiyal etkiler gösterebileceği, kan şekeri kontrolüne katkı sağlayabileceği, kolesterol düşürücü etki ve yara iyileştirici özellikler taşıyabileceği bildirilmektedir (Papadopoulou vd., 2024; Cufaoglu ve Erdinc, 2023). Ayrıca bağırsak-mikrobiyota-beyin ekseni çerçevesinde su kefiri tüketiminin irritabl bağırsak sendromu semptomları ve mental sağlık üzerindeki olası olumlu etkilerine yönelik çalışmalar da sürmektedir (Yeramilli vd., 2023; Nguyen vd., 2025). Bununla birlikte, su kefirinin sağlık etkilerine ilişkin doğrudan çalışmaların sınırlı sayıda olması, konunun daha fazla in vitro ve in vivo araştırmayla desteklenmesi gerektiğini ortaya koymaktadır. Bu derlemede, fermente içecekler genel çerçevesi içinde su kefirinin yeri ele alınmakta; üretim süreci, fiziksel ve kimyasal bileşimi, duyusal özellikleri, tane mikrobiyal yapısı, sağlık üzerindeki etkileri ile dünyada ve Türkiye'deki pazar potansiyeli incelenmektedir.

FERMENTE İÇECEKLER

FERMENTE İÇECEKLERİN TARİHÇESİ

Fermente içeceklerin tarihçesi incelendiğinde; insanlık tarihiyle eş zamanlı bir geçmişe sahip olduğu görülür. Arkeolojik verilere göre şarap ve bira gibi alkollü içeceklerin üretimi binlerce yıl öncesine kadar izlenebilmektedir. Fransa topraklarında tespit edilen en eski şarap üretimi kanıtları MÖ 425 yılına kadar tarihlenmekte olup, Roma İmparatorluğu döneminde bağcılığın yaygınlaşmasıyla birlikte fermente içecek üretimi önemli bir ekonomik etkinliğe dönüşmüştür (Estreicher, 2023). Benzer şekilde, Japonya'da sake üretiminde kullanılan *Saccharomyces sake* mayasının Meiji döneminde izole edilmesi ve ardından çeşitli Kyokai maya suşlarının geliştirilmesi, fermente içeceklerin tarihsel evrimine ilişkin dikkat çekici bir örnek oluşturmaktadır (Ohya ve Kashima, 2019).

Bira, MÖ 4000 civarında antik Mısır ve Mezopotamya'da ortaya çıktığı düşünülmektedir. Benzer fermente içecekler MÖ 2000'de Meksika'da ve MÖ 1500'de Sudan'da ortaya çıkmıştır. Genel olarak, bu tarihler çeşitli arkeolojik alanlardan elde edilen kalıntıların arkeolojik ve kimyasal incelemelerine dayanmaktadır. İran'daki arkeolojik alanlardan elde edilen benzer kanıtlar, şarap yapımının daha da erken, MÖ 6000 civarında gerçekleşmiş olabileceğini düşündürmektedir. Güney Amerika'da üretilen alkollü bir içecek olan "Pulque", 1000 yıl önce Azteklerden miras kalmıştır. Hindistan'dan gelen alkollü ürünlerin MÖ 300 ile 75 yılları arasına tarihlendiği belirtilmiştir (Tamang vd., 2020).

Fermente içeceklerin tarihsel gelişim sürecinde, özellikle şarap ve bira üretiminde kullanılan maya türlerinin evrimsel geçmişi ve sınıflandırılması dikkat çekici bir konu başlığıdır. *Saccharomyces* cinsi içerisinde yer alan mayalar, özellikle *Saccharomyces cerevisiae*, fermentasyon uygulamalarında en sık başvurulan mikroorganizma olma özelliğini taşır. Bu türün endüstriyel açıdan değerli olmasının nedeni, yüksek fermentasyon kapasitesi ve farklı ham maddelerden etanol elde edebilme yeteneği sayesinde şarap, bira ve benzeri alkollü içecek üretiminde öncelikli olarak tercih edilmesidir (Nya ve Etukudo, 2023). *S. cerevisiae'ye* yakın akraba türler olan *Saccharomyces uvarum* ve *Saccharomyces kudriavzevii*, düşük sıcaklık koşullarında fermentasyon gerçekleştirebilme kapasiteleriyle diğer türlerden ayrışmakta olup, bu türlerin proteomik ve metabolik yapılarını konu alan araştırmalar fermentasyon etkinliğinin ve nihai ürün kalitesinin iyileştirilmesine yönelik değerli bulgular ortaya koymaktadır (García-ríos vd., 2016). Bira üretiminde kullanılan mayaların taksonomik geçmişi de fermente içecek endüstrisinin şekillenmesinde belirleyici olmuştur. Geçmişte bira mayaları büyük ölçüde fenotipik kriterlere dayalı olarak gruplandırılırken, moleküler biyoloji alanındaki ilerlemelerle birlikte filogenetik esaslı sınıflandırma yöntemleri ön plana çıkmıştır; *Saccharomyces cerevisiae'*nin "üst maya" (top-fermenting),

Saccharomyces carlsbergensis'in ise "alt maya" (bottom-fermenting) olarak nitelendirilmesi, bira üretim sürecinde kalite denetiminin sağlanması açısından önem kazanmıştır (Matoulková ve Šavel, 2007).

MİKROORGANİZMALARIN ROLÜ

Fermente içecek üretiminde rol alan mikroorganizmalar (Tablo 1) yalnız mayalarla sınırlı değildir; laktik asit bakterileri (LAB) de bu süreçte önemli bir konuma sahiptir. LAB grubu genel olarak gram-pozitif, katalaz-negatif yapıda olup anaerobik veya mikroaerofilik koşullarda yaşayabilme özelliğine sahiptir ve özellikle süt bazlı ürünler başta olmak üzere birçok fermente gıdada hem koruyuculuk hem de aroma oluşturma işlevleriyle tanınır (Biçer ve Uçar, 2017; Bintsis, 2018). Fermente içecekler açısından da LAB'lerin katkısı giderek daha fazla önem kazanmaktadır; örneğin kombuça gibi fermente çay ürünlerinde bakteriyel ve mayasal unsurları bir arada barındıran simbiyotik kültürler bulunur ve bu mikroorganizma topluluğu, içeceğin asitlenmesini sağlayarak kendine özgü tat ve koku özelliklerinin oluşumuna katkıda bulunur (Nyhan vd., 2022). Son dönemde LAB'lerin biyokoruyucu ajan olarak gıda muhafazasında kullanılması da öne çıkan konulardan biridir. Bu bakteriler tarafından sentezlenen bakteriyosinler ve organik asitler, patojen mikroorganizmaların çoğalmasını baskılayarak ürünün raf ömrünü uzatmaya yardımcı olmaktadır (Veskovic-moracanin vd., 2014; Strack vd., 2020). LAB'lerin fermentasyon sürecindeki katkısı yalnız asit üretimiyle sınırlı olmayıp, probiyotik özellikleri sayesinde sağlık açısından da değer taşımaktadır. Nitekim bazı LAB suşlarının bağırsak mikrobiyotasını düzenleyerek obezite gibi metabolik rahatsızlıkların yönetiminde faydalı olabileceği bildirilmiştir (Burakova vd., 2022). Bunun yanı sıra, LAB'ler tarafından üretilen ekzopolisakkaritlerin (EPS) hem teknolojik hem de biyolojik açıdan işlevsel olduğu, bu bileşiklerin gıda dokusunu iyileştirmenin ötesinde bağışıklık sistemini destekleyici etkiler de gösterebildiği belirtilmektedir (Werning vd., 2022).

Tablo 1. Bazı Fermente İçecekler ve Kullanılan Mikroorganizmalar (Tamang vd., 2016)

Grup	Tür	İçecek/Uygulama
Bakteri	*Acetobacter aceti* subsp. *aceti*	Sirke
	A. pasteurianus subsp. *pasteurianus*	Sirke, kakao
	L. brevis	Ekmek mayalanması, şarap, süt ürünleri
	L. buchneri	Şarapta malolaktik fermantasyon; ekşi maya
	L. hilgardii	Şarapta malolaktik fermantasyon
	L. kefiri	Fermente süt (kefir), narenciye suyunda acılığın azaltılması
	L. oeni	Şarap
	L. paracasei subsp. *paracasei*	Peynir fermantasyonu, probiyotik peynir, probiyotikler, şarap, et
	L. sakei subsp. *sakei*	Peynir ve et ürünleri fermantasyonu; içecekler
	Oenococcus oeni	Şarapta malolaktik fermantasyon
	Zymomonas mobilis subsp. *mobilis*	İçecekler
Maya	*Candida krusei*	Kefir fermantasyonu; ekşi maya fermantasyonu
	S. bayanus	Kefir fermantasyonu; meyve suyu ve şarap fermantasyonu
	S. florentius	Kefir fermantasyonu
	S. pastorianus	Bira
	S. sake	Sake fermantasyonu
	S. unisporus	Kefir fermantasyonu
	Schizosaccharomyces pombe	Şarap
Küf	*A. niger*	İçecekler, sitrik asit üretimi (gıda katkı maddesi)
	A. oryzae, *A. sojae*	Soya sosu, içecekler; α-amilazlar (gıda katkı maddesi)

SINIFLANDIRILMASI

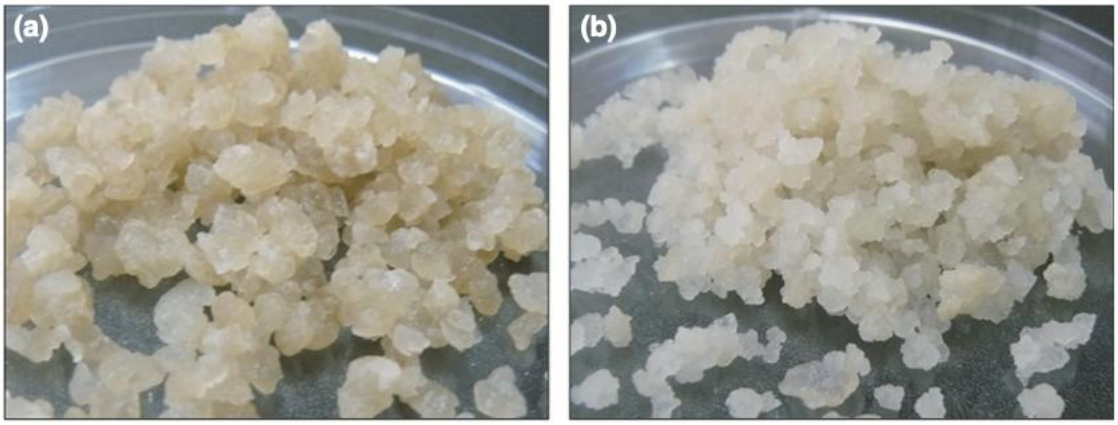
Fermente içeceklerin sınıflandırılmasında genel yaklaşım, kullanılan ham madde türü, fermentasyon çeşidi ve baskın mikroorganizma grubunu temel almaktır. Bu çerçevede alkolik fermente içecekler (şarap, bira, sake, distile içkiler, meyve şarapları), laktik asit fermantasyonuna dayalı içecekler (kefir, fermente süt ürünleri ve bazı geleneksel içecekler) ile asetik asit fermantasyonuna dayalı ürünler (sirke) başlıca kategoriler olarak öne çıkmaktadır (Abiola vd., 2022; Pereira vd., 2024). Elma sirkesi üretim sürecinde kullanılan starter kültürlerde asetik asit bakterileri (AAB) mayalarla birlikte bulunmakta ve bu iki grubun etkileşimi fermentasyon verimini artırmaktadır (Mathew vd., 2019). Şarap üretim sürecinde *Saccharomyces cerevisiae* mayasının yanı sıra *Oenococcus oeni* gibi bakteriler malolaktik fermentasyonu gerçekleştirerek şarabın asitliğini düşürmekte ve böylece lezzet profilinin iyileşmesine katkıda bulunmaktadır (Borneman vd., 2011). Bira üretiminde ise *Saccharomyces* türlerinin dışında *Brettanomyces* gibi non-*Saccharomyces* mayalar, özellikle lambic ve gueuze gibi özel bira çeşitlerinde istenen aroma ve tat özelliklerinin elde edilmesi amacıyla kullanılmaktadır (Kochláňová vd., 2016). Meyve kökenli fermente içecekler de bu sınıflandırmada ayrı bir başlık altında değerlendirilmektedir. Elma, portakal ve ananas gibi meyvelerden elde edilen şaraplar, *Saccharomyces cerevisiae* kullanılmak suretiyle başarıyla üretilebilmektedir. Bu şarapların alkol oranı, pH seviyesi ve şeker içeriği kullanılan meyvenin türüne göre farklılaşabilmektedir (Anyaegbu vd., 2020). Meyve şarabı üretiminde tercih edilen maya türü, fermentasyon başarısı ve elde edilen ürünün kalitesi bakımından belirleyici bir unsurdur (Nya ve Etukudo, 2023).

SU KEFİRİ

SU KEFİRİ TANIMI VE TARİHÇESİ

Su kefiri, su kefiri tanelerinin su, şeker, kuru meyveler, limon gibi katkılarla birlikte oda sıcaklığında 2-4 gün süreyle anaerobik koşullarda fermantasyonuyla üretilen fermente bir içecektir. Meyvemsi, hafif asidik ve hafif tatlı bir tada sahip olan su kefiri, aynı zamanda gazlı ve hafif alkol aroması içeren bir içecektir. Su kefirinin üretiminde kullanılan mikroflora, standart bir üretim yöntemi olmaması nedeniyle kullanılan hammaddeler ve fermantasyon koşullarına bağlı olarak değişkenlik göstermektedir (Değirmencioğlu, 2020). Bu değişkenlik, su kefirinin fonksiyonel gıda üretiminde kullanımını ve sağlık üzerindeki etkilerini doğrudan etkilemektedir.

Su kefir taneleri, 5 ila 20 mm çapında ve düzensiz, karnabahar benzeri bir şekle sahip jelatinimsi yapılardır (Şekil 1). Tanelerin yaklaşık kuru madde içeriği %10 ila %14 (ağırlık/ağırlık) arasında değişebilir. Su kefiri üretiminde fermantasyonlar tipik olarak kendiliğinden gerçekleşir ve su kefir taneleri, kurutulmuş meyveler veya meyve özleri ile birlikte veya bunlar olmadan bir sakaroz ortamına yerleştirilir. Fermantasyonlar 21 ila 30 °C arasında bir sıcaklıkta gerçekleştirilir. Su kefiri taneleri, fermente edilmiş sıvıdan geri kazanılabilir ve taze şekerli su ortamına yerleştirilerek esasen sonsuza kadar yeniden kullanılabilir (Lynch vd., 2021).



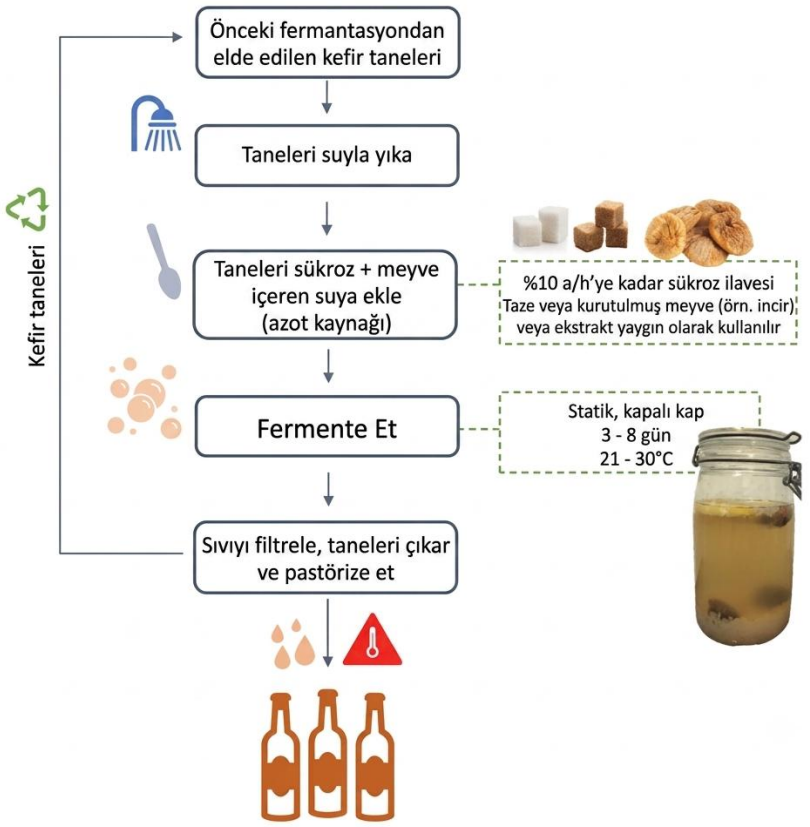
Şekil 1. Su Kefiri Tanesi (Pendón vd., 2022)

Su kefirinin tarihçesi incelendiğinde; fermente içeceklerin insanlık tarihi kadar eski olduğu ve farklı kültürlerde geleneksel olarak tüketildiği görülmektedir. Özellikle süt kefiri, Kafkaslar bölgesinde

yüzyıllardır bilinen ve tüketilen bir ürün iken, su kefiri daha çok Orta Amerika ve Avrupa'nın bazı bölgelerinde geleneksel olarak hazırlanmıştır (Onaran ve Çufaoğlu, 2017). Onaran ve Çufaoğlu (2017), süt kefirinin Kafkaslar'da keşfedildiğini ve günümüzde hala sağlık yararları nedeniyle yaygın tüketildiğini belirtirken, su kefirinin ise farklı coğrafyalarda alternatif bir fermente içecek olarak geliştiğini ifade etmektedir. Ayrıca, Pihurov vd. (2021) su kefirinin ve süt kefirinin mikroorganizma çeşitliliği açısından farklılıklar gösterdiğini ve bu farklılıkların fermentasyon sürecini ve ürün kalitesini etkilediğini vurgulamaktadır.

SU KEFİRİ ÜRETİMİ

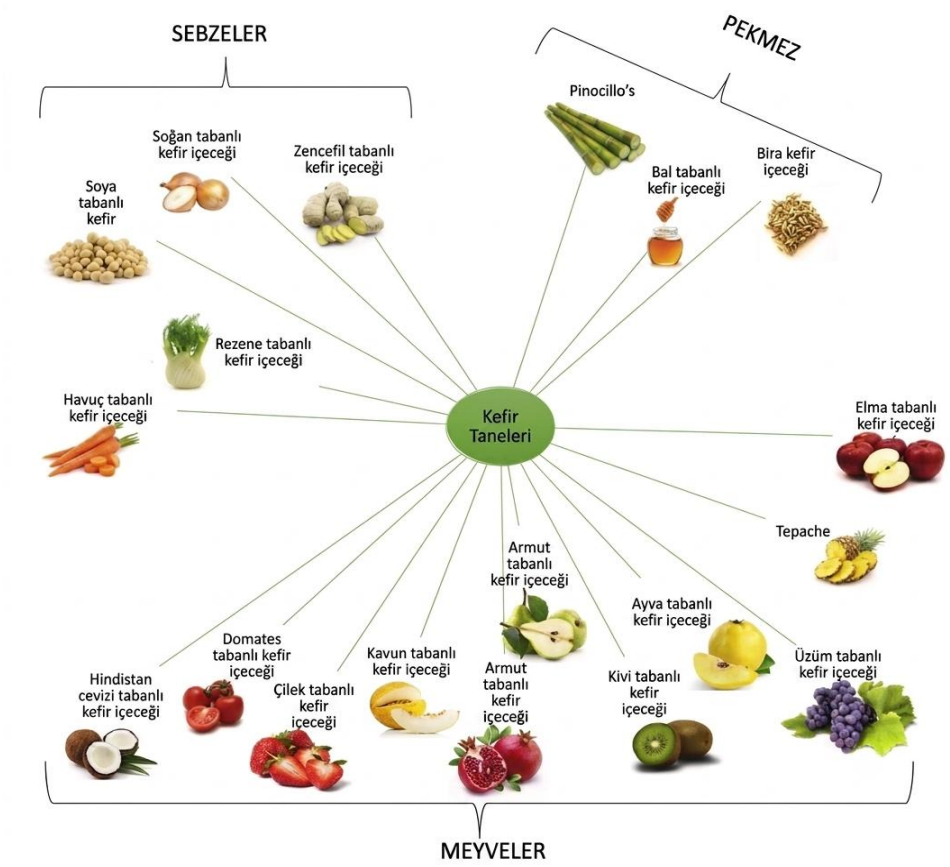
Su kefirinin üretim prosesi (Şekil 2), temel olarak su kefiri tanesi olarak adlandırılan simbiyotik mikroorganizma topluluğunun (bakteri ve maya) şekerli sıvı ortamda fermente edilmesiyle gerçekleşir. Bu tanecikler, laktik asit bakterileri, asetik asit bakterileri ve mayalardan oluşan kompleks bir mikrobiyal ekosistemi barındırır. Kefirin üretiminde kullanılan bu mikroorganizmalar, fermente ortamda laktik asit ve alkol gibi metabolitlerin oluşumunu sağlarlar. Kefirin alkol içeriği genellikle %1.80'in altında olmakla birlikte, bu oran fermentasyon süresi, maya sayısı ve kullanılan kültür tipine bağlı olarak değişkenlik göstermektedir (Sarıca, 2022).



Şekil 2. Su Kefiri Üretim Aşamaları (Lynch vd., 2021)

SU KEFİRİ FİZİKSEL VE KİMYASAL BİLEŞENİ

Su kefirinin fiziksel ve kimyasal bileşenleri, kullanılan suyun kalitesi, ilave edilen şeker türü ve miktarı, kullanılan meyve ve sebze türleri (Şekil 3), fermantasyon süresi ve sıcaklığı gibi faktörlere bağlı olarak değişiklik gösterir. Su kefirinin temel bileşenleri arasında karbonhidratlar (özellikle sukroz), organik asitler (laktik asit, asetik asit), etanol, karbon dioksit ve çeşitli aromatik bileşikler yer alır (Değirmencioğlu, 2020). Fermentasyon sırasında mikroorganizmalar sakarozu parçalayarak laktik asit ve diğer organik asitleri üretirken, karbon dioksit gazı da oluşur. Bu da içeceğin gazlı yapısını sağlar. Ayrıca düşük miktarda etanol oluşumu da su kefirine hafif alkollü bir tat verir (Yerlikaya vd., 2022).



Şekil 3. Su Kefirinde Kullanılabilen Meyveler ve Sebzeler (Fiorda vd., 2017)

Su kefiri üretiminde kullanılan şekerin türü ve miktarı da ürünün kimyasal bileşimini etkiler. Sakarozun mikroorganizmalar tarafından parçalanması sonucu oluşan laktik asit ve diğer organik asitlerin miktarı fermantasyon süresiyle artar. Aynı zamanda etanol konsantrasyonu da artabilir, ancak genellikle %5'in altında kalır (Değirmencioğlu, 2020; Viogenta vd., 2021). Süt kefirinde ise laktozun parçalanması sonucu oluşan laktik asit miktarı daha yüksektir ve aroma bileşenleri (asetaldehit, diasetil) daha belirgindir (Tian vd., 2019).

Fiziksel özellikler açısından incelendiğinde; su kefiri genellikle berrak veya hafif bulanık bir sıvı olup gazlıdır. Fermantasyon süresine bağlı olarak pH değeri düşer ve asidite artar. Su kefirinin viskozitesi süt kefirine kıyasla daha düşüktür çünkü protein içeriği oldukça azdır (Değirmencioğlu, 2020). Süt kefiri ise daha yoğun kıvamlıdır ve viskozitesi yüksek olup pH değeri genellikle 4 civarındadır. Süt içerisindeki proteinlerin fermantasyonla oluşturduğu yapı süt kefirinin karakteristik yapısını oluşturur (Luo vd., 2023).

DUYUSAL ÖZELLİKLERİ

Duyusal özellikler açısından su kefiri, fermente tatlı ve hafif ekşi aromalarıyla tüketiciler tarafından tercih edilmektedir. Fermentasyon süresi ve kullanılan mikroorganizma türleri, ürünün tadını, kokusunu ve dokusunu doğrudan etkiler. Kefirin alkol içeriğinin düşük olması, özellikle alkol tüketimini sınırlayan tüketici grupları için önemli bir avantajdır (Sarıca, 2022). Ayrıca, su kefirinin probiyotik etkisi ve fonksiyonel özellikleri, sağlık bilincine sahip tüketicilerin ilgisini çekmektedir. Bu bağlamda, diyet liflerinin süt ürünlerine eklenmesiyle fonksiyonel özelliklerin artırılması yönündeki çalışmalar da dikkat çekmektedir. Örneğin ayran üretiminde psyllium, bezelye ve yulaf liflerinin kullanımı, ürünün mikrobiyolojik stabilitesini artırırken fonksiyonel değerini yükseltmiştir (Yalçın vd., 2022). Benzer şekilde su kefirinde de lif içeriklerinin artırılması duyusal ve sağlık açısından olumlu etkiler yaratabilir.

Su kefirinde kullanılan mikroorganizmaların ekzopolisakkarit (EPS) üretme yeteneği, ürünün duyusal ve teknolojik özelliklerini önemli ölçüde etkiler. Ekzopolisakkaritler, fermente ürünlerde jelleştirici, emülsifiye edici ve stabilize edici özellikler göstererek ürünün viskozitesini artırır ve serum ayrılmasını

engeller. Ayrıca EPS'ler prebiyotik özellik taşıyarak sindirim sistemine olumlu katkılar sağlarlar (Soyuçok vd., 2016).

SU VE SÜT KEFİRİNİN KARŞILAŞTIRILMASI

Su kefiri ile süt kefiri arasındaki temel farklar (Tablo 2), hem içerik hem de mikrobiyal kompozisyon açısından ortaya çıkar. Süt kefiri, süt bazlı bir ürün olup, süt içerisindeki laktozun fermantasyonu ile oluşurken, su kefiri şekerli su ortamında fermente edilir. Süt kefiri taneleri genellikle *Lactobacillus kefiranofaciens* gibi süt kaynaklı laktobasillerin baskın olduğu bir mikrobiyal topluluğa sahiptir (Garofalo vd., 2015; Nejati vd., 2020). Buna karşın su kefiri tanelerinde ise *Lactobacillus ruminis* ve *Bacillus methanolicus* gibi farklı bakteri türleri baskındır ve maya türleri olarak *Pichia kudriavzevii, Saccharomyces cerevisiae* gibi türler yaygındır (Yerlikaya vd., 2022). Ayrıca su kefiri tanelerinde bulunan *Gluconobacter* türleri gibi asetik asit bakterileri de önemli rol oynar (Jakob vd., 2012).

Su kefirinin aksine süt kefiri temel kimyasal bileşenler arasında laktozun fermantasyonu sonucu oluşan laktik asit, asetaldehit, diasetil gibi aroma bileşenleri bulunur. Süt kefirinin kimyasal bileşimi ayrıca protein, yağ ve mineral içeriği bakımından zengindir. Süt kefirinde *bulunan Lactobacillus kefiranofaciens* gibi türler, polisakkarit üretimiyle (kefiran) süt kefirinin viskozitesini artırırken, bu polisakkaritler aynı zamanda probiyotik özelliklere de katkıda bulunur (Luo vd., 2023; Garofalo vd., 2015). Su kefiri ise daha düşük protein içeriğine sahip olup, polisakkarit yapısı daha çok levans ve diğer fruktanlardan oluşur; bu da su kefirinin farklı bir tekstür ve yapıya sahip olmasına neden olur (Jakob vd., 2012; Bechtner vd., 2020).

Mikrobiyal çeşitlilik açısından su kefiri ve süt kefiri taneleri farklılık gösterir. Süt kefirinde *Lactobacillus kefiranofaciens* başta olmak üzere *Lactococcus lactis, Streptococcus thermophilus* gibi laktik asit bakterileri baskınken (Garofalo vd., 2015; Kalamaki ve Angelidis, 2020), su kefirinde *Lactobacillus ruminis* ve *Bacillus methanolicus* gibi türler ön plandadır (Yerlikaya vd., 2022). Mayalar açısından ise su kefirinde *Pichia kudriavzevii* ve *Saccharomyces cerevisiae* gibi türler yaygınken (Yerlikaya vd., 2022), süt kefirinde *Kazachstania* ve *Kluyveromyces marxianus* gibi türler bulunur (Ding vd., 2022). Bu farklılıklar, her iki ürünün fermantasyon süreci ve sonuç ürünün fiziksel-kimyasal özelliklerini etkiler.

Mikrobiyal kompozisyonun yanı sıra su ve süt kefiri arasındaki farklar üretim tekniklerinde de kendini gösterir. Süt kefiri üretiminde genellikle süt kullanılırken, su kefiri üretiminde şekerli suya kuru meyveler veya limon gibi katkılar eklenerek fermantasyon desteklenir. Bu katkılar hem mikroorganizma çeşitliliğini artırır hem de fermantasyonun hızını etkiler (Değirmencioğlu, 2020). Ayrıca su kefiri üretiminde kullanılan tanelerin orijini ve bakımı da mikrobiyal çeşitlilik üzerinde belirleyici olur; farklı coğrafi bölgelerden gelen taneler farklı mikrobiyal profillere sahip olabilir (Yerlikaya vd., 2022).

Tablo 2. Su kefiri ile süt kefiri arasındaki temel farklar (Lynch vd., 2021)

Su Kefiri	**Süt Kefiri**
Su kefiri taneleri kullanılarak üretilir	Süt kefiri taneleri kullanılarak üretilir
Ana substrat, kurutulmuş meyve veya meyve eklendiği bir sakaroz çözeltisidir	Ana substrat, inek veya keçi sütünden elde edilen bir süttür
Tane ekzopolisakkariti esas olarak α-glukanlardan oluşur	Tane ekzopolisakkariti esas olarak kefirandan oluşur
Tane şeffaf, mukuslu ve daha az dayanıklıdır	Tane beyaz veya krem renginde ve daha dirençlidir
Asetik asit bakterisi türleri daha yaygındır	Asetik asit bakterisi türleri daha az yaygındır
Saccharomyces maya türleri baskındır	Saccharomyces maya türleri az miktarda bulunur
Lactococcus bakterisi türleri nadiren bulunur	Lactococcus bakterisi türleri daha baskındır
Candida maya türleri nadiren bulunur	Candida maya türlerinin bulunma olasılığı daha yüksektir
Daha fazla çeşitlilikte substrat fermente edilebilir	Fermente edilebilecek farklı substratlar açısından çeşitlilik daha azdır.
Vegan veya laktoz intoleransı olan tüketiciler için uygundur	Vegan veya laktoz intoleransı olan tüketiciler için uygun değildir

SU KEFİRİ TANELERİNİN MİKROBİYAL YAPISI

Su kefiri taneleri, doğal polisakkarit ve protein matrisi içinde simbiyotik bir ilişki içerisinde bulunan laktik asit bakterileri (LAB), mayalar ve zaman zaman asetik asit bakterilerinden oluşan kompleks bir mikrobiyal topluluktur (Tablo 3) (Garofalo vd., 2015). Bu mikrobiyal topluluk, su kefirinin karakteristik özelliklerini belirleyen temel unsurlardan biridir. Su kefiri tanelerinde bulunan mikroorganizmalar, fermantasyon sürecinde şekerleri enerji kaynağı olarak kullanarak çeşitli metabolitler üretirler. Bu metabolitler arasında organik asitler, karbon dioksit ve düşük miktarda alkol yer alır ki bu da su kefirine özgü tat ve aroma profiline katkıda bulunur (Yerlikaya vd., 2022).

Tablo 3. Su kefirinin mikrobiyal çeşitliliği (Lynch vd., 2021)

Laktik asit bakteri türleri	Asetik asit bakteri türleri	Diğer bakteri türleri	Maya türleri
Lactobacillus (Lb.) brevis, Streptococcus (St.) lactis	-	-	*Saccharomyces (S.) cerevisiae*
Lb. casei, Lb. hilgardii, Leuconostoc (Leuc.) mesenteroides ssp. dextranicum, Lb. casei ssp. rhamnosus, Lb. plantarum, St. lactis, St. cremoris	-	-	*Zygosaccharomyces (Zy.) florentinus, Torulaspora pretoriensis, Kloeckera (Hanseniaspora) apiculata, Candida (C.) lambica, C. valida*
Lb. casei subsp. casei, Lb. casei subsp. pseudoplantarum, Leuc. mesenteroides subsp. mesenteroides, Pediococcus spp., Lb. buchneri, Lb. fructivorans, Lb. collinoides	-	-	*S. cerevisiae, Hanseniaspora (H.) valbyensis, H. vinae, S. florentinus, S. pretoriensis*
Kısa ve uzun çubuk şekilli laktobasiller; bakteriyel kokların baskınlığı	-	-	*Zy. florentinus, H. valbyensis*
Lb. paracasei, Lb. parabuchneri, Lb. kefiri, Lactococcus lactis, Lb. casei, Lb. paracasei subsp. paracasei, Leuc. citreum, Lb. paracasei subsp. tolerans, Lb. buchneri	*Acetobacter (A.) lovaniensis*	-	*S. cerevisiae, Kluyveromyces lactis, Lachancea meyersii, Kazachstania (Kz.) aerobia*
Lb. hordei, Lb. nagelii, Leuc. mesenteroides, Leuc. citreum	*A. fabarum, A. orientalis*	-	*S. cerevisiae, Lachancea (La.) fermentati, H. valbyensis, Zygotorulaspora (Z.) florentina*
Lb. casei, Lb. sunkii, Lb. kefiri, Lb. satsumensis, Lb. paracasei, Lb. helveticus, Lb. buchneri	*Gluconobacter (G.) liquefaciens, A. lovaniensis*	*Bacillus cereus*	*S. cerevisiae, Pichia (P.) cecembensis, Yarrowia lipolytica, P. membranifaciens, P. caribbica, P. fermentans, C. valdiviana, Zy. (Lachancea) fermentati, Kz. aerobia*
Lactobacillus, Leuconostoc, Bifidobacterium	*Gluconacetobacter, Acetobacter*	*Zymomonas*	*Dekkera anomala, Dekkera (D.) bruxellensis, S. cerevisiae, H. valbyensis, H. vineae, La. fermentati, Torulaspora, Zy. lentus, Meyerozyma caribbica*
Lb. hordei, Lb. nagelii, Lb. hilgardii, Lb. satsumensis, Leuc. citreum, Leuc. mesenteroides, Bifidobacterium (B.) psychraerophilum	-	-	-
Lb. casei/paracasei, Lb. hilgardii, Lb. harbinensis, Lb. nagelii, Lb. hordei/mali, B. psychraerophilum/crudilactis	*A. lovaniensis/fabarum*	-	*S. cerevisiae ve D. bruxellensis*
Lb. casei, Lactococcus lactis, Lb. perolens, Lb. parafarraginis, Lb. diolivorans, Oenococcus (O.) oeni, Lb. kefiranofaciens, Lb. hilgardii, Lb. satsumensis, Lb. nagelii, O. kitaharae	-	*Klebsiella pneumoniae, Enterobacter ludwigii*	-
Lb. perolens, Lb. rhamnosus	*Gluconobacter japonicus*	*Bacillus cereus*	*S. cerevisiae, C. ethanolica, D. bruxellensis*

Laktik asit bakteri türleri	Asetik asit bakteri türleri	Diğer bakteri türleri	Maya türleri
Lb. hilgardii, Lb. nagelii, Lb. satsumensis, Lb. harbinensis, L. paracasei, Lb. mali/hordei, Oenococcus spp., B. aquikefiri	-	-	*S. cerevisiae, Z. florentina, D. bruxellensis*
Lb. ghanensis, Lb. casei/paracasei, Lb. hilgardii	*A. orientalis, A. tropicalis ve A. okinawensis*	*Pseudarthro-bacter chloro-phenolicus*	*S. cerevisiae, C. californica ve P. membranifaciens*
Lb. paracasei, Lb. hilgardii, Lb. nagelii, Lb. harbinensis, B. aquikefiri	*G. roseus/oxydans, A. indonesiensis, A. fabarum*	-	*S. cerevisiae, D. bruxellensis*
Lb. harbinensis, Lb. hilgardii, Lb. nagelii, Lb. paracasei, Lb. hordei/mali, B. aquikefiri, Candidatus O. aquikefiri	-	-	*S. cerevisiae, D. bruxellensis*
Lb. hilgardii, Lb. nagelii, Lb. paracasei, Leuc. pseudomesenteroides, Lb. harbinensis, Lb. mali/hordei, B. aquikefiri	-	-	*S. cerevisiae, D. bruxellensis*

Su kefiri tanelerinin mikrobiyal yapısı incelendiğinde; *Lactobacillus* türlerinin yanı sıra *Bacillus methanolicus* gibi sporluların da bulunduğu görülür. Bu durum su kefirinin dayanıklılığını artırırken, fermantasyon sürecinde farklı metabolik yolların kullanılmasına olanak tanır (Yerlikaya vd., 2022). Ayrıca su kefiri tanelerinde bulunan *Gluconobacter* türleri levansucrase enzimleri aracılığıyla yüksek moleküler ağırlıklı fruktanlar (levan) üretirler ki bu bileşikler prebiyotik özelliklere sahiptir (Jakob vd., 2012). Süt kefirinde ise *Lactobacillus kefiranofaciens* tarafından üretilen kefiran polisakkaritleri benzer şekilde probiyotik etki gösterir (Luo vd., 2023).

Su kefiri tanelerinin mikrobiyal yapısının detaylı incelenmesi için kültür bağımsız yöntemlerin kullanılması önemlidir. Yüksek verimli dizileme teknikleri ile yapılan çalışmalar, su kefiri tanelerindeki bakteri ve maya topluluklarının çeşitliliğini ortaya koymuştur. Örneğin metagenomik analizler, *Lactobacillus ruminis*'in baskın bakteri türü olduğunu göstermiştir (Yerlikaya vd., 2022). Ayrıca PCR-DGGE gibi moleküler tekniklerle yapılan analizlerde su kefiri tanelerinde *Pichia kudriavzevii* ve *Saccharomyces cerevisiae* gibi maya türlerinin yaygın olduğu saptanmıştır (Wang vd., 2008). Bu teknikler sayesinde kültürle çoğaltılamayan veya az bulunan mikroorganizmalar da tanımlanabilmektedir.

FERMANTASYON ÖZELLİKLERİNİ ETKİLEYEN SUBSTRATLAR VE FAKTÖRLER

Su kefiri üretiminde genellikle incir ve çeşitli meyveler fermantasyon substratı olarak kullanılırsa da havuç, zencefil, rezene ve soğan gibi sebzeler, inek ve keçi sütü gibi süt ürünleri ve soya gibi süt alternatifleri de denenmiştir (Lynch vd., 2021). Bu substratlardan en yaygın kullanılanı taze veya kuru incirdir. Reiß (1990), incirin diğer meyvelere göre daha iyi fermantasyon ortamı sağladığını saptamıştır. Formülasyondan incir çıkarılmasının glikoz tüketimini ve dolayısıyla fermantasyon hızını önemli ölçüde yavaşlattığını, kuru üzüm, hurma ve erik gibi diğer kuru meyvelerle ikame edilmesinin ise fermantasyonu ve laktik asit ve asetik asit üretim hızını değiştirdiğini kaydetmiştir. 18 gün boyunca kefir tane kütlesindeki artışın incir içeren ortam hariç tüm ortamlarda azaldığını gözlemlemiştir. Araştırıcı, incirin, soğuk suda ekstrakte edilebilen ve orta derecede ısıya dayanıklı bir büyüme teşvik edici faktör içerdiğini öne sürmüştür.

Fermantasyonu teşvik edici en etkili faktör kalsiyumdur (Lynch vd., 2021). Laureys vd. (2019), tamponlama kapasitesinin ve kalsiyum içeriğinin, özellikle tane büyümesi (kütle artışı) olmak üzere, su kefiri fermantasyon özelliklerini etkilediğini bulmuşlardır. Fermantasyon için kullanılan suyun daha yüksek tamponlama kapasitesi ve kalsiyum konsantrasyonları, büyümeyi artırmıştır. Tamponlama kapasitesi ve/veya kalsiyum içeriği belirli bir seviyenin altında olduğunda, fermantasyonun başlangıcında bile pH değerleri önemli ölçüde daha düşük belirlenmiş ve geri besleme işlemi boyunca tane büyümesinin azaldığını gözlemlemişlerdir. Sürekli düşük pH'dan kaynaklanan aşırı asit stresi, düşük tane büyümesinin nedeni olarak öne sürülmüş, düşük pH'ın LAB glukansükrazlarının üretimini ve potansiyel olarak aktivitesini inhibe ederek glukan oluşumunu ve buna bağlı tane büyümesini

engellediği öne sürülmüştür. Kalsiyumun olumlu etkisinin, glukansukraz aktivitesini teşvik etmesinden kaynaklanabileceği öne sürülmüştür.

