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Impacts of climate change on groundwater recharge in Küçük Menderes River Basin in Western Turkey

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Groundwater is an important component of the global freshwater supply and is affected by climate. There is a strong need to understand and evaluate the impacts of climate change over the long term, in order to better plan and manage precious groundwater resources. Turkey, located in Mediterranean basin, is threatened by climate change. The purpose of this study was, through a quantitative overview, to determine the impacts of climate change on the groundwater recharge rates in Küçük Menderes River Basin in western Turkey. According to the data of Ödemiş and Selçuk meteorological stations located in the basin, there is a significantly decreasing trend in precipitation combined with increasing trends in temperature and evaporation observed in 1964–2011. The calculations of groundwater recharge with hydrologic budget method for the observation period showed an approximately 15% decline in groundwater recharge in the basin. Thus, the combined impacts of climate change and excessive groundwater pumping, due to increasing water demand, have caused a significant decline in groundwater levels. Consequently, the proper management of the groundwater resources threatened by climate change requires effective governance to both mitigate the adverse impacts of climate change and facilitate the adaptation of sustainable integrated water management policies.

Keywords: groundwater recharge; climate change; Küçük Menderes River Basin; groundwater levels; sustainable water management

1. Introduction

Groundwater is an essential part of the hydrological cycle and is a valuable natural resource, providing the primary source of water for agricultural, industrial and domestic uses in many countries. Groundwater is a significant source of water for human consumption, supplying about half of all drinking water in the world (WWAP, 2009) and around 43% of all water effectively consumed in irrigation (Siebert et al., 2010).

Global groundwater resources are threatened by the consequences of climate change and human activity. Changes in global climate are expected to affect the hydrological cycle, altering groundwater recharge to aquifers and surface water levels with other associated impacts on natural ecosystems. The groundwater is the ultimate and invisible indicator of the atmospheric anomalies in the hydrologic cycle. As a direct consequence of warmer temperatures, the hydrologic cycle will undergo significant impact due to changes in the rates of precipitation and evaporation (Loaiciga, Valdes, & Vogel, 1996). The occurrence of drought and heavy precipitation is the most important climatic extremes having both short- and long-term impacts on groundwater availability. These impacts include changes in groundwater recharge resulting from the erratic behaviour of the annual and seasonal distribution of precipitation and temperature, and changes in evapotranspiration and increased demands for groundwater as a source of water supply (Alley, 2001). Despite the critical importance of groundwater resources in many parts of the world, there have been very few direct studies of the effect(s) of climate change on groundwater recharge (Intergovernmental Panel on Climate Change (IPCC) 1996).

Turkey is one of several countries in the Mediterranean basin that could be profoundly affected by climate change (IPCC, 2007, 2013). The projected changes in the climate of Turkey in the future were obtained by conducting general circulation models simulations. Temperatures will increase in all seasons, but increases will be higher in summer than in winter. Precipitation will decrease mainly in the southern parts of Turkey (Şen, 2013). Climate change projections reveal that the precipitation Turkey receives will decrease in future, which will result in a reduction of water resources and hence the amount of useable water. Based on an IPCC – A2 pessimistic scenario, the model projections indicate that there will be 16 and 27% reductions in the water potentials in Turkey by 2050 and 2075, respectively. The decline in precipitation and the rise in temperatures will increase aridity in Turkey. The per capita water amount will decrease to the level classified as ‘water scarcity’ at country scale (Şen, 2013).

This study presents the impacts of climate change on the groundwater recharge in Küçük Menderes River Basin in western Turkey. In recent years, the Küçük

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Menderes River Basin has struggled under existing water stress from pressures such as increased irrigation demand and water pollution. These pressures are significantly exacerbated by climate change, which for many areas is resulting in decreasing precipitation, increasing temperature and evaporation, further reducing the availability of water for agricultural, industrial and domestic use. The calculations of groundwater recharge with the hydrologic budget method for the observation period (1964–2011) showed approximately 15% decline in groundwater recharge in the basin. Many aquifers in Turkey, like other aquifers around the world (Alley, Healy, LaBaugh, & Reilly, 2002; USGS, 2009), are under threat of climate change and depletion of water resources imposed by human demand in the next few decades. Understanding the impact of climate change is vital for ecosystems and society, particularly with regard to complex changes affecting the sustainability and availability of both ground and surface water resources (USGS, 2009).