Tamponlama kapasitesinin ve kalsiyum içeriğinin fermantasyon ve tane büyümesi üzerindeki olumlu etkisi göz önüne alındığında, fermantasyon için kullanılan suyun özellikleri dikkate alınmalıdır. Dolayısıyla, daha yüksek oranda kalsiyum ve magnezyum iyonu içeren sert suyun, su kefiri fermantasyonu için daha uygun olması beklenmektedir (Lynch vd., 2021).

Laureys vd. (2018), oksijenin, besin konsantrasyonunun ve besin kaynağının su kefiri fermantasyonu üzerindeki etkisini incelemişlerdir. Asetik asit bakterilerinin (AAB) hem anaerobik hem de aerobik koşullar altında mevcut olduğunu bulmuşlardır. Aerobik koşullar altında AAB daha bol miktarda bulunmuştur. AAB'nin çoğalması, yüksek asetik asit konsantrasyonlarına ve düşük pH değerlerine yol açmış, bu da muhtemelen aşırı asidik strese bağlı olarak, geri besleme döneminde kademeli olarak azalan tane büyümesiyle birlikte görülmüştür. Ek olarak, aerobik fermantasyonlarda AAB türlerinin çoğalması, daha yüksek etil asetat konsantrasyonları ve daha düşük meyvemsi ester konsantrasyonları ile ilişkilendirilmiştir. Düşük besin konsantrasyonları (yani kuru incir eklenmemesi), yavaş fermantasyona ve yüksek toplam artık karbonhidrat konsantrasyonlarına, düşük metabolit konsantrasyonlarına ve yüksek pH değerlerine neden olmuş, geri besleme döngüleri boyunca tane büyümesinde yavaş ve kademeli bir azalma görülmüştür.

SAĞLIK ÜZERİNE ETKİSİ

Su kefiri, son yıllarda sağlık üzerindeki olumlu etkileri nedeniyle giderek artan bir ilgiyle incelenen geleneksel fermente içeceklerden biridir. Su kefiri, şekerli suyun kefir taneleri adı verilen simbiyotik mikroorganizma toplulukları ile fermente edilmesiyle elde edilen, hafif karbonatlı ve probiyotik özellikler taşıyan bir içecektir (Cufaoglu ve Erdinc, 2023).

Son yıllarda, diyet kısıtlamaları, gıda alerjileri veya intoleransları olan bireyler de dahil olmak üzere geniş bir tüketici yelpazesi için uygun, süt ürünü içermeyen fermente bir içecek olarak artan ilgi görmüştür. Bu artan ilgi, karmaşık mikrobiyal ekosistemi ve fermantasyon sırasında üretilen biyoaktif metabolitlerin çeşitliliği ile birlikte, potansiyel fonksiyonel özelliklerini araştıran deneysel araştırmaları teşvik etmiştir (Yerovi-López & Gamero, 2026).

Kefir taneleri, bir polisakkarit jeline bağlı simbiyotik bir mikroorganizma kolonisinden oluşur. Kefir tanelerinin mikroflorası, laktik asit aktif bakteriler (LAB), asetik asit bakterileri (AAB), *Bifidobakteriler* ve *Zymomonas mobilis* gibi çeşitli diğer bakterilerin yanı sıra bazı mantarlar ve mayaları içerir ve bunların tümü örnek konumuna göre değişir. Bu mikroorganizmalar granüllerde bir arada bulunur ve bazıları sıvı faza aktarılabilir. Ayrıca, patojenik değillerdir ve son fermantasyon ürününde bulunan ürettikleri metabolitlerle birlikte, probiyotik özellikler, bağırsak mikroflorasının bileşimini ve düşük dereceli iltihabı düzenleme, çeşitli patojenik mikroorganizmaların büyümesini engelleyerek antimikrobiyal özellikler gösterme ve genel bağışıklık ve metabolik sağlığı iyileştirme gibi çeşitli sağlık yararları sağlarlar; bunlar arasında kefirin kanser önleyici, antihipertansif, antihiperlipidemik, antiinflamatuar ve antioksidan etkileri de yer almaktadır. Araştırmalar, süt kefirinden izole edilen bakterilerin önemli antioksidan aktivite gösterdiğini ve bu içeceğin daha sonraki terapötik özellikleri taşıdığını göstermektedir. Ancak tüketicilerin büyük bir kısmı, alerji veya intolerans gibi tıbbi nedenlerden dolayı veya yalnızca bitki bazlı bir diyeti (vegan diyet) benimsemeleri nedeniyle süt ürünlerini günlük diyetlerinden çıkarmıştır. Kefir fermente süt ürünlerinin sağlık faydalarından yararlanamayan bu tüketiciler için antioksidanlar ve diğer sağlıklı biyoaktiflerin alternatif bir kaynağı su kefiridir. Süt içermeyen su kefiri türevli içecekler, kefirde bulunan simbiyotik mikroorganizmalara atfedilen önemli antioksidan aktiviteler ve diğer sağlık faydaları göstermektedir (Papadopoulou vd., 2024).

Su kefirinin mikroflorası 1980-2011 yılları arasında birçok araştırıcı tarafından incelenmiş olup, *Lactobacillus* gibi bazı bakteriler ve *Saccharomyces cerevisiae* gibi mayalar belirlenmiştir. Birçok ticari su kefir tanesi, *Acetobacter, Bifidobacterium, Leuconostoc* ve *Lactococcus lactis* cinslerine ait diğer bakteri türlerini ve *Dekkera, Hanseniaspora, Lachancea, Zygosaccharomyces* ve *Zygotorulaspora* cinsleri altında sınıflandırılan çeşitli mantar türlerini içermektedir. Kefirin mikroflarasında yer alan laktik asit ve asetik asit bakterilerinin biyoaktif metabolitleri ile sağlık üzerine yararları Tablo 4 ve 5'te özetlenmiştir (Papadopoulou vd., 2024).

Probiyotiklerin genel sağlık üzerindeki etkileri uzun süredir araştırılmakta olup, özellikle bağırsak mikrobiyotasının düzenlenmesi yoluyla bağışıklık sisteminin desteklenmesi, inflamasyonun azaltılması ve metabolik hastalıkların önlenmesi gibi faydalar sağladığı bilinmektedir (Croci vd., 2021). Su kefiri de bu kapsamda, bağırsak mikrobiyotasını olumlu yönde etkileyebilecek bir fermente içecek olarak değerlendirilmektedir (Cufaoglu ve Erdinc, 2023).

Tablo 4. **Su kefiri laktik asit bakterilerinin (LAB) biyoaktif bileşikleri ve sağlık geliştirici özellikleri**

LAB Mikroorganizması	Biyoaktif Bileşikler	Sağlığı Geliştirici Etki
Lactobacillus casei	Bitki yapraklarının mikroorganizma ile fermantasyonu	Gymnemagenin nütrasötikleri; diyabet ve çeşitli metabolik bozuklukların iyileştirilmesine yönelik potansiyel, antimikrobiyal, antitümör, anti-obezite, anti-hiperglisemik ve anti-inflamatuar aktivite
	Fermente ürünler	Probiyotik aktivite
	Mikroorganizmanın kendisi	Fenolik bileşiklerin artışı
		Karotenoid artışı
		Antioksidan aktivite ve biyoaktif metabolit üretiminde artış
	Probiyotik olarak mikroorganizmanın kendisi	Kronik yorgunluk sendromu için probiyotik aktivite
	Mikroorganizmanın konjuge linoleik asitleri	Salmonella ve E. coli ile bağırsak mikrobiyotası bileşimine karşı koruyucu, pro-inflamatuar sitokin azalması
	Propionibacterium ile birlikte mikroorganizma	Aterojenik ve trombojenik indekslerin azalması
Lactobacillus hilgardii	Üretilen EPS (Ekzopolisakkarit)	Glisemik kontrol, kolesterol düşürücü, antikarsinojenik, immünomodülatör ve antioksidan etkiler
	L. hilgardii için LPS ile indüklenen inhibitörler	TNF-α, IL-1β, IL-6 salgılanması
	Probiyotik olarak mikroorganizmanın kendisi	Glikoz ve lipid metabolizmasının geliştirilmesi, pankreas fonksiyonunun iyileştirilmesi (GLP-1 ve PYY peptidi ile)
	Sesbania cannabina'nın L. hilgardii ve diğer LAB'ler ile fermantasyonu	Anti-inflamatuar bileşiklerin üretimi (psoralidin ve alnuston), antioksidan bileşik üretimi (litospermik asit)
Lactobacillus hordei	Diğer LAB suşları ile birlikte mikroorganizma	Antioksidan perspektifler
Lactobacillus kefiri	Mikroorganizmanın kendisi	Pro-inflamatuar ve anti-inflamatuar aktivite
	L. kefiri ile fermente edilmiş süt	Periodontitis inflamasyonunun azalması
	Mikroorganizma suşu	Bağırsak mikrobiyotasının modülasyonu, gastrointestinal hastalıklara karşı etkili

	Üretilen MSR101 EPS	Antitümör aktivitesi
Lactococcus lactis	L. lactis suşları	Sitokin yanıt üretimi ile pro- ve anti-inflamatuar aktivite (TNF-α, IL-6, IFN-γ, iNOS, MIP-2), İnflamatuar Bağırsak Hastalığı (İBH) tedavisi (IL-1β azalması ve IL-8 salgılanması), Sitokin IL-35 ile anti-inflamatuar aktivite, DSS ile indüklenen kolit iyileşmesi, pro-inflamatuar sitokinlerin azalması
	L. lactis peptidleri	Sitokin inhibisyonu ile inflamatuar aktivite (IL-1β, TNF-α, IL-6)
	L. lactis'in proteolitik sistemi	Antioksidan etkiler ve antikoagülan immünoregülatör eylem
	Bağırsak mikrobiyotasındaki L. lactis suşları	Antitümör aktivite ve potansiyel antikanser aktivitesi
	Rekombinant L. lactis	Th1 sitokin üretiminin teşviki, potansiyel antikanser kullanımı
Lactobacillus mali	Fenolik asitler	Fermente balkabağı suyunda artan diyetsel antioksidan içeriği
	Flavonoidler	Artan antioksidan aktivite (FRAP, DPPH)
	Bütirat	İndüklenmiş metabolik değişiklikler, bağırsak sağlığı için potansiyel olarak faydalı
	GLP-1	SIRT-1 ekspresyonunun aktivasyonu ve müteakip antioksidan etkiler
	SIRT-1	Nrf2 aktivasyonu yoluyla hepatik oksidatif stresin baskılanması
	Nrf2	Karaciğerde antioksidan enzimlerin yukarı yönlü düzenlenmesi
	Hem oksijenaz-1 (HO-1)	Artan hepatik antioksidan aktivite
	Mikroorganizmanın kendisi	İnflamatuar sitokinlerin baskılanması
		Treg sitokinlerinin artırılması
	IL-8 salgılanması	Önerilen anti-inflamatuar yetenekler
	M1/M2 makrofajlarının modülasyonu	Obezite ile ilişkili inflamasyonun düzenlenmesi
Lactobacillus nagelii	Farelerde Bretanin ve *L. nagelii* suşları	Gelişmiş lipid profili ve kan glikoz seviyelerinde değişim
	Ürünlerdeki mikroorganizma	Hipertansiyon önleyici, hipoglisemik, kolesterol düşürücü aktiviteye sahip ürünlerde gözlemlenmiştir. Antioksidan etki (polifenol artışı)
	L. nagelii'nin flagellin proteinleri	IL-8 ekspresyonunda azalma, potansiyel anti-inflamatuar aktivite
Leuconostoc mesenteroides	Probiyotik olarak mikroorganizmanın kendisi	Periodontitise karşı oral probiyotik anti-inflamatuar sağlığı geliştirici etkiler, kolondaki inflamatuar yanıtı ve mukozal bariyer fonksiyonunu iyileştirerek ülseratif koliti hafiflettiği için probiyotik faydalar

	Hücre içi ekstraktlar	Domuz epidemik diyare virüsü enfeksiyonlarına karşı konakçı koruması
	EPS	Çeşitli endüstriyel uygulamalarda sağlığı geliştirme beklentileriyle antioksidan, anti-inflamatuar, antitümör etkiler
	Hydroponic Ginseng'in (HPG) *L. mesenteroides* ile fermantasyonu	Artan toplam fenolik ve flavonoid içeriği, gelişmiş antioksidan aktivite, artan anti-inflamatuar etkiler ve gelişmiş anti-adipojenik özelliklere sahip fonksiyonel gıda ürünü
	Sarımsağın *L. mesenteroides* ile fermantasyonu- Etanollü ekstraktlar	Artan toplam fenolik ve flavonoid içeriği, gelişmiş antioksidan aktivite, anti-inflamatuar pektolinarin ve pektolinarigenin seviyelerinde ve salınımında artış, anti-enfeksiyöz etkiler için inflamatuar hücre profilinin modülasyonu sağlayan fonksiyonel gıda ürünü
	L. mesenteroides dekstransükarazı tarafından üretilen ampelopsin glikozitleri	Fonksiyonel kozmetikler için beyazlatıcı etki (tirozinaza karşı rekabetçi inhibisyon), gelişmiş anti-inflamatuar farmasötik özellikler
Leuconostoc citreum	*L. citreum* metabolitleri	Obezite ve metabolik bozuklukların tedavisi
	L. citreum'un bakteriyosin üreten suşları	Antibakteriyel ve anti-inflamatuar aktivite (inflamatuar sitokin ve kemokinlerin azalması)
	L. citreum	Yaşlanma karşıtı, antitümör, antioksidan özellikler (izoflavon biyoaktifleri)
	Üretilen EPS	Antioksidan aktivite
	Üretilen glukansükaraz, glukooligosakkaritler	Prebiyotik ve anti-inflamatuar etki
Oenococcus oeni	Mikroorganizma suşları	Antioksidan aktivite, *E. coli*, *Salmonella typhimurium* ve *Listeria monocytogenes*'e karşı antioksidan ve antibakteriyel etki, Kolit tedavisi için anti-inflamatuar perspektifler
	Elma şıralarında *O. oeni* ile yapılan Malolaktik Fermantasyon (MLF)	Antihipertansif ve antioksidan etki (artan anjiyotensin 1)

Tablo 5. Su kefiri asetik asit bakterilerinin (AAB) biyoaktif bileşikleri ve sağlık geliştirici etkileri

AAB Mikroorganizması	Biyoaktif Bileşik	Sağlığı Geliştirici Etki
Acetobacter fabarum	Kültür süzüntüsü	Doğal gıda koruyucusu ve probiyotik ajan olma potansiyeliyle, gıda kaynaklı patojenik bakterilere karşı antimikrobiyal aktivite
	Süpernatant	Potansiyel probiyotik özelliklerle güçlü antibakteriyel aktivite, önemli gıda kaynaklı küf türlerine karşı antifungal aktivite ve bir gıda

		patojenine karşı antibakteriyel aktivite
	Diğer mikroorganizmaların yanı sıra *A. fabarum* içeren kefir taneleri ile pastörize tam inek sütünün fermantasyonu	Alzheimer benzeri sineklerin hayatta kalma oranını ve nörodejenerasyon indeksini iyileştirdiği için Alzheimer Hastalığına karşı güçlü probiyotik ve terapötik kaynak
Acetobacter orientalis	Diğer mikroorganizmaların yanı sıra *A. orientalis* içeren kefir taneleri ile inek sütünün fermantasyonu	Önemli antioksidan kapasiteye ve güçlü antibakteriyel aktiviteye sahip fonksiyonel gıda ürünü
	A. orientalis ve *Lactococcus lactis* subsp. cremoris suşlarından oluşan Hazar Denizi Yoğurdu bakteri topluluğu ile sütün fermantasyonu	Artan toplam fenolik içerik ve gelişmiş antioksidan aktiviteye sahip fonksiyonel gıda ürünü
	Saccharomyces ve ardından *A. orientalis* ile iki aşamalı soğan suyu fermantasyonu	Artan toplam flavonoid ve polifenol içeriği ile gelişmiş antioksidan aktiviteye sahip fonksiyonel gıda ürünü
Acetobacter pasteurianus	Toplam Fenolik İçerik	Antioksidan aktivite (ABTS ve DPPH)
		Kolon kanseri hücre hatlarında anti-kanser aktivitesi
	Mikroorganizma ile fermente edilmiş sirke	Anti-inflamatuar, LPS ile uyarılmış makrofaj hücrelerinde IL-6 üretiminin inhibisyonu
	Polifenol ve flavonoid içeriği	Yüksek antioksidan aktivite
	EPS (Ekzopolisakkarit)	Güçlü antioksidan kapasite ve anti-tirozinaz aktivitesi
		Gıda ve kozmetik endüstrilerinde potansiyel uygulama
	Mikroorganizmanın kendisi	Alkol kaynaklı bilişsel hasar ve karaciğer yaralanmasının hafifletilmesi
		Bağırsak mikrobiyotası-beyin/karaciğer akslarının modülasyonu
		Nöro-inflamasyonun baskılanması ve bilişsel fonksiyonun iyileştirilmesi
		Serum lipid seviyelerinin ve oksidatif stresin azaltılması
		Anti-inflamatuar, TLR4/MyD88/NF-κB yolağının ve inflamatuar sitokinlerin inhibisyonu

Acetobacter tropicalis	Mikroorganizmanın kendisi	B vitaminleri kaynağı; Anjiyotensin dönüştürücü enzim inhibisyonu, antioksidan ve antibakteriyel aktivite

Yapılan çalışmalar, su kefirinin hem in vitro hem de in vivo ortamda bağırsak mikrobiyota bileşimini ve aktivitesini modüle edebileceğini göstermektedir. I*n vitro* bir çalışmada, insan kolonik fermantasyon modelinde pastörize edilmiş formundaki su kefirinin, *Bifidobacteriaceae* ailesinin üyelerinin büyümesini teşvik ederken, *Lachnoclostridium* ve Eggerthella gibi potansiyel olarak olumsuz cinslerin bolluğunu azalttığını bildirmiştir. Bu bileşimsel değişikliklere, bağırsak homeostazında rol oynayan temel metabolitler olan asetat, propiyonat ve bütirat dahil olmak üzere kısa zincirli yağ asitlerinin (SCFA'lar) üretiminde artış eşlik etmiştir. Fonksiyonel olarak, SCFA'ların artan mevcudiyeti özellikle önemlidir, çünkü bu metabolitler epitel bariyerinin korunmasında, bağışıklık düzenlemesinde ve konak enerji metabolizmasında merkezi roller oynar ve böylece mikrobiyota bileşimsel değişimlerini potansiyel fizyolojik faydalarla ilişkilendirir. *Liquorilactobacillus satsumensis* tarafından üretilen polisakkaritlerin, *bifidobakterilerin* ve laktobasillerin büyümesini seçici olarak uyardığı ve SCFA üretimini artırdığı, işlevsel bir prebiyotik etki gösterdiği rapor edilmiştir (Yerovi-López & Gamero, 2026).

Su kefirinin bağırsak sağlığı üzerindeki etkilerine ilişkin doğrudan çalışmalar sınırlı olsa da, benzer probiyotik fermente içeceklerin bağırsak mikrobiyotasını modüle etme potansiyeli üzerine önemli bulgular mevcuttur. Örneğin, fermente kahverengi pirinç içeceğinin metabolik sendromlu bireylerde bağırsak mikrobiyotasını olumlu yönde değiştirdiği ve kısa zincirli yağ asidi (SCFA) üretimini artırdığı gösterilmiştir. Fermente kahverengi pirinç içeceği tüketiminin *Clostridia* sınıfına ait faydalı bakteri türlerinin sayısını artırdığı ve inflamasyonu azalttığı belirtilmiştir (Akamine vd., 2022). Benzer şekilde, başka bir çalışmada da fermente kahverengi pirinç içeceğinin bağırsak mikrobiyotasını metabolik sendrom hastalarında olumlu yönde modüle ettiği rapor edilmiştir (Masuzaki vd., 2022).

Su kefirinin sağlık üzerindeki etkileri sadece bağırsak sağlığı ile sınırlı değildir. Kefir türlerinin genel olarak anti-inflamatuar, antioksidan, antimikrobiyal ve metabolik hastalıkları önleyici özelliklere sahip olduğu literatürde belirtilmektedir (Azizi vd., 2021). Örneğin, kefirin antienflamatuar ve antioksidan aktiviteleri sayesinde kronik hastalıkların önlenmesinde potansiyel faydaları olduğu ifade edilmektedir (Azizi vd., 2021). Ayrıca kefirin kan şekeri kontrolü, kolesterol düşürücü etkileri ve yara iyileştirici özellikleri de rapor edilmiştir (Ozmeric ve Şahin, 2021).

Su kefirinin kronik metabolik ve inflamatuar hastalıklardaki terapötik potansiyeli deneysel çalışmalarla desteklenmiştir. *In vitro* araştırmalar, metabolik düzenleyici özelliklere sahip kefir kaynaklı suşları tanımlamıştır. Koh vd. (2018) α-glukozidaz aktivitesini inhibe edebilen *Lactiplantibacillus mali*'yi izole etmiş ve bu da yemek sonrası glikoz metabolizmasının modülasyonunda olası bir rolü olduğunu öne sürmüştür. *L. mali*'ye bağışıklık tepkilerinin modülasyonu, antioksidan kapasitenin artırılması, SIRT-1 ve Nrf2 yollarının aktivasyonu, hepatik oksidatif stresin baskılanması ve inflamatuar sitokinlerin düzenlenmesi dahil olmak üzere çok sayıda biyolojik aktivite atfedilmiştir. Glikoz düzenlemesinin ötesinde, önceki çalışmalar, *L. mali* kaynaklı biyoaktif bileşenlerin Th1 sitokin üretimini teşvik edebileceğini, düzenleyici T hücresi (Treg) ile ilişkili sitokinleri uyarabileceğini ve daha geniş immünomodülatör etkiler gösterebileceğini bildirmiş ve bu suşun metabolik ve inflamatuar bağlamlarda pleiotropik fonksiyonel profilini vurgulamıştır (Yerovi-López & Gamero, 2026).

Nrf2, redoks dengesi ve inflamasyon kontrolündeki merkezi rolü nedeniyle diyabet, kanser, nörodejeneratif bozukluklar ve kardiyovasküler hastalık gibi kronik hastalıklarda terapötik bir hedef olarak yaygın olarak incelenmiştir. Su kefiri mikroorganizmaları tarafından üretilen bazı ekstraselüler enzimlerin Nrf2 aktif bölgesine yüksek bağlanma afinitesi gösterdiği ve deneysel koşullar altında bu yol üzerinde potansiyel bir modülatör etki gösterdiği öne sürülmüştür. Bu bulgular, su kefiri kaynaklı bileşenlerin, en azından mekanistik olarak, oksidatif stresle ilgili patolojileri hafifletmeyi amaçlayan stratejilere katkıda bulunabileceğini göstermektedir (Ye vd., 2023).

Oksidatif stres ve inflamasyon, karaciğer ve metabolik hastalıkların ilerlemesinde merkezi bir rol oynayan yakından bağlantılı süreçlerdir. Deneysel kanıtlar, su kefirinin antioksidan, antiinflamatuar ve mikrobiyota düzenleyici özellikleri aracılığıyla bu yolları etkileyebileceğini göstermektedir. Karaciğer

hasarında oksidatif stres ve inflamatuar sinyalizasyon arasındaki sinerjik etkileşim göz önüne alındığında, su kefirine atfedilen çok faktörlü etki mekanizması, karmaşık kronik hastalık durumlarında özellikle önemli olabilir (Yerovi-López & Gamero, 2026).

Su kefiri ve benzeri fermente içeceklerin psikolojik sağlık üzerindeki etkileri de araştırma alanlarından biridir. Bağırsak-mikrobiyota-beyin ekseni kavramı çerçevesinde probiyotiklerin anksiyete ve depresyon gibi durumlarda olumlu etkiler gösterebileceği öne sürülmektedir (Yeramilli vd., 2023). Su kefiri tüketiminin irritabl bağırsak sendromu (IBS) semptomları ve mental sağlık üzerindeki etkilerini inceleyen pilot çalışmalar devam etmektedir (Nguyen vd., 2025). Bu çalışmalar, su kefirinin gastrointestinal semptomları hafifletebileceği ve mental sağlık üzerinde olumlu etkiler yaratabileceği yönünde umut vaat etmektedir (Nguyen vd., 2025).

DÜNYADA VE TÜRKİYEDE POTANSİYELİ

Dünyada su kefiri ve genel olarak kefir ürünlerinin pazar potansiyeli giderek büyümektedir. Özellikle Kafkasya kökenli geleneksel kefir ürünleri, sağlık faydalarının ortaya çıkmasıyla tüm dünyaya yayılmıştır (Sarıca, 2022). Kazakistan gibi Orta Asya ülkelerinde süt ve süt ürünleri sektörü önemli bir ekonomik alan oluştururken, kefir de bu ürünler arasında yer almaktadır. Kazakistan'da inek sütü başta olmak üzere keçi, koyun, kısrak ve deve sütünden çeşitli geleneksel süt ürünleri üretilmekte olup, kefir de yaygın tüketilen fermente ürünler arasında bulunmaktadır. Bu durum Orta Asya pazarında kefirin kültürel ve ekonomik önemini göstermektedir (Koboyeva & Güzeler, 2020)

Türkiye'de ise süt ve süt ürünleri sektörü dinamik bir yapıya sahiptir. Küçükbaş hayvan varlığı ve süt üretimindeki artışlar, yerel süt ürünlerinin çeşitlenmesini sağlamaktadır (Sevinç vd., 2022). Türkiye'de geleneksel süt ürünleri gastronomi açısından önemli bir yere sahip olup, yerel yoğurt türleri gibi ürünlerin farklı tatlılarda kullanımı yaygınlaşmaktadır (Özer vd., 2021). Benzer şekilde su kefiri gibi fermente içeceklerin Türkiye pazarında fonksiyonel gıda talebinin artmasıyla birlikte daha fazla ilgi görmesi beklenmektedir.

Su kefirinin Türkiye'deki pazar potansiyelini değerlendirirken, tüketici bilincinin artması ve sağlıklı yaşam trendlerinin etkisi göz önünde bulundurulmalıdır. Kefirin probiyotik özellikleri ve düşük alkol içeriği, özellikle genç nüfus ve sağlık odaklı tüketiciler arasında tercih edilmesini sağlamaktadır (Sarıca, 2022). Ayrıca yerel üretimin desteklenmesi ve geleneksel yöntemlerin modern üretim teknikleriyle harmanlanması pazardaki rekabet gücünü artırabilir.

Sürdürülebilirlik perspektifinden bakıldığında, alternatif gıda kaynaklarının kullanımı giderek önem kazanmaktadır. Algler gibi biyolojik kaynaklar, yüksek protein, diyet lifi ve omega-3 yağ asitleri içeriği ile fonksiyonel gıdalarda kullanılmak üzere araştırılmaktadır (Şirinyıldız & Yorulmaz, 2022). Su kefiri üretiminde bu tür alternatif bileşenlerin kullanımı, ürünün besin değerini artırarak pazar potansiyelini genişletebilir.

SONUÇ

Fermente içecekler, mikroorganizma türü, hammadde ve fermantasyon koşullarına bağlı olarak büyük bir çeşitlilik göstermektedir. Alkollü fermente içecekler, laktik asit fermantasyonuna dayalı içecekler ve asetik asit fermantasyonuna dayalı ürünler başlıca kategoriler olarak öne çıkmakta; her bir kategoride *Saccharomyces cerevisiae* gibi mayalar ile laktik asit bakterileri ve asetik asit bakterileri belirleyici rol oynamaktadır. Su kefiri özelinde incelendiğinde, standart bir üretim yönteminin bulunmaması nedeniyle mikroflorasının kullanılan hammaddelere ve fermantasyon koşullarına göre değişkenlik gösterdiği, bu değişkenliğin de ürünün fiziksel, kimyasal ve duyusal özelliklerini doğrudan etkilediği görülmektedir. Su kefiri taneleri; *Lactobacillus ruminis, Bacillus methanolicus* ve *Gluconobacter* gibi bakteriler ile *Pichia kudriavzevii* ve *Saccharomyces cerevisiae* gibi mayalardan oluşan simbiyotik bir topluluk barındırmakta, bu yönüyle süt kefirinden hem mikrobiyal kompozisyon hem de kimyasal bileşim bakımından ayrışmaktadır. Su kefirinde *Gluconobacter* türlerinin ürettiği prebiyotik fruktanlar, süt kefirindeki kefiran polisakkaritine karşılık gelen fonksiyonel bir bileşen olarak değerlendirilmektedir. Sağlık etkileri açısından su kefirinin; probiyotik özellikleriyle bağırsak mikrobiyotasını olumlu yönde

etkileyebileceği, anti-inflamatuar, antioksidan ve antimikrobiyal etkiler gösterebileceği, kan şekeri kontrolüne katkı sağlayabileceği, kolesterol düşürücü ve yara iyileştirici özellikler taşıyabileceği literatürde bildirilmektedir. Bağırsak-mikrobiyota-beyin ekseni kapsamında su kefiri tüketiminin irritabl bağırsak sendromu semptomları ve mental sağlık üzerindeki olası etkilerine dair çalışmalar da devam etmektedir. Ancak bu etkilere ilişkin doğrudan ve klinik düzeyde çalışmaların sınırlı sayıda olması, konunun daha fazla *in vitro* ve *in vivo* araştırmayla desteklenmesi gerektiğini göstermektedir. Pazar potansiyeli bakımından, kefir ürünlerinin özellikle Kafkasya kökenli geleneksel üretimden başlayarak dünya genelinde, özellikle Orta Asya ülkelerinde yaygınlaştığı görülmektedir. Türkiye'de ise dinamik yapıya sahip süt ve süt ürünleri sektörü, artan tüketici bilinci ve sağlıklı yaşam trendleri, su kefiri gibi düşük alkollü ve probiyotik özellikli fermente içeceklerin fonksiyonel gıda pazarında daha fazla ilgi görmesine zemin hazırlamaktadır. Sonuç olarak, su kefirinin üretim prosesi, mikroorganizma yapısı ve fermantasyon parametreleri literatürde nispeten detaylı şekilde incelenmiş olmakla birlikte, sağlık üzerindeki etkilerine dair bilimsel kanıtların sınırlı kalması, bu alanda ileri düzey *in vitro* ve *in vivo* çalışmalara duyulan ihtiyacı açıkça ortaya koymaktadır.

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THE EPISTEMOLOGICAL STATUS OF SYNTHETIC KNOWLEDGE: GENERATIVE ARTIFICIAL INTELLIGENCE, TRUTH, AND THE PROVENANCE OF KNOWLEDGE

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ABSTRACT

Generative artificial intelligence is producing increasingly fluent and authoritative texts in academic, professional, and everyday contexts. This study examines a philosophical question rather than a technical one: What epistemological status should be assigned to the content produced by these systems? The article introduces the concept of synthetic knowledge. This concept refers to claim-like outputs produced by statistical language models that lack a direct experiential basis, a knowing subject, or a recoverable connection to original sources. Based on the classical justified-true-belief understanding of knowledge, the verifiable understanding of semantic knowledge, and the social epistemology of testimony, the study argues that synthetic output can mimic the linguistic form of knowledge while lacking two fundamental epistemic conditions: reliable truth tracking and transparent sourcing. Based on the stochastic parrot critique and recent analyzes suggesting that large language models are structurally indifferent to truth, the article argues that hallucination should not be seen merely as an occasional glitch. Instead, it reflects the nature of systems designed to produce plausible continuities rather than determining whether their claims are true. The study also identifies a source issue. Generative outputs often conceal the sources, contexts, and chains of testimony from which their content is statistically derived. This weakens the shared epistemic environment and makes verification more difficult. The technical phenomenon of model collapse is considered a parallel example of this risk. The article concludes by proposing three conditions under which synthetic output can gain real epistemic value: verifiability, traceability, and human approval. These conditions provide a practical framework for evaluating claims produced by machines.

Keywords: synthetic knowledge, generative artificial intelligence, epistemology, truth, testimony, model collapse.

INTRODUCTION

In recent years, generative artificial intelligence, especially large language models, has become part of everyday and professional life. These systems answer questions, draft texts, explain concepts, and sometimes provide references. Their output is often fluent and convincing. In many cases, readers may find it difficult to distinguish it from an expert response. However, fluent language does not guarantee that a claim is true, reliable, or properly justified.

This paper focuses on a philosophical rather than a technical question. It does not primarily examine how language models work or which architecture they use. Instead, it asks: what epistemic status should be assigned to machine-generated content? Can such content be considered knowledge, or does it only resemble knowledge? If it is not knowledge, how should it be distinguished from ordinary error or random information?

To address this question, the paper introduces the concept of synthetic knowledge. This term refers to output produced by statistical language models through the recombination of patterns found in their training data. Such output has the external form of a knowledge claim. However, it is produced without direct experience, a knowing subject, or a clear connection to its original sources. The paper argues that synthetic knowledge may appear similar to knowledge while failing to meet its core epistemic conditions.

The central argument is that synthetic knowledge is neither full knowledge nor simple error. It is a distinct form of output that has the syntax of knowledge but may lack a reliable connection to truth and identifiable origins. The study proceeds in three stages. First, it examines the classical definition of knowledge and its distinction from information. Second, it analyzes the relationship between generative models and truth. Third, it discusses the provenance problem, namely the loss of source transparency in machine-generated content. Finally, the paper proposes practical conditions under which synthetic output may gain genuine epistemic value. This issue is important because the growing circulation of synthetic text affects how people read, cite, teach, and verify information.

CONCEPTUAL FRAMEWORK

What knowledge is: the classical definition and its difficulties

The most enduring definition of knowledge in Western epistemology reaches back to Plato. In the Theaetetus, knowledge is presented as "true judgement accompanied by an account (logos)" [1] (Plato, Theaetetus, 201c–d). Modern philosophy has distilled this into the formula of justified true belief: to know something, one must, first, believe it; second, the belief must be true; and third, it must be justified. On reflection, none of these conditions suffices on its own. A belief that is true but unjustified is merely a lucky guess; a belief that is justified but false is not knowledge at all.

This classical formula has not gone unchallenged. In a short but influential paper, Edmund Gettier showed that “a person can hold a justified true belief and yet still fail to know, because the truth of the belief may be accidental” [2] (Gettier, 1963, p. 121). The value of Gettier's problem for us is this: it clarifies that knowledge depends not only on the outcome but on the process that leads to it. For knowledge, it is not enough that the answer be true; there must be an appropriate, reliable connection between the truth of the answer and the cause that produces it. This subtlety will be the key to the argument that follows.

From information to knowledge: the veridicality condition

Before discussing knowledge, it is necessary to distinguish it from related concepts. Three levels are commonly identified: data, information, and knowledge. Data consist of unprocessed signs or observations. Information is data that has been organized and given meaning. Knowledge goes further, as it involves information that is justified, understood, and accepted by a knowing subject. Truth is the key condition linking these levels.

Luciano Floridi’s theory of semantic information provides an important perspective on this issue. According to Floridi, “information must be not merely well-formed and meaningful but also truthful (veridical) data; false content, strictly speaking, does not count as information at all” [3] (Floridi, 2011). Although this position may initially seem strict, it highlights an important point: when something is described as information, its truthfulness is already assumed.

This framework offers a useful criterion for assessing the output of generative artificial intelligence. The key question is whether a model’s output meets the condition of veridicality or merely imitates the language and structure of truthful content. Generative models can produce coherent and convincing statements. However, they do not have an internal mechanism that guarantees the truth of those statements. They learn statistical patterns in language, not the direct relationship between a claim and the world. Therefore, the main problem is not simply that a model may produce false information. It is that the model can reproduce the appearance of reliable information without being able to verify whether its claims are true.

[1]Plato. (1997). Theaetetus (M. J. Levett, Trans.; M. Burnyeat, Ed.). In J. M. Cooper (Ed.), Plato: Complete works (pp. 157–234), 201c–d. Hackett. (Original work published ca. 369 BCE)

[2]Gettier, E. L. (1963). Is justified true belief knowledge? Analysis, 23(6), 121–123, at p. 121.

[3]Floridi, L. (2011). The philosophy of information. Oxford University Press.

What synthetic knowledge is and is not

The central concept of this paper requires a clear definition because it may easily be misunderstood. In this study, synthetic knowledge refers to output that takes the form of a knowledge claim and is produced by a generative model through the probabilistic recombination of linguistic patterns in its training data. Three aspects are important. First, this output is not based on the model's direct experience of the world or of the original source. Second, it is not produced by a knowing subject that holds beliefs or understands reasons. Third, it usually lacks a traceable connection to the sources from which its content is derived.

Synthetic knowledge should be distinguished from two related concepts. First, it is not the same as synthetic data in machine learning. Synthetic data are artificially created examples used for training or testing systems. Synthetic knowledge, by contrast, concerns the epistemic status of the final output generated by a model. Second, the term should not be confused with Kant's concept of synthetic judgment. In Kant's philosophy, a synthetic judgment adds new information to the subject. In this paper, "synthetic" refers to content produced through artificial recombination rather than through human cognitive activity.

The working definition is therefore as follows: synthetic knowledge is machine-generated output that displays the external features of knowledge, such as fluency, confidence, and the form of assertion, while failing to meet key internal conditions of knowledge. These conditions include reliable truth-tracking and source transparency. The following sections explain why these conditions are necessary and why generative systems do not fully satisfy them.

HOW GENERATIVE ARTIFICIAL INTELLIGENCE PRODUCES "KNOWLEDGE"

The operating principle of a large language model is, in essence, to predict the next word. The model is trained on an enormous corpus of text and computes which linguistic unit is most probable in a given context. The strength of this process is that it masters the formal regularities of language—grammar, style, genre—with remarkable accuracy. But there is an epistemological gap here. Emily Bender and Alexander Koller point out that "mastering the form of language is not the same as mastering its meaning; access to meaning requires a connection to the world outside language" [4] (Bender & Koller, 2020, p. 5185). Their well-known point can be grasped as a chain of reasoning: if someone has only ever observed linguistic forms and never seen the reality those forms point to, they may polish the forms but cannot know what they refer to.

There is an even sharper formulation that extends this logic. Bender and her co-authors call the large language model a "stochastic parrot": a system that, "without reference to meaning, haphazardly stitches together the linguistic sequences it has observed on the basis of probabilistic information" [5] (Bender et al., 2021, p. 617). The parrot metaphor is not an insult but a precise description: the output may be fluent because the sequences are plausible; yet the system does not "know" what it is referring to, because within it there is no intention that points to the world.

At this stage, the argument can be developed further. From the perspective of the classical account of knowledge, a model's output should be understood as an assertion-like statement rather than a genuine belief. Likewise, its apparent justification is not actual justification but a simulation of it. A language model does not produce a sentence because it possesses evidence, evaluates reasons, or holds a commitment to the claim. It generates the sentence because similar linguistic patterns have appeared frequently in comparable contexts within its training data. Therefore, the traditional conditions of knowledge—belief, truth, and justification—are not fully present in model-generated output. What appears instead is their linguistic representation. This does not mean that synthetic output is always

[4]Bender, E. M., & Koller, A. (2020). Climbing towards NLU: On meaning, form, and understanding in the age of data. In Proceedings of the 58th Annual Meeting of the Association for Computational Linguistics (pp. 5185–5198), at p. 5185. Association for Computational Linguistics.

[5]Bender, E. M., Gebru, T., McMillan-Major, A., & Shmitchell, S. (2021). On the dangers of stochastic parrots: Can language models be too big? In Proceedings of the 2021 ACM Conference on Fairness, Accountability, and Transparency (pp. 610–623), at p. 617. Association for Computing Machinery.

false. It may sometimes be accurate. However, when it is accurate, that accuracy does not necessarily result from a truth-sensitive or epistemically reliable process. In this respect, synthetic output resembles Gettier-type cases: a statement may turn out to be correct, yet its correctness is not sufficiently connected to the process that produced it.

THE PROBLEM OF TRUTH: INDIFFERENCE, "BULLSHIT," AND HALLUCINATION

Let us now place the question of truth directly before us. It is commonly said that the model sometimes "makes mistakes" or "hallucinates." These expressions make the problem look small, as though it were a matter of occasional malfunction. In our view the issue runs deeper. Recall Harry Frankfurt's well-known analysis: “the liar knows the truth and conceals it, whereas the "bullshitter" is wholly indifferent to what the truth is—his aim is to make an impression, not to be accurate” [6] (Frankfurt, 2005). Frankfurt's distinction gives us a powerful analytic tool.

There already exists a study that applies this tool directly to the generative model. Hicks, Humphries, and Slater argue that “the word which describes the output of large language models more precisely than "hallucination" is "bullshit" in Frankfurt's sense, because the system is structurally indifferent to whether its output is true” [7] (Hicks, Humphries, & Slater, 2024). Note that this is not to disparage the model but to name its nature correctly. The model does not lie, for lying requires knowing the truth and deliberately departing from it; the model simply takes no position along the axis of truth.

An important implication follows from this argument. If a generative system is not designed to assess truth, hallucination should not be understood simply as an unusual failure. Correct and incorrect answers are produced through the same process of probabilistic word selection. Therefore, the system does not generate true statements because it has established their truth. When its output is accurate, this may result from patterns in the training data rather than from a truth-sensitive process. The key distinction is between producing a statement that happens to be true and producing it through a method that reliably tracks truth.

This also has practical implications for users. A confident tone may create the impression that an answer is reliable, but confidence is mainly a feature of style. The risk becomes clear when a model generates a reference that appears credible but is false, such as a non-existent author, article, or page number. For this reason, machine-generated citations should always be checked against original sources. The main risk of synthetic knowledge lies in its appearance of reliability. It can be most misleading when it seems most accurate and convincing.

THE PROVENANCE PROBLEM: TESTIMONY, THE LOSS OF ORIGIN, AND MODEL COLLAPSE

We now turn to the central and, in our view, least-discussed issue of the paper. We acquire most of our knowledge not from direct experience but from what others say—from testimony. C. A. J. Coady's philosophy of testimony shows that “testimony is not a marginal source but one of the principal and irreplaceable foundations of knowledge” [8] (Coady, 1992). But the epistemic value of testimony depends on one condition: we must be able to evaluate who is speaking and whether the source is reliable. The links of the testimonial chain must be visible.

Social epistemology reinforces this point. According to Alvin Goldman's "veritistic" position, “the central criterion for evaluating cognitive practices and institutions is the degree to which they serve truth; our ability to separate reliable sources from unreliable ones is the core of this system” [9] (Goldman, 1999). It is precisely here that generative synthetic knowledge creates a serious problem. When the model produces output, it does not show from which specific source, which author, or which context it

[6]Frankfurt, H. G. (2005). On bullshit. Princeton University Press.

[7]Hicks, M. T., Humphries, J., & Slater, J. (2024). ChatGPT is bullshit. Ethics and Information Technology, 26(2), Article 38.

[8]Coady, C. A. J. (1992). Testimony: A philosophical study. Clarendon Press.

[9]Goldman, A. I. (1999). Knowledge in a social world. Clarendon Press.

comes; the statistical average of thousands of texts dissolves into a single sentence. The trace of the source is erased.

We call this the provenance problem. Synthetic output is severed not only along the true–false axis but along the axis of origin as well: it cuts the chain that binds a claim to the world and to its original source. When this happens, the very possibility of evaluation that testimony requires disappears. We see what is said but cannot reconstruct who said it or on what basis. This amounts to a disintegration in the social fabric of knowledge.

What is striking is that this philosophical problem has an extremely concrete, technical mirror. Shumailov and colleagues showed in Nature that "when generative models are trained repeatedly on their own output (that is, on data produced by other models), the models gradually deteriorate, a phenomenon they termed model collapse" [10] (Shumailov et al., 2024, p. 755). The mechanism is clear: as the system feeds on its own product, the rare, outlying examples coming from the real world are lost, the "tails" of the distribution vanish, and the output grows progressively impoverished. Here technology and philosophy coincide: knowledge that loses its connection to the original source decays.

This parallel is not accidental. Model collapse provides a technical example of why the provenance problem is more than a theoretical concern. As synthetic content becomes more common online, new models may increasingly be trained on material produced by earlier models. In this process, original sources based on human experience, research, observation, and expert judgment can become mixed with machine-generated copies, summaries, and reformulations. Over time, the distinction between original material and synthetic repetition may become less visible. This does not mean that every machine-generated text is false or useless. However, it creates a growing difficulty for readers, researchers, and institutions that need to identify where a claim comes from and how it can be verified. When source chains become unclear, the reliability of information becomes harder to assess. The problem is therefore not only the possibility of isolated false statements. A single inaccurate answer can often be corrected through checking and comparison. The deeper risk is the gradual weakening of the shared epistemic environment itself. If synthetic content repeatedly circulates, is cited, summarized, and reused without clear links to original sources, the common pool of reliable knowledge may slowly lose its diversity, traceability, and connection to lived human experience. In this sense, model collapse illustrates a broader epistemic danger: knowledge may appear to expand in volume while becoming poorer in origin, verification, and reliability.

This concern also has a wider epistemological dimension. As artificial intelligence systems become more widespread, they do not simply function within an existing epistemic environment. They also reshape that environment by producing an increasing share of the texts, explanations, and interpretations through which knowledge is communicated and understood. The implication for this argument is clear: when the interpretation of the shared knowledge environment is increasingly generated by machines, the human links in the testimonial chain may become weaker. Questions about the continuity, distortion, and verification of knowledge therefore become more urgent. Synthetic knowledge creates particular challenges in each of these areas. It may interrupt continuity by separating claims from their original contexts. It may increase distortion by repeatedly transforming and recombining earlier content. It may also make verification more difficult when sources and chains of transmission are no longer clear.

At the same time, the problem should not be presented in overly catastrophic terms. Some technological deterministic views, as well as discussions of a possible technical singularity, suggest that the development and effects of machine-generated output are already fixed. This paper takes a different position. The epistemic status of machine output is not determined in advance. It does not have to remain unreliable content, or output that is indifferent to truth. Whether it becomes a useful source of knowledge depends largely on how people evaluate, verify, and use it. It also depends on the standards that institutions, researchers, and users require from such systems. The next section examines these conditions in more detalı.

[10]Shumailov, I., Shumaylov, Z., Zhao, Y., Papernot, N., Anderson, R., & Gal, Y. (2024). AI models collapse when trained on recursively generated data. Nature, 631(8022), 755–759, at p. 755.

WHEN CAN SYNTHETIC OUTPUT BECOME KNOWLEDGE?

Up to this point, the discussion has focused mainly on the limitations and risks of synthetic output. However, the purpose of this paper is not to reject generative artificial intelligence or to deny its practical value. These systems can support research, writing, education, analysis, and communication. They can help users organize information, generate alternatives, identify patterns, and formulate initial explanations. For this reason, treating all machine-generated output as useless would be as unproductive as treating it as automatically trustworthy. The more appropriate position lies between these two extremes. Synthetic output should be treated as candidate knowledge: material that may contribute to knowledge but does not yet qualify as knowledge on its own. It should be understood as a provisional epistemic resource that requires further examination before it can be accepted, cited, taught, or used in decision-making. The central question, therefore, is not whether synthetic output should be used at all, but under what conditions it can become epistemically reliable.

The first condition is verifiability. Claims produced by a generative system must be open to independent checking. They should be compared with observable facts, empirical evidence, primary documents, or reliable scholarly sources. A statement may be coherent, detailed, and persuasive, yet still fail to count as knowledge if there is no way to test its accuracy. Verifiability is important because it reconnects synthetic output to the truth condition of knowledge. It prevents users from treating linguistic plausibility as evidence. In this sense, verification does not merely correct individual errors; it establishes whether a claim has a defensible relationship with the world.

The second condition is traceability. It should be possible, at least in principle, to reconstruct the origin of a claim. Users should be able to ask which sources support the claim, in what context those sources were produced, and whether they are reliable. Traceability is especially important because generative systems often combine information from many possible sources into a single seamless response. This may make the final output appear clear while hiding the path through which it was formed. Without identifiable sources, users cannot properly assess authorship, authority, context, or possible distortion. Traceability therefore responds directly to the provenance problem. It restores the possibility of evaluating claims within a visible chain of testimony rather than accepting them as anonymous statements.

The third condition is human warrant. Even when a claim is verifiable and its sources are traceable, a competent human subject must still assess the material and assume responsibility for using it. Knowledge involves more than the presence of correct information. It also involves judgement about relevance, context, interpretation, and justification. A model can produce text, summarize arguments, or suggest possible answers, but it cannot genuinely take responsibility for the truth or significance of what it produces. Human warrant is therefore the final epistemic step. It requires a researcher, professional, teacher, or other competent user to examine the output, evaluate the evidence, and decide whether the claim should be accepted.

These three conditions operate together rather than separately. Verifiability connects a claim to truth. Traceability connects it to identifiable sources and contexts. Human warrant connects it to justification, responsibility, and accountable judgement. If one of these elements is missing, the epistemic status of the output remains incomplete. A verified claim without a clear source may still be difficult to evaluate in context. A traceable claim without human assessment may still be misinterpreted or misapplied. A humanly endorsed claim without verification may remain unreliable. The proposed framework therefore does not place artificial intelligence outside the process of knowledge production. Instead, it assigns it a limited but important role. Generative systems can serve as powerful tools for producing hypotheses, summaries, drafts, and informational leads. Yet they should not be treated as final authorities. Synthetic output is best understood as raw epistemic material. It becomes knowledge only when it is checked against reality, linked to reliable sources, and accepted through responsible human judgement.

CONCLUSION

This paper examined the epistemological status of content generated by artificial intelligence and developed the concept of synthetic knowledge to describe it. The main conclusion is that synthetic output

can resemble knowledge in form while lacking key epistemic conditions. In particular, it does not reliably track truth and often provides no transparent connection to its original sources. For this reason, it should not be treated as knowledge in the full sense. At the same time, it should not be reduced to simple error. Synthetic knowledge is better understood as a distinct form of output: it has the linguistic structure of knowledge claims, but its relation to truth, justification, and provenance remains incomplete.

The argument was developed in three stages. First, the paper showed that large language models can learn and reproduce formal patterns of language without possessing human-like understanding, belief, or justification. Their outputs may be correct, but correctness alone does not prove that they were produced through a reliable truth-sensitive process. Second, the paper examined the problem of truth. Generative systems are designed to produce plausible continuations of language rather than to determine whether a statement is true. As a result, hallucination should not be seen only as an occasional technical failure. It reflects a broader limitation of systems that prioritize linguistic plausibility over epistemic reliability. Third, the paper addressed the provenance problem. Synthetic output may hide the sources, contexts, and chains of testimony on which its content depends. This makes verification more difficult and may weaken the shared epistemic environment. The phenomenon of model collapse illustrates the possible long-term consequences of increasingly training models on synthetic material.

However, this analysis does not require a pessimistic conclusion. The paper proposes three conditions under which synthetic output may gain genuine epistemic value: verifiability, traceability, and human warrant. Verifiability connects a claim to evidence and reality. Traceability makes it possible to identify and evaluate the sources behind a claim. Human warrant ensures that a competent person examines the output, interprets it responsibly, and accepts accountability for its use. Together, these conditions offer a practical framework that avoids both blind trust and blanket rejection of artificial intelligence.

The central challenge of the age of synthetic knowledge is therefore not to remove humans from knowledge production. It is to strengthen the human role as verifier, interpreter, and responsible guarantor. This issue is especially relevant in Azerbaijan, where digital transformation is expanding and synthetic content is becoming more visible in education, public communication, research, and professional practice. Future studies may examine how verifiability, traceability, and human warrant can be applied in specific fields such as education, journalism, public administration, and academic publishing. Ultimately, the epistemic future of synthetic knowledge will depend not only on technological development, but also on the standards, institutions, and human responsibilities that shape its use.

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HOW DO SUSTAINABILITY (ESG) ACTIVITIES IMPACT FINANCIAL PERFORMANCE? A REVIEW OF THE S&P 500 HEALTH CARE SECTOR

SÜRDÜRÜLEBİLİRLİK (ESG) FAALİYETLERİNİN FİNANSAL PERFORMANSA ETKİSİ NASILDIR? S&P 500 SAĞLIK SEKTÖRÜ ÜZERİNE BİR İNCELEME

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ÖZET

Giriş ve Amaç: Dünyamız hızla değişirken insanoğlunun da doğaya ve topluma karşı yaklaşımı da değişmektedir. Daha yaşanılabilir bir dünya için insan; çevreye, insana ve çağdaş yaklaşımlara daha fazla dikkat etmek zorundadır. Günümüzde bu bakış açısının bir diğer adı da sürdürülebilirlik (ESG)'tir. Sürdürülebilirlik yaklaşımı bireyler, gruplar, toplumlar, ülkeler ve hatta dünyamız için dikkate değerdir. Dolayısıyla nispeten yeni bir araştırma sahası olan sürdürülebilirlikle ilgili teorik ve deneysel çalışmaların artması gerekmektedir. Bu bağlamda çalışmanın amacı sürdürülebilirlik yaklaşımının uzun dönemde finansal performansa etkisini ampirik olarak test eden literatüre yeni bir sektör incelemesi ile yeni kanıtlar sunmaktır.

Metaryal ve Metot: Çalışmada S&P 500 endeksinde işlem gören 52 sağlık şirketinin 2008-2024 yıllık verileri analiz edilmiştir. Veriler "Thomson Reuters Datastream" veri tabanı ve "Dünya Bankası" veri tabanından temin edilmiştir. Sektör olarak "sağlık" sektörünün seçilmesinin nedeni araştırma konusunu sınırlandırma ve bu alanda yapılmış benzer bir çalışmanın henüz tespit edilememiş olmasıdır. Nitekim doğrudan AR-GE'ye dayalı ve teknolojik gelişim odaklı bir sektör olan sağlık sektörü ABD'de nitelik ve nicelik açısından büyük şirketlerden oluşmaktadır. Söz konusu şirketlerin kesit ve zaman boyutlu verilerine ilk olarak temel panel veri tahmincileri uygulanmıştır. Daha sonra geleneksel modellerin temel varsayımları (homoskedasite, otokorelasyonsuzluk, yatay kesit bağımsızlığı vs.) sağlamadığı tespit edilmiş ve dirençli tahmincilerin (Driscoll-Kraay) kullanılması kararlaştırılmıştır.

Sonuç: Sürdürülebilirliğin finansal performans üzerindeki etkisi literatürde uzunca bir süredir araştırılmaktadır. Bu alandaki yeni kanıtlar literatür ve uygulama açısından önemlidir. Çalışmada yapılan analizlere göre; ABD sağlık sektöründe sürdürülebilirliğin aktif karlılığı (ROA) üzerinde istatistiksel açıdan anlamlı ve pozitif yönlü etkisi vardır. Özsermaye karlılığı (ROE) üzerinde ise anlamlı bir etki bulunmamaktadır. Sonuç olarak; ABD sağlık sektörü şiketlerinin sürdürülebilirlik skorları söz konusu şirketlerin tüm varlıklarını kullanabilme becerilerini olumlu etkilerken, öz sermaye sahiplerinin karlılıklarını etkilememektedir.

Anahtar Kelimeler: Sürdürülebilirlik (ESG); Finansal Performans; ABD Sağlık Sektörü, Panel Veri Analizi, Driscoll-Kraay Dirençli Tahmincisi

ABSTRACT

Introduction and Purpose: As our world rapidly changes, so does humanity's approach to nature and society. For a more livable world, humans must pay more attention to the environment, people, and contemporary approaches. Today, another name for this perspective is sustainability (ESG). The sustainability approach is noteworthy for individuals, groups, societies, countries, and even our world. Therefore, there is a need for more theoretical and experimental studies on sustainability, which is a relatively new field of research. In this context, the aim of this study is to present new evidence to the literature that empirically tests the long-term impact of the sustainability approach on financial performance, through a new sector analysis.

Materials and Methods: In this study, annual data from 52 health care companies listed on the S&P 500 index for the period 2008-2024 were analyzed. Data were obtained from the "Thomson Reuters Datastream" database and the "World Bank" database. The reason for choosing the "health care" sector

is to limit the research topic and because a similar study has not yet been conducted in this area. Indeed, the health care sector in the USA, a sector directly based on R&D and focused on technological development, consists of large companies in terms of both quality and quantity. Initially, basic panel data estimators were applied to the cross-sectional and time-effect data of these companies. Subsequently, it was determined that traditional models did not meet the basic assumptions (homoskedacity, lack of autocorrelation, cross-sectional independence, etc.), and it was decided to use robust estimators (Driscoll-Kraay).

Results: The impact of sustainability on financial performance has been investigated in the literature for a long time. New evidence in this area is important in terms of literature and application. According to the analyses conducted in this study, sustainability has a statistically significant and positive effect on return on assets (ROA) in the USA health care sector. However, there is no significant effect on return on equity (ROE). In conclusion, the sustainability scores of USA health care companies positively affect their ability to utilize all their assets, while not affecting the profitability of equity owners.

Key Words: Sustainability (ESG); Financial Performance; USA Health Care Sector; Panel Data Analysis; Driscoll-Kraay Robust Estimator

GİRİŞ

Sürdürülebilirlik günümüzde hem akademik çevrelerde hem de uygulama sahasında giderek artan bir öneme sahiptir. Özellikle son yıllarda sürdürülebilirliğe yükselen bir ilgi görülmektedir. Sürdürülebilirlik kısaca; daha yaşanılabilir bir dünya (E), çalışanlara ve diğer tüm paydaşlara karşı daha insancıl uygulamalar (S) ve yönetim alanında çağdaş tekniklerin kullanılması (G) olarak özetlenebilir. Bu yaklaşım literatürde üçlü yaklaşım (ESG) olarak da bilinmektedir. Dolayısıyla çalışmamızda srdürülebilirlik doğrudan ESG olarak da tanımlanabilir. Nhayetinde ESG faaliyetleri içinde bulunduğumuz dönemde rekabetçiliğin ve iyi yönetişimin anahtarıdır. Dahası ESG faaliyetleri tek yaşam alanımız olan dünyamız dolayısıyla gelecek nesillerimiz için kritik bir öneme ve değere sahiptir.

Sürdürülebilirlik literatürde farklı boyutlarıyla ele alınmış ve yine bu alanda çok sayıda ampirik araştırma yapılmıştır. Ampirik uygulamalar yeni bir veri seti ya da farklı örneklemleri kapsadığı için literatür ve uygulama açısından her bir araştırma özgün bir değere sahiptir. Bu çalışmada, literatürde sıklıkla incelenen bir konu olan, sürdürülebilirk ve finansal performans ilişkisi farklı bir sektör (sağlık sektörü) üzerinden incelenmeye çalışılmıştır. Çalışmanın amacı ABD sağlık sektöründe sürdürülebilirlik ile finansal performans arasında anlamlı bir ilişki var mı yoksa yok mu olduğunun tespit edilmesidir. Nitekim bu sayede ulaşılan bulgular ile sağlık sektörü yöneticileri ya da yatırımcıları sürdürülebilirlik bağlantılı doğru finansal pozisyonlar alabileceklerdir. Çalışmanın önemi ise sürdürülebilirlik ve finansal performans bağlamında sağlık sektörü üzerine literatürde henüz bir çalışmanın tespit edilememiş olmasıdır. Çalışmanın literatürden farklılığı ya da literatüre katkısı ise yeni bir örneklem ve yeni bir veri setiyle ampirik literatüre özgün bir katkıda bulunmasıdır.

Bu çalışma giriş bölümünün ardından dört bölümden oluşmaktadır. İzleyen bölümde çalışmanın konusuna ilişkin geniş literatürden örnekler sunularak kavramsal çerçeveye giriş yapılmak istenilmiştir. Bir sonraki bölümde ise çalışmada kullanılan metodoloji özet olarak açıklanmaya çalışılmıştır. Analiz ve bulgulara ayrılan daha sonraki bölümde de uygulama gerçekleştirilmiş ve analiz bulguları özetlenmiştir. Çalışmada son olarak sonuç ve tartışma başlığı alltında analizlerle ulaşılan temel bulgular özetlenmiş ve kısa bir tartışma girişimiyle çalışma sonlandırılmıştır.

KAVRAMSAL ÇERÇEVE

Literatürde sürdürülebilirlik ile finansal performans ilişkisini inceleyen çok sayıda ampirik çalışma yapılmıştır. Bu çalışmalardan bazıları genel bir yaklaşımda bulunurken bazıları ise alt sektörleri analiz konusu yapmıştır. Bu çalışma da da sektörel bir kısıt konulmuş ve yalnızca ABD'deki sağlık sektörü incelemeye alınmıştır. Bu doğrultuda ilgili literatürden öne çıkan örnekler aşağıda sıralanmıştır.

Abdi vd. (2022) çalışmalarında sürdürülebilirlik açıklamalarının firma değeri ve finansal performans üzerindeki etkilerini havacılık endüstrisi kapsamında incelemişlerdir. Elde edeilen bulgulara göre

sürdürülebilirlik faaliyetlerinin şirketlerin finansal performansları üzerinde pozitif ve anlamlı etkisi vardır. Ayrıca, söz konusu ilişki açısından firma büyüklüğünün düzenleyici (moderating) bir rolü bulunmaktadır.

Kumar & Firoz (2022) Hindistan örneklemini inceledikleri çalışmalarında ESG'nin kurumsal finansal performans üzerindeki etkilerini ele almışlardır. Sonuç olarak, daha iyi kurumsal sürdürülebilirlik performansının (CSP=ESG) kurumsal finansal performans (CFP) üzerinde beklenildiği gibi anlamlı ve pozitif bir etkisinin olduğu gözlemlenmiştir.

Gubareva vd. (2023) çalışmalarında kurumsal finansal performansın sürdürülebilirliği ve ESG yatırımları ilişkisini incelemişlerdir. Çalışmada sonuç olarak ESG yatırımlarının ele alınan pazarlarda, özellikle ABD ve gelişmekte olan piyasalarda, cazip getiriler ve riskten korunma özelliklerine sahip olduğu bulgulanmıştır.

Grajales & Albanés Uribe (2024) ESG ve finansal performans ilişkilerinin dilsel özelliklerini öncelikle Latin Amerika nezdinde incelemektedir. Çalışmada söz konusu şirketlerin ESG faaliyetlerinin bölgeye sürdürülebilirlik katkılarının sınırlı olduğu gözlemlenmiştir. Bununla birlikte, ESG ile finansal performans ölçütleri arasındaki dilsel ilişkilerin hiç birinin söz konusu bölgeye olumlu etkisi yoktur.

Xiang vd. (2024) çalışmalarında sürdürülebilirliğe giden yol bağlamında Çinli firmalarda finansal performans, ESG performansı ve dijital finans ilişkilerini incelemişlerdir. Çalışmanın bulgularına göre, dijital finans ESG performansına olumlu yönde etkide bulunmaktadır. Dijital finans ayrıca, dolaylı olarak firmaların kısa ve uzun vadeli finansal performanslarını ESG aracılığı ile arttırmaktadır.

Al Azizah & Haron (2025) COVID-19 pandemisinden önce ve sonra ESG'nin kurumsal finansal performansın üzerindeki etkisini değerlendirmişlerdir. Panel veri analizi sonuçlarına göre ESG etkisi zamanla dinamik bir şekilde değişmiştir. Pandemiden önce sosyal (S) ve yönetişim (G) boyutlarının performans üzerinde olumlu etkisi var iken, çevresel (E) boyutun etkisi önemsizdi. Pandemiden sonra ise sosyal (S) boyutun etkisi olumsuza dönmüş ve yönetişim (G) boyutunun önemi azalmıştır.

Carreira vd. (2025) çalışmalarında karlılığın sürdürülebilirliği destekleyip desteklemediğini araştırmışlardır. Yapılan analizler neticesinde daha yüksek karlılık oranlarına (ROA, Net Gelir, vs.) sahip olan firmaların daha yüksek oranda ESG performansı gösterdikleri bulgulanmıştır. Söz konusu ilişki aynı zamanda ESG alt sütunlarında da (Çevresel, Sosyal, Yönetişim) gözlemlenmiştir.

Li vd. (2025) finansal performans ile sürdürülebilirlik arasında denge kurulmasına yönelik bir araştırma yapmışlardır. Elde edilen bulgulara göre CEO yoğunluğu arttıkça finansal performans yükselme eğilimine girerken, ESG yoğunluğu ise ters yönde seyretmektedir. Bu sonuçlara göre finansal piyasalarda faaliyet gösteren şirketler açısından söz konusu dengenin kurulması kritik bir öneme sahiptir.

Migliaccio & Mozzillo (2025) kantitatif araştırmalarında finansal performansın ESG üzerindeki etkisini Avrupa elektronik sektörü aracılığıyla incelemişlerdir. Söz konusu çalışmada elde edilen bulgulara göre ESG stratejilerinin benimsenmesi şirketlerin rekabetçiliği ve dayanıklılığı üzerinde orta ve uzun vadede önemlidir.

Miljenović & Ban (2025) çalışmalarında sürdürülebilirlik perspektifi çerçevesinde ESG uygulamasının kredi derecelendirme ve finansal performans üzerindeki etkisini incelemişlerdir. Çalışmada yapılan nihai analizler sonucunda ESG uygulaması ya da stratejileri bir bütün olarak şirket performansı üzerinde olumlu bir etkiye sahiptir.

Balan vd. (2026) derecelendirme şirketlerinin ESG skoru tayin etmelerinin arka planını sorgulamışlardır. Yazarlar araştırma sorusu olarak derecelendirme şirketleri ESG puanlamasında gerçeği mi yansıtıyorlar yoksa finansal performanstan orantısız bir şekilde etkileniyorlar mı? Sorusunu belirlemişlerdir. Elde edilen bulgulara göre daha yüksek finansal performans gösteren şirketlerin ESG puanları da yüksek çıkma eğilimindedir.

Cepêda vd. (2026) ampirik araştırmalarında finansal performansın ve AB sürdürülebilirlik raporlama düzenlemelerindeki kurumsal baskıların ESG ayrışması üzerindeki etkisini incelemişlerdir. Çalışmada elde edilen bulgulara göre; daha yüksek finansal performansa ve daha yüksek piyasa değerine sahip şirketler ESG ayrışmasına daha yatkındırlar.

Chomachaei vd. (2026) havayolu sektöründe ESG ve finansal performans ilişkisi açısından verimliliğin aracılık etkisinin nasıl olduğunu araştırmışlardır. Bulgulara göre; ESG performansının iyileşmesi daha yüksek bir verimliliğe ve daha yüksek bir finansal performansa yol açmaktadır. Ayrıca ESG ve finansal performans ilişkisinde verimlilik aracı rolü oynamaktadır.

Guan vd. (2026) çalışmalarında gelişmekte olan piyasalarda ESG aracılığıyla finansal performansın şekillenmesinde iç kontrolün rolünü incelemişlerdir. Ulaşılan bulgulara göre: 1) İç kontrol kalitesi kurumsal sosyal sorumluluk performansını arttırmaktadır; 2) Kurumsal sürdürülebilirlik ile finansal performans arasındaki pozitif bir ilişki vardır; 3) Kurumsal sürdürülebilirlik iç kontrol kalitesi ile finansal performans ilişkisini düzenler ve güçlendirir.

Mateev vd. (2026) stratejik uyum ihtiyacını inceledikleri çalışmalarında ESG faktörlerinin bankaların finansal performansları ve sürdürülebilirlikleri üzerindeki bağlantısını ele almışlardır. Araştırmacıların bulgularına göre; bankalarda ESG boyutları ile finansal performans arasında doğrusal olmayan fakat pozitif bir ilişki vardır.

Yukarıdaki çalışmalar genel olarak değerlendirilirse sürdürülebilirlik (ESG) faaliyetleri ile finansal performans arasında pozitif yönlü bir ilişkinin var olduğu açıktır. Diğer bir ifadeyle ESG faaliyetleri genel olarak finansal performansı arttırmaktadır. Literatürdeki çalışmalar gözden geçirildiğinde söz konusu net ilişki bağlamında aracı (mediating) ya da düzenleyici (moderating) etkilerin ya da bir başka üçüncü değişkenin etkilerinin incelendiği görülmektedir.

METODOLOJİ

Bilim, yöntemsel çeşitlilik üzerine kurulan diğer bir deyişle metodolojik yaklaşım temelli derinlikli bir konudur. Bilimde metodoloji yani kullanılan yöntem bilimsel farklılığı ve geçerliliği açığa çıkaran temel unsurdur. Sosyal bilimlerde ise genellikle iki tür bilimsel metot vardır: Kalitatif (kavramsal) araştırmalar ve kantitatif (niceliksel) araştırmalar... Kalitatif yani nitel araştırmalar daha ziyade pür teorik yaklaşımlardır. Elbette ki bunların sosyal bilimler açısından değeri tartışılamazdır. Kantitatif yani nicel araştırmalar ise daha ziyade veri analizlerine dayanmaktadır. Söz konusu araştırmalarda teorik ilişkiler yeniden ve yeniden test edilerek literatüre önemli katkılar sunulmaktadır. Nicel araştırmalarda özellikle her defasında farklı bir veri seti ya da farklı bir örneklemle bilinen teorik ilişkiler test edildiği için söz konusu analizlerin literatüre katkısı çoğu zaman özgün ve kıymetlidir. Hatta bu anlamda veri analizlerini içeren nicel araştırmaların ilgili alandaki teorinin ilerlemesine katkıda bulunduğu da ileri sürülebilir. Kısacası veri analizi içeren nicel araştırmalar ilgili alandaki teorik ilişkilere yön verebilir ve teorinin yeniden güncellenmesine hizmet edebilir. Nihayetinde, veri analizleri uygulama sahası için de daima güncel ve geçerli bulgular da ortaya çıkarabilir.

Bu çalışmada yapılan literatür incelemesi ile oluşturulan araştırma hipotezleri şöyledir:

H1: *Sağlık sektörü şirketlerinde sürdürülebilirlik faaliyetleri (ESG) ile aktif karlılığı (ROA) arasında anlamlı bir ilişki vardır.*

H2: *Sağlık sektörü şirketlerinde sürdürülebilirlik faaliyetleri (ESG) ile öz sermaye karlılığı (ROE) arasında anlamlı bir ilişki vardır.*

Yukarıdaki hipotezleri test etmek için kurulan ekonometrik modeller ise;

$$ROA_{it} = \beta_0 + \beta_1 ESG_{it} + \beta_2 SIZE_{it} + \beta_3 LEV_{it} + \beta_4 GDP_{it} + \beta_5 GE_{it} + \varepsilon_{it} \quad \text{(Model 1)}$$

$$ROE_{it} = \beta_0 + \beta_1 ESG_{it} + \beta_2 SIZE_{it} + \beta_3 LEV_{it} + \beta_4 GDP_{it} + \beta_5 GE_{it} + \varepsilon_{it} \quad \text{(Model 2)}$$

Yukarıdaki modelde yer alan değişkenlerin tanımlanması, kısaltılmış gösterimleri, hesaplama formülleri ve veri kaynakları Tablo 1'de sunulmuştur.

Tablo 1: Değişkenlerin Tanımlanması

Değişkenler	Kısaltma	Formül	Veri Kaynağı
Bağımlı Değişken			
Aktif Karlılığı	ROA	Kar / Aktif Tutarı	Thomson Reuters
Öz Sermaye Karlılığı	ROE	Öz Sermaye / Aktif Tutarı	Thomson Reuters
Bağımsız Değişken			
Sürdürülebilirlik Endeksi	ESG	Hesaplanan Endeks Değeri	Thomson Reuters Veri Tabanı
Kontrol Değişkenleri (Firma-Spesifik)			
Firma Büyüklüğü	SIZE	Toplam Varlıkların Logaritması	Thomson Reuters
Finansal Kaldıraç	LEV	Toplam Borçlar / Toplam Kaynaklar	Kendi Hesaplamamız
Kontrol Değişkenleri (Makro-Spesifik)			
Ekonomik Büyüme	GDP	Yıllık GSMH Büyümesi %	Dünya Bankası
Yönetişim	GE	Dünya Yönetişim Endeksi (ABD)	Dünya Bankası

Analizlerde kullanılan değişkenler literatürde sıklıkla kullanılan değişkenlerdir. Tablo1'den de görüldüğü üzere bazı veri setleri veri tabanlarından direk çekilmiş, bazıları ise söz konusu veri kaynaklarından alınan veri setleri kullanılarak tarafımızca hesaplanmıştır. Nihayetinde, bu çalışmada kullanılan veriler "*Thomson Reutors Eikon (Datastream)*" veri tabanı ve "*Worldbank Data*"dan temin edilmiştir.

ANALİZ VE BULGULAR

Çalışmanın analiz kısmında öncelikle, kullanılan veri setlerinin genel görünümüne bir göz atmak için tanımlayıcı istatistiklere yer verilmiştir. Daha sonra ise yukarıda belirlenen değişkenlere ait ikili korelasyon analizi sonuçları sunulmuştur. Söz konusu analiz ile kurulan ekonometrik modelin doğru kurulup kurulmadığına dair bir ön fikir edinebilir . Bununla birlikte korelasyon ilişkilerinin yönü, gücü ya da anlamlılığının temel analizlerle kısmen de olsa örtüştüğü gözlemlenebilecektir. Çalışmanın esas analiz bölümünde ise aktif karlılığı (ROA) ve öz sermaye karlılığı(ROE) bağımlı değişken olarak ele alınmış ve söz konusu panel verilere sırasıyla tesadüfi etkili panel veri analizi, sabit etkili panel veri analizi ve nihayetinde dirençli tahminci (Driscoll-Kraay) uygulanmıştır.

Tablo 2'de yukarıda tanımlanan ve toplamda yedi adet (ROA, ROE, ESG, SIZE, LEV, GDP ve GE) olan değişkenlere ilişkin tanımlayıcı istatistikler yer almaktadır.

Tablo 2: Tanımlayıcı İstatistikler

Değişken	Gözlem	Ortalama	Std. Sap.	Min.	Max.
ROA	880	7.837	12.102	-105.78	62.16
ROE	836	58.681	998.223	-366.53	28805.77
ESG	827	59.979	19.405	8.41	92.21
SIZE	882	7.141	.69	4.647	8.475
LEV	882	.285	.2	0	1.705
GDP	884	1.976	1.932	-2.577	6.055
GE	884	76.444	2.829	71.965	80.057

Tablo 2'ye bakıldığında değişkenlerin gözlem sayısının 827 ile 884 arasında değişim gösterdiği görülmektedir. Değişkenlerin ortalama değerlerine bakıldığında ise literatürle uyumlu olarak öz sermaye karlılığının (ROE) aktif karlılığından (ROA) daha yüksek bir sayısal değerde olduğu görülmektedir. Diğer taraftan sürdürülebilirlik faaliyeti göstergesi olan ESG değişkeninin minimum değeri % 8,41 ve maksimum değeri % 92,21'dir. Söz konusu değişkenin ortalama değeri ise % 59,97'dur.

Tanımlayıcı istatistiklere bir göz attıktan sonra Tablo 3'te Pearson korelasyon analizi sonuçları sunulmuştur.

Tablo 3: Pearson Korelasyon Analizi

Değişken	(1)	(2)	(3)	(4)	(5)	(6)	(7)
(1) ROA	1.000						
(2) ROE	0.013	1.000					
	(0.709)						
(3) ESG	**0.071***	**0.022**	1.000				
	(0.041)	**(0.534)**					
(4) SIZE	0.187*	0.032	0.568*	1.000			
	(0.000)	(0.356)	(0.000)				
(5) LEV	-0.203*	-0.027	0.036	-0.044	1.000		
	(0.000)	(0.440)	(0.304)	(0.196)			
(6) GDP	0.088*	0.014	0.147*	0.126*	0.026	1.000	
	(0.009)	(0.688)	(0.000)	(0.000)	(0.432)		
(7) GE	-0.139*	-0.049	-0.469*	-0.299*	-0.042	-0.341*	1.000
	(0.000)	(0.158)	(0.000)	(0.000)	(0.213)	(0.000)	

* p<0.05, Not: Üstteki rakamlar korelasyon katsayıları, parantez (…..) içindeki değerler olasılık (probability) değerleridir.

Tablo 3'te (1) sütununa bakıldığında değişkenlerin genel olarak istatistiksel anlamlılığa sahip olduğu gözlemlenmektedir. Bu görünüm ROA için yukarıda kurulan Model 1'in büyük olasılıkla doğru kurgulandığı anlamına gelmektedir. Fakat (2)'inci sütunda yani ROE modelinde (Model 2) ise aynı benzerlik yoktur. Tablo 3'e göre aktif karlılığı (ROA) ile sürdürülebilirlik skoru (ESG) arasında [0.071, (0.041)] istatistiksel olarak anlamlı, pozitif yönlü fakat zayıf bir ilişki vardır. Öz sermaye karlılığı (ROE) ile sürdürülebilirlik skoru (ESG) arasında ise [0.022, (0.534)] istatistiksel olarak anlamsız ve pozitif yönlü bir ilişki vardır.

Özetlemek gerekirse, ilk analizimiz olan korelasyon analizi kapsamında sürdürülebilirliğin aktif karlılığı ile ilişkili olduğu, öz sermaye karlılığı ile ise ilişkisiz olduğuna dair önemli bulgular elde edilmiştir. Şimdi sırasıyla temel panel veri analizlerine geçelim.

Tablo 4: Tesadüfi Etkili Model (ROA) Sonuçları

ROA	Coef.	St.Err.	t-value	p-value	[95% Conf	Interval]	Sig
ESG	.068	.025	2.78	.005	.02	.116	***
SIZE	-1.575	1.101	-1.43	.153	-3.732	.583	
LEV	-10.141	2.42	-4.19	0	-14.884	-5.398	***
GDP	.018	.136	0.13	.893	-.249	.285	
GE	-.139	.124	-1.12	.261	-.382	.104	
Constant	29.58	13.867	2.13	.033	2.401	56.759	**

Mean dependent var	8.942	SD dependent var	8.667
Overall r-squared	0.022	Number of obs	827
Chi-square	32.958	Prob > chi2	0.000
R-squared within	0.043	R-squared between	0.023

*** p<.01, ** p<.05, * p<.1

Tesadüfi etkili model tahminlemesi sonuçlarını veren Tablo 4'e göre sürdürülebilirlik ile aktif karlılığı arasında istatistiksel olarak anlamlı ve pozitif yönlü bir ilişki vardır. Söz konusu tabloda ESG katsayısı (0.068) ve p olasılık değeri (0.005<0.05)'dir. Diğer bağımsız değişkenlere bakıldığında ise sadece finansal kaldıraç (LEV) değişkenin istatistiksel olarak anlamlı fakat bağımlı değişken olan ROA ile negatif yönlü ilişkide olduğu görülmektedir.

Tablo 5: Tesadüfi Etkili Model (ROE) Sonuçları

ROE	Coef.	St.Err.	t-value	p-value	[95% Conf	Interval]	Sig
ESG	-.506	2.546	-0.20	.843	-5.496	4.484	
SIZE	38.953	73.517	0.53	.596	-105.137	183.044	
LEV	-253.044	251.585	-1.01	.315	-746.142	240.053	
GDP	-.474	19.875	-0.02	.981	-39.429	38.48	
GE	-18.745	15.193	-1.23	.217	-48.523	11.033	
Constant	1308.919	1292.773	1.01	.311	-1224.87	3842.707	

Mean dependent var	62.308	SD dependent var	1022.768
Overall r-squared	0.004	Number of obs	796
Chi-square	3.022	Prob > chi2	0.697
R-squared within	0.003	R-squared between	0.017

*** p<.01, ** p<.05, * p<.1

Tesadüfi etkili model tahminlemesi sonuçlarını öz sermaye karlılığı (ROE) açısından veren Tablo 5'e göre sürdürülebilirlik ile aktif karlılığı arasında istatistiksel olarak anlamsız ve negatif yönlü bir ilişki vardır. Söz konusu tabloda ESG katsayısı (-0.506) ve p olasılık değeri (0.843>0.05)'dir. Diğer bağımsız değişkenlere bakıldığında ise tüm bağımsız değişkenlerin istatistiksel olarak anlamsız olduğu görülmektedir.

Tablo 6: Sabit Etkili Model (ROA) Sonuçları

ROA	Coef.	St.Err.	t-value	p-value	[95% Conf	Interval]	Sig
ESG	.051	.027	1.90	.057	-.002	.103	*
SIZE	2.217	1.881	1.18	.239	-1.475	5.91	
LEV	-14.44	2.837	-5.09	0	-20.01	-8.871	***
GDP	.016	.136	0.12	.907	-.251	.283	
GE	.009	.147	0.06	.952	-.28	.298	
Constant	-6.834	21.526	-0.32	.751	-49.091	35.423	

Mean dependent var	8.942	SD dependent var	8.667
R-squared	0.050	Number of obs	827
F-test	8.076	Prob > F	0.000
Akaike crit. (AIC)	5529.491	Bayesian crit. (BIC)	5557.798

*** p<.01, ** p<.05, * p<.1

Sabit etkili model tahminlemesi sonuçlarını veren Tablo 6'ya göre sürdürülebilirlik ile aktif karlılığı arasında istatistiksel olarak anlamlı ve pozitif yönlü fakat kısmi bir ilişki vardır. Söz konusu tabloda ESG katsayısı (0.051) ve p olasılık değeri (0.057<0.10)'dır. Diğer bağımsız değişkenlere bakıldığında ise sadece finansal kaldıraç (LEV) değişkeninin istatistiksel olarak anlamlı fakat bağımlı değişken olan ROA ile yine negatif yönlü ilişkide olduğu görülmektedir.