2. Physiography, climate and geological setting

The Küçük Menderes River Basin is located in western Turkey (Figure 1). The catchment area of the basin is 3502 km^2 where 1100 km^2 of that area is covered by a plain. The plain area is elongated in E-W direction and surrounded by steeply rising mountain ranges and the Aegean Sea (Figure 2). The river basin is divided into four sub-basins: from east to west, Kiraz, Ödemiş-Tire, Bayındır-Torbalı and Selçuk (Figure 3). The Küçük Menderes River Basin is a very productive agricultural area, with industrial sites concentrated in the west. Almost all irrigation and industrial water needs in the basin have been supplied using groundwater resources. A continuously increasing water demand in the basin requires a sustainable water management plan (Pusatli, Camur, & Yazicigil, 2009; Sakiyan & Yazicigil, 2004).

The Küçük Menderes River and its tributaries constitute the only surface water system in the study area, with an annual average discharge rate of 9.5 m^3/s. The study area has hot and dry summers with mild and rainy winters. The mean annual precipitation calculated for the study area is 640 mm. The basement rocks in the basin are composed mainly of highly metamorphosed rock sequences called the Menderes Masif (Figure 4). Lower parts of the metamorphic sequence are generally characterised by augen gneisses, mica schists, granitic schists and calc schists, which extensively crop out in the north,



Figure 1. Location map of the study area.