Tablo 7: Sabit Etkili Model (ROE) Sonuçları

ROE	Coef.	St.Err.	t-value	p-value	[95% Conf	Interval]	Sig
ESG	.776	4.004	0.19	.846	-7.085	8.637	
SIZE	135.588	282.144	0.48	.631	-418.309	689.486	
LEV	-57.729	470.622	-0.12	.902	-981.642	866.184	
GDP	.747	19.986	0.04	.97	-38.489	39.983	
GE	-8.753	21.884	-0.40	.689	-51.715	34.21	
Constant	-282.54	3212.586	-0.09	.93	-6589.409	6024.329	

Mean dependent var	62.308	SD dependent var	1022.768
R-squared	0.004	Number of obs	796
F-test	0.537	Prob > F	0.998
Akaike crit. (AIC)	13245.641	Bayesian crit. (BIC)	13273.719

*** p<.01, ** p<.05, * p<.1

Sabit etkili model tahminlemesi sonuçlarını öz sermaye karlılığı (ROE)'na göre veren Tablo 7'ye göre sürdürülebilirlik ile aktif karlılığı arasında istatistiksel olarak anlamsız ve pozitif yönlü bir ilişki vardır. Söz konusu tabloda ESG katsayısı (0.776) ve p olasılık değeri (0.846>0.05)'dir. Diğer bağımsız değişkenlere bakıldığında ise tüm bağımsız değişkenlerin istatistiksel olarak anlamsız olduğu görülmektedir.

Temel panel veri analiz teknikleri uygulandıktan sonra yapılan testler (LM Testi, F Testi, Hausman Testi) sonucunda sabit etkili modelin kullanılmasının ekonometrik açıdan daha doğru olacağı sonucuna varılmıştır. Daha sonra sabit etkili modele ise yine bazı testler (Homoskedasite, Otokorelasyonsuzluk, Birimler Arası Korelasyonsuzluk) uygulanmış ve bazı varsayımların sağlanamadığı görülmüştür. Bu nedenle hem ROA hem de ROE'ye uygun bir dirençli tahminci olan Driscoll-Kraay analizi uygulanmıştır.

Tablo 8: Driscoll-Kraay Dirençli Tahminci (ROA) Sonuçları

Regression with Driscoll-Kraay standard errors				Number of obs =		827
Method: Fixed-effects regression				Number of groups =		52
Group variable (i): ID				F(5, 16) =		14.89
maximum lag: 2				Prob > F =		0.0000
				within R-squared =		0.0498
			Drisc/Kraay			
ROA	**Coef.**	**Std.Err.**	**t value**	**P>t**	**[95%Conf.**	**Interval]**
ESG	0.051	0.011	4.760	0.000	0.028	0.074
SIZE	2.217	2.238	0.990	0.337	-2.527	6.961
LEV	-14.440	4.902	-2.950	0.009	-24.831	-4.049
GDP	0.016	0.136	0.120	0.909	-0.273	0.305
GE	0.009	0.123	0.070	0.944	-0.253	0.271
_cons	-6.834	23.226	-0.290	0.772	-56.071	42.403

Driscoll-Kraay dirençli tahmincisi ekonometrik varsayımların sağlanmadığı durumlarda başvurulabilecek kuvvetli ve ileri bir tahminleme metodudur. Yukarıda bağımlı değişkenler olan ROA ve ROE'ye sırasıyla temel panel veri teknikleri (Sabit Etkili, Tesadüfi Etkili) uygulanmış ve değişkenler arasındaki araştırılan ilişkiye dair ön bilgiler edinilmiştir. "Stata" programıyla yapılan analizlerin bu aşamasında Drsicoll-Kraay tahminci sonuçlarına bir bakalım.

Tablo 8'e göre bağımsız değişkenler (ESG, SIZE, LEV, GDP, GE, Sabit) ile bağımlı değişken olan aktif karlılığı (ROA) arasında istatistiksel açıdan anlamlı ve pozitif yönlü bir ilişkinin olduğu görülmektedir. Söz konusu tabloda ESG değişkeninin katsayısı ise (0.051) ve olasılık değeri (0.000<0.05)'dir. Bu görünüm bize sürdürülebilirlik (ESG) ile aktif karlılığı (ROA) arasındaki kuvvetli ve istikrarlı bir ilişkiyi vermektedir. Modelde diğer değişkenlerden ise sadece finansal kaldıraç (LEV) değişkeni anlamlıdır. Söz konusu değişkenin katsayısı (-14.44) ve olasılık değeri (0.009<0.05)'dir. Yani ROA ile LEV arasında ters yönlü bir ilişki vardır.

Tablo 9: Driscoll-Kraay Dirençli Tahminci (ROE) Sonuçları

Regression with Driscoll-Kraay standard errors	Number of obs =		796
Method: Fixed-effects regression	Number of groups =		51
Group variable (i): ID	F(5, 16) =		0.8
maximum lag: 2	Prob > F =		0.5614
	within R-squared =		0.0036
Drisc/Kraay			

ROE	Coef.	Std.Err.	t value	P>t	[95%Conf.	Interval]
ESG	0.776	0.997	0.780	0.448	-1.338	2.890
SIZE	135.588	120.612	1.120	0.278	-120.098	391.275
LEV	-57.729	153.293	-0.380	0.711	-382.696	267.237
GDP	0.747	6.217	0.120	0.906	-12.432	13.926
GE	-8.753	5.804	-1.510	0.151	-21.056	3.550
_cons	-282.540	762.021	-0.370	0.716	-1897.951	1332.871

Tablo 9'daki "Stata" programı sonuçlarına göre bağımsız değişkenler (ESG, SIZE, LEV, GDP, GE, Sabit) ile bağımlı değişken olan öz sermaye karlılığı (ROE) arasında istatistiksel açıdan anlamsız ve pozitif yönlü bir ilişkinin olduğu görülmektedir. Söz konusu tabloda ESG değişkeninin katsayısı ise (0.776) ve olasılık değeri (0.448>0.05)'dir. Bu görünüm bize sürdürülebilirlik (ESG) ile öz sermaye karlılığı (ROE) arasında istatistiksel açıdan anlamlı bir ilişkinin olmadığı sonucunu vermektedir. Modelde diğer değişkenlerin tamamı ise yine istatistiksel olarak anlamsızdır. Bu sonuçlara göre sürdürülebilirlik (ESG) ile öz sermaye karlılığı (ROE) arasında herhangi bir ilişkiye rastlanılmamıştır.

SONUÇ VE TARTIŞMA

Sürdürülebilirlik (ESG) ve finansal performans ilişkisi literatürde farklı analiz araçları ve farklı örneklemlerle birçok kez incelenmiştir. Bu alanda son yıllarda özellikle enerji, bilişim, turizm, bankacılık vd. gibi sektörel açıdan konuyu inceleyen çalışmalar da yapılmıştır. Bu çalışma da söz konusu ampirik literatüre yeni bir sektör, yeni bir örneklem ve yeni bir veri setiyle nedensellik ilişkilerine dair yeni kanıtlar sunmayı amaçlamaktadır. Bu bağlamda çalışmada sürdürülebilirliğin (ESG) finansal performans (ROA, ROE) üzerindeki etkisi panel veri teknikleriyle detaylıca incelenmiştir. Çalışmada ilk olarak değişkenlerin tanımlanması yapılmış, daha sonra değişkenlere ilişkin tanımlayıcı istatistikler sunulmuş, hemen ardından ikili korelasyon analizi ile nedensellik ilişkilerine dair ön bulgulara ulaşılmış, daha sonra ise temel panel veri tekniklerine başvurulmuş ve son olarak da sağlamlığın gerçekleştirilmesi için dirençli tahminciler (Driscoll-Kraay) ile sonuca gidilmesi amaçlanmıştır.

Elde edilen bulgulara göre ABD sağlık sektöründe sürdürülebilirlik skorları (ESG) ile aktif karlılığı (ROA) arasında istatistiksel açıdan anlamlı ve pozitif yönlü bir ilişki vardır. Buna göre sürdürülebilirlik faaliyetlerinin sağlık şirketlerin tüm varlıklarını kullanma becerilerini arttırdığı söylenebilir. Bu anlamda ESG faaliyetlerinin operasyonel verimliliği arttırdığına dair güçlü kanıtlar vardır. Diğer taraftan ABD sağlık şirketlerinde sürdürülebilirliğe (ESG) yatırım yapmak öz sermaye karlılığını (ROE) etkilememektedir. Buna göre sağlık şirketlerinin ESG faaliyetleri firma sahipleri ya da ortaklarının kazançları/payları üzerinde etkili değildir.

Yukarıdaki bu görünüm farklı açılardan tartışılabilir. Öncelikle, öz sermaye karlılığı üzerindeki nötr etki sürdürülebilirlik yatırımları maliyetlerinin daha ziyade öz kaynaklardan karşılanması olarak da değerlendirilebilir. Diğer bir deyişle sürdürülebilirliğe ilişkin yatırım maliyetlerinin önemli bir kısmı öz kaynaklardan temin edilmiştir. Diğer taraftan aktif karlılığı üzerindeki güçlü, pozitif ve anlamlı etki ise sürdürülebilirliğin şirketlerin bütünü açısından değer yaratıcı bir faaliyet olduğunun göstergesidir. Bununla birlikte genel bir sonuç olarak denilebilir ki sürdürülebilirlik (ESG) bu çalışmada olduğu gibi sadece bazı rakamsal bulgular üzerinden değerlendirilmemesi gereken önemli ve değerli bir alandır. Kısacası, unutulmamalıdır ki sürdürülebilirlik yaklaşımının ya da yatırımlarının dünyamız, insanoğlu ve çağdaş yönetim anlayışına katkısı sınırsızdır!

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NUMERICAL INVESTIGATION OF THE EFFECT OF SIMULTANEOUS ROUNDING OF INNER AND OUTER CORNER GEOMETRY ON DRAG AND PRESSURE LOSS IN AN IN-CHANNEL OBSTACLE ARRAY

KANAL İÇİ ENGEL DİZİSİNDE İÇ VE DIŞ KÖŞE GEOMETRİSİNİN EŞ ZAMANLI YUVARLATILMASININ SÜRÜKLEME VE BASINÇ KAYBINA ETKİSİNİN SAYISAL İNCELENMESİ

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ABSTRACT

The corner geometry of obstacles placed inside a channel is an important design variable governing flow separation and, in turn, the flow resistance. This study numerically investigates the effect of rounding the corner geometry on the obstacle drag force, drag coefficient, and pressure loss in an array of five obstacles positioned in a cross pattern inside a water-filled channel, using three-dimensional computational fluid dynamics. The cross-section is varied from a sharp-cornered square ($r^* = 0$) to a full circle ($r^* = 1$) through one intermediate geometry controlled by the normalized corner radius r^*. Importantly, this variation rounds not only the obstacle corners but also, simultaneously, the outer corners of the flow passage surrounding the obstacles, while the relation OR = 2 IR is preserved between the inner and outer corner radii. The results are therefore interpreted as the combined effect of the inner and outer corner geometry. The analyses are performed with the Simcenter FLOEFD finite-volume solver under a fixed inlet flow rate. The results show that corner rounding reduces the total axial force of the obstacle array by 32.2% and the pressure loss between the inlet and outlet by 33.6%, lowering the array drag coefficient from 1.640 to 1.111. The share of the leading obstacle in the total force is 75.4% in the sharp case, drops to 29.7% for the intermediate rounded geometry, and is 33.3% for the circular geometry; rounding transfers the load to the obstacles located in the wake. The high local coefficient of the leading obstacle is attributed to the strong blockage inside the channel. The observed trends are consistent with the literature reporting reduced drag in the transition from a square to a circular cross-section.

Keywords: Drag coefficient, Corner rounding, Pressure loss, Computational fluid dynamics, Bluff body

INTRODUCTION

Separated flow around a bluff body is one of the most studied canonical problems in fluid mechanics. On a sharp-edged body the separation point is fixed geometrically; the developing free shear layers create a wide wake and a pronounced momentum deficit, which raises the pressure-based drag acting on the body. When the body is placed inside a channel, the wall confinement accelerates the flow and raises the drag coefficient above its free-stream value. Obstacle arrays placed inside channels are encountered in a wide range of applications, from heat exchangers to fuel cell flow channels (Karabulut et al., 2018; Jung et al., 2024). When several bodies are arranged in tandem, wake interactions and shielding determine the distribution of the load along the array.

Corner sharpness is one of the governing parameters of this behavior. Increasing the corner radius shifts the separation point downstream, allows the shear layer to reattach to the surface, and reduces the drag by narrowing the wake width. Adeeb et al. (2018) showed that increasing the corner radius of two side-by-side square cylinders reduces the drag and that sharp-cornered cross-sections produce the widest

wake. Wang et al. (2023), by continuously varying the corner ratio, revealed that both the mean force coefficients and the Strouhal number of three square-like cylinders depend strongly on the corner geometry and differ with position in the array. Sarout et al. (2022) examined the effect of the transition from a square to a circle on flow-induced vibration and heat transfer by sweeping the normalized corner radius between zero and one. Mahmood et al. (2020) numerically investigated the drag and lift forces on a square cylinder located in a channel-driven cavity.

The confinement effect is decisive in interpreting the coefficients in channel flow. Korukçu (2020) showed that, for a square cylinder in a confined channel, the drag and friction coefficients increase and the reattachment length shortens as the blockage ratio rises; similar confinement effects were also reported by Korukçu (2015) and Xu et al. (2023). Interaction is dominant in multiple-body arrays. Kahila et al. (2019) solved the flow around four cylinders in a square arrangement using large eddy simulation, and Kanna et al. (2025) addressed the flow and heat transfer for twin circular cylinders. Ferreira et al. (2021) investigated the drag of a square-cylinder array. Li et al. (2018) addressed the free-surface flow around two side-by-side circular cylinders, and Naqvi et al. (2024) addressed the effect of gas injection from multiple cylinders on crossflow dynamics.

Most of these studies are two-dimensional, at low Reynolds number, and limited to a single or a few bodies. The combined effect of corner rounding on the drag coefficient of each body, on the total coefficient of the array, and on the pressure loss in a five-body array inside a confined water channel has not been systematically addressed. In this study, the effect of corner rounding on the local and array drag coefficients, on the load distribution among the bodies, and on the pressure loss is determined by three-dimensional computational fluid dynamics for a five-body array whose cross-section is varied from a sharp-cornered square to a full circle through the normalized corner radius.

METHOD

Geometry

The computational domain is a flow volume 290 mm long in the flow direction and 10 mm deep. Five obstacles are located in the middle region in a cross arrangement perpendicular to the flow axis. The obstacle side length is D = 10 mm. Since the height of the main passage containing the obstacles is 20 mm, the linear blockage ratio, defined as the ratio of the obstacle side to the passage height, is approximately 0.50. The ratio of the obstacle frontal projected area to the local channel cross-sectional area gives the same value, 100 mm2 / 200 mm2 = 0.50. The hydraulic diameter of the main channel, obtained for a rectangular cross-section from four times the area divided by the wetted perimeter, is approximately 13.3 mm. This high blockage is the main reason for the high local coefficients presented below. Because the outer passage corners are rounded according to the configuration, the local open area changes somewhat, so the blockage does not remain exactly the same across the three configurations. The five obstacles are arranged in a cross pattern, with a triad on the flow axis (front, center, and rear; 1, 3, and 5, respectively) and a pair on the arm perpendicular to this axis (2 and 4); the layout and dimensions are given in Figure 1. The corner geometry is defined by the inner corner radius IR and the outer corner radius OR, and the relation OR = 2 IR is preserved. A critical point is that IR rounds the corners of the obstacles, whereas OR rounds the outer corners of the flow passage surrounding the obstacles. Therefore, as the cross-section changes from a square to a circle, the obstacle geometry and the outer passage geometry change simultaneously, and the resulting effects are the combined outcome of the two. For comparison consistent with the literature, the corner sharpness is expressed through the normalized corner radius r* defined by Eq. (11). Owing to the relation OR = 2 IR, the inner and outer normalizations give the same r* value. Accordingly, the sharp square corresponds to r* = 0, the intermediate section to r* = 0.5, and the full circle to r* = 1.0. The configuration parameters are given in Table 1 and the geometry is shown in Figure 1. As Figure 1 shows, the outer boundary of the passage is not a simple rectangle but widens in a cross shape and is rounded according to the configuration.

Table 1. Geometric parameters of the three configurations

Configuration	IR (mm)	OR (mm)	r*	Cross-section
IR0-OR0	0.0	0.0	0.0	Sharp square
IR2.5-OR5	2.5	5.0	0.5	Rounded square
IR5-OR10	5.0	10.0	1.0	Circle

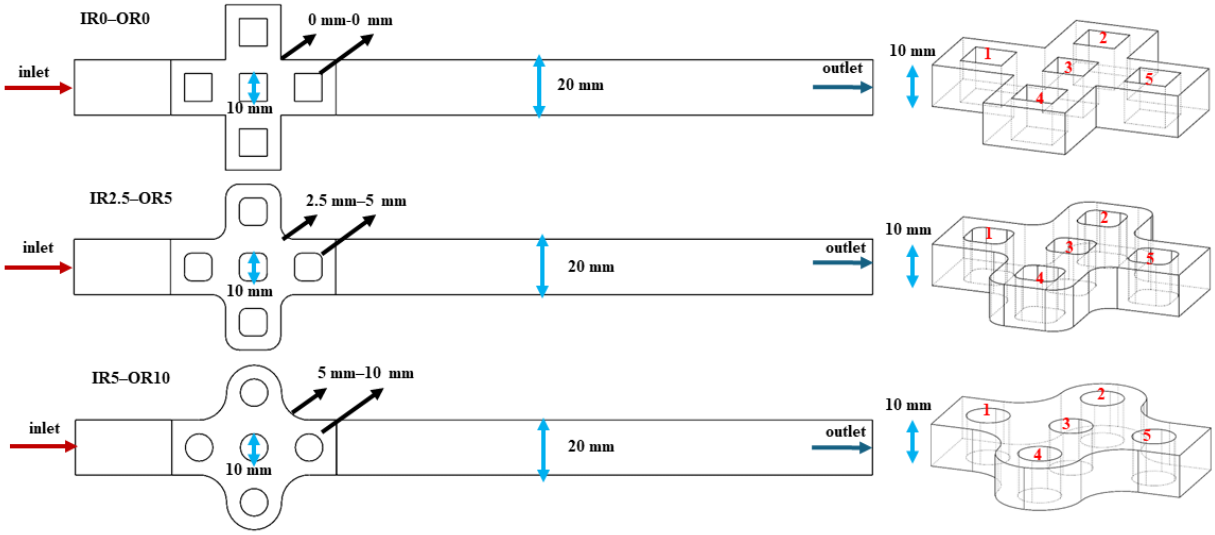

Figure 1. Flow volume geometry and the three configurations defined by the normalized corner radius (IR inner corner, OR outer corner radius; obstacles numbered 1-5).

Governing equations and turbulence model

The flow is assumed to be steady, incompressible, turbulent, and of constant properties. The conservation of mass and momentum is expressed in Reynolds-averaged form by Eq. (1) and Eq. (2), respectively. The effect of turbulence on the mean flow is represented by the modified k-ε turbulence model with low-Reynolds-number damping functions used by the Simcenter FLOEFD solver. The turbulent viscosity is computed by Eq. (3) in terms of the turbulent kinetic energy k and the dissipation rate ε, where C_mu is a model constant and f_mu is a damping function. The flow near solid surfaces is treated with the two-scale wall functions approach of the solver. The transport equations for k and ε and the damping functions of the model are used as defined in the technical theory documentation of the Simcenter FLOEFD solver. The pressure p in Eq. (2) is the modified mean pressure, which includes the isotropic component of the turbulent kinetic energy.

$$\nabla \cdot \mathbf{V} = 0 \tag{1}$$

$$\rho\,(\mathbf{V}\cdot\nabla)\mathbf{V} = -\nabla p + \nabla\cdot[(\mu+\mu_t)(\nabla\mathbf{V}+(\nabla\mathbf{V})^T)] \tag{2}$$

$$\mu_t = \rho\, C_\mu\, f_\mu\, \frac{k^2}{\epsilon} \tag{3}$$

Flow conditions and boundary conditions

The working fluid is water (density 998 kg/m3, dynamic viscosity 1.002 x 10-3 Pa.s). The inlet cross-section is 10 x 20 mm, and a fixed volumetric flow rate Q = 1 L/s is applied, corresponding to a mean

inlet velocity V = 5 m/s. Taking the obstacle side length D as the characteristic length, the Reynolds number computed by Eq. (4) is approximately 49800, which corresponds to the turbulent bluff-body regime. The channel outlet is at atmospheric pressure and all solid surfaces are defined as no-slip walls. The flow field is solved by the finite-volume method on a Cartesian computational mesh with cut boundary cells, locally refined around the solid surfaces. The IR0-OR0 configuration consists of 101232 cells. Because the geometry changes, the same mesh settings can yield a different number of cells and a different surface representation quality among the configurations; therefore the cell count of each configuration should be reported separately. Convergence is evaluated according to the goal-based criterion of the solver: convergence is considered achieved when the oscillation of each goal over an analysis interval of 47 iterations falls below the criterion defined for that goal. In all three configurations all goals reached 100% progress, and the solutions were completed in 144, 257, and 160 iterations, respectively.

$$\mathrm{Re} = \frac{\rho\, V\, D}{\mu} \tag{4}$$

Drag and pressure loss definitions

The drag force acting on an obstacle is defined by Eq. (5) as the integral over the obstacle surface of the flow-direction component of the pressure and viscous shear stresses. The local and array drag coefficients are given by Eq. (6) and Eq. (7). The reference velocity is the inlet velocity V, common to the three configurations, and the reference area is the obstacle frontal projected area A = D x (depth) = 100 mm2. The value A_tot = 5A used in the array coefficient is not a physical total frontal projected area but a normalization choice that sums the contributions of the five obstacles into a single dimensionless number; since obstacles 1, 3, and 5 lie on the flow axis, their frontal projections partly overlap. The percentage contribution of each obstacle to the total force is defined by Eq. (8). The main indicator of the internal flow performance is the pressure loss between the inlet and outlet; this is computed by Eq. (9) from the absolute static and area-averaged pressures, and the dimensionless pressure loss coefficient is given by Eq. (10). The normalized corner radius is defined by Eq. (11).

$$F_D = \int_S (-p\,\mathbf{n} + \tau \cdot \mathbf{n}) \cdot \mathbf{e}_x \, dS \tag{5}$$

$$C_{D,i} = \frac{F_{D,i}}{1/2\,\rho V^2 A} \tag{6}$$

$$C_{D,\mathrm{arr}} = \frac{F_{D,\mathrm{arr}}}{1/2\,\rho V^2 A_{\mathrm{tot}}}, \quad A_{\mathrm{tot}} = 5A \tag{7}$$

$$s_i = \frac{F_{D,i}}{\sum_{k=1}^{5} F_{D,k}} \times 100\% \tag{8}$$

$$\Delta p = p_{\mathrm{in}} - p_{\mathrm{out}} \tag{9}$$

$$K = \frac{\Delta p}{1/2\,\rho V^2} \tag{10}$$

$$r^* = \frac{\mathrm{IR}}{D/2} = \frac{\mathrm{OR}}{D} \tag{11}$$

Here F_D,i is the drag force on obstacle i, F_D,arr is the sum of the forces on the five obstacles, p is the pressure, n is the surface normal, tau is the viscous stress tensor, e_x is the flow-direction unit vector, rho is the density, V is the inlet velocity, IR and OR are the inner and outer corner radii, and D is the obstacle side length. The computational mesh, the streamlines, and the cross-sectional images of the flow field are presented in Figure 2 and Figure 3.

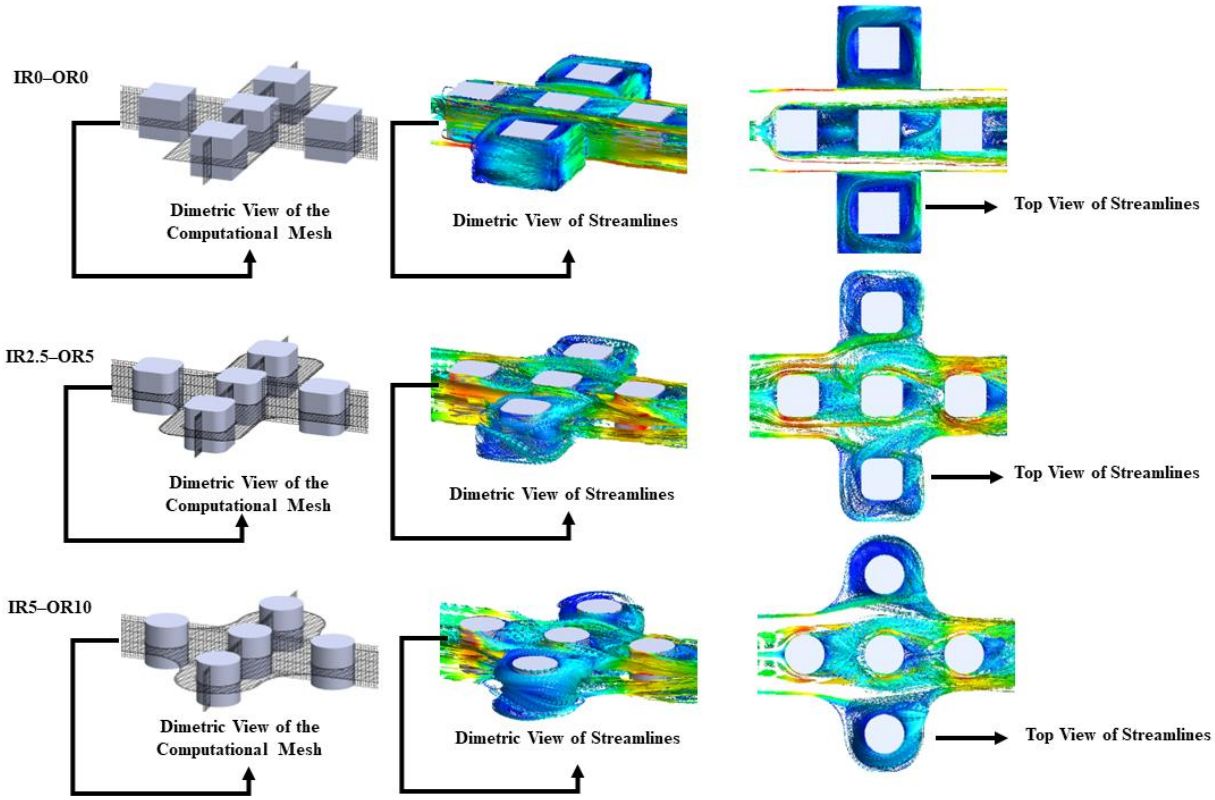

Figure 2. Computational mesh and streamlines for the three configurations (colored by velocity magnitude, dimetric and top views).

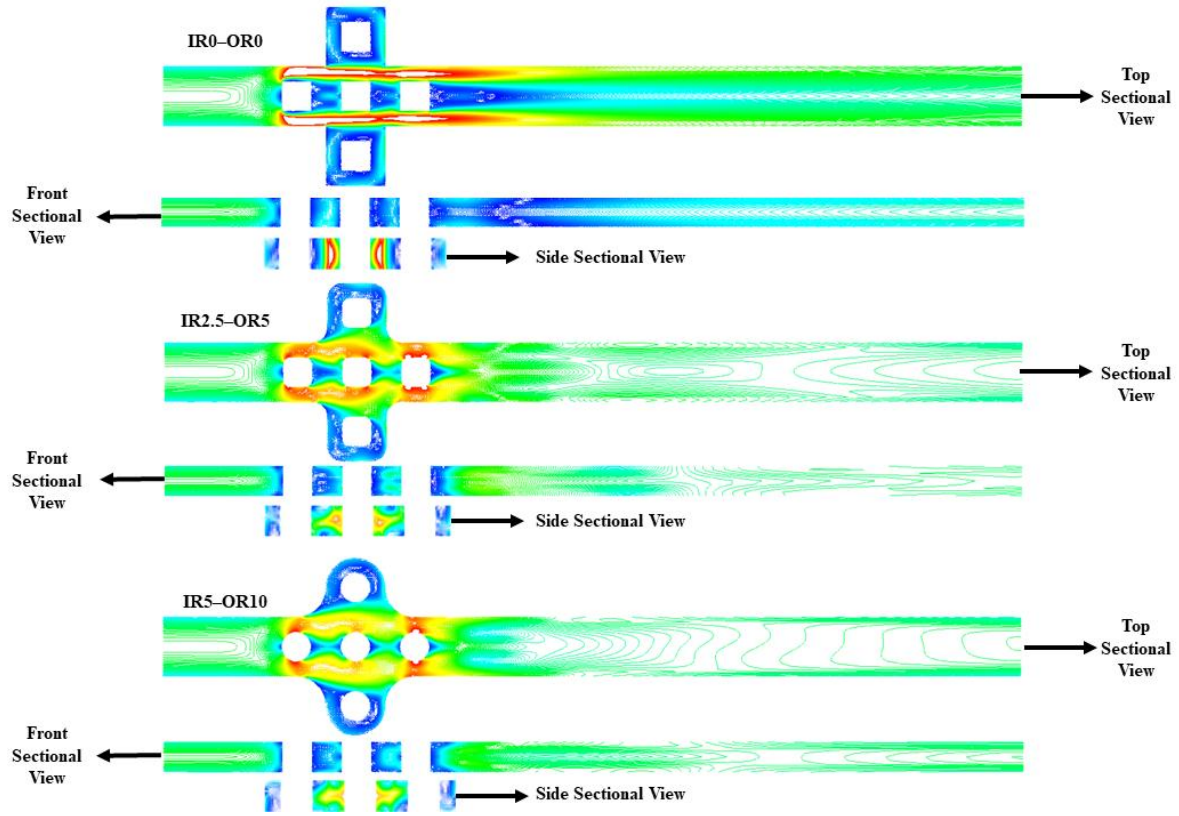

Figure 3. Top, front, and side cross-sectional images of the flow field for the three configurations (velocity magnitude distribution).

RESULTS

The streamlines and cross-sectional images (Figure 2 and Figure 3) show that the corner geometry qualitatively transforms the flow field. In the sharp-cornered array (r* = 0), wide and low-velocity wake regions are observed behind the obstacles. The velocity distributions give the impression that, as the corner radius increases, the low-velocity wake region shrinks and the flow follows the obstacles more smoothly. Since these images were produced with the color ranges automatically scaled by the solver, they are presented only for qualitative comparison; a quantitative color comparison across configurations is not drawn from these images.

The drag forces on the obstacles, their percentage contributions to the total force, and the array sum are given in Table 2, and the variation of the distribution with the normalized corner radius is shown in Figure 4. The total axial force of the array decreases from 10.229 N in the sharp-cornered case to 6.933 N in the circular case, a reduction of 32.2%. This total is the sum of the axial forces of the five obstacles only and does not include the forces on the channel walls.

Table 2. Drag force (N) and its percentage contribution s (%) for each obstacle, with the array sum

Obstacle	IR0-OR0		IR2.5-OR5		IR5-OR10	
	F (N)	s (%)	F (N)	s (%)	F (N)	s (%)
1	7.709	75.4	2.568	29.7	2.308	33.3
2	-0.119	-1.2	0.154	1.8	0.122	1.8
3	0.369	3.6	1.942	22.5	1.179	17.0
4	-0.101	-1.0	0.125	1.4	0.091	1.3
5	2.373	23.2	3.855	44.6	3.234	46.6
Array sum	**10.229**	**100.0**	**8.642**	**100.0**	**6.933**	**100.0**

Array drag reduction: -15.5% and -32.2%. Small differences between the array sum and the listed values arise from rounding.

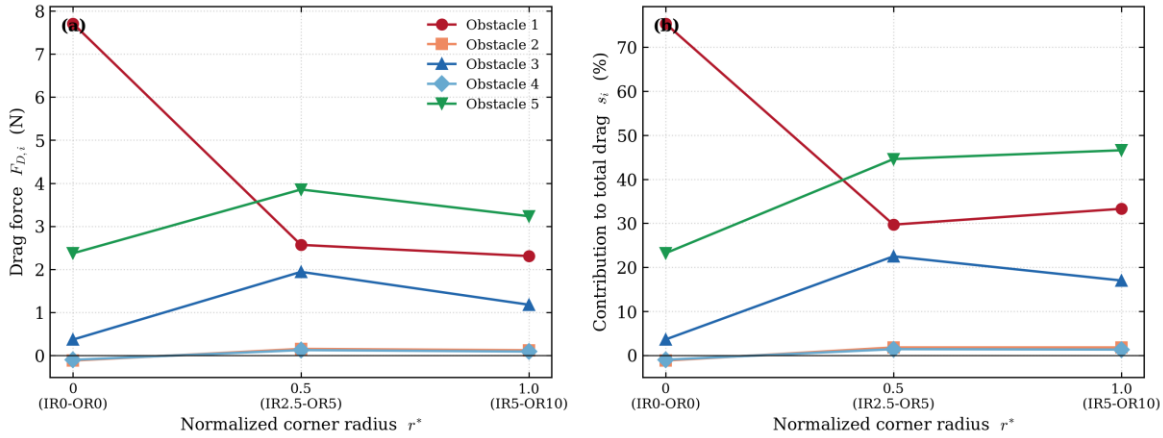

Figure 4. Variation of (a) the drag force and (b) the percentage contribution to the total force with the normalized corner radius.

The load distribution reveals the most pronounced result of corner rounding. The share of the leading obstacle 1 drops from 75.4% in the sharp case to 29.7% for the intermediate rounded geometry and is 33.3% for the circular geometry. In contrast, the share of the rearmost obstacle 5 rises from 23.2% to 46.6%. The share of the center obstacle (3) first increases from 3.6% to 22.5% and then decreases to 17.0%, showing a non-monotonic behavior. This behavior is considered to be related to the increase in the momentum reaching the rear obstacles due to the change in the wake of the front obstacle. The obstacles 2 and 4, located perpendicular to the flow, carry very small axial force in all three cases.

Although these two obstacles are geometrically symmetric, their forces differ somewhat from each other (for example, -0.119 N and -0.101 N in the sharp case). The absolute magnitude of these differences is very small, and the percentage difference is inflated by the near-zero denominator. These differences are considered to be attributable to mesh asymmetry, the level of convergence, or the steady solution approach; since a mesh-independence study and a time-dependent solution are not available, the cause cannot be separated with certainty. The negative axial force obtained for obstacles 2 and 4 in the sharp case indicates that the force is directed toward the inlet; these negative forces are considered to be related to the low pressure and the local reverse-flow regions around the lateral obstacles.

The local and array drag coefficients are given in Table 3, and the variation of the coefficient and the pressure loss with the normalized corner radius is shown in Figure 5. The array coefficient decreases from 1.640 to 1.111. The most striking result is that the local coefficient of the leading obstacle reaches a high value of 6.18 in the sharp-cornered array. This value is markedly above the magnitude generally known for a single square cylinder in free stream. The difference is explained by a high blockage ratio of about 0.50; Korukçu (2020) showed that the drag coefficient increases as the blockage ratio increases in a confined channel, and the high local coefficient here is consistent with that finding. Corner rounding reduces the coefficient of the same obstacle to 1.85.

Table 3. Local drag coefficient of each obstacle and the array drag coefficient

Obstacle	IR0-OR0	IR2.5-OR5	IR5-OR10
1	6.179	2.058	1.850
2	-0.096	0.123	0.098
3	0.295	1.557	0.945
4	-0.081	0.100	0.073
5	1.902	3.090	2.592
Array	1.640	1.386	1.111

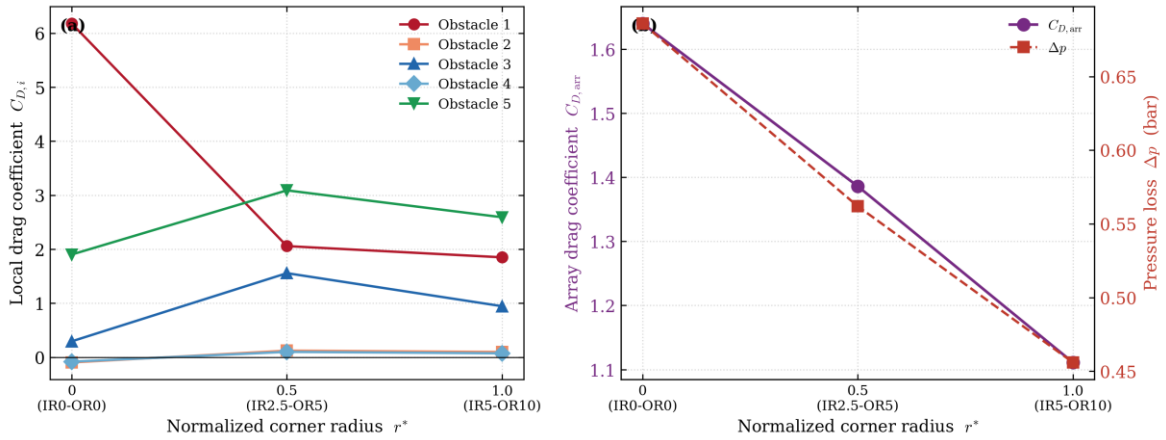

Figure 5. Variation of (a) the local drag coefficient and (b) the array coefficient and the pressure loss with the normalized corner radius.

The pressure loss is the main indicator of the internal flow performance. The absolute static pressure difference between the inlet and outlet decreases from 0.6857 bar in the sharp-cornered case to 0.4556 bar in the circular case, a reduction of 33.6%. The inlet and outlet pressures, the pressure loss, and the dimensionless pressure loss coefficient K for the three configurations are given in Table 4. The similar decreasing trend observed in the two quantities shows that the change in the obstacle force is related to the total system pressure loss; however, since the pressure loss also includes, besides the obstacle pressure forces, the channel wall friction, the contraction and expansion losses, and the change in the outer passage geometry, a precise separation of the contributions requires the wall and obstacle forces to be evaluated separately.

Table 4. Inlet and outlet pressures, pressure loss, and loss coefficient for the three configurations

Configuration	Inlet p (bar)	Outlet p (bar)	Δp (bar)	K
IR0-OR0	1.6989	1.0132	0.6857	5.50
IR2.5-OR5	1.5748	1.0132	0.5616	4.50
IR5-OR10	1.4688	1.0132	0.4556	3.65

DISCUSSION

The main mechanism of the drag reduction obtained is the effect of corner rounding on flow separation. In the sharp-cornered cross-section the separation point is fixed at the corner, and a wide wake and a high form drag develop. As the corner radius increases, separation is considered to be delayed and the wake width to decrease, so the form drag is considered to fall. This trend is in the same direction as Adeeb et al. (2018), Sarout et al. (2022), and Wang et al. (2023), who report reduced drag in the transition from a square to a circle. This study carries the same effect to a five-body array inside a confined water channel.

Unlike single-body studies, wake shielding in the array leads to a redistribution of the load among the bodies. As the front obstacle is rounded, its wake weakens and the momentum reaching the rear obstacles increases; as a result, the total load shifts from the front obstacle to the rear obstacles. The share of the leading obstacle drops from 75.4% to 33.3%, while the share of the rearmost obstacle rises from 23.2% to 46.6%. This interaction and shielding behavior is consistent with the results reported for multiple-cylinder arrays (Kahila et al., 2019; Kanna et al., 2025; Li et al., 2018; Naqvi et al., 2024) and is an array-specific feature that does not appear in single-body analysis.

Blockage is decisive in the absolute magnitude of the coefficients. The high blockage of about 0.50 raises, in particular, the local coefficient of the leading obstacle above its free-stream value; this behavior is consistent with confined-channel studies (Korukçu, 2020; Xu et al., 2023; Ferreira et al., 2021). In addition, because the inner and outer corners are rounded simultaneously in this study, the observed reduction is due not only to the obstacle corner but to the combined geometry change. Rounding the

outer passage corners also changes the local open area, and hence the effective blockage, to some extent; therefore the results are not attributed to a single geometric variable.

The governing of the in-channel flow and pressure performance by the obstacle geometry and arrangement is a known design lever in various systems, from heat exchangers to fuel cells. Çelik and Akçay (2025) showed that circular obstacles significantly affect the flow in a wavy channel, and Özdemir et al. (2023) showed that semi-cylindrical obstacles change the in-channel transport depending on the geometry. This study isolates the drag and pressure loss dimension of this general effect and reveals that, among the three combined geometries examined, the circular cross-section gives the lowest resistance.

The general trend is qualitatively consistent with the literature reporting reduced drag in the transition from a square to a circular cross-section (Adeeb et al., 2018; Sarout et al., 2022). On the other hand, the Reynolds number, the three-dimensional confinement, and the five-body arrangement here differ from the two-dimensional, low-Reynolds-number, single-cylinder studies in the literature. For this reason, the trends across configurations and the redistribution among the bodies, rather than the absolute values of the coefficients, should be considered as the main output. The free-stream single-cylinder coefficients (approximately 2.0-2.2 for a square and 1.0-1.2 for a circle at high Reynolds number) are mentioned only for a directional comparison, as canonical values that depend on the Reynolds number, the blockage ratio, and the surface conditions. All results in this study should be considered as comparative trends obtained within the steady RANS approach.