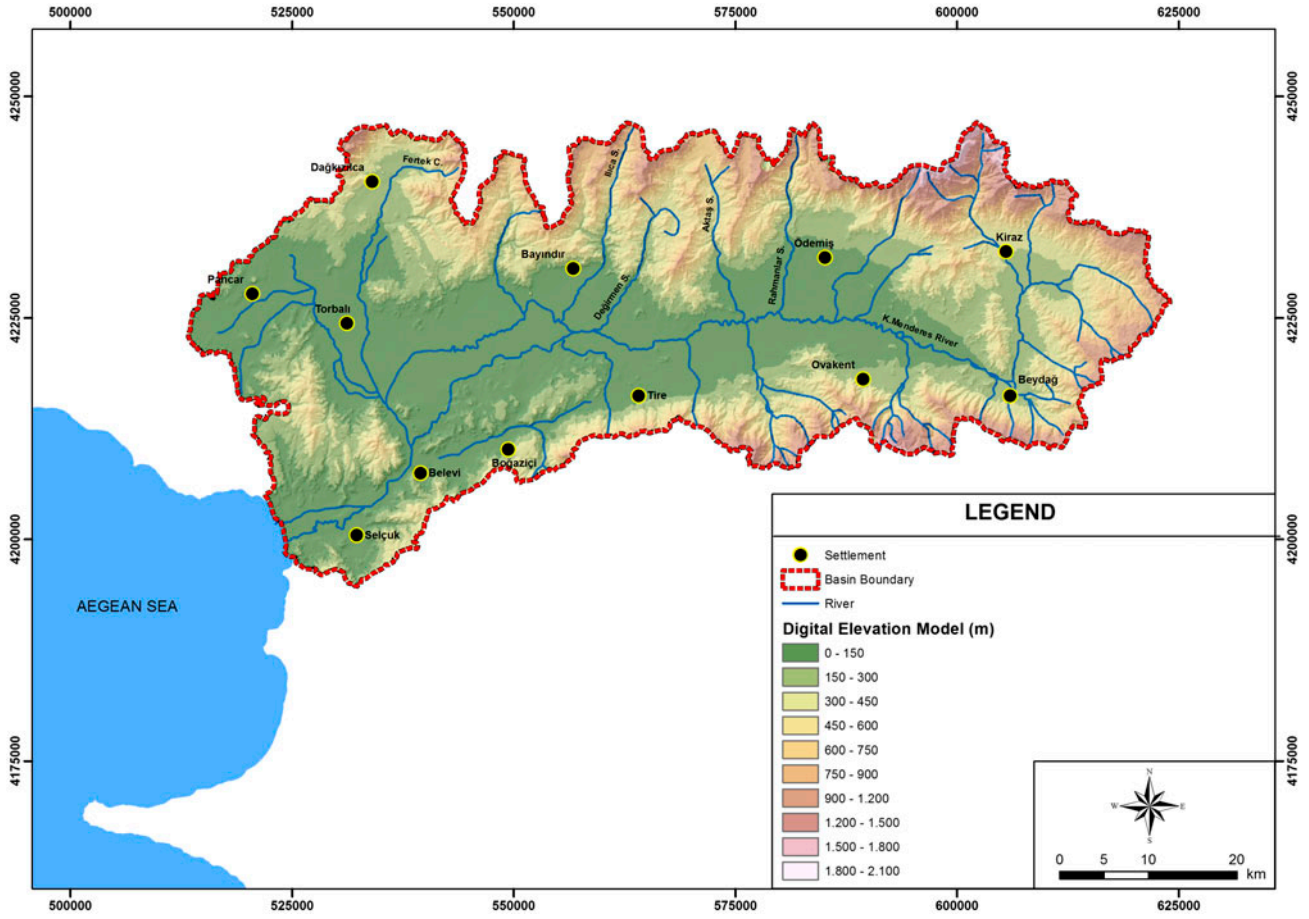

Figure 2. Digital elevation map of the Küçük Menderes River Basin.

east and south of the basin (Yazicigil et al., 2000). Schist–gneiss sequences observed all along the southern margin, transitionally grade into marbles to the west. The basement rocks are overlain by sediments of either Cretaceous flysch, a Neogene sedimentary sequence or Quaternary alluvial deposits. Cretaceous f lysch crops out locally in the western part of the study area where a Neogene sedimentary sequence, characterised by a conglomerate–sandstone–mudstone alternation, is widely observed. Alluvial deposits are the most widely distributed geologic unit in the plain area (Figure 5).

The various geologic units cropping out in the basin were classified into hydrogeologic units based on their water-bearing potential and productivity of the wells tapping them (Sakiyan & Yazicigil, 2004). The lithological descriptions in the borehole logs were classified as alluvial fill, alluvial fan, Neogene units, marble and schist, considering the hydrogeological characteristics of the units. The General Directorate of the State Hydraulic Works (DSI, 1973) and the Bank of Municipalities conducted pumping and recovery tests on more than 300 wells that they had drilled. The results of these tests were evaluated by Yazicigil et al. (2000) and frequency distributions of well yields, specific capacity values and hydraulic conductivity values were analysed. In terms of water-bearing capacities, schist and gneiss units in the basement are regarded as impervious due to their low water storage, transmitting capacities and lack of significant fractures (Peksezer Sayit & Yazicigil, 2012). On the other hand, alluvial fan deposits and alluvium, which are characterised by high porosity and permeability, form a combined aquifer system of regional extent that has been tapped with numerous wells (Yazicigil et al., 2000). The alluvium aquifer is unconfined. Unconfined aquifers, especially shallow and surficial ones, are particularly sensitive to changes in climatic conditions and are at high risk from surface contamination (Lee, Lawrance, & Price, 2006). Water levels in unconfined aquifers are susceptible to changes in key climate variables (De Vries & Simmers, 2002). Global changes in temperature and precipitation will influence groundwater recharge to aquifers, causing shifts in water table levels in unconfined aquifers representing a first response to climate trends (Changnon, Huff, & Hsu, 1988; Zektser & Loaiciga, 1993).

3. Hydrometeorological assessment

It is important to consider the impacts of climate change on groundwater systems for the sustainable management