Limitations

This study carries deliberate limitations within the scope of the present congress. First, since the cross-section change rounds the obstacle corners and the outer passage corners simultaneously, the resulting effects are a combined effect and the two contributions are not separated individually; separating them requires a separate run with the outer boundary held fixed, or a factorial design in which IR and OR are varied independently. Second, at this Reynolds number the flow may contain time-dependent vortex shedding; since the analyses were carried out with a steady approach, the mean forces may suppress this effect to some extent, and a time-dependent solution is left to further work. Third, a full mesh-independence study and experimental validation are not presented within this scope. Fourth, since only three r* points were examined, the behavior at intermediate values and the possible optimum can be assessed only to a limited extent.

CONCLUSION

In this study, the effect of rounding the corner geometry on the drag force, drag coefficient, and pressure loss in a five-body array inside a water-filled channel was investigated by three-dimensional computational fluid dynamics. Changing the cross-section from a sharp-cornered square to a full circle rounds the obstacle corners and the outer passage corners simultaneously, and the main results obtained are as follows. The combined rounding of the inner and outer corners reduced the total axial force of the array by 32.2% and the inlet-outlet pressure loss by 33.6%, and lowered the array drag coefficient from 1.640 to 1.111. The contribution of the front body, which carries most of the total load in the sharp-cornered array, decreased markedly with rounding, and the load was transferred to the bodies located in the wake; owing to wake shielding, the coefficients of the rear bodies did not change monotonically. The high blockage of about 0.50 raised the local coefficient of the front body above its free-stream value in the sharp-cornered case. Among the three combined geometries examined, the IR5-OR10 configuration provided the lowest total obstacle force and pressure loss. This result is limited to the three points examined and the combined inner-outer geometry change; a claim of a general optimum corner radius requires more intermediate points and the separation of the inner and outer effects.

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MULTI-CRITERIA SUSTAINABILITY EVALUATION OF WASTE-BASED ADSORBENTS FOR WATER TREATMENT

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ABSTRACT

Waste-derived adsorbents provide a promising approach to water treatment by enabling the beneficial use of waste materials and supporting circular resource management. However, their overall suitability cannot be determined solely from adsorption performance, since material production and use involve interconnected technical, environmental, and economic considerations. In this study, a multi-criteria decision-making framework was developed to support the integrated sustainability assessment of waste-derived adsorbents used in water-treatment applications.

The selected waste-based adsorbents were evaluated under different energy-use scenarios using quantitative and semi-quantitative information reported in the literature. The assessment criteria included adsorption performance, raw material availability, preparation complexity, chemical and energy requirements, regeneration potential, operational stability, secondary pollution risk, production cost, and end-of-life options. To ensure comparability among criteria with different units and preference directions, the indicators were harmonised through benefit- and cost-based normalisation procedures and subsequently incorporated into a weighted decision matrix.

The findings indicated that sustainability performance is governed by trade-offs among feedstock demand, preparation intensity, energy consumption, chemical use, cost, regeneration behaviour, and operational durability. Production routes with lower resource and energy requirements may provide broader sustainability advantages even when their adsorption performance is not the highest. The integration of renewable energy was also found to improve the environmental profile of thermally intensive production pathways. Nevertheless, the results should be interpreted as a preliminary assessment because they are limited by the selected adsorbent alternatives, system boundaries, data availability, and the assumptions used for semi-quantitative scoring. It also highlights data gaps requiring consistent reporting across future adsorption studies and scale-up assessments. The proposed framework offers a systematic, and adaptable decision-support approach for comparing waste-derived adsorbents and identifying critical sustainability trade-offs before economic, and pilot-scale evaluations are undertaken.

Keywords: waste-derived adsorbents; sustainability assessment; water treatment; multi-criteria decision analysis

INTRODUCTION

Adsorption is one of the principal physicochemical methods used for the removal of organic and inorganic contaminants from aquatic environments. The relative simplicity of the process, its applicability to different classes of pollutants, and the possibility of employing a broad range of materials as adsorbents are among its major advantages. However, the environmental sustainability of an adsorption process is not determined solely by the amount of pollutant adsorbed or the removal efficiency. The energy and chemicals consumed during adsorbent production, the origin of the raw material, the regeneration method, the service life, and the end-of-life management of the saturated adsorbent are of critical importance in determining the overall system performance (Kamali et al., 2021).

In this context, research on the utilization of agricultural residues, food-processing wastes, lignocellulosic residues, sewage sludge, and industrial by-products as adsorbents has increased

considerably. The use of waste materials in adsorbent production not only limits the consumption of virgin raw materials but also enables existing waste streams to be converted into value-added products. Nevertheless, Jaria et al. (2022) emphasized that describing waste-based activated carbons as "low-cost" or "environmentally friendly" solely on the basis of the use of waste feedstocks is insufficient, and that production, activation, energy use, and regeneration stages should also be included in economic and environmental assessments.

Similarly, although high adsorption capacity is necessary for the sustainability of an adsorbent, it is not sufficient as a standalone indicator. High-temperature carbonization or activation, intensive chemical functionalization, prolonged washing procedures, or multi-step synthesis protocols may enhance adsorption performance; however, they may simultaneously increase the demand for energy, water, chemicals, and economic resources. Therefore, a systematic comparison is required between performance improvements in adsorbent development and the resources required to achieve these improvements. Sustainability assessments of biochar and activated carbon have demonstrated that production conditions may substantially influence the overall environmental performance of the material (Arena et al., 2016; Kamali et al., 2021).

Because this situation requires the simultaneous evaluation of numerous criteria that do not vary in the same direction, it can be treated as a multi-criteria decision-making problem. Various studies have used multi-criteria decision-making methods to integrate technical performance, economic feasibility, and environmental burdens in wastewater treatment. Kalbar et al. (2012) used a multi-criteria approach for the scenario-based evaluation of wastewater treatment technologies, whereas Heidari et al. (2022) integrated technical, life-cycle, and economic indicators of carbonaceous adsorbents using TOPSIS.

The aim of this study is to establish a literature-based multi-criteria evaluation framework for assessing the sustainability of waste-derived adsorbents by considering adsorption performance together with resource requirements, process complexity, energy and chemical consumption, regeneration, economic feasibility, and end-of-life management. The possible effects of different energy-use scenarios, particularly on the sustainability profiles of thermally intensive adsorbent production pathways, were also considered.

METHODOLOGY

Evaluation Approach and Adsorbent Alternatives

The study comprises a comparative sustainability assessment based on the integration of data reported in the literature. Rather than calculating the absolute environmental impact of a specific adsorbent product, the objective is to examine the principal technical, environmental, and economic advantages and trade-offs associated with different waste-derived adsorbent production approaches within a common decision framework.

For this purpose, waste-derived adsorbents were evaluated under general material classes by considering production intensity and feedstock characteristics: minimally pretreated agricultural- and food-waste-derived biosorbents, biochars produced from waste biomass, waste-derived activated carbons prepared through physical or chemical activation, sewage-sludge-derived adsorptive materials, and adsorbents developed from industrial or mineral wastes.

The purpose of this classification is to compare adsorbents not only in terms of feedstock origin but also with respect to the process intensity required to convert the raw material into a functional adsorbent. The literature emphasizes that the production stages of waste-derived activated carbons have substantial economic and environmental implications, while pyrolysis conditions and subsequent modifications should be incorporated into the sustainability assessment of biochars (Jaria et al., 2022; Kamali et al., 2021).

Determination of Sustainability Criteria

The criteria were selected to represent not only the treatment performance of the adsorbent but also the principal resource-related and environmental impacts from feedstock acquisition to end-of-life. Studies

addressing adsorbent sustainability and multi-criteria environmental technology selection were used as the basis for criterion selection (Attri et al., 2022; Heidari et al., 2022; Jaria et al., 2022).

Table 1. Criteria used in the multi-criteria sustainability assessment

Criterion	Definition	Preferred direction
Adsorption performance	Working adsorption capacity, removal efficiency, selectivity, and performance in real water matrices	Higher is preferred
Raw material availability	Local availability, continuity of supply, seasonal variation, and transportation requirements	Higher availability is preferred
Preparation complexity	Number and severity of pretreatment, conversion, washing, drying, and modification steps	Lower complexity is preferred
Chemical requirements	Quantity, toxicity, corrosiveness, recovery, and disposal requirements of reagents	Lower demand and hazard are preferred
Energy requirements	Energy required for drying, pyrolysis, carbonisation, activation, grinding, and regeneration	Lower demand is preferred
Regeneration potential	Recovery of adsorption capacity and structural integrity over repeated cycles	Higher is preferred
Operational stability	Resistance to attrition, leaching, swelling, dissolution, and performance deterioration	Higher is preferred
Secondary pollution risk	Release of fines, dissolved organic matter, metals, residual chemicals, or regeneration effluents	Lower risk is preferred
Production cost	Feedstock logistics, chemicals, energy, labour, equipment, waste treatment, and quality control	Lower cost is preferred
End-of-life management	Feasibility of regeneration, resource recovery, repurposing, energy recovery, stabilisation, or safe disposal	More circular options are preferred

While adsorption performance represents technical adequacy, raw material availability reflects the regular and regional availability of the waste feedstock. Preparation complexity is associated with the number of process steps, the need for specialized equipment, and pretreatment intensity. Chemical and energy requirements are directly related to resource consumption, whereas regeneration and operational stability represent the functional service life of the adsorbent. The secondary pollution criterion includes additional waste streams that may arise during production, use, and regeneration, while the end-of-life criterion considers reuse, recovery, or safe disposal options for the saturated adsorbent.

Standardization and Integration of Literature-Derived Data

Data describing adsorbent performance and sustainability characteristics are not reported in the literature using identical units or under identical experimental conditions. In particular, adsorption capacity depends on experimental conditions such as pollutant type, initial concentration, pH, adsorbent dosage, and temperature; therefore, direct comparison of absolute capacity values reported in different studies is methodologically limited. Similarly, energy consumption and production costs vary depending on the system boundaries and production scale considered.

Accordingly, quantitative data were not used directly as indicators of absolute superiority. Quantitative indicators were employed where comparable information was available in the literature, whereas semi-quantitative evaluations based on recurring trends reported in the literature were used in other cases. Semi-quantitative indicators were not considered absolute values representing experimental measurements of a specific material, but rather decision inputs expressing the relative position of alternatives.

This approach is consistent with environmental decision-making applications in which fuzzy and semi-quantitative indicators are incorporated into Multi-Criteria Decision Making (MCDM) frameworks, particularly when available data are limited or heterogeneous. Attri et al. (2022) integrated economic, technical, environmental, and social indicators using fuzzy weighting and ranking methods in the sustainability assessment of wastewater treatment technologies.

Normalization and Weighted Decision Matrix

To evaluate criteria expressed in different units within a common decision matrix, the indicators were converted into dimensionless values. Two different normalization directions were employed because higher values are preferred for benefit-type criteria, whereas lower values are preferred for cost-type criteria (Eq. (1) and (2)).

Normalization was generally expressed as:

$$\textit{For a benefit-type criterion:} \quad r_{ij} = (x_{ij} - x_{j,min}) / (x_{j,max} - x_{j,min}) \tag{1}$$

$$\textit{For a cost-type criterion:} \quad r_{ij} = (x_{j,max} - x_{ij}) / (x_{j,max} - x_{j,min}) \tag{2}$$

where, x_{ij} represents the evaluation value of alternative i with respect to criterion j, while r_{ij} represents the normalized criterion value. Thus, for all indicators, a higher normalized value represents a more preferable sustainability performance.

The weighted normalized decision matrix was subsequently constructed using Eq.(3):

$$v_{ij} = w_j \, r_{ij} \tag{3}$$

where v_{ij} represents the weighted normalized score of alternative i for criterion j, w_j denotes the relative importance weight assigned to criterion j, and r_{ij} represents the corresponding normalized criterion value. Regarding criterion weighting, the present study was designed as a preliminary assessment; therefore, a balanced weighting approach was adopted to avoid assigning disproportionate influence to any individual criterion in the absence of sufficient empirical or expert-based justification.Accordingly, the results were interpreted not as an absolute sustainability ranking but as decision-support outputs indicating the relative strengths and weaknesses of the different adsorbent classes.

In the literature, AHP or SWARA are commonly used to determine criterion weights through expert assessments, whereas TOPSIS, VIKOR, and other MCDM methods are used to rank alternatives. For example, Aydiner et al. (2016) applied hierarchical prioritization for the selection of sustainable wastewater treatment systems, while Heidari et al. (2022) used TOPSIS for the environmental and economic evaluation of carbonaceous adsorbents.

Energy-Use Scenarios

The energy source is an important parameter influencing the environmental profile of thermally intensive production pathways, particularly carbonization, pyrolysis, and activation. Therefore, three general energy-source scenarios were defined to evaluate the effect of energy requirements on adsorbent production pathways:

Scenario I – conventional energy: thermal and electrical energy are predominantly supplied by fossil-based or high-carbon-intensity systems;

Scenario II – mixed energy: conventional and low-carbon/renewable energy sources are used together;

Scenario III – renewable-energy-dominated production: a substantial proportion of process energy is supplied by low-carbon renewable sources.

The energy scenarios were not considered variables that alter the intrinsic adsorption performance of the adsorbent, but rather system variables affecting the interpretation of the environmental burden associated with the production stage. Life-cycle studies have demonstrated that the energy source may have a considerable effect on the overall environmental performance of thermally intensive processes such as pyrolysis and activation. Arena et al. (2016) demonstrated that the environmental impacts of activated carbon production are sensitive to the energy source and that the use of renewable energy has the potential to produce significant improvements in several important environmental impact categories.

Accordingly, in the scenario comparison, the environmental profiles of energy-intensive adsorbent production pathways were re-evaluated according to the energy source. However, it was not assumed that the energy scenario automatically eliminated structural disadvantages associated with other criteria, such as chemical consumption or regeneration waste.

Methodological Position of MCDM Methods

MCDM methods used in sustainability assessment can functionally be classified under criterion weighting, alternative ranking, compromise/outranking analysis, and uncertainty management. AHP and SWARA are used to determine the relative importance of criteria; TOPSIS, VIKOR, and MOORA are used to rank normalized alternative performances; PROMETHEE and ELECTRE are used to evaluate criterion-based outranking relationships. Fuzzy extensions enable uncertainty in expert judgments or semi-quantitative data to be incorporated into the decision model.

Table 2. Comparison of major MCDM methods applicable to sustainability analysis

Method Group	Examples	Main Function	Main Advantage	Main Limitation
Weighting	AHP, SWARA	Determining criterion importance	Systematizes expert assessments	Sensitive to subjective judgments
Weighted sum	SAW/WSM	Integrating normalized criteria	Transparent and easy to interpret	High compensation among criteria
Ideal-solution based	TOPSIS	Ranking according to proximity to the ideal solution	Integrates numerous criteria with different units	Sensitive to weighting and normalization choices
Compromise based	VIKOR	Balancing overall utility and the weakest criterion	Considers conflicting criteria	Sensitive to compromise parameters
Outranking based	PROMETHEE, ELECTRE	Criterion-based preference relationships	Can limit full compensation for critical criteria	Requires thresholds and preference functions
Fuzzy/hybrid	Fuzzy AHP, Fuzzy TOPSIS, Fuzzy SWARA	Incorporating uncertain information	Suitable for semi-quantitative criteria	Increases model complexity

Applications in the field of wastewater treatment indicate that these methods are generally used in a complementary manner at different stages of the decision-making process rather than simply as alternatives to one another. Mahjouri et al. (2017) combined AHP, TOPSIS, and fuzzy logic, whereas Attri et al. (2022) used Fuzzy SWARA for criterion weighting and Fuzzy MOORA/Fuzzy TOPSIS for ranking. Ahmed et al. (2024) evaluated the same decision problem using TOPSIS, VIKOR, and PROMETHEE II and compared method-dependent changes in ranking.

CONCLUSION AND DISCUSSION

Principal Trade-Offs in Sustainability Performance

The multi-criteria assessment demonstrates that adsorbent sustainability is not determined by a single variable. High technical performance does not necessarily imply that an adsorbent will exhibit a superior sustainability profile throughout the entire production or use cycle. In particular, as the intensity of feedstock processing increases, adsorption-related characteristics such as surface area, porosity, and functional-group density may be improved; however, energy and chemical inputs may also increase.

Minimally processed agricultural- and food-waste-derived biosorbents exhibit an advantageous profile in terms of low production intensity and feedstock valorization. However, the potentially lower mechanical strength, more limited regeneration, or more heterogeneous adsorption properties of such materials may constrain their technical sustainability.

Although biochar production requires greater process intensity than raw biomass, it converts the material into a more stable carbonaceous structure. Kamali et al. (2021) also emphasized that the sustainability potential of biochar in water and wastewater treatment depends not only on adsorption performance but also on feedstock characteristics, pyrolysis conditions, regeneration, and end-of-life management.

In chemically or physically activated carbons, enhanced pore structures and high adsorption performance can be achieved; however, the activation stage may require additional energy, reagents, and process water. Therefore, a clear trade-off exists between the technical advantages of activated carbons and their production intensity. Jaria et al. (2022) stated that the sustainability of waste-derived activated carbons should be carefully evaluated, particularly with respect to energy demand, chemical inputs, and production costs.

On the basis of this assessment, it is evident that the production pathway providing the highest adsorption performance cannot necessarily be considered the most sustainable option under all conditions. An adsorbent that provides adequate treatment performance with lower processing intensity may exhibit a more balanced sustainability profile, particularly in systems where energy and chemical resources are constrained.

Effects of Feedstock Availability and Process Intensity

The use of a waste-derived feedstock represents a favorable starting point in terms of reducing the demand for virgin raw materials. However, feedstock sustainability does not depend solely on its classification as "waste." The quantity and continuity of waste generation, regional availability, storage potential, moisture content, transport distance, and alternative utilization pathways should also be considered.

The use of a locally abundant agricultural waste as an adsorbent with minimal pretreatment may provide substantial advantages in terms of resource efficiency because of reduced transport and processing requirements. In contrast, transporting a low-density and geographically dispersed feedstock to a centralized facility may reduce the advantages arising from its low raw material cost.

Similarly, complex production protocols may limit industrial applicability even when they improve performance at the laboratory scale. Therefore, the number of production steps, processing time, high-temperature requirements, need for controlled atmospheres, and washing-drying stages are integral components of sustainability assessment.

Effect of Energy-Use Scenarios on the Sustainability Profile

Comparison of the energy scenarios indicates that the energy source is a critical variable, particularly for thermally intensive adsorbent production pathways. For raw or minimally processed adsorbents, the total energy requirement is relatively limited; therefore, changes in the energy source exert a more limited influence on the overall sustainability profile. In contrast, for biochars and especially carbonaceous materials requiring high-temperature activation, energy input constitutes an important component of the production system.

Under conventional and high-carbon-intensity energy systems, the environmental disadvantages associated with thermal processing become more pronounced. The integration of renewable or low-carbon energy sources can reduce energy-related environmental burdens and improve the relative sustainability performance of thermally intensive production pathways. Life-cycle studies of activated carbon production have shown that the energy source, as well as the feedstock, can be an important determinant of environmental outcomes (Arena et al., 2016).

Nevertheless, the use of renewable energy does not eliminate all environmental burdens associated with thermally intensive production pathways. Consumption of activation agents, washing-water requirements, generation of chemical wastes, and end-of-life management of the adsorbent are criteria that must be evaluated independently of the energy source. Therefore, although renewable energy represents an important improvement option for reducing the impacts of high process intensity, it is not the sole determinant of sustainability.

This finding indicates that energy scenarios should be explicitly incorporated into adsorbent sustainability analyses. The same adsorbent production route may exhibit different environmental

performance under different regional energy systems. Accordingly, when evaluating the sustainability of a synthesis route defined at the laboratory scale, the energy mix of the geographical region in which production will occur should also be considered.

Regeneration, Operational Durability, and Secondary Pollution

Regeneration may provide an important sustainability advantage because it allows the raw material and energy requirements associated with adsorbent production to be distributed over multiple use cycles. However, reuse potential cannot be adequately evaluated solely on the basis of removal efficiency after a specified number of cycles.

Acids, bases, or organic solvents used during regeneration introduce additional chemical inputs and may transfer adsorbed pollutants into a more concentrated liquid phase. Therefore, desorption does not imply destruction of the pollutant. Preservation of the structural integrity, active sites, and pore system of the adsorbent over multiple cycles should also be considered in terms of operational sustainability.

Accordingly, the contribution of regeneration potential to sustainability should be evaluated together with the number of reuse cycles, regenerant demand, material loss, performance deterioration, and management of regeneration wastes. An adsorbent with a high adsorption capacity but requiring intensive chemical regeneration after every use may not necessarily be more advantageous at the system level than a material with a lower initial capacity but suitable for simple and low-resource regeneration.

Economic Feasibility and End-of-Life Management

Economic evaluation of waste-derived adsorbents should not be based solely on raw material price. Feedstock collection and transportation, drying, grinding, thermal conversion, activation, chemical consumption, washing, separation of the adsorbent after treatment, and regeneration may determine the final cost. Assessments of waste-based activated carbons have shown that the use of low-cost or free feedstocks alone does not guarantee low production costs (Jaria et al., 2022).

The economic value of an adsorbent is also directly related to its service life. An adsorbent with a higher initial production cost but capable of prolonged reuse may be more advantageous at the operational scale than a cheaper material with a short service life. Therefore, production cost should, where possible, be related to the total use cycle of the adsorbent or to the amount of pollutant removed per unit basis.

The end-of-life stage is also a critical component of sustainability, although it is frequently not evaluated in sufficient detail in the literature. Because adsorbed heavy metals or persistent organic contaminants accumulate on the saturated adsorbent, uncontrolled disposal may result in the release of pollutants back into the environment. Therefore, an ideal system should not only convert waste into an adsorbent but should also define regeneration, pollutant recovery, or safe final-management options once the adsorbent becomes saturated.

The use of waste-derived adsorbents has considerable potential for sustainable resource management because it integrates water treatment with waste valorization. However, the sustainability of these materials cannot be assessed solely on the basis of their waste-derived origin or high adsorption performance.

The multi-criteria evaluation framework developed in this study considers adsorption performance, raw material availability, preparation complexity, chemical and energy requirements, regeneration potential, operational stability, secondary pollution risk, production cost, and end-of-life options within a common decision structure.

The assessment demonstrates that sustainable adsorbent selection involves important trade-offs between technical performance and resource consumption. Intensive activation and modification methods may improve adsorption properties while simultaneously increasing energy, chemical, and water consumption. In contrast, materials with lower process intensity may provide a more balanced sustainability profile in certain applications even when they do not achieve maximum adsorption performance.

Energy scenarios emerge as an important variable, particularly for thermally intensive production pathways. The integration of renewable energy sources into the production system may reduce energy-

related environmental burdens and improve the environmental profile of materials such as biochar and activated carbon. Nevertheless, other sustainability components, including chemical consumption, regeneration, and end-of-life management, should be evaluated independently of the energy source. Life-cycle studies of activated carbon production also support the importance of the production energy source in determining environmental performance.

In conclusion, the principal objective of sustainable adsorbent development should be to achieve the required treatment performance with minimum resource consumption, acceptable economic cost, and low environmental burden rather than merely maximizing adsorption capacity. The proposed multi-criteria framework may enable systematic comparison of different adsorbents and identification of critical sustainability trade-offs before proceeding to pilot-scale or detailed techno-economic evaluations.

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THE DIGITAL STATE THROUGH THE PRISM OF A COMPARATIVE ANALYSIS OF TECHNOLOGICAL DETERMINISM AND SOCIAL CONSTRUCTIVISM

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ABSTRACT

In order to better understand the emergence of the digital state, this study compares and contrasts two of the most influential theories that explain the relationship between technology and political systems: technological determinism and social constructivism. One of the main topics of discussion in political theory and Science and Technology Studies (STS) is the relationship between technology and politics as digitalization, artificial intelligence, big data, algorithmic governance, and platform-based public administration continue to change modern governance. The study intends to assess both theoretical views' contributions to comprehending current political and institutional changes by looking at their conceptual underpinnings, underlying presumptions, and explanatory powers. The study uses conceptual analysis, document analysis, and comparative theoretical analysis as part of its qualitative methodology. Classical and contemporary contributions to technological determinism and social constructivism are systematically reviewed, with particular attention to the works of Jacques Ellul, Lewis Mumford, Langdon Winner, Thomas P. Hughes, Trevor Pinch, and Wiebe E. Bijker. The analysis demonstrates that technological determinism interprets technology as a structural force capable of reshaping political institutions, governance mechanisms, and power relations, whereas social constructivism argues that technological development itself is shaped by political choices, institutional arrangements, social interests, and cultural values. While the former emphasizes the transformative effects of technological innovation on society and the state, the latter highlights the reciprocal interaction between technological change and the broader social and political environment. According to the study, these methods should be viewed as complimentary analytical frameworks that provide light on various aspects of the relationship between technology and politics rather than as mutually exclusive. It concludes that as modern digital governance arises from the dynamic interaction between technological innovation, political institutions, regulatory frameworks, and societal actors, the idea of the digital state offers a suitable framework for integrating various viewpoints. This integrated perspective offers a more comprehensive theoretical basis for explaining the transformation of political systems in the digital age.

Keywords: Technological Determinism, Social Constructivism, Digital State, Political Systems, Digital Governance.

ÖZET

Bu çalışma, dijital devlet olgusunun ortaya çıkışını daha iyi izah ede bilmek amacıyla teknoloji ile siyasal sistemler arasındaki ilişkiyi açıklayan en etkili iki kuramsal yaklaşım olan teknolojik determinizm ile sosyal konstrüktivizmi (sosyal inşaçılık) karşılaştırmalı olarak incelemektedir. Dijitalleşme, yapay zekâ, büyük veri (big data), algoritmik yönetişim ve platform temelli kamu yönetimi uygulamalarının çağdaş yönetişim anlayışını dönüştürdüğü günümüzde, teknoloji ile siyaset arasındaki ilişki siyaset teorisi ile bilim ve teknoloji çalışmaları (Science and Technology Studies-STS) literatürünün temel tartışma alanlarından biri hâline gelmiştir. Çalışmanın amacı, her iki kuramsal yaklaşımın kavramsal temellerini, temel varsayımlarını ve açıklayıcılık kapasitelerini analiz ederek günümüz siyasal ve kurumsal dönüşümlerini açıklamadaki katkılarını değerlendirmektir. Araştırma, nitel araştırma yöntemi çerçevesinde karşılaştırmalı teorik analiz, kavramsal analiz ve doküman incelemesine dayanmaktadır. Teknolojik determinizm ve sosyal konstrüktivizm literatürü sistematik biçimde incelenmiş, özellikle Jacques Ellul, Lewis Mumford, Langdon Winner, Thomas P. Hughes, Trevor Pinch ve Wiebe E. Bijker'in kuramsal yaklaşımları karşılaştırmalı olarak değerlendirilmiştir.

Analiz sonucunda teknolojik determinizmin teknolojiyi siyasal kurumları, yönetişim mekanizmalarını ve iktidar ilişkilerini dönüştüren yapısal bir güç olarak ele aldığı, sosyal konstrüktivizmin ise teknolojik gelişmenin siyasal tercihler, kurumsal düzenlemeler, toplumsal çıkarlar ve kültürel değerler tarafından şekillendirildiğini savunduğu görülmektedir. Çalışmada bu iki yaklaşımın birbirini dışlayan kuramlar olarak değil, teknoloji-siyaset ilişkilerinin farklı boyutlarını açıklayan tamamlayıcı analitik çerçeveler olarak değerlendirilmesi gerektiği ileri sürülmektedir. Sonuç olarak dijital devlet kavramının, teknolojik yenilikler ile siyasal kurumlar, düzenleyici mekanizmalar ve toplumsal aktörler arasındaki dinamik etkileşimi açıklamada bütünleştirici bir kuramsal çerçeve sunduğu ve dijital çağda siyasal sistemlerin dönüşümünü anlamaya önemli katkı sağladığı sonucuna ulaşılmıştır.

Anahtar Kelimeler: Teknolojik Determinizm, Sosyal Konstrüktivizm, Dijital Devlet, Siyasal Sistemler, Dijital Yönetişim.

INTRODUCTION

Against the backdrop of twenty-first century societal dynamics, the growing influence of digital technologies on state governance and political systems has made it imperative to reassess the relationship between technology and politics from a theoretical perspective. Technological innovations such as artificial intelligence (AI), big data, algorithmic decision-making, digital platforms, and e-government applications not only transform the technical instruments employed in public administration but also reshape the exercise of political power, institutional decision-making processes, patterns of civic participation, prevailing conceptions of legitimacy, and the nature of state-citizen relations. Within this context, one of the central theoretical debates concerns the role of technology in political transformation, the mechanisms through which technological change affects the state and society, and the underlying dynamics that shape these transformations. Indeed, these questions have become central to contemporary scholarly discussions on the relationship between technology and society.

In the current academic literature, these debates are largely structured around two major theoretical perspectives: technological determinism and social constructivism. Technological determinism regards technology as the principal structural driver of social and political transformation, arguing that both the state and society adapt to the new realities created by technological progress. In contrast, social constructivism maintains that technological development does not follow an autonomous or predetermined internal logic. Rather, it is shaped through the interaction of political institutions, economic interests, legal frameworks, cultural values, and diverse social actors. From this perspective, these two approaches not only offer contrasting explanations of the nature of technology but also present distinct methodological frameworks for interpreting the concept of the digital state.

Against the backdrop of the rapid expansion of the digital state model, this theoretical debate has become increasingly noteworthy. The emergence of digital state cannot be explained solely by the implementation of new technological solutions. Since the same technologies are deployed within different political systems under distinct legal frameworks, institutional arrangements, and governance models, their political consequences likewise vary considerably. Consequently, a comprehensive understanding of the nature of the digital state requires not only an examination of the transformative potential of technology but also an analysis of how technological development is shaped by its broader social and political environment. It is precisely at this juncture that technological determinism and social constructivism emerge as two influential analytical frameworks for explaining the theoretical foundations of the digital state.

Although the existing literature contains a substantial body of research on technological determinism and social constructivism, comparative studies examining these two theoretical approaches within the context of the digital state remain relatively limited. Moreover, the combined analytical potential of these perspectives has yet to receive sufficient scholarly attention. Yet, the digital state may be regarded as one of the clearest manifestations of the reciprocal interaction between technology and political institutions. Accordingly, a comprehensive examination of the theoretical foundations of the digital state through an integrated analytical perspective constitutes an important scholarly imperative.

The aim of this article is to conduct a comparative analysis of the fundamental conceptual propositions of technological determinism and social constructivism, to evaluate their analytical capacity for explaining the relationship between technology and politics, and, on the basis of the theoretical findings obtained, to provide a more comprehensive theoretical account of the digital state. The article argues that the digital state should be understood not merely as the natural outcome of technological innovation but rather as a complex sociotechnical system emerging from the dynamic interaction among political institutions, legal frameworks, social actors, and processes of technological development. In this respect, the study seeks to make an original contribution to the existing literature by examining the theoretical foundations of the technology-politics relationship from a comparative perspective.

RESULTS AND DISCUSSION

Technological determinism is a theoretical approach that regards technology as one of the principal driving forces behind social and political changes. According to this perspective, technological advances not only give rise to new tools and modes of production but also profoundly influence the reconfiguration of economic and social relations, governance mechanisms, and political institutions (Hallström, 2022; Volti, 2020). Within the framework of technological determinism, technology is viewed as the primary structural factor shaping the trajectory of societal development. In this regard, technological innovations such as the Industrial Revolution, the Internet, digital platforms, and AI are associated with far-reaching transformations in public administration, political participation, power relations, and other broad dimensions of social life (Wyatt, 2021; Hallström, 2022).

Technological determinism is widely regarded in the contemporary social and political science literature as one of the earliest and most extensively debated theoretical paradigms in explaining the relationship between technology and society. Nevertheless, current scholarship no longer treats technological determinism as a single, unified theoretical framework. Instead, it is viewed as a family of theoretical perspectives that explain the role of technology in processes of social development at different levels of analysis. The intellectual origins of technological determinism can be traced back to the late 19th and early 20th centuries. Although scholars from diverse disciplines have contributed to its development, its theoretical foundations have been shaped most significantly by researchers working in economics, sociology, political theory, and science and technology studies. Among the earliest contributors, the American economist and sociologist Thorstein Veblen examined the relationship between technological progress and economic and institutional change, arguing that transformations in production technologies directly influence the economic organization of society and the functioning of its social institutions. In later years, thinkers such as Jacques Ellul, Lewis Mumford, Langdon Winner, and Thomas Hughes developed more systematic accounts of technology's societal impact, emphasizing that technology should not be understood merely as a collection of material artefacts but rather as a complex phenomenon that actively shapes social and political relations (Wyatt, 2021; Hallström, 2022).

Within the framework of technological determinism, technology is generally understood not as a neutral instrument but as a dynamic system endowed with its own functional logic that gradually permeates other spheres of society. According to this perspective, the emergence of new production methods, communication technologies, and information systems resulting from technological advancement has the capacity to transform patterns of individual behaviour, the operating principles of social institutions, and political decision-making processes. In other words, technology is regarded not merely as a tool employed by human actors but also as a structural force that reshapes the social environment within which they operate (Volti, 2020). Consequently, technological determinism places greater emphasis on examining how technology influences the organization of society than on investigating how society chooses to use technology.

In contemporary scholarship, one of the defining conceptual characteristics of technological determinism is its association with the notion of the relative autonomy of technological development. From this perspective, although technology does not evolve entirely independently of social processes, it gradually acquires its own internal developmental dynamic, which, beyond a certain stage, generates constraints that compel society to adapt accordingly (Hallström, 2022). Consequently, the direction of technological development is determined not solely by political decisions or societal preferences.

Rather, the functional advantages of technology, together with its efficiency, economic utility, and competitive benefits, are also regarded as fundamental factors driving its widespread diffusion.

Another fundamental proposition of technological determinism is that technology exerts a revolutionary influence on social and political institutions. According to this perspective, emerging technologies not only enhance the functioning of existing institutions but also have the capacity to reshape their structures and functions. For instance, the development of industrial technologies strengthened the economic and administrative capacity of nation-states. The emergence of mass communication technologies shifted the mechanisms through which political propaganda and public opinion are produced. Digital technologies have paved the way for new forms of governance, including e-government, open data policies, digital participation, and algorithmic decision-making within public administration (Wyatt, 2021; Volti, 2020). From this standpoint, technology is understood not merely as a technical innovation but also as a significant institutional force that facilitates the reconfiguration of the ways in which political power is exercised.

It would be inaccurate to suggest that all proponents of technological determinism share an identical position. Contemporary scholarship generally distinguishes between hard and soft forms of technological determinism. Hard technological determinism views technological development as a largely inevitable and autonomous process that determines the course of societal development. Soft technological determinism, by contrast, while acknowledging the decisive influence of technology, argues that political decisions, social norms, culture, legal institutions, and the broader social context also exert a significant influence on this process (Smith & Marx, 1994; Hallström, 2022). The majority of contemporary studies adopt the latter perspective, recognizing the groundbreaking impact of technology without treating it as an absolute of social and political change. Leading scholars of the 21th century played a pivotal role in the systematic development of technological determinism as a theoretical framework. In particular, the works of Lewis Mumford, Langdon Winner, and other influential thinkers mentioned above contributed significantly to the emergence of new theoretical approaches for explaining the relationship between technology and society. Although each scholar examined the societal implications of technology from a distinct perspective, they shared a common premise: technology is not only a neutral instrument employed by human beings but also a structural force that plays a crucial role in transforming social institutions, political relations, and political systems. One of the most systematic theoretical formulations of technological determinism was developed by the French sociologist Jacques Ellul. In his seminal work *The Technological Society*, Ellul conceptualizes technology not as the mere aggregate of individual machines or technical devices but as a universal organizing principle, which he refers to as *la technique* (Ellul, 1964). According to Ellul, *la technique* does not denote technological artefacts themselves. Rather, it represents a mode of action founded upon the principles of maximum efficiency, productivity, standardization, calculability, and optimization. In his view, virtually all institutions of modern society - including public administration, the economy, the legal system, education, the media, and even everyday social relations - have increasingly come to operate according to the logic of technical efficiency. As a consequence, technology gradually acquires a degree of relative autonomy that enables it to shape the direction of societal development, while individuals increasingly lose their capacity to exercise meaningful control over this process. Ellul drew attention not only to the benefits generated by technological progress but also to its broader social and political consequences, including the restriction of individual freedoms, the expansion of bureaucratic governance, and the increasing subordination of political decision-making to criteria of technical efficiency.

Another influential thinker who made significant contributions to the development of technological determinism was Lewis Mumford. According to Mumford, the concept of technology should not be confined solely to the development of material artefacts but should instead be understood as a historical process that shapes the overall organization of civilization (Mumford, 1964; 1967). He argued that technological progress does not invariably enhance human freedom. On the contrary, under certain conditions, technological systems can transform individuals into passive components of a vast techno-bureaucratic apparatus. One of the most compelling illustrations of this argument is his concept of the *megamachine*. According to Mumford, large state structures, bureaucratic administration, and large-scale organizational systems operate as an integrated mechanism through the use of technology, thereby

constraining individuals' capacity to participate meaningfully in decision-making processes. From this perspective, technological development plays a significant role not only in the spheres of economic activity and production but also in the organization of power relations and the formation of models of political governance.

Among the scholars who have explored the political dimensions of technology most comprehensively, the American political theorist Langdon Winner occupies a prominent place. His landmark article, *Do Artifacts Have Politics?,* is widely recognized as a foundational contribution to scholarship on the intersection of technology and political life (Winner, 1980). In this influential work, Winner challenges the conventional assumption that technological artefacts are not politically neutral, arguing instead that they may embody particular political objectives and reflect underlying configurations of power. In his view, the structural properties of certain technologies inherently privilege some forms of social organization while constraining others. Urban infrastructure, transportation networks, surveillance technologies, digital platforms, and systems of algorithmic governance, for example, can reshape patterns of access to resources, redefine modes of political participation, and facilitate the concentration of political authority. On this basis, Winner contends that the processes through which technologies are designed, developed, and implemented should themselves be understood as inherently political, rather than merely technical, undertakings. This perspective has subsequently provided one of the most influential theoretical foundations for contemporary analyses of the digital state, artificial intelligence, big data, and other emerging forms of digital governance within political theory.

A more nuanced and balanced interpretation of technological determinism can be found in the work of Thomas Hughes. In an effort to explain the relationship between technology and society, Hughes introduced the concept of technological momentum (Hughes, 1983). According to Hughes, newly emerging technological systems are initially shaped to a considerable extent by political decisions, economic interests, and societal preferences. As these systems evolve, however, they expand in scale, become increasingly complex, and incorporate a wide range of technical, economic, and institutional components, thereby acquiring a degree of institutional inertia. At this stage, rather than continuing to shape technology, societies are increasingly required to adapt to the constraints generated by existing technological systems. Hughes characterizes this process as technological momentum, arguing that although technology is initially shaped by society, it gradually develops a dynamic of its own and eventually becomes a force capable of influencing the direction of societal development. Because it establishes a middle ground between strong technological determinism and social constructivism, Hughes's approach has become one of the most influential theoretical perspectives in contemporary science and technology studies.

Although the theoretical perspectives advanced by Ellul, Mumford, Winner, and Hughes highlight different dimensions of technological determinism, they converge on a common premise: technology exerts a profound transformative influence on society, the state, and political systems. From the late twentieth century onward, however, a growing number of scholars in the field of science and technology studies began to challenge technological determinism, arguing that it conceptualizes technology as an excessively autonomous and unidirectional driver of social change. According to these scholars, technology should not be understood as an independent force that single-handedly shapes society. Rather, technological development itself is embedded within and influenced by broader social, political, economic, and cultural processes. These critiques ultimately gave rise to the social constructivist approach, which has since evolved into a major alternative theoretical framework for explaining the relationship between technology and society (Pinch & Bijker, 1987; Bijker, Hughes, & Pinch, 1987; Wyatt, 2021).

Although technological determinism occupied a dominant position in science and technology studies for many years, its explanatory power came under increasing scrutiny within academic circles from the final quarter of the twentieth century onward. While scholars generally acknowledged the significant influence of technology on society, they argued that portraying it as the primary or sole driver of social and political change failed to capture the complexity of empirical reality. From this perspective, technology is not an autonomous system governed by a predetermined internal logic of development. Rather, it is understood as a socially constructed phenomenon shaped by the interplay of competing social interests, political decisions, economic relations, cultural values, and institutional processes

(Wyatt, 2021; Mackenzie & Wajcman, 1999). This perspective subsequently evolved into what became known as social constructivism, emerging as one of the most influential alternative theoretical frameworks for interpreting the relationship between technology and society.

The intellectual foundations of social constructivism extend beyond the field of technology studies and are rooted in a broader tradition of social theory. During the second half of the twentieth century, theoretical approaches emphasizing the socially constructed nature of knowledge, particularly those developed by Thomas S. Kuhn, Peter L. Berger, and Thomas Luckmann, provided the conceptual foundations for the development of social constructivism. These scholars argued that neither scientific knowledge nor social reality should be regarded as fixed and objective entities. Instead, they maintained that both are constituted through human interaction and are continuously shaped by shared norms, social practices, and historical conditions (Berger & Luckmann, 1966). This perspective was subsequently extended to the study of technology, giving rise to the argument that the trajectory of technological development cannot be understood independently of the social relations, political institutions, and cultural contexts within which it evolves.