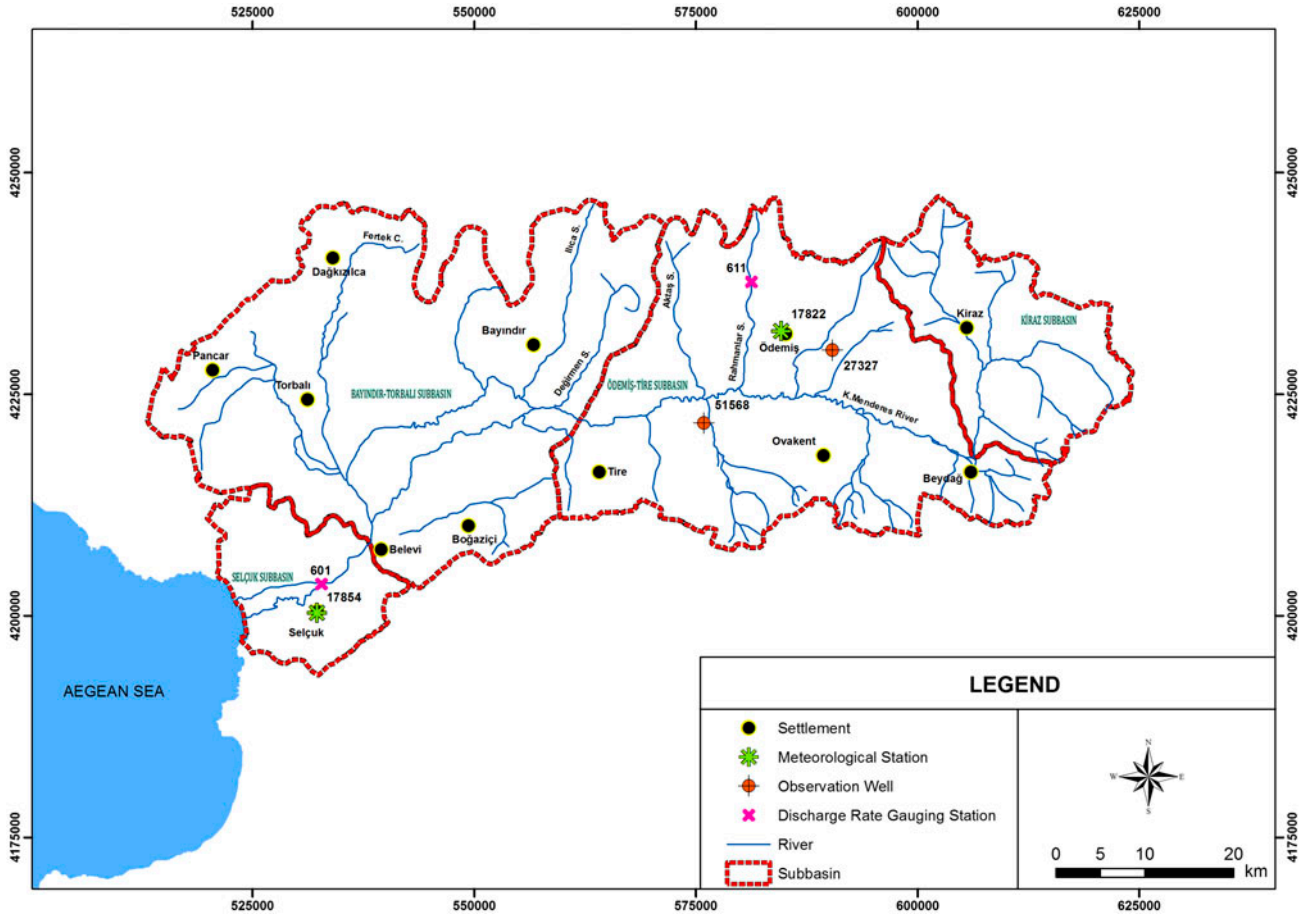

Figure 3. Drainage map of the Küçük Menderes River Basin.

of water resources. As part of the hydrologic cycle, it can be stated that groundwater systems will be affected by changes in recharge (which encompasses changes in precipitation, temperature and evapotranspiration), potentially by changes in the nature of interactions between groundwater and surface water systems. Variations in precipitation and temperature determine the amount of water that reaches the surface, evaporates or transpires back to the atmosphere, stored as snow or ice, and infiltrates back into the groundwater system, running off the land, and ultimately becoming baseflow to streams and rivers (Allen, Mackie, & Wei, 2004).The principle focus of climate change investigations with regard to groundwater should be on quantifying the direct impacts of changing precipitation, temperature and evaporation trends. The data of the Ödemiş (no: 17822) and Selçuk (no: 17854) meteorological stations (Figure 3) located in the basin were utilised to identify the long-term variation in precipitation, temperature and evaporation between 1964 and 2011.

3.1. *Precipitation*

There is a direct influence of climate change on variations in precipitation. Increased global temperatures lead to greater evaporation and thus surface drying, thereby increasing intensity and duration of drought. Understanding the profound consequences of climate change on precipitation trends in the long term is important for groundwater management studies. Thus, although there are several meteorological stations in the basin, only Ödemiş and Selçuk meteorological stations have the long-term data for the analyses of the trends. The annual precipitation, the cumulative deviation from mean annual precipitation and the long-term trend for these stations are shown in Figures 6 and 7. Both figures in general show a wet period between 1964 and 1981 and a dry period between 1981 and 1995. However, the long-term trends for both stations show significant decreasing trends in precipitation over a 50-year period (1964–2013) (Figures 6 and 7).

3.2. *Temperature*

Temperature is a direct expression of the energy balance of the Earth, which powers weather and surface circulation, and ultimately defines climate. Long and accurate records of surface temperature are vital to indicate the climatic trends. The relative phasing of temperature versus forcing mechanisms reveals the response time of

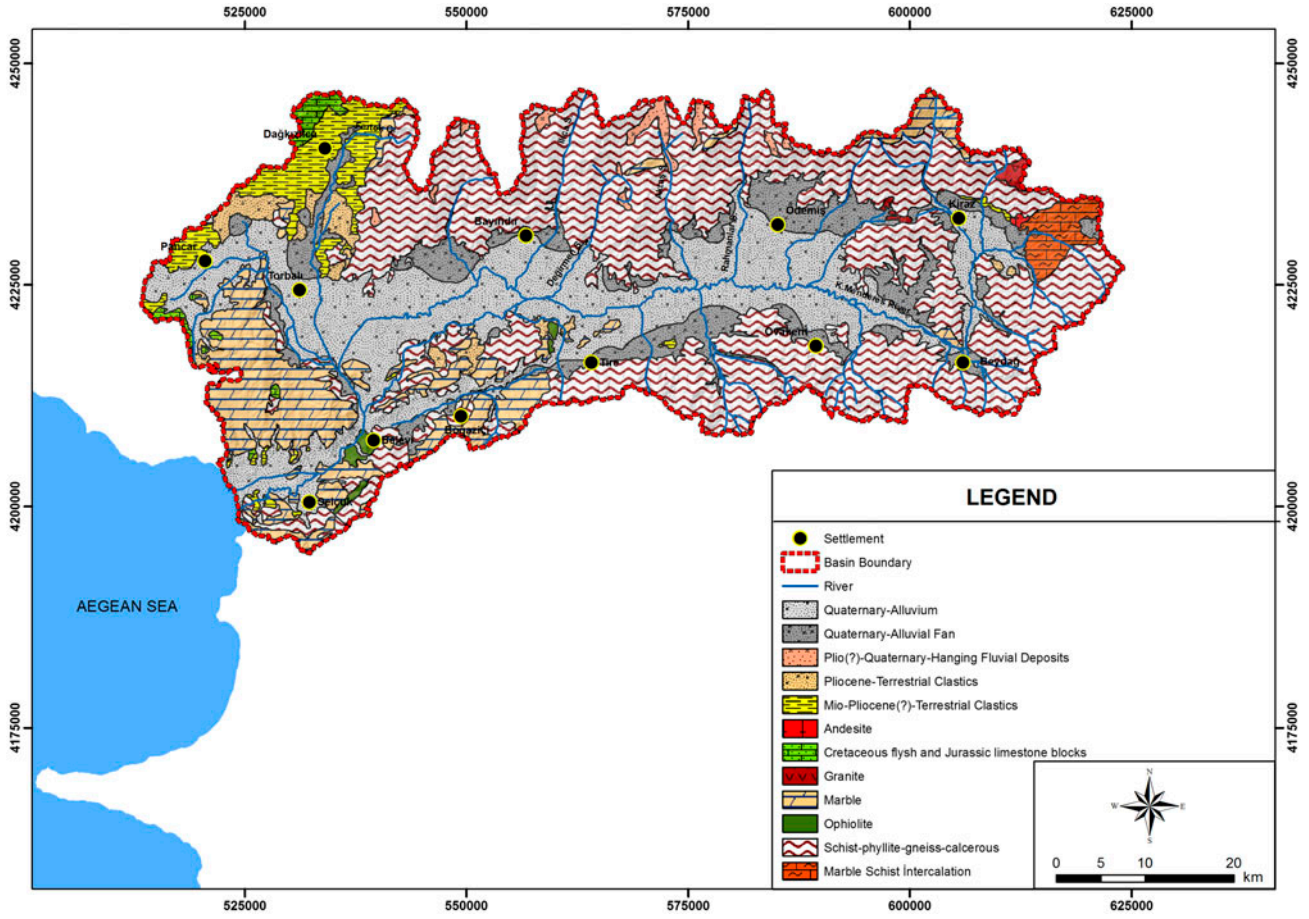

Figure 4. Geological map of the Küçük Menderes River Basin (Yazicigil et al., 2000).

climate change. According to the data of Ödemiş and Selçuk meteorological stations located in the Küçük Menderes River Basin, significant increasing trends in temperature were observed especially after 1970s (Figures 8 and 9).

3.3. *Evaporation*

Hydrological impact assessments require information on changes in evapotranspiration because it is one of the key components of the water balance. In order to calculate the unmeasured evaporation rates of the meteorological stations, the correlations generated between measured average temperature and evaporation were used. According to the data of the Ödemiş and Selçuk meteorological stations located in the basin, significant increasing trends in evaporation were observed in 1964–2011 (Figures 10 and 11).