In explaining the dynamics of technological change, social constructivists attach particular importance to the concept of *relevant social groups*. This concept reflects the view that different social actors interpret and evaluate the same technology in accordance with their own interests, objectives, and expectations. Engineers, public institutions, manufacturers, users, investors, and civil society organizations may therefore assign different meanings and functions to the same technological artefact. Consequently, the final form of a technology is shaped not only by the technical design process but also by the negotiations, interactions, and compromises that emerge among these actors. From this perspective, technological development is understood not as a linear or predetermined process but as the outcome of choices made among multiple alternative developmental pathways.

The transformation of social constructivism into a systematic conceptual framework within the field of science and technology studies took place during the 1980s. In particular, the *Social Construction of Technology (SCOT)* model developed by Trevor Pinch and Wiebe E. Bijker is widely regarded as one of the most influential theoretical approaches for explaining how technologies are socially shaped (Pinch & Bijker, 1987). Challenging the central assumption of technological determinism, the SCOT framework argues that the trajectory of technological development is not predetermined. Instead of that, the ways in which a technological innovation evolves, is interpreted, is used, and ultimately gains social acceptance are determined through the interactions among diverse social actors.

One of the core concepts of the SCOT framework is *interpretive flexibility*. According to this principle, the meaning and function of a technology are not fixed in advance. The same technological artefact may be interpreted and employed in different ways by different social groups. These competing interpretations, in turn, shape the subsequent direction of technological development. However, once a sufficient degree of social consensus has been achieved, both the design and the function of the technology gradually become stabilized. Within the SCOT framework, this process is conceptualized through the notions of *closure* and *stabilization* (Pinch & Bijker, 1987). The significance of this perspective for the analysis of political systems becomes particularly evident in the context of contemporary digital technologies. Artificial intelligence algorithms, for example, may possess similar technical capabilities, yet their implementation can produce markedly different political outcomes across different political systems. Within the European Union, the development and deployment of artificial intelligence are guided largely by principles of human rights protection, transparency, and ethical regulation. By contrast, in certain political regimes, the same technologies are employed to strengthen social control, expand systems of mass surveillance, and reinforce security-oriented governance. Although the underlying technology remains essentially the same, its political functions and societal consequences vary according to the legal, institutional, and political contexts in which it is implemented. This clearly illustrates one of the central propositions of social constructivism: technology cannot be understood independently of the social and political environments in which it is embedded. From this perspective, social constructivism also possesses considerable methodological significance for contemporary political theory. Whereas technological determinism emphasizes the adaptation of political systems to technological change, social constructivism focuses instead on the capacity of political institutions, public policies, and social actors to shape the direction of technological

development. Consequently, this perspective provides a more flexible and comprehensive theoretical framework for analysing contemporary political phenomena such as the digital state, e-government, the legal regulation of AI, digital democracy, and the platform economy.

Within the social constructivist perspective, the state is understood not merely as a user of technology but also as one of the principal political actors shaping its progress. The legal frameworks adopted by governments, together with national digital development strategies, innovation policies, cybersecurity approaches, and normative frameworks governing data governance, exert a direct influence on the direction of technological development and the extent to which technological innovations contribute to society. At the same time, investment strategies pursued by the private sector, the scientific activities of universities, the engagement of civil society, and public opinion also play significant roles in shaping technological advancement. From this perspective, social constructivism demonstrates that technological innovation emerges not only within laboratories but also through broader systems of political and social relations. Whereas technological determinism takes the transformative impact of technology on society as its central proposition, social constructivism emphasizes the reciprocal nature of this relationship. In other words, while technology shapes society, society simultaneously influences the direction in which technology evolves. Accordingly, technological development is understood not as a linear process but as a multidimensional process characterized by multiple possible trajectories. At different stages of development, a variety of alternatives may emerge, and which of these ultimately becomes dominant depends less on technical superiority than on social, political, and economic factors (Mackenzie & Wajcman, 1999).

CONCLUSION

Although technological determinism and social constructivism approach the relationship between technology and society from different theoretical perspectives, both recognize technology as an integral component of social and political processes. The principal distinction between these approaches lies in how they explain the origins, direction, and underlying drivers of technological change, as well as the role of human agency within this process. Technological determinism conceptualizes technology as the primary structural force behind social and political transformation, arguing that society adapts to the new institutional and functional realities generated by technological advancement. Social constructivism, by contrast, maintains that the trajectory of technological development is not predefined. Instead, it is shaped through the interaction of diverse social actors' interests, the operation of political institutions, economic relations, legal frameworks, and broader cultural contexts. From this perspective, technology is understood neither as an autonomous force evolving independently of society nor as a purely passive social product. Rather, it is conceived as a dynamic sociotechnical system that evolves through continuous processes of mutual interaction and co-construction with society.

In contemporary scholarship, these two approaches are no longer viewed as entirely mutually exclusive theoretical positions. Rather, they are increasingly understood as complementary conceptual frameworks that illuminate different analytical dimensions of the relationship between technology and society (Wyatt, 2021). On the one hand, it is impossible to explain contemporary political issues without taking into account the structural changes that technological innovations generate in public governance, political institutions, and power relations. On the other hand, an objective assessment of the political and social consequences of technology requires careful consideration of the purposes for which technologies are designed, the ways in which they are regulated, the interests they serve, and the meanings attributed to them within different social contexts. For this reason, contemporary political and social theory no longer regards technology solely as either the cause of change or its simple consequence. Instead, technology is understood as a complex sociotechnical phenomenon that is shaped through continuous interaction with social, political, economic, and institutional structures while simultaneously influencing the reconfiguration of those very structures. From this perspective technology and society are not separate domains connected by a one-way causal relationship but rather mutually constitutive elements within an ongoing process of transformation.

A comparative analysis of these two theoretical approaches is of considerable methodological significance for explaining the political implications of contemporary technological transformations,

including digitalization, AI, big data, algorithmic governance, and related developments. The practical relevance of this theoretical debate has become particularly evident with the emergence of the digital state. As digital transformation accelerates, public administration is increasingly being reorganized around e-government systems, cloud computing technologies, and algorithmic decision-making mechanisms. This transformation demonstrates that technology serves not merely as a technical infrastructure within political systems but also reshapes the institutional logic of governance, state-citizen relations, decision-making processes, and the exercise of political power. At the same time, the emergence of the digital state should not be understood as the inevitable outcome of technological progress alone. Rather, it should be viewed as a complex political process shaped by the interaction of government policies, legal frameworks, institutional choices, ethical principles, and societal demands. In this respect, the digital state constitutes an important analytical domain in which the perspectives of technological determinism and social constructivism converge. On the one hand, digital technologies fundamentally transform the organizational structure of public administration, modes of governance, and the functioning of political institutions, thereby confirming the structural transformations emphasized by technological determinism. On the other hand, the purposes for which these technologies are deployed, the legal frameworks within which they are regulated, and the extent to which they are accepted by society depend largely on the political choices of governments, market actors, and civil society, thereby reinforcing the central propositions of social constructivism.

Accordingly, the contemporary digital state cannot be adequately explained either as the product of the one-way influence of technology on political systems or solely as the outcome of social preferences. Instead, it should be understood as a dynamic sociotechnical model of governance that evolves through the continuous interaction between technology and political institutions. Consequently, the study of the digital state requires an integrated application of the analytical insights offered by both technological determinism and social constructivism. Considering these two perspectives in conjunction provides a more comprehensive and nuanced understanding of the role of technology in contemporary political systems.

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TRIANGLE OF TORMENT IN THE JORDAN VALLEY AND THE HIGHLANDS: A STUDY IN HISTORICAL GEOGRAPHY AND ARCHAEOLOGICAL SURVEYS OF THE CIVILIZATIONS OF LOT, MADYAN, AND ASHAAB AL-AYKAH

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ABSTRACT

This archaeological and geomorphological study examines the nature of spatial and historical interconnectedness among successive ancient civilizations in the Dead Sea Basin, the Jordan Valley (Ghor), and the Karak and Sharah Highlands. It focuses on the geographical realm that witnessed the emergence and disappearance of the civilizations of the People of Lot, Midian, and the Companions of the Wood (*Ashāb al-Aykah*).

The study aims to analyze the topographic relationship between the rift valley depressions and the mountainous elevations, trace ancient trade routes and corridors (such as the King's Highway and the Incense Route), and re-evaluate and analyze the outputs of archaeological excavations and surveys conducted in the region over the past century.

The study concludes that geographic proximity and geomorphological contrast created an integrated region and an interconnected economy reliant on seasonal movement (summer and winter retreats). Furthermore, archaeological evidence demonstrates the presence of destruction layers and abrupt cultural disruptions resulting from successive natural and seismic disasters, which led to a sequential collapse of the economic and urban systems across this stretch through various eras.

Introduction and Research Concerns

The Dead Sea Basin, the Jordan Valley, and the Karak and Sharah Highlands represent one of the richest geographical environments globally in terms of geomorphological and historical interplay. This region hosted the rise and fall of ancient civilizations whose bonds were linked to historical international trade networks, such as the Silk Road, the Incense Route, and the King's Highway.

Despite the chronological gaps between these societies, their close geographical proximity and spatial interconnectedness forged an integrated region and a setting for pivotal historical and geographical events detailed in religious and holy texts. This encompasses what is geographically designated as the "Triangle of Torment" or the "Belt of Extinction," which consecutively comprised the civilizations of the People of Lot, Midian, and the Companions of the Wood.



Fig :1 Map of Jordan Showing the location of Tell Hammam

Objectives and Research Questions

This study seeks to shed light on the field and spatial connections among these three civilizations by addressing the following primary objectives:

- **Spatial and Topographic Analysis:** Uncovering the nature of the relationship between the Jordan Valley depressions and the mountainous highlands, and the role of this topographic contrast in shaping the settlement and urban landscape of these groups.
- **Tracing Ancient Trade Corridors:** Studying the field distances and ancient communication routes connecting the Southern Jordan Valley (the realm of Lot), the Eastern Highlands (Midian / Karak), and the Central Jordan Valley (the Companions of the Wood).
- **Evaluating Archaeological Data:** Reading and analyzing the findings of field surveys and archaeological excavations conducted by national and foreign expeditions over the past century in this geographical zone.

Geographical and Spatial Analysis of the Cultural Network

The Realm of Lot (Southern Jordan Valley / Ghor)

Located at the lowest point on Earth (encompassing the southern zone of the Dead Sea: Bab edh-Dhra', Ghor an-Numeira, Ghor es-Safi, and Feifa). It was characterized by a highly fertile rift valley environment surrounded by harsh mountainous terrain. Archaeological evidence and field surveys (particularly excavation results from Bab edh-Dhra' and Numeira) indicate dense human settlement that suffered comprehensive destruction and abrupt extinction during the Early Bronze Age. (Waheeb,2026B)

The Midian Civilization (Highland Region - Karak)

The Midian civilization settled in the elevated mountainous region adjacent to the Southern Jordan Valley, at a distance not exceeding 50 kilometers from the realm of Lot. This close proximity highlights a complementary topographic relationship (elevation vs. depression contrast). This is reflected in the Quranic context, which highlights the direct communication between the realm of Prophet Jethro (*Shu'ayb*, peace be upon him) and the realm of the People of Lot despite the chronological gap, citing spatial proximity:

"And the people of Lot are not far off from you."

The Companions of the Wood (*Ashāb al-Aykah*) (Central Jordan Valley)

The homeland of the Companions of the Wood extended north of the realm of Lot by an estimated distance of approximately 80 kilometers within the central rift valley strip. This area shares environmental and valley characteristics with the realm of Lot (thicket trees, water abundance, and extreme heat). It also intersects with Midian in terms of trade patterns and control over passages and gateways, making this "Valley–Mountain" continuum a connected path and a single trajectory for historical transformations and the divine retribution that befell them.

Interpretation of Archaeological Surveys and Excavations Results

Over the past century, the region witnessed intensive archaeological activity led by specialized international and local expeditions (most notably the works of Albright, Nelson Glueck, Paul Lapp, Rast and Schaub, David McCreery, James Sauer, Khair Yassine, Moawiyah Ibrahim, Mohammad Waheeb, among others (Collins & Hussein 2011)



Fig :2 General view of Tell Hammam (Aykah) Jordan Valley.

1. **Documenting Destruction Layers and Cultural Disruption:** Excavations at sites such as Bab edh-Dhra', Numeira, Midian, and Tall el-Hammam revealed thick ash layers, evidence of burning, and rapid collapses caused by sudden deposits as well as harsh environmental and seismic events. This confirms the occurrence of a decisive natural/divine catastrophe that led to the abrupt extinction of urban life.

2. **Mapping Trade Networks and Sequential Economic Collapse:** Archaeological studies of ancient tracks proved that these three centers controlled key junctions of international trade extending between the northern Arabian Peninsula and the southern Levant. The fall of one center triggered a sequential collapse of the region's economic and connectivity framework across different historical periods.

3. **Environmental and Spatial Alignment (Summer and Winter Retreats):** Geological and archaeological outputs clarified the close interdependence between the nature of the highlands and the rift valley, reflecting an archaeological pattern of ancient summer and winter transhumance. This explains the seasonal mobility of these civilizations' inhabitants between the lowlands and the elevated mountainous regions.

Archaeological Excavation Evidence

Archaeological Surveys and Excavations at Tall el-Hammam – Al-Kafrayn

(Points to severe punishment associated with the Companions of the Wood)

A team from Trinity Southwest University, under the direction of Steven Collins, conducted excavations and research searching for the realm of Lot at Tall el-Hammam. Collins, the expedition director, acknowledges the necessity of reaching "scientific proof" regarding the reality of Tall el-Hammam in the northern Dead Sea basin, where no definitive, confirmed scientific evidence exists for the discovery of Sodom in the northeastern part of the Dead Sea. Furthermore, questions remain regarding the nature of the natural catastrophe that might have destroyed Tall el-Hammam while leaving other neighboring cities intact. Collins correlates the excavation results with the Biblical text / Old Testament, making significant strides in this domain by matching the Patriarchal Age with excavation findings (Collin's metal 2009)



Figure: 3 Photograph showing the results of archaeological excavations at the site of tall el-Hammam in Southern Shuna (Collins, 2013)

Cosmic Event and the Destruction of Tall el-Hammam

An international research team has announced discovering the cause behind the abrupt collapse of the ancient cities located in the area of Tall el-Hammam (southern Jordan Valley, northeast of the Dead Sea) during the Middle Bronze Age, approximately 3,600 years ago.

The Celestial Meteor

According to the study published in the journal *Scientific Reports* and officially announced by participating institution UC Santa Barbara the destruction was caused by a cosmic event: a meteor exploded in the atmosphere directly above the region, completely devastating it.

To arrive at these conclusions, the research team conducted a meticulous examination of rock components at tall el-Hammam dating back to that era. The results revealed extraordinarily unusual materials, as described by the researchers in their study.

In addition to typical debris associated with warfare and earthquakes, researchers discovered pottery fragments with glass-melted outer surfaces, bubbled mudbricks, and partially melted building materials.

These indicators point to an abnormal thermal pulse (reaching approximately 2,000 °C) temperatures that no technology of that era could have produced.

This evidence reinforces our proposition that the torment of the "Day of the Shadow" (*Yawm al-Zhullah*) was immense. While the excavation mission originally sought to locate the realm of Lot, the results in our view align closely with the history of the Companions of the Wood (*Ashāb al-Aykah*), given the physical evidence of divine retribution present on the ground.

Furthermore, various soil and sediment analyses revealed the presence of iron- and silica-rich spherules, as well as melted minerals, which corroborate this theory.

According to the study, another line of evidence confirming a cosmic impact burst is the presence of "shocked quartz" at the site sand grains containing micro-fractures that only form under extreme pressure conditions. (Collins etal 2009)

Scale of the Impact and Historical Context

Using these data, researchers estimated that the airburst at tall el-Hammam was comparable to the 1908 Tunguska event in eastern Siberia, generating a blast yield of roughly 12 megatons from a meteor estimated to be 56–60 meters in diameter.

The site of tall el-Hammam in Jordan (in the plains of er-Rama and al-Kafrayn / Livias) attracts scholarly interest because historical references suggest it was a flourishing and prosperous city. This supports the argument connecting this celestial event to the destruction and disappearance of the civilization of the Companions of the Wood.

The civilization at tall el-Hammam thrived during the Middle Bronze Age (approx. 3,600 years ago; 1800–1650 BCE) before suffering total destruction from a cosmic impact airburst near the city, which sat on elevated ground in the southern Jordan Valley northeast of the Dead Sea.

More than 3,000 years ago, tall el-Hammam served as a major urban center in the southern Levant. Around 1650 BCE, it became a hub of early civilization following the decline of the Midian civilization to the south, attracting merchants and trade goods as a key alternative center. However, it soon met a sudden collapse. (Glueck 1943,1945)

Researchers identified a dark destruction layer approximately 1.5 meters thick, consisting of charcoal, ash, melted mudbrick, and Middle Bronze Age pottery sherds. Considering that a meteor impact destroyed the city, its surrounding agricultural lands, and affiliated settlements, the realm of Prophet Jethro (*Shu'ayb*) aligns naturally with this interpretation—matching the Quranic narrative. While other researchers attribute this destruction layer to the realm of Lot, we find it more consistent with the account and destruction of the Companions of the Wood (*Ashāb al-Aykah*) from the realm of Prophet Shu'ayb.

James Kennett, Emeritus Professor of Earth Science at UC Santa Barbara and co-author of the study, noted that Tall el-Hammam represents the second known ancient settlement destroyed by a cosmic impact, following Tell Abu Hureyra in the Syrian Euphrates region (destroyed ~12,800 years ago).

Conclusion:

This research paper concludes that the concept of the "Triangle of Torment" is not merely a rhetorical expression, but a living geographical and historical reality attested by archaeological and topographic evidence in Jordan. Across its three domains (the Southern Jordan Valley, the Highlands, and the Central Jordan Valley), this region formed a spatially interconnected and geographically close unit that ultimately shared a single fate of comprehensive destruction and extinction due to moral and economic transgressions.

Recommendations:

- **Remote Sensing and GIS:** Calling upon researchers and academics to intensify remote sensing and Geographic Information Systems (GIS) studies to map the ancient trade and travel routes that connected the Jordan Valley to the mountainous highlands.

- **Comparative Archaeological Stratigraphy:** Conducting comparative stratigraphical studies between archaeological layers in the Central and Southern Jordan Valley to establish the chronological synchronicity of catastrophic events across the region.

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8. 9th INTERNATIONAL BLACK SEA MODERN SCIENTIFIC RESEARCH CONGRESS August 1-3, 2026, Düzce, Türkiye (TRIANGLE OF TORMENT IN THE JORDAN VALLEY AND THE HIGHLANDS: A STUDY IN HISTORICAL GEOGRAPHY AND ARCHAEOLOGICAL SURVEYS OF THE CIVILIZATIONS OF LOT, MADYAN, AND ASHAAB AL-AYKAH)

THERMAL CONDUCTIVITY OF DENSIFIED REINFORCED LAMINATED TIMBERS

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ABSTRACT

Wood is a versatile and fundamental building material derived from nature and utilized in many areas of life. However, as an organic material, it is susceptible to damage from external factors; as an anisotropic material, it exhibits different properties in three directions; and as a hygroscopic material (absorbing and releasing moisture), its service life can be shortened. In recent years, modification studies aimed at mitigating these disadvantages of wood materials have gained importance. Regarding building materials and performance characteristics, the thermal conductivity of wood or wood-based composite materials is crucial for energy efficiency, user comfort, and appropriate application selection. In this study, samples of Uludağ fir (*Abies nordmanniana subsp. bornmülleriana mattf*.) and Black poplar (*Populus nigra L.*) wood were impregnated with melamine-formaldehyde resin and subsequently subjected to a densification process at temperatures of 120°C–140°C, achieving densification rates of 25% to 50%. Carbon fiber and fiberglass reinforcement materials were placed between the resulting densified boards to create 3-, 5-, and 7-layer laminated materials, after which their thermal conductivity values were measured. Thermal conductivity testing of the experimental samples was conducted in accordance with the TS ISO 8302 (2002) standard. The study found that densification increased the thermal conductivity of the wood. Furthermore, it was determined that the highest thermal conductivity value was obtained from the 5-layer laminated materials. It was also found that Uludağ fir had higher thermal conductivity than black poplar.

Keywords: Thermal conductivity, densification, densified wood material, carbon fiber, fiberglass

INTRODUCTION

Wood—foremost among the oldest sustainable materials—is an indispensable structural element that is renewable, capable of continuous production, and plays a vital role in the carbon cycle. While the thermal conductivity of wood varies depending on species, moisture content, density, and grain direction, for wood-based laminates, it is important to consider additional factors, such as the number of layers, layer orientation, and adhesive type. Studies have shown that thermal conductivity ranges from 0.0855 to 0.4298 W/mK across different wood species and forms (Oluyamo et al., 2017; Çavuş et al., 2019). Softwoods such as fir and pine generally exhibit lower thermal conductivity compared to hardwoods such as beech and oak (Örs, 1999; Yapıcı et al., 2011). Particulate wood samples exhibit lower thermal conductivity than solid wood samples, and smaller particles (300 μm) show higher conductivity than larger ones (Oluyamo et al., 2017). Moisture content and density show a positive correlation with thermal conductivity (Örs, 1999; Çavuş et al., 2019). Conductivity is also influenced by grain direction; measurements taken perpendicular to the grain are typically lower than those taken in parallel (Yapıcı et al., 2011). These findings indicate that wood, particularly in particulate form, can serve as an effective thermal insulator for various applications, including building construction and solar energy devices. Laminated Veneer Lumber (LVL) made from Scots pine—treated with creosote impregnation and urea-formaldehyde adhesive—exhibits the lowest thermal conductivity, and Oriental

beech LVL, the highest (Uysal et al., 2009). Laminated Strand Lumber (LSL) exhibited higher thermal conductivity than spruce across various moisture content levels (Tripathi & Rice, 2017). Analytical models have been developed to estimate the effective thermal conductivity of laminated wood composites, such as Cross-Laminated Timber (CLT), which take into account the orthotropic nature of wood and the effects of edge bonding (Pal & Malek, 2025). Among different wood species, Scots pine exhibits the lowest thermal conductivity in the longitudinal direction, and Oriental beech, the highest (Yapıcı et al., 2011). These findings underscore the importance of considering multiple factors when evaluating the thermal properties of wood laminates for construction applications.

This study was conducted to determine the effects of lamination conditions on the thermal conductivity of laminated wood material. This involved measuring the thermal conductivity values of the laminated wood materials in accordance with the TS ISO 8302 (2002) standard.

MATERIALS AND METHODS

The focus of the experiments was Uludağ fir (*Abies nordmanniana subsp. bornmülleriana mattf.*), a low-density coniferous species, and black poplar (*Populus nigra L.*), a broad-leaved species. The timber was procured via random selection from forest product suppliers in Safranbolu. Selection criteria adhered to TS ISO 3129 (2021), prioritizing factors such as Grade 1 quality, dryness, natural coloration, soundness, and the absence of wood defects, grain deviation, or damage from wood-boring insects and fungi; parallel grain alignment was also required. The wood specimens were prepared to the dimensions of 330x220x25 mm in accordance with TS ISO 13061-2 (2021) and conditioned in a climate-controlled chamber—set to 20±2°C and 65±5% relative humidity—until a constant weight was achieved.

Conditioned black poplar and Uludağ fir samples were impregnated with melamine-formaldehyde resin at the Karabük University Faculty of Forestry Wood Mechanics Laboratory using the full-cell method, for a period of 10 minutes and using 6 bar pressure. The melamine-formaldehyde adhesive used in the impregnation process was obtained from GENTAŞ Kimya. Technical data regarding the melamine-formaldehyde adhesive are presented in Table 1.

Table 1. Technical data for melamine formaldehyde resin

Technical Data	Value
pH (20 °C)	9,50
Viscosity (20 °C)	20 cPs
Solid Content (120 °C 2 h)	52%
Flow Time (FC4, 20 °C, s)	14

Impregnated black poplar and Uludağ fir samples were subjected to a 25%–50% thermo-mechanical (TM) densification process at temperatures of 120°C–140°C for 10 minutes. The densification process was performed using a Cemil Usta SSP 180-T press (60x60 cm) at the Karabük University Wood Mechanics Laboratory. A pressure of 25.6 kg/cm² was applied for densification. Metal guides were used to ensure that the materials reached the desired thickness during the densification process. In the process, 14 mm thick laminated samples were densified to 7 mm for 3-layer boards densified by 50%, and 9.3 mm thick samples were densified to 7 mm for 3-layer boards densified by 25%. For 5-layer boards, 8 mm thick samples were densified to 4 mm (50% densification), and 5.3 mm thick samples were densified to 4 mm (25% densification). For 7-layer boards, 6 mm thick samples were reduced to 3 mm (50% densification), and 4 mm thick boards were reduced to 3 mm (25% densification).

Polyurethane adhesive was used for the reinforcement-supported lamination of densified board blanks produced from Black poplar and Uludağ fir wood materials. Technical data for the polyurethane adhesive are presented in Table 2.

Table 2. Technical data for polyurethane adhesive

Factor	Value
Press Time (h)	12
Press Condition	20±3 °C, 65±5%
Pressure (kg/cm^2)	25,6
Amount of glue (g/m^2)	200±20
Viscosity (cP) (20 °C)	5.000 - 15.000
Hardener Content	-

In the study, E-glass fiberglass fabric (200 g/m² density) and carbon fiber plain-weave fabric (200 g/m² density) were used as reinforcement materials between the laminated layers, composed of densified sheets. The reinforcement materials used were procured from the company DOST KİMYA. Technical data regarding these are presented in Table 3.

Table 3. Technical data for reinforcement materials

Technical Information	Carbon fiber	Fiberglass
Weave Type	Plain	Plain
Density (g/m^2)	200	200
Warp Density (warp/cm)	6	6
Weft Density (weft/cm)	6	6
Tensile Strength (MPa)	3800	1900-3400
Tensile Coefficient (GPa)	240	72

To measure the samples' thermal conductivity coefficients, ten specimens measuring 100x100x20 mm were prepared in accordance with the TS ISO 8302 (2002) standard, and three measurements were performed on each (Figure 1). The thermal conductivity coefficient for each specimen was calculated as the average of the three measurements. The resulting values were input into the software, and the thermal conductivity coefficient was calculated using Equation 1, based on Fourier's law. The experimental setup for thermal conductivity is shown in Figure 1.

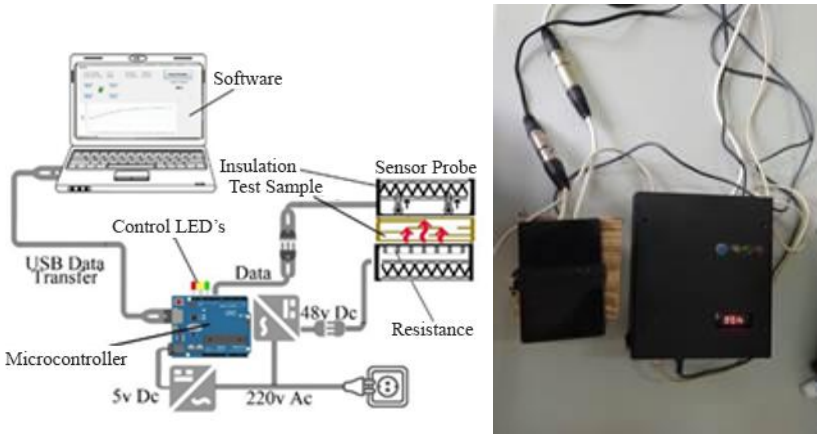

Figure 1. Thermal conductivity apparatus schematic and testing device (Korkmaz, 2018)

$$\lambda = \frac{Q.L}{A.\Delta T} \text{ W/mK}$$

Here, λ represents the material's thermal conductivity coefficient, L (m) the distance between opposing surfaces, A (m²) the surface area of the heater, and ΔT the temperature difference (°C) between the two opposing surfaces. The value Q represents the actual power generated in the heating element.

RESULTS AND DISCUSSION

Table 4 presents the mean air-dry density values for the 25% and 50% densified black poplar and Uludağ fir wood samples used in the study, as well as for the control group samples.

Table 4. Average air-dry density values of the test specimens

Wood Type	Densification Amount (%)	Density(gr/cm^3)
Black Poplar	Control	0.44
	25	0.73
	50	1.14
Uludağ Fir	Control	0.49
	25	0.63
	50	1.2

The melamine-formaldehyde retention rates of Black Poplar and Uludağ Fir samples, densified at rates of 25% and 50% and processed at temperatures of 120°C and 140°C, are presented in Table 5.

Table 5. Retention rates

Wood Type	Densification Ratio (%)	Densification Temperature (°C)	Retention Amount (%)
Black Poplar	25	120	16
		140	16
	50	120	21
		140	25
Uludağ Fir	25	120	11
		140	5
	50	120	4
		140	9

Table 5 reveals that the highest retention was achieved with black poplar samples impregnated at 50% concentration at 140°C, while the lowest, with Uludağ fir samples impregnated at 50% concentration at 120°C. Average values of the thermal conductivity coefficient are given in Table 6.

Table 6. Average thermal conductivity coefficient data (W/mK)

Wood Type	Number of Layers	Densification Conditions	Reinforcement Material	Mean	Standard Deviation
Black Poplar	3	25% - 120°C	Carbon fiber	0.12	0.00095
			Fiberglass	0.14	0.00087
			Control	0.12	0.00378
		25% - 140°C	Carbon fiber	0.12	0.00095
			Fiberglass	0.14	0.00363
			Control	0.12	0.00095
		50% - 120°C	Carbon fiber	0.12	0.00095
			Fiberglass	0.12	0.00434
			Control	0.13	0.00109
		50% - 140°C	Carbon fiber	0.12	0.00095
			Fiberglass	0.13	0.00440
			Control	0.13	0.00095
	5	25% - 120°C	Carbon fiber	0.13	0.00930
			Fiberglass	0.12	0.00093
			Control	0.12	0.00087
		25% - 140°C	Carbon fiber	0.12	0.00095
			Fiberglass	0.12	0.00096
			Control	0.12	0.00087
		50% - 120°C	Carbon fiber	0.13	0.00101
			Fiberglass	0.13	0.00222

			Control	0.13	0.00096
		50% - 140°C	Carbon fiber	0.13	0.00376
			Fiberglass	0.14	0.00434
			Control	0.13	0.00093
	7	25% - 120°C	Carbon fiber	0.11	0.00106
			Fiberglass	0.13	0.00085
			Control	0.12	0.00212
		25% - 140°C	Carbon fiber	0.11	0.00085
			Fiberglass	0.11	0.00099
			Control	0.12	0.00283
		50% - 120°C	Carbon fiber	0.12	0.00170
			Fiberglass	0.13	0.00134
			Control	0.13	0.00354
		50% - 140°C	Carbon fiber	0.13	0.00014
			Fiberglass	0.14	0.00148
			Control	0.12	0.00141

Table 6. Average thermal conductivity coefficient data (W/mK)(Continues)

Wood Type	**Number of Layers**	**Densification Conditions**	**Reinforcement Material**	**Mean**	**Standard Deviation**
Uludağ Fir	3	25% - 120°C	Carbon fiber	0.12	0.00085
			Fiberglass	0.13	0.00354
			Control	0.12	0.00071
		25% - 140°C	Carbon fiber	0.14	0.00099
			Fiberglass	0.13	0.00141
			Control	0.12	0.00141
		50% - 120°C	Carbon fiber	0.15	0.00134
			Fiberglass	0.14	0.00106
			Control	0.13	0.00212
		50% - 140°C	Carbon fiber	0.16	0.00071
			Fiberglass	0.14	0.00085
			Control	0.13	0.00283
	5	25% - 120°C	Carbon fiber	0.12	0.00099
			Fiberglass	0.13	0.00141
			Control	0.12	0.00141
		25% - 140°C	Carbon fiber	0.13	0.00106
			Fiberglass	0.14	0.00085
			Control	0.13	0.00212
		50% - 120°C	Carbon fiber	0.15	0.00148
			Fiberglass	0.15	0.00085
			Control	0.13	0.00283
		50% - 140°C	Carbon fiber	0.14	0.00170
			Fiberglass	0.15	0.00134
			Control	0.14	0.00354
	7	25% - 120°C	Carbon fiber	0.12	0.00085
			Fiberglass	0.13	0.00354
			Control	0.13	0.00071
		25% - 140°C	Carbon fiber	0.13	0.00099
			Fiberglass	0.14	0.00141
			Control	0.13	0.00141
		50% - 120°C	Carbon fiber	0.14	0.00134
			Fiberglass	0.15	0.00106
			Control	0.14	0.00212
		50% - 140°C	Carbon fiber	0.14	0.00071
			Fiberglass	0.14	0.00085

			Control	0.14	0.00283
Black Poplar	Massive	-	-	0.11	0.00095
Uludağ Fir	Massive	-	-	0.12	0.00141

Control: Laminated Control (Unreinforced)

As presented in Table 6, variations in the thermal conductivity coefficient were observed with respect to wood species, number of layers, densification conditions, and reinforcement material. To identify the factors responsible for these differences and to evaluate their statistical significance, a multifactor analysis of variance (ANOVA) was conducted. The results of the analysis are presented in Table 7.

Table 7. Results of the Multifactor Analysis of Variance (ANOVA)

Factor	**Sum of Squares**	**Degrees of Freedom**	**Mean Square**	**F**	**P (P<0.05)**
Wood Type (A)	0.004	2	0.002	395.514	0.000*
Number of Layers (B)	6.46E-02	2	3.23E-02	6.731	0.002*
Densification Conditions (C)	0.004	3	0.001	270.759	0.000*
Reinforcement Material (D)	0.002	2	0.001	176.701	0.000*
Error	0.000	74	4.79E-03		
Total	2.693	148			
Corrected Total	0.017	147			

According to Table 7, statistically significant effects were observed for all factors. Duncan's multiple range test was subsequently performed to identify the homogeneous groups responsible for these differences. The results of Duncan's test, conducted to determine the effects of wood types, number of layers, densification conditions, and reinforcement material on the thermal conductivity coefficient, are presented in Table 8.

Table 8. Duncan Test Results

Wood Type	**$\bar{x}$**	**HG**
Uludağ Fir Massive	0.13	AB
Black Poplar	0.13	AB
Black Poplar Massive	0.12	B
Uludağ Fir	0.14*	A
Number of Layers	**$\bar{x}$**	**HG**
Massive Control	0.12	B
3	0.13*	A
5	0.14*	A
7	0.13*	A
Densification Conditions	**$\bar{x}$**	**HG**
25% - 120°C	0.13	C
25% - 140°C	0.13	B
50% - 120°C	0.14*	A
50% - 140°C	0.14*	A
Control	0.12	D
Reinforcement Material	**$\bar{x}$**	**HG**
Fiberglass	0.14*	A
Carbon fiber	0.13	B
Control	0.13	C
Massive Control	0.12	D

Table 8 shows the thermal conductivity coefficient based on four different factors. Comparison of the wood species factor shows that the thermal conductivity coefficient of Uludağ fir was higher than that of black poplar samples. The densification process was found to increase the thermal conductivity coefficient by 7% for Uludağ fir and by 8% for black poplar. This increase may be attributed to the replacement of air within the cell cavities by the more conductive impregnating agent. These results are consistent with similar studies (Couturier et al., 1996). Furthermore, the increase in the density of the wood material may have also raised the thermal conductivity coefficient, as shown in a review of studies on thermal conductivity (Pelit et al., 2017; Çavuş et al., 2019).

Regarding the number of layers, all densified laminated wood groups exhibited thermal conductivity values 8–16% higher than those of the solid wood control samples. Although the overall effect of the number-of-layers factor was statistically significant, Duncan's multiple range test showed that this difference originated from the comparison between the solid wood control and laminated groups. No statistically significant differences were observed among the 3-, 5-, and 7-layer laminated groups.

The examined densification conditions indicated that the coefficient of thermal conductivity changed based on densification ratio and temperature combination. Compared with the control group, the 50% densification conditions at both 120°C and 140°C resulted in a 16% increase in thermal conductivity, while 25% densification at 140°C resulted in an 8% increase. In contrast, 25% densification at 120°C did not result in a significant increase. Duncan's multiple range test also indicated differences among these densification conditions. With increasing densification ratio, the void fraction per unit volume of the wood material decreased, which may have contributed to the increase in thermal conductivity. These findings are consistent with previous studies (Pelit et al., 2017; Çavuş et al., 2019; Kurt et al., 2009). Results for the reinforcement material factor reveal that the use of fiberglass reinforcement increased the thermal conductivity coefficient by 18%, but that carbon fiber reinforcement had no significant effect.

The thermal conductivity coefficient of 5-layer glass fiber-reinforced laminated materials (densified by 50% at 140°C) was found to be 25% higher than that of control samples representing the same wood species, and that the thermal conductivity coefficient of 3-layer carbon fiber-reinforced Uludağ Fir samples (densified by 50% at 120°C and 140°C) was 23% higher than that of solid control samples from the same group. Thus, thermal conductivity increases with greater density of the wood material. The greater thermal conductivity coefficient of the laminated material may have been to some extent due to the impregnating agent filling the air voids within the wood material and the polyurethane adhesive used in the lamination process. A review of studies indicates that impregnation, lamination, and densification processes increase wood material's thermal conductivity (Şahin Kol et al., 2008, Çavuş et al., 2019, Esen, 2019, Şahin and Döngel, 2018, Srivaro et al., 2021). The thermal conductivity results obtained from this experimental study are therefore consistent with the literature.

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A STUDY ON THE DYNAMIC STABILITY OF INSTANTON SOLUTIONS IN THE 2D THIRRING SPINOR MODEL

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ABSTRACT

The Thirring model is one of the fundamental nonlinear fermionic field theories and provides an important framework for studying exactly solvable quantum field systems. Its classical instanton solutions describe topological vacuum configurations and reveal the nonlinear dynamics of spinor fields. The purpose of this study is to investigate the dynamical stability of instanton solutions in the two-dimensional Thirring spinor model within the framework of nonlinear dynamical systems. The nonlinear equations of motion were reduced to a dimensionless autonomous dynamical system using the Heisenberg ansatz. The equilibrium points corresponding to the instanton solutions were determined analytically, and their local stability was examined through linearization. The Jacobian matrix was evaluated, and the associated eigenvalues were calculated to determine the stability characteristics of the equilibrium points. In addition, the analytical results were supported by phase-space analysis to examine the qualitative behavior of the dynamical system. The resulting eigenvalue spectrum consists of purely complex eigenvalues, indicating elliptic fixed points and stable periodic trajectories around the equilibrium configurations. The corresponding phase-space portraits display regular closed orbits and confirm the local dynamical stability of the system. The obtained results demonstrate the dynamical stability of instanton solutions in the two-dimensional Thirring model. The agreement between the analytical stability analysis and the phase-space structures provides a consistent geometric interpretation of the nonlinear dynamics. These findings contribute to a better understanding of instanton behavior in nonlinear spinor field theories and provide a theoretical basis for future studies on topological field configurations and nonlinear dynamical systems.

Keywords: Thirring model; instanton; nonlinear dynamical systems; stability analysis; phase space.

INTRODUCTION

Nonlinear field theories constitute an important area of mathematical and theoretical physics because they allow the existence of localized and dynamically nontrivial solutions that cannot generally be described within the framework of linear theories. Among such configurations, solitons represent an important class of solutions characterized by localized and particle-like behavior. In Lagrangian-type classical field equations, stable solutions exhibiting particle-like properties are commonly referred to as soliton-type solutions (Dunajski, 2010). The concept of the soliton has subsequently become an important framework for investigating nonlinear phenomena in different areas of mathematics and physics.

A particularly significant class of nonlinear field configurations is represented by instanton solutions. Instantons are localized classical configurations associated with the nontrivial vacuum structure of a field theory. In contrast to ordinary propagating particle-like solutions, instantons are connected with different vacuum configurations and provide an important framework for examining nonperturbative phenomena in field theory (Dunajski, 2010; Rajaraman, 1987).

Instantons are generally formulated in the Euclidean representation of the corresponding field theory and are associated with finite-action classical field configurations. Their mathematical structure provides a connection between nonlinear classical field equations and phenomena associated with the vacuum structure of quantum field theories (Dunajski, 2010; Rajaraman, 1987). Consequently, the

investigation of instanton solutions has become an important part of the study of nonlinear and topological field configurations.

The investigation of instanton-type configurations is not limited to bosonic field theories. Nonlinear fermionic field theories involving spinor fields can also possess localized classical solutions. The nonlinear self-interaction of the spinor field can lead to nontrivial dynamical behavior and makes such systems suitable for studying the relationship between classical field configurations and nonlinear dynamical systems.