4. Groundwater recharge

Understanding the process of groundwater recharge is essential for the management of groundwater resources. Quantifying the impact of climate change on groundwater resources requires not only changes in the major climatic variables, but also accurate estimation of groundwater recharge (Jyrkama & Sykes, 2007). Groundwater recharge is defined as the fraction of total precipitation falling into a drainage basin, which eventually reaches the water table in the saturation zone of an aquifer (Jukić & Jukić, 2004). The fraction of precipitation that reaches the phreatic zone in an aquifer depends upon several factors including climate, soil, vegetation and topography (Moon, Woo, & Lee, 2004). Groundwater recharge is a fundamental component of groundwater systems (Sanford, 2002), because information on groundwater recharge rates is essential for integrated water resources management, inputs to groundwater models and predictions of climate change impacts (De Silva & Rushton, 2007). Thus, groundwater recharge is an important hydrological parameter, which may need to be estimated at spatial and temporal scales depending on the investigation. The calculation of groundwater recharge and its accurate estimation is vital for the sustainable management of the water resources (Healy, 2010). Assessment of the impacts of climate change on groundwater resources also requires an approach for estimating groundwater recharge.

Spatial and temporal distribution of recharge from precipitation and surface run-off into the Küçük

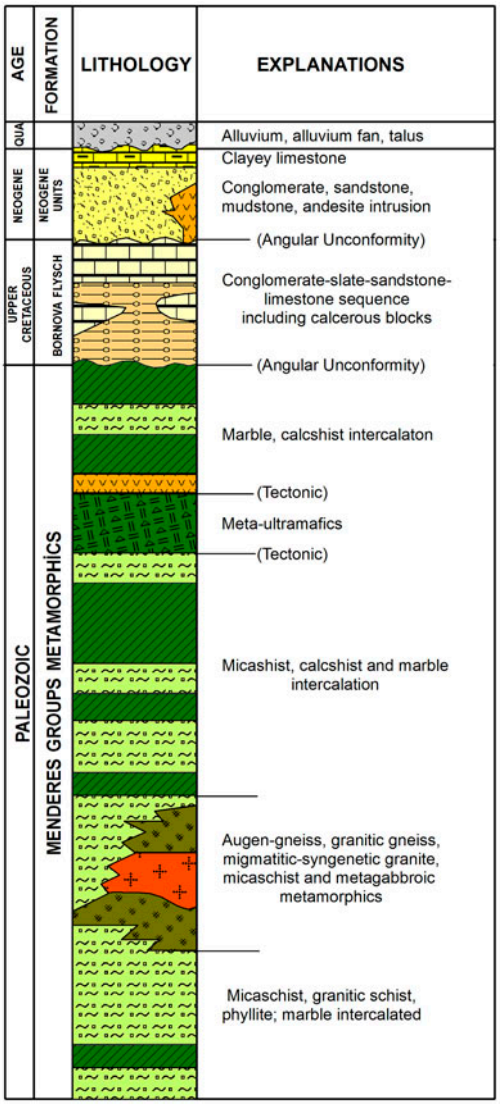

Figure 5. Generalised columnar section of the Küçük Menderes River Basin (Yazicigil et al., 2000).

Menderes River Basin aquifer system was quantified by conducting a hydrologic simulation. In this method, it is presumed that rainfall, in excess of evapotranspiration losses, is utilised in bringing the soil moisture to its field capacity with the remainder available for groundwater recharge and surface run-off. The hydrologic budget can be stated as:

$$P = Q + \mathrm{ET} + R + \Delta S$$

where P = precipitation, Q = surface run-off, ET = evapotranspiration, R = groundwater recharge and ΔS is change in soil water storage. The analysis for identification of groundwater recharge was carried out for the plain area in the Ödemiş-Tire and Selçuk sub-basins, separately. The analysis covered 48 years from 1964 to 2011, tracing monthly changes in soil moisture using the precipitation and evapotranspiration data of the Ödemiş and Selçuk meteorological stations and excess water from effective rainfall in plain areas. The results of the analysis for Ödemiş-Tire and Selçuk sub-basins demonstrated an approximately 15% decline in groundwater recharge in the basin (Figures 12 and 13). The examination of both figures shows significantly low groundwater recharge amount between 1985 and 1992 which corresponds to prolonged severe drought that lasted during this time period (see Figures 6 and 7).

The analysis of the trends of precipitation on the yearly flow of the Küçük Menderes River (discharge rate gauging station no: 601 in Figure 3) and calculated groundwater recharge was performed using the 5-year moving averages method, emphasising the impact of the climate on groundwater resources. Groundwater recharge and river flow rates showed a decreasing trend greater than the annual precipitation rates' of Selçuk Meteorological Station (Figure 14). The Küçük Menderes River's 5-year moving average annual base flow rates also indicated a decreasing trend, most likely caused by the extended drought observed in 1981–1995 (Figures 6 and 7), decreased groundwater recharge and overexploitation of the aquifer system (Figure 15). As pointed out by Yilmaz and Yazicigil (2011), the overexploitation of groundwater resources in the basin initiated in the early 1980s caused significant declines in water table depth, making deeper wells necessary. However, the average well yields declined in response to increase in well depths. It is expected that as the climate becomes drier the water tables will continue to drop in response to both decrease in recharge and increase in dependence on groundwater due to reduced surface waters. Thus, due to the combined effect of all these factors, the Küçük Menderes River changed its status from gaining into losing over the period 1964 to 2011 with significant impacts on the river's ecosystem. In addition to these impacts, the already existing seawater intrusion problem (Camur & Yazicigil, 2005) along the coastal part of the basin will be exacerbated as a result of predicted sea-level rise and increased groundwater extraction, causing further deterioration in groundwater quality along the coastal part.

5. Groundwater consumption

The Küçük Menderes River Basin has been facing a continuous groundwater level decline for decades. Almost all of the plain area in the Küçük Menderes River Basin is used for agricultural purposes. In the basin, most of the groundwater is used for the irrigation of crops in the summer season when the Küçük Menderes River and its tributaries are mostly dry. In addition to the wells drilled by government agencies, private wells play a major role in the over-utilisation of groundwater in the basin (Sakiyan & Yazicigil, 2004). It is estimated that there are more than 40,000 private wells in the plain area, only half of which are registered. These wells are mostly utilised for irrigation purposes. Unfortunately, the groundwater consumption in the basin is neither measured nor estimated on a regular basis. Yazicigil et al. (2000) estimated that the initiation of over-utilisation of