One of the fundamental examples of nonlinear fermionic field theories is the Thirring model. Originally introduced by Walter Thirring as a soluble relativistic field theory, the model describes a self-interacting fermionic field in two dimensions (Thirring, 1958). Its relatively compact mathematical structure and nonlinear interaction have made the model useful for examining fundamental properties of interacting fermionic systems.

Classical soliton solutions for fermionic models, including the Thirring system, have also been investigated in previous studies (Akdeniz & Smailagic, 1979). The existence of such classical solutions makes it possible to investigate not only their analytical structure but also their dynamical characteristics.

The determination of a classical instanton solution does not by itself provide a complete description of its dynamical behavior. An additional question concerns how the corresponding configuration behaves in the presence of small deviations from an equilibrium state. This problem can naturally be investigated by reformulating the field equations within the framework of nonlinear dynamical systems.

A nonlinear autonomous system can be represented geometrically in phase space, where every point corresponds to a possible state of the system and the evolution of the system is represented by trajectories. Equilibrium or fixed points play a central role in this representation because the local behavior of trajectories around these points provides information concerning the dynamical character of the corresponding configurations (Çambel, 1993; Morris et al., 2003; Rizaoglu & Sünel, 2011).

For a nonlinear autonomous system, the local behavior around an equilibrium point can be investigated by linearizing the equations in the neighborhood of that point and examining the eigenvalues of the resulting linearized system. The eigenvalue structure provides a mathematical criterion for classifying the local behavior of the equilibrium configuration. Phase-space trajectories can then be used to provide a geometrical representation of the dynamics and to support the interpretation obtained from the linear stability analysis.

In this study, the instanton solutions of the two-dimensional Thirring spinor model are investigated from the perspective of nonlinear dynamical systems. The nonlinear field equations are reduced using the Heisenberg ansatz and appropriate dimensionless variables. The resulting autonomous system is analyzed by determining its equilibrium points and evaluating the corresponding linearized system and eigenvalue spectrum.

In addition to the analytical stability analysis, phase-space portraits are examined for $\alpha = 1$, $\alpha = 1.2$ and $\alpha = 0.7$. This allows the analytical behavior around the fixed points to be compared with the geometrical structure of the trajectories in phase space. The principal aim of this study is therefore to investigate the local dynamical behavior of the Thirring instanton configurations and to determine the consistency between the analytical eigenvalue results and the corresponding phase-space structures.

THEORETICAL FRAMEWORK: THE TWO-DIMENSIONAL THIRRING MODEL

The Thirring model is a nonlinear fermionic field model introduced as a soluble relativistic field theory (Thirring, 1958). The model is formulated in two dimensions and involves a nonlinear self-interaction of a spinor field.

The Lagrangian density of the two-dimensional Thirring model is written as

$$L = i\bar{\psi}\sigma_\mu \partial_\mu \psi + \frac{g}{2}(\bar{\psi}\psi)^2 \quad (1)$$ Where

g denotes the coupling constant and the matrices appearing in the spinor structure are the σ_μ Pauli spin matrices (Thirring, 1958). The nonlinear interaction term is one of the characteristic features of the model. Variation of the Lagrangian with respect to the corresponding spinor fields yields the equation of motion,

$$i\sigma_\mu \partial_\mu \psi + g\left(\bar{\psi}\psi\right)\psi = 0 \quad (2)$$

which describes the nonlinear evolution of the fermionic field.

For the analysis of instanton-type solutions, the original spinor field equation must be transformed into a form suitable for dynamical systems analysis. In the present treatment, this transformation is performed using the special Heisenberg ansatz employed in the original analysis **(Aydogmus, 2013).** After inserting the ansatz into the equation of motion and performing the appropriate dimensionless transformations, the field equations can be represented in terms of two coupled functions $F(z)$ and $G(z)$.

The resulting coupled nonlinear equations are

$$2\dot{F}(z) + \frac{1}{2}F(z) - gAB(\bar{c}c)G(z)(F^2(z) + G^2(z)) = 0$$
$$2\dot{G}(z) - \frac{1}{2}G(z) + gAB(\bar{c}c)F(z)(F^2(z) + G^2(z)) = 0 \quad (3)$$

The two equations constitute a coupled nonlinear system. Their nonlinear structure originates from the self-interaction of the fermionic field. The reduction is important because it transforms the original spinor field problem into a mathematical form that can be examined through the standard tools of nonlinear dynamical systems.

For the subsequent analysis, the variables are introduced according to the definitions used in the original study,

$$F(z) = x, \qquad G(z) = y,$$

together with the corresponding definition of the effective parameter α.

Using these definitions, the equations can be rewritten as the following autonomous dynamical system:

$$\dot{x} = -\frac{1}{4}x + \frac{1}{2}a\left(x^2 + y^2\right)y \quad (4)$$
$$\dot{y} = \frac{1}{4}y - \frac{1}{2}a\left(x^2 + y^2\right)x$$

This autonomous representation constitutes the basis for the determination of equilibrium points, linearization, eigenvalue analysis, and phase-space investigation.

MATERIALS AND METHODS

The dynamical stability analysis of the Thirring instanton system was performed by reducing the nonlinear spinor-field equations to an autonomous dynamical system. The resulting system was investigated through equilibrium-point determination, local linearization, eigenvalue analysis, and phase-space representation. These methods provide complementary analytical and geometrical descriptions of the nonlinear dynamics (Çambel, 1993; Morris et al., 2003; Rizaoglu & Sünel, 2011).

For the two-dimensional system considered in this study, the dynamical variables are represented by x and y. The evolution of these variables is determined by the coupled nonlinear equations obtained from the dimensionless form of the Thirring model.

The equilibrium points are determined by requiring that the derivatives of both dynamical variables vanish simultaneously:

$$\dot{x} = -\frac{1}{4}x + \frac{1}{2}a\left[x^2 + y^2\right]y = 0 \tag{5}$$

$$\dot{y} = \frac{1}{4}y - \frac{1}{2}a\left[x^2 + y^2\right]x$$

The solutions of Eq. (5) define the fixed points of the autonomous system. These points are particularly important because the behavior of sufficiently small deviations around them can be examined through the corresponding linearized equations.

For $\alpha = 1$, corresponding to the Thirring instanton configuration considered in the analysis, the equilibrium points are

$$\left\{x \to -\frac{1}{2}, y \to -\frac{1}{2}\right\}, \{x \to 0, y \to 0\}, \left\{x \to \frac{1}{2}, y \to \frac{1}{2}\right\} \tag{6}$$

including the origin and two symmetric nonzero equilibrium points.

To examine the behavior of the system for the neighboring parameter values considered in the study, the same fixed-point calculation was repeated for $\alpha = 1.2$ and $\alpha = 0.7$. For $\alpha = 1.2$ the equilibrium points are

$$\{x \to 0, y \to 0\}, \left\{x \to -\frac{\sqrt{\frac{5}{6}}}{2}, y \to -\frac{\sqrt{\frac{5}{6}}}{2}\right\}, \left\{x \to \frac{\sqrt{\frac{5}{6}}}{2}, y \to \frac{\sqrt{\frac{5}{6}}}{2}\right\} \tag{7}$$

Whereas for $\alpha = 0.7$, they are

$$\{x \to 0, y \to 0\}, \left\{x \to -\sqrt{\frac{5}{14}}, y \to -\sqrt{\frac{5}{14}}\right\}, \left\{x \to \sqrt{\frac{5}{14}}, y \to \sqrt{\frac{5}{14}}\right\} \tag{8}$$

The dependence of the equilibrium-point positions on α makes it possible to compare the local dynamical characteristics of the system for the three parameter values.

After determining the equilibrium points, the nonlinear system is linearized in their neighborhood. The differentiated equations used in the linear stability analysis are

$$\begin{aligned} x'' &= -\frac{1}{4}x' + \frac{1}{2}\alpha\left[x^2 + y^2\right]y' + \frac{1}{2}\alpha y\left[2xx' + 2yy'\right] \\ y'' &= \frac{1}{4}y' - \frac{1}{2}\alpha\left[x^2 + y^2\right]x' - \frac{1}{2}\alpha x\left[2xx' + 2yy'\right] \end{aligned} \tag{9}$$

and the corresponding matrix representation is

$$\begin{pmatrix} x'' \\ y'' \end{pmatrix} = \begin{pmatrix} -\frac{1}{4} + \alpha xy & \alpha y^2 + \frac{1}{2}\alpha(x^2 + y^2) \\ -\alpha x^2 - \frac{1}{2}\alpha(x^2 + y^2) & \frac{1}{4} - \alpha xy \end{pmatrix} \begin{pmatrix} x' \\ y' \end{pmatrix} \tag{10}$$

The matrix in Eq. (10) determines the local evolution of small deviations around an equilibrium configuration. The corresponding characteristic eigenvalues were therefore calculated at the nonzero fixed points for each of the investigated values of α.

In addition to the analytical eigenvalue analysis, phase-space portraits were used to investigate the qualitative behavior of the system. Phase space provides a geometrical representation of the coupled evolution of x and y. The resulting trajectories therefore make it possible to compare the local analytical classification of the equilibrium points with the qualitative behavior of the nonlinear system.

RESULTS AND DISCUSSION

Equilibrium Points and Their Parameter Dependence

The fixed points of the autonomous Thirring system were obtained by simultaneously imposing the equilibrium conditions given in Eq. (5). For $\alpha = 1$, the system contains the origin and a symmetric pair of nonzero equilibrium points, as shown in Eq. (6).

The same qualitative fixed-point structure is obtained for $\alpha = 1.2$ and $\alpha = 0.7$, as presented in Eqs. (7) and (8), respectively. Although the numerical positions of the nonzero equilibrium points vary with α, the symmetric structure of the fixed points is preserved for the investigated parameter values.

The displacement of the equilibrium points with changing α reflects the parameter dependence of the reduced autonomous system. However, the positions of the fixed points alone do not determine their local dynamical character. For this reason, the eigenvalues of the linearized system were evaluated at the corresponding nonzero equilibrium points.

Eigenvalue Analysis

For $\alpha = 1$, evaluation of the linearized system gives the eigenvalues

$$\lambda_{\pm}^{\left(-\frac{1}{2},-\frac{1}{2}\right)} = \pm\frac{i}{2} \quad \text{and} \quad \lambda_{\pm}^{\left(\frac{1}{2},\frac{1}{2}\right)} = \pm\frac{i}{2} \tag{11}$$

For $\alpha = 1.2$, the corresponding eigenvalues are

$$\lambda_{\pm}^{\left(-\frac{\sqrt{\frac{5}{6}}}{2},-\frac{\sqrt{\frac{5}{6}}}{2}\right)} = \pm 0.51031i \quad \text{and} \quad \lambda_{\pm}^{\left(\frac{\sqrt{\frac{5}{6}}}{2},\frac{\sqrt{\frac{5}{6}}}{2}\right)} = \pm 0.51031i \tag{12}$$

whereas for $\alpha = 0.7$, the eigenvalues are

$$\lambda_{\pm}^{\left(-\sqrt{\frac{5}{14}},-\sqrt{\frac{5}{14}}\right)} = \pm 0.472456i \text{ and } \lambda_{\pm}^{\left(\sqrt{\frac{5}{14}},\sqrt{\frac{5}{14}}\right)} = \pm 0.472456i \tag{13}$$

A common characteristic is observed for all three parameter values: the eigenvalues are purely imaginary, i.e., complex conjugate eigenvalues with vanishing real parts. Within the local linearized description employed in the present analysis, the corresponding equilibrium configurations therefore exhibit elliptic fixed-point behavior.

Although the numerical magnitudes of the eigenvalues change with , their qualitative character does not change for the three cases considered. This indicates that the local oscillatory character around the nonzero equilibrium configurations is preserved throughout the investigated parameter set.

The general characteristic behavior of the Thirring system can also be expressed through the eigenvalue relation obtained for the instanton configurations,

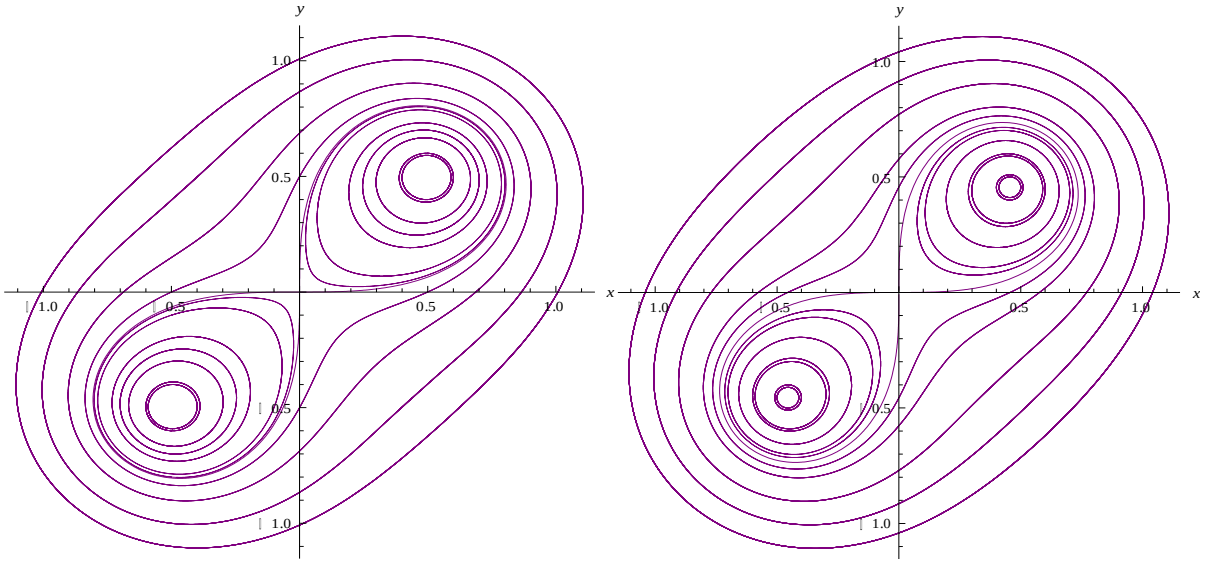
$$\lambda = \pm\frac{1}{4}\sqrt{1-8\alpha FG-12\alpha^2(F^2+G^2)^2} \qquad (14)$$

When the α-dependent fixed-point expressions are substituted into the characteristic relation and positive values of α are considered, the expression under the square root yields the value obtained in the original calculation for the two-dimensional Thirring system.

Thus, both the direct calculations for $\alpha = 1$, $\alpha = 1.2$ and $\alpha = 0.7$ and the general characteristic relation lead to the same qualitative conclusion concerning the local character of the investigated nonzero equilibrium points.

Phase-Space Analysis

The analytical results were further examined through phase-space representations of the two-dimensional Thirring system.



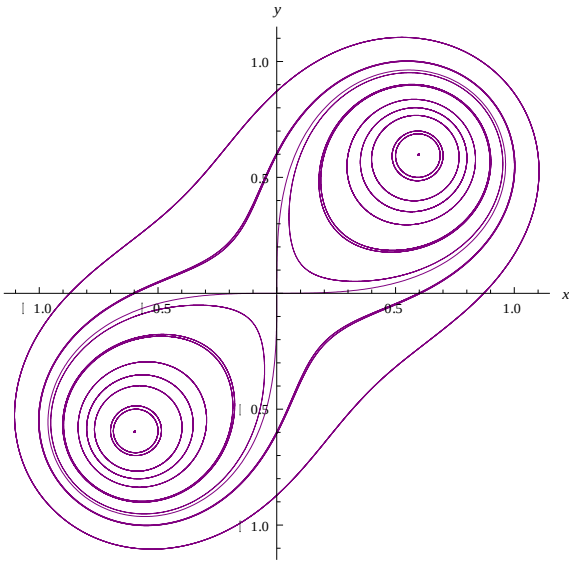


Figure 1. Phase-space portraits of the Thirring instanton system for $\alpha = 1$,1.2 and 0.7 respectively.

The phase-space portraits exhibit regular bounded trajectories surrounding the corresponding equilibrium configurations. These geometrical structures are consistent with the elliptic character inferred from the eigenvalue spectrum.

For $\alpha = 1$,, the trajectories form regular closed structures around the nonzero equilibrium configurations. A qualitatively similar phase-space structure is observed when the parameter is increased to $\alpha = 1.2$. Likewise, for $\alpha = 0.7$, the trajectories remain organized around the corresponding equilibrium configurations.

The principal effect of changing α within the investigated cases is therefore reflected in the quantitative locations of the equilibrium points and the numerical values of the eigenvalues rather than in a change of the qualitative local dynamical character. For all three cases, the phase-space trajectories remain bounded around the equilibrium configurations.

The agreement between the analytical and geometrical descriptions is an important feature of the present results. The eigenvalue calculations indicate elliptic fixed-point behavior, while the phase-space portraits display the corresponding regular and bounded trajectories. The two approaches therefore provide mutually consistent descriptions of the reduced Thirring system.

The use of dynamical-systems methods also provides information that is complementary to the existence of the classical field solution itself. Classical soliton solutions of fermionic models have previously been considered within the Thirring framework (Akdeniz & Smailagic, 1979). In the present treatment, the autonomous-system formulation allows the local behavior of the corresponding instanton configurations to be examined explicitly through fixed points and phase-space trajectories.

The results should nevertheless be interpreted within the scope of the adopted analysis. The eigenvalue classification follows from the linearized system in the neighborhood of the equilibrium configurations. Therefore, the present calculation primarily characterizes the local dynamical behavior of the reduced autonomous system. The phase-space portraits provide additional qualitative support by displaying regular bounded trajectories around the corresponding equilibrium configurations.

Within this framework, the results obtained for $\alpha = 1$, $\alpha = 1.2$ and $\alpha = 0.7$ consistently indicate elliptic local behavior of the investigated Thirring instanton configurations. The preservation of this qualitative phase-space structure for the three parameter values also demonstrates the consistency of the dynamical behavior within the investigated parameter range.

CONCLUSION

In this study, the dynamical behavior of instanton solutions in the two-dimensional Thirring spinor model was investigated using the methods of nonlinear dynamical systems. Starting from the nonlinear fermionic field equations, the special Heisenberg ansatz and appropriate dimensionless variables were used to reduce the field equations to a coupled autonomous system.

The equilibrium points of the resulting system were determined analytically for $\alpha = 1$, $\alpha = 1.2$ and $\alpha = 0.7$. The system was subsequently linearized around the nonzero equilibrium configurations, and the corresponding eigenvalues were calculated.

For all three parameter values considered, the eigenvalues were found to be purely imaginary, corresponding to elliptic fixed-point behavior within the local linearized description. Although changes in α modify the locations of the equilibrium points and the numerical magnitudes of the eigenvalues, the qualitative local character of the investigated configurations remains unchanged.

The phase-space portraits provide a geometrical representation consistent with these analytical findings. Regular bounded trajectories are observed around the corresponding equilibrium configurations for each of the investigated values of α. The agreement between the fixed-point analysis, eigenvalue spectrum, and phase-space structures therefore provides a coherent description of the local nonlinear dynamics of the two-dimensional Thirring instanton system.

The present analysis demonstrates that dynamical-systems methods provide a useful framework for examining classical instanton configurations in nonlinear fermionic field theories. In particular, the combined use of equilibrium-point analysis, linearization, eigenvalue calculations, and phase-space representations makes it possible to connect the analytical structure of the reduced field equations with their qualitative dynamical behavior. The results may provide a basis for further investigations of nonlinear spinor-field configurations and their stability properties.

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FROM EMPIRE TO FEDERATION: THE PARADOX OF KORENIZATSIYA AND CONSTRUCTIVIST NATION-BUILDING IN THE TRANSCAUCASIAN PERIPHERY (1922-1936)

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ABSTRACT

Introduction and Aim: For centuries, the South Caucasus was the scene of major power struggles between the Ottoman, Iranian, and Russian Empires. When Soviet rule was established in the region in the first quarter of the 20th century, a series of policies were implemented to shift the balance of power and strengthen central authority. *Korenizatsiya* (indigenization) was at the forefront of these policies. This study examines the effects of the *korenizatsiya* policy on the constituent republics of the Transcaucasian Socialist Federative Soviet Republic (Georgian SSR, Armenian SSR, and Azerbaijani SSR), its implementation phases, and the tension between ideological stances and the necessary policies in the path of modern state-building.

Materials and Methods: This article uses a comparative historical methodology to evaluate the implementation of *korenizatsiya* in the Transcaucasian Socialist Federative Soviet Republic. Qualitative and quantitative developments and changes related to regions, languages, social formations, and cultures are examined and analysed through primary sources like the 1926 Soviet census, alongside an examination of alphabet reforms and bureaucratic employment data.

Findings: The results varied significantly. Reflecting the institutional impact of *korenizatsiya*, in the Georgian SSR, over 96% claimed Georgian as their native tongue by 1926. Furthermore, local elites gained power. The Armenian SSR achieved unprecedented bureaucratic homogenization, with ethnic Armenians comprising 94.9% of government personnel by 1929. In the Azerbaijani SSR, nation-building policies, including alphabet changes and historical revisionism aimed at severing transnational ties with Iran and Turkey and thus constructing a new “Azerbaijani” identity, largely achieved their objectives.

Discussion and Conclusion: While *korenizatsiya* successfully institutionalized Soviet administrative power through the local people, it also deeply embedded national consciousness and fragmentation into the region's cultural structure. As a result, this constructivist policy, by crystallizing the very ethnic divisions it sought to overcome, laid the groundwork for geopolitical conflicts in the Caucasus.

Keywords: Transcaucasia; USSR; Korenizatsiya; Constructivism; Center-Periphery Relations.

ACOUSTIC SIGNATURES OF AI-GENERATED MUSIC: A REVIEW OF INTERPRETABLE AND DATA-DRIVEN DETECTION METHODS

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ABSTRACT

Introduction and Purpose: The increasing prevalence of generative artificial intelligence systems in music production has led to a rapid rise in synthetic content uploaded to streaming platforms and to growing uncertainty regarding the origin of the resulting works. This situation makes the need for detection methods capable of distinguishing whether a recording was produced by a human or by an artificial intelligence system increasingly apparent. The purpose of this study is to evaluate the approaches used in the detection of AI-generated music along the tension between interpretable acoustic features and data-driven deep learning methods.

Materials and Methods: This study is a review covering the current literature in the field of audio and music fake detection. The examined methods are addressed in two main groups. The first group comprises approaches based on interpretable acoustic descriptors such as Mel-frequency cepstral coefficients, linear-frequency cepstral coefficients, and spectral contrast; the second group comprises deep learning architectures such as spectro-temporal graph attention networks and models operating directly on the raw waveform. The methods are compared in terms of accuracy, generalizability, and interpretability.

Results: While deep learning-based methods provide superior detection accuracy, the lack of transparency in their decision processes and their limited generalizability to unseen generation systems stand out as notable problems. Methods based on interpretable acoustic features, by clearly revealing the spectral traces left by synthetic generation, contribute to the understanding of the music signal, yet may lag behind in terms of accuracy.

Discussion and Conclusion: The findings indicate that, from the perspective of music technology, interpretability is not merely a detection tool but a framework for understanding generation processes. Hybrid models that combine interpretable features with deep learning approaches are considered a promising direction for balancing the trade-off between accuracy and transparency.

Key Words: AI-Generated Music; Audio Deepfake Detection; Spectral Features; Deep Learning; Music Information Retrieval

DYNAMIC VIRTUAL CREDIT CARDS IN OTA B2B PAYMENTS: AN INDUSTRIAL CASE STUDY

OTA B2B ÖDEMELERİNDE DİNAMİK SANAL KREDİ KARTLARI: ENDÜSTRİYEL BİR VAKA ÇALIŞMASI

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ABSTRACT

Introduction and Purpose: Online travel agencies (OTAs) rely on secure B2B payment integrations. Conventional models often use a "stored-card exposure" approach, storing customer cards reversibly without usage limits, creating severe security vulnerabilities. This study evaluates an architectural transformation to a centralized Virtual Credit Card (VCC) pipeline, WingieVCC, designed for transaction isolation and automated balance management within a high-volume OTA ecosystem, specifically targeting the hospitality sector.

Materials and Methods: An industrial case study methodology evaluated this transformation over a one-year deployment period (Q2 2024 to Q1 2025). The system dynamically generates transaction-isolated, disposable VCCs with strict, currency-based limits. It integrates multi-currency balance tracking, automated threshold routing, and an idempotent API framework with retry mechanisms to handle network timeouts. During deployment, the system utilized shadow traffic and staged rollout strategies to ensure seamless integration. The evaluation focused on architectural resilience, security posture, and operational improvements.

Results: The architectural shift yielded profound qualitative improvements. By migrating from a limitless, stored-card model to a transaction-isolated, disposable VCC architecture, card data exposure was structurally eliminated. Defining strict currency-based limits for each transaction guaranteed that even in breach scenarios, unauthorized usage is technically impossible; unused or failed cards are automatically invalidated. Operationally, centralized balance management significantly reduced failed transactions caused by insufficient personal card limits, minimizing the need for manual interventions. Performance-wise, the system successfully met a Service Level Agreement (SLA) target of < 600 ms for transaction response times. Replacing traditional, stored-card infrastructures with a dynamic, transaction-isolated VCC pipeline fundamentally mitigates critical security risks in OTA platforms. This architectural transformation demonstrates that integrating strict transaction limits, shadow traffic deployment, and idempotent APIs maximizes transaction reliability and operational efficiency. Ultimately, this isolated architecture offers a highly scalable and secure blueprint for advancing fintech integrations within the global tourism sector.

Key Words: Virtual Credit Card, B2B Payments, Online Travel Agency, Payment Security, Fintech Integration.

ÖZET

Giriş ve Amaç: Çevrimiçi seyahat acenteleri (OTA'lar) için güvenli B2B ödeme entegrasyonları çok önemlidir. Geleneksel modeller genellikle müşteri kartlarını kullanım limiti olmaksızın geri döndürülebilir şekilde saklayan "saklanan kart maruziyeti" (stored-card exposure) yaklaşımını kullanır ve bu da ciddi güvenlik açıkları yaratır. Bu çalışma, öncelikle otelcilik sektörünü hedefleyen, yüksek hacimli bir OTA ekosisteminde işlem izolasyonu ve otomatik bakiye yönetimi için tasarlanmış merkezi bir Sanal Kredi Kartı hattı olan WingieVCC'ye yönelik mimari dönüşümü değerlendirmektedir.

Materyaller ve Yöntemler: Bu dönüşümü bir yıllık süre (2024 2. Çeyrek - 2025 1. Çeyrek) boyunca değerlendirmek için endüstriyel bir vaka çalışması metodolojisi uygulanmıştır. Sistem, kesin ve kur bazlı limitlere sahip, işleme özel, tek kullanımlık VCC'ler üretmektedir. Çoklu kur bakiye takibini, otomatik eşik yönlendirmesini ve ağ zaman aşımlarını ele almak için yeniden deneme mekanizmalarına sahip (eşzamanlı) (idempotent) bir API çerçevesini entegre eder. Dağıtım sırasında, sorunsuz bir geçiş sağlamak için gölgeli trafik (shadow traffic) ve kademeli açılış (staged rollout) stratejileri kullanılmıştır. Değerlendirme, mimari dayanıklılığa, güvenlik seviyesine ve operasyonel iyileştirmelere odaklanmıştır.

Sonuçlar: Mimari geçiş, köklü iyileştirmeler sağlamıştır. Limitsiz, saklanan kart modelinden işlem izolasyonlu, tek kullanımlık VCC mimarisine geçilerek kart verisi maruziyeti yapısal olarak ortadan kaldırılmıştır. Her işlem için kesin kur bazlı limitler tanımlanması, sızıntı senaryolarında bile yetkisiz kullanımın teknik olarak imkansız olmasını garanti etmiş; kullanılmayan veya başarısız olan kartların otomatik olarak geçersiz kılınması sağlanmıştır. Operasyonel olarak, merkezi bakiye yönetimi, yetersiz kişisel kart limitlerinden kaynaklanan başarısız işlemleri önemli ölçüde azaltarak manuel müdahaleleri en aza indirmiştir. Performans açısından sistem, işlem yanıt süreleri için < 600 ms olan Hizmet Seviyesi Sözleşmesi (SLA) hedefini başarıyla karşılamıştır. Geleneksel, saklanan kart altyapılarının dinamik, işlem izolasyonlu bir VCC hattıyla değiştirilmesi, OTA platformlarındaki kritik güvenlik risklerini temelden azaltmaktadır. Bu mimari dönüşüm; kesin işlem limitlerinin, gölgeli trafik dağıtımının ve idempotent API'lerin entegre edilmesinin işlem güvenilirliğini ve operasyonel verimliliği üst düzeye çıkardığını göstermektedir. Sonuç olarak bu izole mimari, küresel turizm sektöründeki fintech entegrasyonlarını ileriye taşımak için oldukça ölçeklenebilir ve güvenli bir altyapı sunmaktadır.

Anahtar Kelimeler: Sanal Kredi Kartı, B2B Ödemeler, Çevrimiçi Seyahat Acentesi, Ödeme Güvenliği, Fintech Entegrasyonu.

Declaration of AI Usage

During the preparation of this work, the authors used Google Gemini to assist with brainstorming and refining research ideas, drafting preliminary text, improving the ABSTRACT’s academic English, supporting translation tasks. The authors critically reviewed, verified, and edited all AI-assisted outputs and retained full control over the intellectual content of the work. The authors accept full responsibility for the accuracy, integrity, and final content of this ABSTRACT.

TRANSITION TO THE INNOVATIVE DEVELOPMENT OF THE NATIONAL ECONOMY IN AZERBAIJAN: AN ECOSYSTEM APPROACH

AZERBAYCAN'DA ULUSAL EKONOMİNİN YENİLİKÇİ GELİŞİMİNE GEÇİŞ: EKOSİSTEM YAKLAŞIMI

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ABSTRACT

In an environment where economic relations are characterized by significant transformations and global competition is deepening, national economic development cannot be successfully realized without the application of innovative technologies. Within Azerbaijan’s strategic economic development programs strategic economic development programs and the main directions of economic development, the creation of an innovation ecosystem is considered one of the key components of the national development strategy. The conceptual basis for creating an innovation ecosystem lies in J. Schumpeter's scientific views on the development of socio-economic entities. These views are based on principles that examine the development of economic actors in terms of structural transformations and the development process that occurs in coordination with the structural elements of the economic system. These principles emphasize the importance of establishing an interconnected system composed of three components to ensure development: entrepreneurial activity, innovation, and economic entities. This is because there is a close interaction and link between the effectiveness of innovation processes, which are the fundamental driving forces of development, and methodological principles and application mechanisms. Economic development requires the formation of an innovation ecosystem. The ecosystem ensures the systemic coherence of economic activity participants. Furthermore, the ecosystem forms the basis for the institutional coherence of most participants in the economic system by integrating the creative potential of innovations with the aim of creating innovative value for society and a specific social environment. When creating an innovative ecosystem, the cyclical principles and perspectives of service and product production, business models, and the interaction of elements within the system should be considered. The level of interaction of ecosystem elements and the possibilities for integrating their impact mechanisms should be investigated according to various scenarios, and a more efficient model should be preferred. Considering the uncertainty and risk management processes of entrepreneurial organizations in the innovation ecosystem is also an important issue. In this context, the existence of uncertainties in the creation and implementation of innovations poses a certain threat to the overall effectiveness of the ecosystem. Another important component of the ecosystem is the development of individuals with creative thinking abilities. Human capital with these qualities is one of the fundamental conditions for achieving success in innovative entrepreneurial activity, as well as for the development and expansion of the business. Creative individuals directly influence the development of the innovation ecosystem, paving the way for the growth of a new generation of innovators within the ecosystem.

Keywords: economic development, innovation, ecosystem, creative thinking.

ÖZET

Ekonomik ilişkilerin doğasında yaşanan ciddi değişimler ve küresel rekabetin derinleştiği bir ortamda, yenilikçi teknolojilerin uygulanmaması durumunda ulusal ekonomik kalkınmanın sağlanması tam anlamıyla gerçekleştirilememektedir. Azerbaycan da, stratejik ekonomik kalkınma programları ve ekonomik kalkınmanın ana yönleri için benimsenen kavramlarda, inovasyon ekosisteminin oluşturulmasını ulusal kalkınma stratejisinin temel unsurlarından biri olarak kabul etmektedir. İnovasyon ekosisteminin oluşturulmasının kavramsal temeli, J. Schumpeter'in sosyo-ekonomik nesnelerin gelişimine ilişkin bilimsel görüşleridir. Bu görüşler, ekonomik faaliyet öznelerinin gelişimini, yapısal dönüşümler ve ekonomik sistemin yapısal unsurlarıyla koordineli biçimde gerçekleşen gelişim süreci açısından inceleme ilkelerine dayanmaktadır. İlkeler, gelişmeyi sağlamak için üç bileşenden oluşan birbirine bağlı bir sistem kurmanın önemini vurğular: girişimcilik faaliyeti, yenilikçilik ve ekonomik varlık. Çünkü gelişmenin temel itici güçleri olan yenilikçilik süreçlerinin etkinliği ile metodolojik ilkeler ve uygulama mekanizmaları arasında yakın bir etkileşim ve bağlantı vardır. Ekonomik kalkınma, bir inovasyon ekosisteminin oluşmasını gerektirir. Ekosistem, ekonomik faaliyet katılımcılarının içsel tutarlılığını sağlar. Ekosistem ayrıca, inovasyonların yaratıcı potansiyelini toplum ve belirli bir sosyal çevre için yenilikçi değer yaratma amacıyla bütünleştirerek, ekonomik sistemdeki çoğu katılımcının içsel tutarlılığının temelini oluşturur. Yenilikçi bir ekosistem oluşturulurken, hizmet-ürün üretiminin, iş modelinin ve sistem içindeki unsurların etkileşiminin döngüsel ilkeleri ve perspektif yönleri dikkate alınmalıdır. Ekosistem unsurlarının etkileşim düzeyi ve etki mekanizmalarının entegrasyon olanakları çeşitli senaryolara göre araştırılmalı ve daha verimli bir model tercih edilmelidir. İnovasyon ekosisteminde girişimci kuruluşların belirsizlik ve risk yönetimi süreçlerinin dikkate alınması da önemli bir konudur. Bu bağlamda, inovasyonların yaratılması ve uygulanmasındaki belirsizliklerin varlığı, ekosistemin genel etkinliğine belirli bir tehdit oluşturmaktadır. Ekosistemin bir diğer önemli bileşeni ise yaratıcı düşünme yeteneğine sahip bir bireyin yaratılmasıdır. Bu niteliklere sahip insan sermayesi, yenilikçi girişimcilik faaliyetinde başarıya ulaşmanın yanı sıra işletmenin gelişmesi ve genişlemesi için de temel koşullardan biridir. Yaratıcı bireyler, inovasyon ekosisteminin gelişimini doğrudan etkileyerek, ekosistem içinde yeni bir nesil yenilikçinin uyumasının oluşumuna zemin hazırlamaktadır.

Anahtar kelimeler: ekonomik kalkınma, inovasyon, ekosistem, yaratıcı düşünme.

Introduction.

Relevance of the topic. In the modern global economy, innovation is considered one of the main determinants of economic growth, competitiveness and sustainable development. In the context of globalization, digital transformation and the rapid development of the knowledge economy, the formation of innovation ecosystems has become a strategic priority for countries. In terms of the development of the non-oil sector of the Azerbaijani economy, diversification of the economy and technological modernization, the study of the theoretical and practical foundations of the innovation ecosystem is of particular significance.

Object and subject of the study. The object of the study is innovation ecosystems and their role in the process of national economic development.

The subject of the study is the theoretical foundations of the innovation ecosystem, its structural elements, mechanisms of interaction between its participants and the mechanisms through which it contributes to economic development.

Methodology and methods of the study. The methodological basis of the study is the theory of innovation, the systems approach, national innovation systems and the concepts of the innovation ecosystem.

In the course of the research, scientific ABSTRACTion, comparative analysis, systematic approach, content analysis, induction and deduction methods were used.

1.4. Scientific novelty of the study. The scientific novelty of the study is reflected in the following contributions:

-The theoretical foundations of the innovation ecosystem concept have been systematically summarized;

-The mechanisms of the innovation ecosystem's influence on economic development, competitiveness and entrepreneurial development have been identified;

-The development features and current problems of Azerbaijan's innovation ecosystem have been examined from a theoretical perspective;

-The role of human capital, institutional cooperation and digital technologies in the sustainability of the innovation ecosystem has been substantiated;

-The importance of the ecosystem approach in Azerbaijan's transition to an innovation-oriented development model has been empirically and theoretically justified.

Discussion

The modern global economy is characterized by rapid technological changes, increased international competition and the increasing importance of knowledge-based production systems. In such conditions, sustainable economic growth can no longer be achieved solely at the expense of traditional production factors such as labor, capital and natural resources. Instead, innovation, technological progress and the efficient use of human capital have become the main driving force of national competitiveness and economic development (Porter, 1998).

For developing and transition economies, the transition to innovative development is not only an economic necessity, but also a strategic imperative. Azerbaijan, whose economy has traditionally been highly dependent on the oil and gas sector, has adopted a long-term vision aimed at the diversification, digital transformation and development of non-oil sectors. In this context, the development of a national innovation ecosystem has become a central component of national economic policy.

The ecosystem approach provides a comprehensive framework for understanding innovation processes by emphasizing interactions among firms, government agencies, universities, research institutions, investors, and consumers. Rather than viewing innovation as the outcome of isolated activities, this approach conceptualizes innovation as a product of coordinated interactions among multiple actors operating within a shared environment (Moore, 1993). Consequently, Azerbaijan’s transition toward an innovation-driven economy requires not only technological modernization but also the establishment of an effective innovation ecosystem that facilitates knowledge creation and commercialization.

Theoretical foundations of the concept of the innovation ecosystem.

The concept of an innovation ecosystem has become one of the central theoretical approaches to understanding innovative processes in the modern economy. Unlike traditional linear innovation models, which focus primarily on research and development within individual organizations, the concept of innovation ecosystem emphasizes dynamic interactions among multiple actors, institutions, and resources that collectively generate, disseminate, and commercialize innovation. This approach reflects the increasing complexity of innovative processes in the context of globalization, digital transformation and knowledge-based economic development.

The theoretical foundations of the innovation ecosystem concept can be traced to the work of Schumpeter (1934), who identified innovation as the primary driver of economic development. According to Schumpeter (1934), economic progress occurs through the process of "creative destruction", in which new technologies, products and organizational forms replace outdated structures. By introducing innovations that change economic systems, entrepreneurs play a critical role in this process. It was on the basis of Schumpeter's ideas that contemporary scholars developed the ecosystem approach as the basis for understanding the dynamics of innovation.

The theoretical foundations of the innovation ecosystem concept can be traced in systems theory and the innovation systems approach. Early Studies by Freeman (1987) and Lundvall (1992), the idea was put forward that the results of innovation activity depend not only on the capabilities of individual firms, but also on a wider network of relationships between universities, government agencies, research

institutes and business organizations. These interactions create a favorable environment for the exchange of knowledge, learning and technological progress.

The concept of the innovation ecosystem was further developed by Moore (1993), which applied ecological principles to business environments, introducing the concept of a business ecosystem, emphasizing the interdependence among economic actors involved in value creation. According to Moore, organizations function as biological species in the ecosystem, where survival and growth depend on cooperation, competition and adaptation. In this context, innovation does not come from isolated organizational efforts, but from collaborative networks. The ecosystem approach emphasizes the interdependence between participants and the importance of creating value through collective action.

Subsequent research expanded the concept by emphasizing knowledge flows and open innovation practices. Chesbrough (2003) has argued that firms increasingly rely on external sources of knowledge and technology, making cooperation with diverse stakeholders an important part of the success of innovation. Thus, innovation ecosystems include a wide range of participants, including startups, large corporations, universities, investors, government agencies, and consumers who contribute to the innovation process.

A significant contribution to the theoretical understanding of innovation ecosystems was made by Adner (Adner, 2006). He defined innovation ecosystems as collaborative arrangements through which actors integrate their individual value propositions into coherent solutions that deliver value to customers. This approach emphasizes the creation of appropriate behaviors and complementary innovations of the participants in the system. The effectiveness of the innovation ecosystem depends on the quality of relations, institutional support mechanisms and the ability of participants to coordinate their efforts to achieve common goals.

The innovation ecosystem consists of a network of organizations, institutions and individuals, the interaction of which contributes to the creation, dissemination and commercialization of innovations. The ecosystem includes universities, research centers, start-up firms, established corporations, venture capital providers, government agencies, and consumers. The effectiveness of such an ecosystem depends on the quality of the interaction between its participants and the institutional mechanisms that support cooperation and knowledge exchange (Jackson, 2011).

Contemporary innovation theory views ecosystems as adaptive and evolving structures that facilitate knowledge creation, technology diffusion, and economic competitiveness. Such ecosystems play a decisive role in regional and national development by stimulating entrepreneurship, attracting investment and increasing innovation potential. Thus, understanding the theoretical foundations of innovative ecosystems is essential for policymakers, researchers and practitioners who want to promote sustainable economic growth and technological progress.

The ecosystem approach differs from traditional innovation models by focusing not only on individual organizations but also on the interactions, complementarities, and interdependencies among ecosystem participants. This perspective is particularly relevant for countries such as Azerbaijan that seek to achieve structural transformation, technological modernization, and sustainable economic development through innovation-driven growth.

Innovation ecosystems as drivers of national economic development.

Innovation ecosystems significantly contribute to economic development, increase productivity, stimulate entrepreneurship, expand technological capabilities, and create high value-added industries. Through the integration of knowledge, technology and financial resources, innovative ecosystems contribute to the commercialization of research results and accelerate the modernization of the economy.

The ecosystem model supports sustainable economic growth through several mechanisms. First, it facilitates collaboration between universities, enterprises and government agencies, thereby increasing knowledge transfer and innovation potential. Secondly, it fosters entrepreneurial development by providing access to resources, financing and mentoring. Third, it increases regional and national competitiveness by developing innovative products and services that can compete in international markets (Isenberg, 2010).

Human capital is central to the innovation ecosystem. Highly skilled and innovative individuals with entrepreneurial capabilities generate new ideas and contribute to technological advancement. Consequently, educational systems and research institutes play a critical role in the development of the ecosystem, developing highly skilled human capital who can participate in innovation processes.

Furthermore, digital technologies have significantly expanded opportunities for innovation ecosystem development. Artificial intelligence, big data analytics, cloud computing and digital platforms facilitate communication between ecosystem participants and increase the efficiency of innovative processes. Countries that successfully integrate these technologies into their innovation systems have more opportunities to achieve sustainable economic growth and competitiveness.

Current state of the innovation ecosystem of Azerbaijan.

In recent years, Azerbaijan has implemented significant reforms aimed at strengthening innovation capacity and promoting economic diversification. National development strategies emphasize the importance of innovation, digital transformation, and knowledge-based economic growth. The country's strategic priorities include the development of human capital, support for entrepreneurship, expansion of digital infrastructure and enhancement of research and development activities. In particular, the strategic document *"Azerbaijan 2030: National Priorities for Socio-Economic Development"*, approved by the President of the Republic of Azerbaijan in 2021, identifies the transformation of the country into an innovation-driven economy and the development of a national innovation ecosystem among its key priorities.

A number of institutional initiatives have been implemented to support the formation of the innovation ecosystem. To stimulate entrepreneurial activity and technological development, technology parks, innovation centers, startup support programs and digital transformation projects have been created. The expansion of e-government services and digital infrastructure has also created favorable conditions for the business growth and transformation.

Despite these achievements, Azerbaijan continues to face several challenges in the transition to an innovative economy. Research and development (R&D) expenditure remains relatively low compared with leading innovation-driven economies. University-industry cooperation requires further strengthening, access to venture capital and innovation finance remains limited. Moreover, the commercialization of the results of scientific research has not yet reached its full potential.

The development of a comprehensive innovation ecosystem requires closer integration between educational institutions, research organizations, enterprises and government agencies. Effective policy coordination is needed to ensure that ecosystem participants operate within a favorable regulatory and institutional framework.

Risks, uncertainty and sustainability in innovation ecosystems.

Innovative activity is essentially associated with uncertainty and risk. New technologies, products, and business models are often associated with uncertain outcomes and market adoption challenges. Thus, risk management is an important component in the development of the innovation ecosystem.

Uncertainty within the ecosystem affects various stages of the innovation process, including Idea Generation, Research and development, commercialization, and market expansion. Financial, technological, and organizational risks may hinder investment in innovative projects. Therefore, ecosystem participants must apply mechanisms for risk sharing and joint problem solving.

State support plays an important role in reducing uncertainty and increasing investment in innovation. Government funding programs, tax breaks, innovation grants, and regulatory support can help reduce innovation-related risks. At the same time, private investors and venture capital firms promote ecosystem sustainability by providing financial resources to innovative enterprises.

A resilient innovation ecosystem is capable of adapting to changing economic conditions and technological disruptions. Such sustainability depends on the diversity of ecosystem participants, the effectiveness of institutional support mechanisms and the flexibility of organizational structures. The sustainable development of the ecosystem requires continuous learning, continuous learning and adaptation to emerging challenges.

2.5. Human capital and creative thinking in the innovation ecosystem.

Human capital is one of the most valuable resources of the innovation ecosystem. Knowledge, creativity, entrepreneurial skills and technological competencies are the basis of innovative development. Therefore, investing in education and talent development is essential for the success of the ecosystem.

Creative thinking allows people to find non-standard solutions to economic and technological problems. Entrepreneurs, researchers and innovators contribute to the development of the ecosystem by introducing new products, services and business models. Their activities stimulate competition, productivity growth and diversification of the economy.

Educational institutions play an important role in the development of creative and entrepreneurial abilities. Modern education systems should emphasize problem solving, innovation, digital literacy, and interdisciplinary collaboration. Universities, in particular, serve as the main resources for generating knowledge and transmitting technology within innovation ecosystems.

Improving the quality of human capital remains a strategic priority for Azerbaijan. Strengthening STEM education, expanding scientific research opportunities, supporting innovation-oriented entrepreneurship and promoting lifelong learning can significantly increase the country's innovation potential. By developing a culture of creativity and innovation, Azerbaijan can create favorable conditions for the emergence of a new generation of innovators and entrepreneurs.

Conclusion.

Based on our research, the following conclusions were made.

The transition to innovative development has become a fundamental requirement for ensuring sustainable economic growth and international competitiveness of Azerbaijan. The ecosystem approach provides a comprehensive framework for understanding and managing innovative processes based on cooperation between economic institutions, economic stakeholders and individuals.

The concept of the innovation ecosystem, based on the theory of innovation and further further developed in the innovation ecosystem literature, emphasizes the importance of collaboration, interdependence, and co-creation of value. Innovative ecosystems stimulate entrepreneurship, facilitate the transfer of knowledge, support technological progress, increase competitiveness and promote economic development.

Although Azerbaijan has made significant progress in establishing the foundations of the innovation ecosystem, more efforts are needed to strengthen institutional coordination, increase investment in research and development, improve commercialization mechanisms and expand access to innovation financing. Special attention should also be paid to the development of human capital and the creative and innovative capabilities.

The findings suggest that a successful transition toward an innovation-driven economy depends on the capacity of ecosystem participants to collaborate effectively, manage risks and uncertainty, and continuously adapt to technological and economic change. By fostering a dynamic and resilient innovation ecosystem, Azerbaijan can accelerate economic diversification, strengthen national competitiveness, and achieve long-term sustainable development.

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HIGH-RESOLUTION SPECTROSCOPIC STUDY OF C IV ABSORPTION TOWARD Q1422+23

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ABSTRACT

Absorption features imprinted on quasar spectra provide a powerful probe of the physical conditions, chemical enrichment, and spatial distribution of ionised gas over cosmological distances. In this work, we analyse the high-resolution spectrum of the quasar Q1422+23 (z_{em} \approx 3.62; RA = 14:24:38.1, Dec = +22:56:01) to investigate triply ionised carbon (C IV) absorption systems along its line of sight. Owing to its high redshift, Q1422+23 serves as an excellent background source for studying metal-enriched gas associated with the intergalactic medium (IGM), the circumgalactic medium (CGM), and the environments of galaxies during the early stages of cosmic evolution. Our analysis focuses on the C IV resonance doublet at rest-frame wavelengths of 1548.204 Å and 1550.774 Å, which is a well-established tracer of highly ionised gas. The identified absorption features are modelled using Voigt profile fitting to derive the absorber redshift, Doppler parameter (b), and column density (N) with high precision. The fitting procedure accounts for thermal broadening, turbulent motions, and natural line damping, enabling a robust decomposition of the observed absorption profiles into their underlying physical and kinematic components. The derived absorber properties span a broad range of column densities and velocity dispersions, revealing a heterogeneous population of ionised structures distributed along the quasar sightline. These absorbers likely trace chemically enriched gas produced by previous episodes of star formation and redistributed through galactic-scale feedback processes. By characterising the kinematic and physical properties of C IV absorption systems toward Q1422+23, this study provides valuable constraints on the chemical enrichment history, gas dynamics, and evolution of the high-redshift universe.

Keywords: Quasar Absorption Lines; C IV doublet; Voigt profile fitting; Absorber Redshift; Doppler Parameter; Column Density; Intergalactic Medium

URBAN GREEN SPACES AS A REGULATING FACTOR IN THE RELATIONSHIP BETWEEN PARTICULATE MATTER POLLUTION AND OUTDOOR THERMAL COMFORT

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ABSTRACT

Currently, cities are becoming more vulnerable environments in terms of both thermal stress and air pollution due to increasing pressure from urbanisation, high traffic volumes, the expansion of impervious surfaces and the decline in green spaces. In particular, particulate matter such as $PM_{2.5}$ and PM_{10} not only poses risks to the respiratory health of city dwellers but also affects breathing comfort in outdoor spaces, spatial satisfaction, the perception of environmental quality and the desire to use such spaces. Although thermal comfort indices such as PET, UTCI and MRT do not directly incorporate particulate matter levels, the literature indicates that air pollution may have indirect effects on the radiation balance, microclimatic conditions and subjective comfort assessments. Urban green spaces, meanwhile, are strategic spatial components that can improve this relationship through their functions of providing shade, promoting evapotranspiration, reducing surface temperatures, regulating wind circulation and trapping particulate matter. This study examines, on the basis of the literature, the relationship between particulate matter pollution and outdoor thermal comfort in the context of green spaces and emphasises the need to address thermal comfort and air quality jointly in urban design processes. In this context, the scientific studies carried out on the subject have been examined and evaluated within the context of sustainable landscape planning. Although particulate matter pollution is not a direct input into thermal comfort indices, it has a significant impact on the human perception of outdoor comfort, health risks and environmental satisfaction. For this reason, in future urban open space planning, PM2.5, PM10 and perceptions of air quality should be included in the assessment alongside thermal indicators such as PET, UTCI and MRT; green infrastructure strategies, meanwhile, should be designed taking into account both their cooling and pollution-reducing effects.

Keywords: Outdoor Thermal Comfort, Green Infrastructure, Air Quality, Sustainable Landscape Planning.

INTRODUCTION

Ensuring thermal comfort in outdoor spaces is of great importance in landscape architecture, particularly today, as the effects of urbanisation and climate change are becoming increasingly pronounced (Kong et al. 2020). Alongside urban growth, the built environment is expanding whilst green spaces are diminishing (Li et al. 2022). In particular, global warming is causing temperatures in urban areas to rise and making the heat island effect more pronounced. Consequently, heat stress experienced in open spaces is increasing, making it more difficult for people to use these areas comfortably (Singh & Kapoor, 2025). For all these reasons, landscape planning and design must take into account not only aesthetic concerns but also user comfort, sustainability and adaptation to changing climatic conditions (Abdelwahab et al. 2025; Qiu et al. 2025).

Thermal comfort and air pollution are two key interrelated environmental factors in measuring quality of life in urban areas. In particular, high levels of $PM_{2.5}$ and PM_{10} in the atmosphere, when combined with hot weather conditions, give rise to very serious health problems (Dursun & Yavaş, 2024; Polat et al., 2025). PET (Physiological Equivalent Temperature) and UTCI (Universal Thermal Climate Index), which are used to determine thermal comfort, indicate the effect of meteorological conditions on humans, whilst MRT (Mean Radiant Temperature) represents the radiation received by a person from surrounding surfaces and the sun (Jurek et al., 2025). Green spaces help to reduce these values through

shading and evapotranspiration, whilst also ensuring that certain particulate matter is retained on plant surfaces. Although plants contribute to the retention of particulate matter, it is of great importance to establish a planting scheme that does not obstruct airflow and is suited to local climatic conditions (Raihan, 2023; Wang et al., 2024).

METHODOLOGY

This study examined the relationship between air pollution particularly particulate matter pollution and outdoor thermal comfort in the context of green spaces, by reviewing national and international scientific research. The scientific studies conducted on this subject have been interpreted within the framework of sustainable urban landscape planning and design.

RESULT

The Relationship between Air Quality and PET in Urban Landscape Planning and Design

In recent years, urban growth and population increase have accelerated efforts to create healthy and resilient urban landscapes. Furthermore, according to a United Nations report, it is projected that by 2050, two out of every three people that is, approximately 66 % of the population will live in cities (Menteş et al. 2026). It is not only urban growth and population increase but also changes in land use and climate change that are key factors affecting quality of life and safety. The deterioration of outdoor thermal comfort and air pollution are among the most significant environmental challenges facing today's cities (Yeo et al. 2021).

Thermal comfort refers to how an individual perceives the temperature conditions of their environment and the extent to which they are affected by these conditions. As air temperature is not the sole criterion for determining outdoor thermal comfort, variables such as wind speed, relative humidity and solar radiation are also examined (Mahdavinejad et al., 2024). PET, UTCI and MRT are metrics widely used in scientific studies. MRT is not a direct thermal comfort index, but it is one of the key variables determining PET and UTCI values. Particularly in open areas where the effect of shade is low and impervious surfaces are prevalent, an increase in MRT leads to higher PET and UTCI values and causes individuals in the environment to experience greater thermal stress (Li & Liu, 2020; Zhou et al., 2024).

The impact of air pollution in urban areas on human health has become an increasingly important issue. Particulate matter such as $PM_{2.5}$ and PM_{10}, along with gaseous pollutants such as nitrogen dioxide, sulphur dioxide and ozone, can be found in high concentrations in the urban atmosphere due to industrial activities, traffic, heating and dense urban development (Kozłowski et al., 2024). Concentrations of $PM_{2.5}$ and PM_{10} in the air are measured using the gravimetric method which determines the mass of particles collected by passing a specific volume of air through a filter or using optical sensors based on the scattering of laser light; whilst these sensors are portable and cost-effective, they require calibration against reference instruments due to the effects of humidity. gaseous pollutants can be determined using active systems that provide continuous and real-time data, or via passive samplers, which, although unable to show hourly variations, are more cost-effective for spatial comparisons (Hidy et al., 2017; Rahman, 2023).

The Interaction Between PM Pollution and Thermal Comfort in Green Spaces

Their effects on air quality and outdoor thermal comfort are increasingly being examined in conjunction in studies of the urban microclimate (Miao et al., 2023). In their study conducted in the city of Shenyang, China, Miao et al. (2023) found that street trees improved thermal comfort during the summer months by reducing the air temperature by approximately 3 °C and lowering the PET value from 46.3 °C to 44.2 °C. However, the reduction in wind speed caused by the trees in autumn led to an increase in the PET value from 36.4 °C to 37.5 °C. Whilst no significant difference was observed between PM_1, $PM_{2.5}$ and PM_4 levels in tree-lined and treeless areas, PM_{10} and TSP levels were found to be higher in tree-lined areas. The evidence suggests that these two objectives may be compatible but involve significant trade-offs depending on factors such as vegetation type, season and urban geometry.

Scientific studies have shown that in landscape planning, thermal comfort and air quality generally exhibit opposing trends depending on vegetation configuration (Jung & Yoon, 2022). The presence of urban green spaces can improve air quality whilst also having a positive impact on thermal comfort. In a study conducted by Leonardi et al. (2025) in Catania, a 11.5 per cent reduction in $PM_{2.5}$ and a 2.16°C decrease in the UTCI value were observed, thanks to a 50 per cent reduction in traffic and an eastern vegetation design. In their study, Chen et al. (2025) utilised AI-supported design optimisation in a metropolitan park, achieving a 15 per cent reduction in thermal radiation and a 12–15 per cent reduction in $PM_{2.5}$/PM_{10} concentrations. In their scientific study conducted in Wuhan, Liao et al. (2025) demonstrated that better air quality at the same UTCI level enhances comfort, with this effect being particularly pronounced in the 0–10°C range. In a simulation study carried out in Florence by Piselli et al. (2018), it was determined that greening design improves thermal comfort and air quality during the summer but does not have a significant effect during the winter. Yılmaz et al. (2022) found that in Erzurum, wooded and rural areas were approximately 13 °C cooler than the city centre in summer and 10–15 °C cooler in winter. Whilst the average PET value was measured at 11.2 °C in the city centre, 10 °C in forested areas and 4.7 °C in open rural areas, a positive correlation was found between O_3 and PET.

A review of scientific studies indicates that whilst the effect of $PM_{2.5}$ on thermal comfort depends on the temperature range, the impact of air pollution on human comfort is greater under high and low temperature conditions and less pronounced at moderate temperatures (Sun et al., 2025). Urban parks exhibit different behaviour in regulating PM levels depending on the season; whilst a positive correlation with PM is observed in spring and summer due to pollen and spores, in winter, coniferous and broad-leaved evergreen plants effectively adsorb PM (Zhang et al., 2024). In a study conducted by Du et al. (2024) in Guangzhou, China, they found that a reduction in the distance between trees increased the shading effect, thereby lowering PET values and improving thermal comfort. However, dense vegetation restricted air circulation, leading to an increase in $PM_{2.5}$ concentrations. It was determined that trees with broad crowns and high Leaf Area Index (LAI) values are more effective in terms of thermal comfort, whilst species with small crowns and open airflow beneath the trunk are more advantageous in terms of particulate matter dispersion. Furthermore, it was found that shrubs 1.5–2 m in height increase the accumulation of $PM_{2.5}$ at pedestrian level. Picone et al. (2024) found that nearly all green infrastructure applications reduced thermal discomfort by at least 10%, while green walls provided the most effective solution for improving air quality; however, in compact street canyons with an H/W ratio above 0.7, trees could restrict airflow and increase pollutant accumulation. Huang et al. (2025) in their study of 370 Chinese cities, found that O_3 and PM_{10} increased daytime heat stress in summer, whereas $PM_{2.5}$ and CO reduced nocturnal heat loss in winter, demonstrating that their effects on UTCI varied according to season, time of day, and local climatic conditions. Huang et al. (2025) in their study of 370 Chinese cities, found that O_3 and PM_{10} increased daytime heat stress in summer, whereas $PM_{2.5}$ and CO reduced nocturnal heat loss in winter, demonstrating that their effects on UTCI varied according to season, time of day, and local climatic conditions. Table 1 presents the findings of scientific studies conducted on the impact of urban green spaces on thermal comfort and air pollution.

Table 1. Examples of scientific studies conducted on the impact of urban green spaces on thermal comfort and air pollution

Reference	Field of study	Finding
(Miao et al., 2023)	Shenyang, Northeast China	Air quality and thermal comfort work in harmony, but this depends on factors such as vegetation type, season and urban geometry.
(Jung & Yoon, 2022)	Seoul, Korea	PET and air quality generally show opposing trends, depending on the vegetation cover configuration.
(Leonardi et al., 2025)	Catania, Southern Italy	Urban greening has a positive impact on thermal comfort and air pollution.
(Chen et al.,2025)	Hong Kong	The vegetation design, developed using artificial intelligence, has been found to

		reduce thermal radiation and $PM_{2.5}$/PM_{10} concentrations.
(Liao et al., 2025)	Wuhan, China	It has been found that user satisfaction decreases as $PM_{2.5}$ and Air Quality Index levels rise, and that better air quality at the same UTCI value enhances thermal comfort.
(Piselli et al., 2018)	Florence, Italy	It has been shown that the impact of landscaping design on thermal comfort and air pollution varies according to the season.
(Yılmaz et al., 2022)	Erzurum, Türkiye	A positive correlation has been found between O_3 and PET.
(Sun et al., 2025)	Xi'an, China	Although the effect of PM2.5 on thermal comfort depends on the temperature range, the impact of air pollution on human comfort is greater at high and low temperatures, and less pronounced at moderate temperatures.
(Zhang et al., 2024)	Xi'an, China	Whilst PM levels in urban parks rise in spring and summer due to pollen and spores, they decrease in winter as a result of adsorption by evergreen plants.
(Du et al., 2024)	Guangzhou, China	Dense vegetation with a high LAI can increase $PM_{2.5}$ concentrations at pedestrian level by restricting airflow, whilst reducing PET.
(Picone et al., 2024)	Brindisi, İtalya	Whilst all types of green infrastructure reduced thermal discomfort by at least 10 per cent, green walls improved air quality; however, in compact streets with a H/W ratio greater than 0.7, trees increased the accumulation of pollutants.
(Huang et al., 2025)	Chinese cities (370)	A study of 370 Chinese cities found that O_3 and PM_{10} increased summer heat stress, while $PM_{2.5}$ and CO reduced nocturnal heat loss in winter.

CONCLUSION AND DISCUSSION

When scientific studies examining the relationship between urban green spaces and thermal comfort and particulate matter are assessed collectively, it is observed that in 66.7 per cent of the studies, plant species, density, season and urban geometry determined the relationship between thermal comfort and air quality; in 50 per cent of the studies, $PM_{2.5}$ and PM_{10} were treated as key pollutants, and in 41.7 per cent of the studies, it was observed that the effects varied according to season, temperature, time of day or climatic conditions. 33.3 per cent of the studies demonstrated that green infrastructure improved thermal comfort, whilst 25 per cent showed that appropriate planting design yielded positive results in terms of both thermal comfort and air quality. In contrast, in 25 per cent, it was determined that dense or airflow-obstructing planting, whilst reducing the PET, increased pollutant accumulation. Furthermore, whilst a positive correlation between O_3 and heat stress was found in 16.7 per cent of the studies, the improvement in air quality by green walls and the reduction in thermal discomfort by at least 10 per cent across all types of green infrastructure were reported in only one study.

The scientific findings reviewed indicate that the effect of urban vegetation on thermal comfort and air quality is not one dimensional but varies depending on the type and spatial arrangement of the vegetation, as well as seasonal and meteorological conditions. Plants can improve thermal comfort by

reducing thermal radiation, MRT, PET and UTCI values through shading and evapotranspiration; they can also contribute to lowering $PM_{2.5}$ and PM_{10} concentrations by trapping particulate matter on their leaf surfaces. In artificial intelligence-supported design studies, the ability to simultaneously reduce thermal radiation and PM concentrations demonstrates that decisions regarding vegetation can be addressed using a multi-objective optimisation approach.However, an improvement in thermal comfort does not necessarily imply that air quality will improve to the same extent. Whilst dense and impermeable vegetation cover can create a cooling microclimate by reducing wind speed, it may also limit the dispersion of pollutants. The fact that the effect of $PM_{2.5}$ on thermal comfort is more pronounced at high and low temperatures indicates that air pollution and thermal stress must be assessed together. Similarly, the positive correlation between O_3 and PET can be explained more by common meteorological conditions, such as high temperatures and solar radiation, than by direct causality. The fact that cleaner air increases user satisfaction at the same UTCI value demonstrates that outdoor comfort cannot be explained by thermal variables alone.

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LEGAL DELIMITATION OF FORCED MARRIAGE FROM ARRANGED MARRIAGE AND TRAFFICKING IN HUMAN BEINGS: A COMPARATIVE ANALYSIS BETWEEN THE REPUBLIC OF MOLDOVA AND EUROPEAN STANDARDS

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ABSTRACT

Forced marriage, arranged marriage and trafficking in human beings are frequently confused in practice, although they rest on different legal foundations. Faulty delimitation generates errors in the legal classification of facts and weakens victim protection. This article formulates clear delimitation criteria and assesses the correspondence of the law of the Republic of Moldova with European standards. The research applies comparative, formal legal and logical methods, combined with case law analysis, examining the Criminal Code and the Family Code of the Republic of Moldova, Law No. 241/2005 on preventing and combating trafficking in human beings, the Istanbul Convention, the Council of Europe Convention on Action against Trafficking in Human Beings, Directive 2011/36/EU as amended by Directive (EU) 2024/1712, Directive (EU) 2024/1385 on combating violence against women and domestic violence, the case law of the European Court of Human Rights, and the national experience of the United Kingdom, Germany, and Sweden. Law No. 252/2025 introduced Article 167^1 into the Criminal Code and, from February 2026, criminalises forced marriage and forced cohabitation as an autonomous offence, removing that conduct from Article 167. At the level of the European Union, forced marriage is now addressed through two converging instruments, Directive (EU) 2024/1385, which requires its criminalisation as a stand alone offence, and Directive (EU) 2024/1712, which includes the exploitation of forced marriage among the forms of exploitation specific to trafficking. Three criteria are proposed to ensure correct delimitation: free and informed consent, which separates arranged marriage from forced marriage; the coercion exercised; and the purpose of exploitation associated with a typical trafficking action, which requires classification under Article 165 instead of Article 167^1. The article recommends a legal definition of forced marriage and unified methodological guidelines for practitioners.

Keywords: forced marriage, arranged marriage, trafficking in human beings, consent.

INTRODUCTION

Judicial practice and specialised research consistently reveal a terminological overlap between three categories of conduct that, although they may appear similar at first glance, rest on distinct legal foundations: arranged marriage, forced marriage, and trafficking in human beings. The confusion between these notions is not merely theoretical. It produces concrete effects on the legal classification of facts, on the individualisation of sentences, and, above all, on the manner in which victims are identified and protected by State institutions.

Arranged marriage, a practice present in numerous traditional communities, involves the family or community in identifying a prospective partner while preserving, at least in principle, the freedom of the future spouses to accept or decline the proposed union. Forced marriage, by contrast, is characterised by the absence of that freedom, consent being obtained through violence, threats, deception, or psychological pressure. Trafficking in human beings, in turn, presupposes an action, a means of coercion or deception, and a purpose of exploitation, elements which, following recent developments in European law, may now include exploitation through forced marriage.

The present study pursues three principal objectives. The first is to formulate clear and practically applicable criteria for delimiting the three categories of conduct described above. The second is to assess

the degree of correspondence between the law of the Republic of Moldova, as recently amended by Law No. 252/2025, and the relevant European standards, namely the Istanbul Convention, the Warsaw Convention, Directive 2011/36/EU as amended by Directive (EU) 2024/1712, and Directive (EU) 2024/1385. The third is to draw, from the comparative experience of selected European jurisdictions, lessons that may usefully inform the implementation of the Moldovan reform.

The article is organised in six parts. Following the presentation of the conceptual framework applicable to the three categories of conduct, the methodology of the research is described, followed by the findings drawn from the normative and case law analysis. A further section situates the Moldovan reform within a comparative perspective, examining the legislative solutions adopted in the United Kingdom, Germany, and Sweden. The discussion section proposes the three delimitation criteria, and the conclusion formulates recommendations for judicial practice.

RESEARCH AND FINDINGS

I. Conceptual Framework: Arranged Marriage, Forced Marriage, and Trafficking in Human Beings

Arranged marriage is a social practice found across numerous cultures, in which the family or community plays an active role in identifying and proposing a partner. What distinguishes this practice from forced marriage is the preservation of a genuine possibility for the future spouses to accept or decline the proposed union, without the refusal triggering any coercive consequence. International human rights bodies do not, in themselves, regard arranged marriage as a violation of fundamental rights, provided that consent remains free and informed.

Article 37 of the Council of Europe Convention on Preventing and Combating Violence Against Women and Domestic Violence, known as the Istanbul Convention, requires States parties to criminalise the conduct of forcing an adult or a child to enter into a marriage. The defining element of forced marriage is, therefore, the absence of free and informed consent on the part of one of the spouses, consent having been obtained or replaced through violence, threats, deception, or psychological pressure exerted by another person, often from within the victim's family or community circle.

The Council of Europe Convention on Action against Trafficking in Human Beings, adopted in Warsaw, together with Directive 2011/36/EU of the European Parliament and of the Council on preventing and combating trafficking in human beings and protecting its victims, define trafficking in human beings by reference to three cumulative elements: an action, namely the recruitment, transportation, transfer, harbouring, or receipt of a person; a means, namely the threat or use of force, coercion, abduction, fraud, deception, or the abuse of a position of vulnerability; and a purpose of exploitation, which may include exploitation through forced labour, sexual exploitation, begging, the removal of organs, or, following the amendments introduced by Directive (EU) 2024/1712, exploitation through forced marriage.

II. Methodology

The research combines the comparative method, which allows national legislative solutions to be measured against European standards, the formal legal method, through the analysis of the normative texts in force, and the logical method, through the systematic interpretation of the relevant criminal law provisions. These methods are complemented by an analysis of the case law of the European Court of Human Rights, which is relevant to understanding how the European Court addresses the relationship between forced marriage and trafficking in human beings, and by a brief comparative review of the legislative solutions adopted in three European jurisdictions with mature experience in this field.

The sources examined include the Criminal Code of the Republic of Moldova, the Family Code of the Republic of Moldova, Law No. 241/2005 on preventing and combating trafficking in human beings, the Istanbul Convention, the Warsaw Convention, Directive 2011/36/EU as amended by Directive (EU) 2024/1712, Directive (EU) 2024/1385 on combating violence against women and domestic violence, the judgments of the European Court of Human Rights in Rantsev v. Cyprus and Russia, M. and Others v. Italy and Bulgaria, and S.M. v. Croatia, the GREVIO baseline evaluation report on the Republic of Moldova, and the national criminal legislation of the United Kingdom, Germany, and Sweden.

III. The Legislative Reform in the Republic of Moldova and the European Standards

Until the adoption of Law No. 252/2025, the Criminal Code of the Republic of Moldova addressed the coercion of a person to enter into or remain in a relationship of cohabitation or marriage within Article 167, alongside slavery and conditions similar to slavery. This normative placement generated classification difficulties, since forced marriage was treated as a variant of the offence of slavery, without benefiting from its own description of constitutive elements.

Law No. 252/2025 removed that conduct from Article 167 and introduced Article 167^1, which criminalises forced marriage and forced cohabitation as an autonomous offence. Under the new provision, applicable from the end of February 2026, it is an offence to force a person, through violence, threats, deception, or psychological pressure, to enter into a marriage or to begin or maintain a relationship of cohabitation. The reform pursues alignment with the Istanbul Convention and strengthens the protection of victims of violence, including forms carried out through digital means. It should be read together with the GREVIO baseline evaluation report on the Republic of Moldova, published in November 2023, which had identified the absence of a stand alone offence of forced marriage as a gap in the Moldovan legal framework and recommended its introduction, alongside the strengthening of victim identification mechanisms and inter agency cooperation.

A central aspect of the reform concerns the delimitation between Article 167^1 and the offence of trafficking in human beings under Article 165 of the Criminal Code. According to the clarifications formulated by the authorities responsible for drafting the bill, Article 167^1 applies only where the conduct of forced marriage is not preceded, accompanied, or pursued by the typical actions of trafficking, namely the recruitment, transportation, transfer, harbouring, or receipt of a person for the purpose of exploitation. Where these elements are present, the correct classification is that provided by Article 165, and not Article 167^1.

At the level of the European Union, forced marriage is now addressed through two converging instruments. Directive (EU) 2024/1385 of 14 May 2024 on combating violence against women and domestic violence, which Member States must transpose by 14 June 2027, requires forced marriage to be criminalised as a stand alone offence under Article 4, situating it among the forms of gender based violence subject to a common minimum standard of criminalisation, victim protection, and prevention. Directive (EU) 2024/1712 of 13 June 2024, which amends Directive 2011/36/EU and must be transposed by 15 July 2026, takes a different route, including the exploitation of forced marriage, together with surrogacy and illegal adoption, among the forms of exploitation that qualify conduct as trafficking in human beings. The coexistence of these two instruments reflects, at Union level, the same delimitation problem that this article addresses at national level: whether a given instance of forced marriage should be classified as a stand alone offence or as an act of trafficking, depending on whether it is accompanied by the typical elements of trafficking.

IV. The Case Law of the European Court of Human Rights

The European Court of Human Rights has developed, in its case law under Article 4 of the European Convention on Human Rights, a set of benchmarks for identifying trafficking in human beings. In Rantsev v. Cyprus and Russia, the Court held that trafficking in human beings falls within the scope of Article 4, alongside slavery and forced labour, emphasising that the exercise of powers akin to the right of ownership over a person is incompatible with human dignity.

In M. and Others v. Italy and Bulgaria, the Court examined a situation in which facts concerning the marriage of a minor were closely linked to elements of exploitation, confirming the need for an overall assessment of the facts in order to establish whether they fall within the scope of Article 4.

In S.M. v. Croatia, the Grand Chamber clarified that a situation raises an issue under Article 4 concerning trafficking in persons only where the constitutive elements of trafficking, namely the action, the means, and the purpose of exploitation, are cumulatively present. This clarification provides a useful methodological benchmark for delimiting forced marriage from trafficking in human beings at national level as well, since the mere existence of coercion, absent the purpose of exploitation specific to trafficking, does not automatically justify classifying the conduct as trafficking.

V. Comparative Perspectives: Selected National Practices

A brief comparative review of national systems with longer experience in criminalising forced marriage illustrates the range of legislative techniques available and confirms the practical relevance of the delimitation criteria proposed in this article.

In the United Kingdom, forced marriage has been addressed through a combination of civil and criminal measures. The Forced Marriage (Civil Protection) Act 2007 introduced Forced Marriage Protection Orders, a civil remedy allowing courts to intervene before a marriage takes place or to protect a person already in a forced marriage, without requiring a criminal conviction. Section 121 of the Anti social Behaviour, Crime and Policing Act 2014 subsequently created a stand alone criminal offence of forcing a person to marry through violence, threats, or any other form of coercion, carrying a maximum penalty of seven years of imprisonment, while breach of a protection order was itself criminalised. This dual civil and criminal architecture, later reinforced by the Marriage and Civil Partnership (Minimum Age) Act 2022, allows the system to respond flexibly according to whether the victim seeks protection, prosecution, or both, and offers a template that the delimitation criteria proposed in this article could usefully complement at the investigative stage.

In Germany, forced marriage has been a stand alone offence under Section 237 of the Criminal Code since 1 July 2011, punishable by a term of imprisonment of between six months and five years. The provision also criminalises the conduct of taking or inducing a person to travel abroad by force, threat, or deception for the purpose of forcing a marriage there, or preventing that person from returning, thereby addressing the cross border dimension frequently associated with forced marriage cases.

In Sweden, the offence of äktenskapstvång, introduced by an amendment to the Criminal Code that entered into force on 1 July 2014, punishes a person who, through unlawful coercion or the exploitation of a vulnerable position, causes another person to enter into a marriage valid in the State where it is concluded, the State under whose law it is concluded, or a State of which one of the spouses is a national or resident, with imprisonment of up to four years. The Swedish provision extends the same protection to marriage like unions concluded according to the rules of a particular group, and separately criminalises deception for the purpose of a forced marriage journey abroad.

Taken together, these three systems confirm that criminalisation as a stand alone offence, whether combined with civil protection measures as in the United Kingdom, with extraterritorial reach as in Germany, or with an explicit reference to informal marriage like unions as in Sweden, represents the common European direction that the reform of the Republic of Moldova now follows. They also confirm that the delimitation between a stand alone offence of forced marriage and the offence of trafficking in human beings is not a peculiarity of Moldovan law but a structural question that any legal system must resolve once both offences coexist in the same code.

DISCUSSION: THREE CRITERIA OF DELIMITATION

The analysis of the normative framework, of European case law, and of comparative practice allows three principal criteria to be formulated for delimiting arranged marriage, forced marriage, and trafficking in human beings.

The first criterion concerns the existence of free and informed consent on the part of the person entering into the marriage. This is the criterion that separates arranged marriage from forced marriage. As long as the person retains a genuine possibility of declining the proposed union, the conduct remains within the sphere of arranged marriage, however strong the involvement of the family or community in choosing the partner may be.

The second criterion concerns the nature and intensity of the coercion exercised. Physical violence, threats, deception, and sustained psychological pressure constitute forms of coercion that vitiate free consent and qualify the conduct as forced marriage within the meaning of Article 167^1 of the Criminal Code. As the German and Swedish provisions illustrate, this criterion may also extend to the abuse of a position of vulnerability, and to deception aimed at moving the victim to another jurisdiction for the purpose of the forced marriage.

The third criterion concerns the purpose of exploitation associated with a typical trafficking action. Where the coercion into marriage is preceded, accompanied, or pursued by the recruitment, transportation, transfer, harbouring, or receipt of a person for the purpose of exploitation, the correct classification is that provided by Article 165 of the Criminal Code on trafficking in human beings, rather than Article 167[1]. This distinction carries significant consequences for the applicable sanctioning regime and for the protection and assistance measures available to the victim under Law No. 241/2005.

The correct application of these three criteria requires a careful, individualised assessment of each factual situation, taking into account the cultural context, the relationship between the victim and the alleged perpetrator, and the presence of elements specific to trafficking, such as the transportation of the victim to another locality or country, or her isolation from the family support network. As the United Kingdom's dual civil and criminal model suggests, this assessment need not wait for a completed marriage: protective intervention may, and often should, precede the classification of the conduct as a completed offence.

CONCLUSION AND RECOMMENDATIONS

This study confirms that the law of the Republic of Moldova has achieved, through Law No. 252/2025, significant progress toward alignment with European standards on forced marriage. The introduction of Article 167[1] into the Criminal Code provides this conduct with its own description of constitutive elements and delimits it, at least at the normative level, from the offence of slavery previously addressed under Article 167, responding directly to the gap identified by GREVIO in its 2023 baseline evaluation. At the same time, developments in European Union law, embodied in Directive (EU) 2024/1385 and Directive (EU) 2024/1712, confirm the trend of recognising the link between forced marriage and trafficking in human beings, whenever forced marriage constitutes the means or the purpose of an act of exploitation.

The comparative material examined confirms that the systems which perform most effectively are those that combine criminalisation with complementary mechanisms, whether civil protection orders, as in the United Kingdom, extraterritorial reach, as in Germany, or an extended definition covering informal unions, as in Sweden. None of these systems treats the criminal offence as self sufficient, and the Moldovan reform will similarly depend, for its practical effectiveness, on the institutional architecture that surrounds Article 167[1].

Nevertheless, national legislation does not yet contain an explicit, autonomous legal definition of forced marriage, its constitutive elements being described only by reference to the means of coercion used. The study recommends supplementing the normative framework with a clear legal definition of forced marriage, drawing on the conceptual benchmarks of the Istanbul Convention and on the comparative solutions examined above, as well as the elaboration of unified methodological guidelines for prosecutors, judges, and criminal investigation bodies, aimed at the correct application of the three delimitation criteria set out in this article.

It is further recommended that the judicial practice which will develop following the entry into force of Article 167[1] be monitored, in order to identify possible interpretative difficulties and the need for subsequent legislative amendments, that consideration be given to a civil protection mechanism complementing the criminal offence, along the lines of the United Kingdom's Forced Marriage Protection Orders, and that continuing training programmes be organised for practitioners, focused on the early recognition of the signs of forced marriage and its delimitation from trafficking in human beings.

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ENHANCEMENT OF THE MECHANICAL AND TRIBOLOGICAL PROPERTIES OF ST37 STEEL USING NI-W COATINGS

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ABSTRACT

Introduction and Purpose: Ni–W alloys have gained widespread application as protective coating materials in the mechanical, electronics, and chemical industries due to their high hardness, corrosion resistance, superior wear resistance, and stable performance at elevated temperatures. Although numerous studies have been conducted on Ni–W alloy coatings, investigations on the production of these coatings using the pulse-reverse electrodeposition technique and the effects of varying current density, one of the key electrodeposition parameters, on the coating properties remain limited. Therefore, the aim of this study was to investigate the effects of different current densities applied during pulse-reverse electrodeposition on the microstructural and mechanical properties of Ni–W coatings.

Materials and Methods: Following surface preparation, Ni–W alloy coatings were deposited onto low-carbon steel substrates (2,5 × 2,5 cm) using the pulse-reverse electrodeposition technique. The effects of different current densities (0.8, 1.0, 1.2, and 1.4 A/cm²) on the coating properties were investigated. The microstructural, crystallographic, mechanical, and tribological properties of the coatings were characterized by SEM, EDS, XRD, microhardness, and coefficient of friction analyses. The average crystallite size was calculated from the XRD data.

Discussion and Conclusion: The analyses revealed that current density had a significant influence on the surface morphology, elemental composition, mechanical properties, and tribological performance of the Ni–W coatings. Increasing the current density from 0.8 to 1.2 A/cm² resulted in a more homogeneous microstructure and increased W content. However, at 1.4 A/cm², microstructural irregularities and a decrease in W content were observed. XRD analyses showed that increasing the current density up to 1.2 A/cm² enhanced the degree of crystallinity, whereas a further increase to 1.4 A/cm² increased structural defects and microstrain. The average crystallite size calculated from the XRD data decreased from 89 nm at 0.8 A/cm² to 59 nm at 1.2 A/cm² before increasing again at 1.4 A/cm². The highest hardness value (589 HV) was achieved at 1.2 A/cm². Likewise, the lowest coefficient of friction (≈0.35) and wear rate (≈40 × 10^{-6} mm³/Nm) were also obtained at the same current density.

Results: The findings of this study indicate that a current density of 1.2 A/cm² provides the optimum coating condition for Ni–W coatings in terms of microstructure, composition, mechanical properties, and tribological performance.

Keywords: ST37, electrodeposition, Ni-W, pulse-reverse current

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