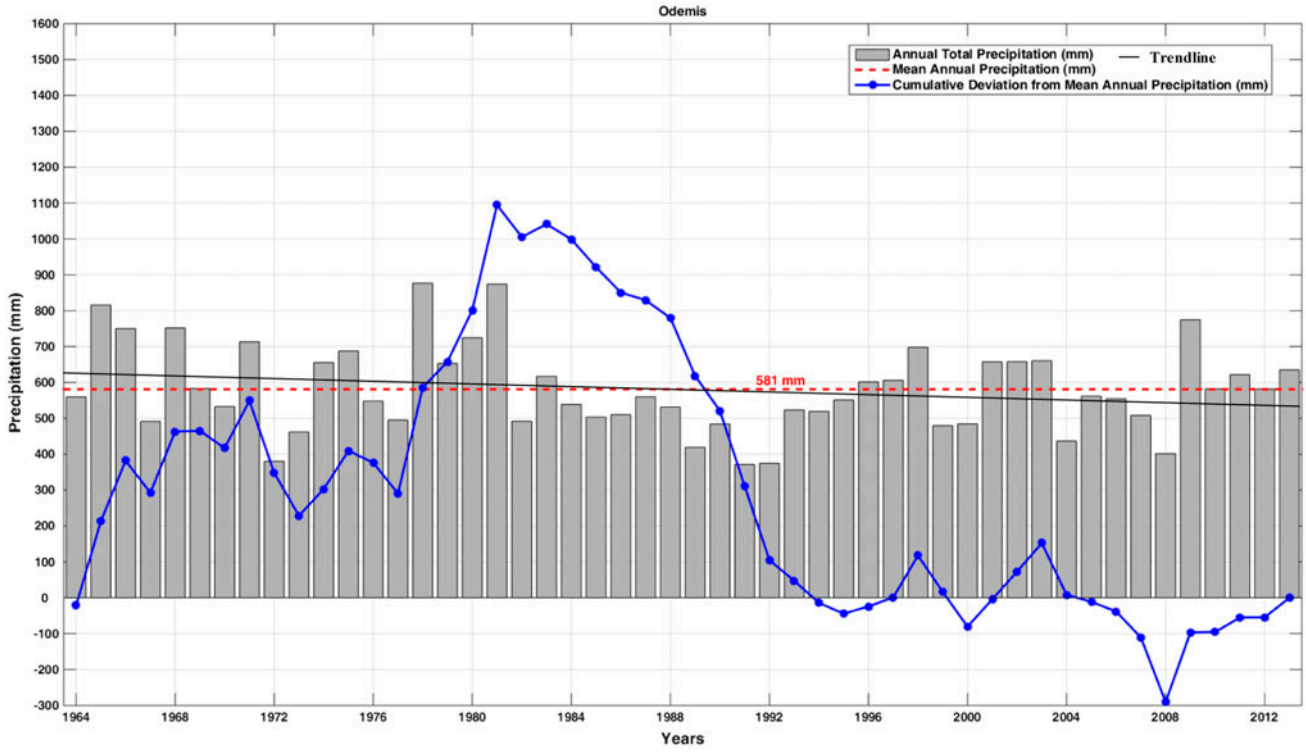

Figure 6. Variation of annual precipitation, the cumulative deviation from mean annual precipitation and the long-term trend at Ödemiş meteorological station (1964–2013).

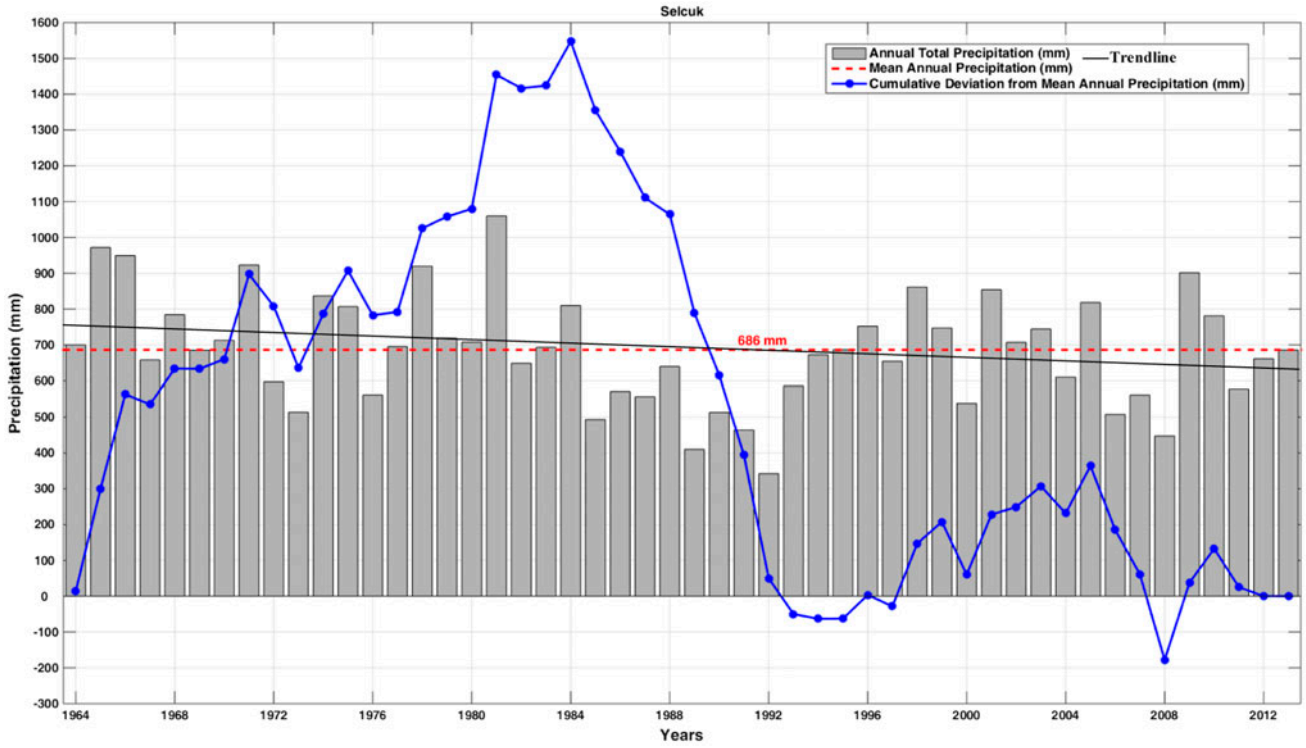

Figure 7. Variation of annual precipitation, the cumulative deviation from mean annual precipitation and the long-term trend at Selçuk meteorological station (1964–2013).

groundwater resources in the basin began in the early 1980s. According to their estimates, the groundwater pumped for irrigation in the basin increased from 88.7 Mm^3/year in 1974 to 237.2 Mm^3/year in 1998

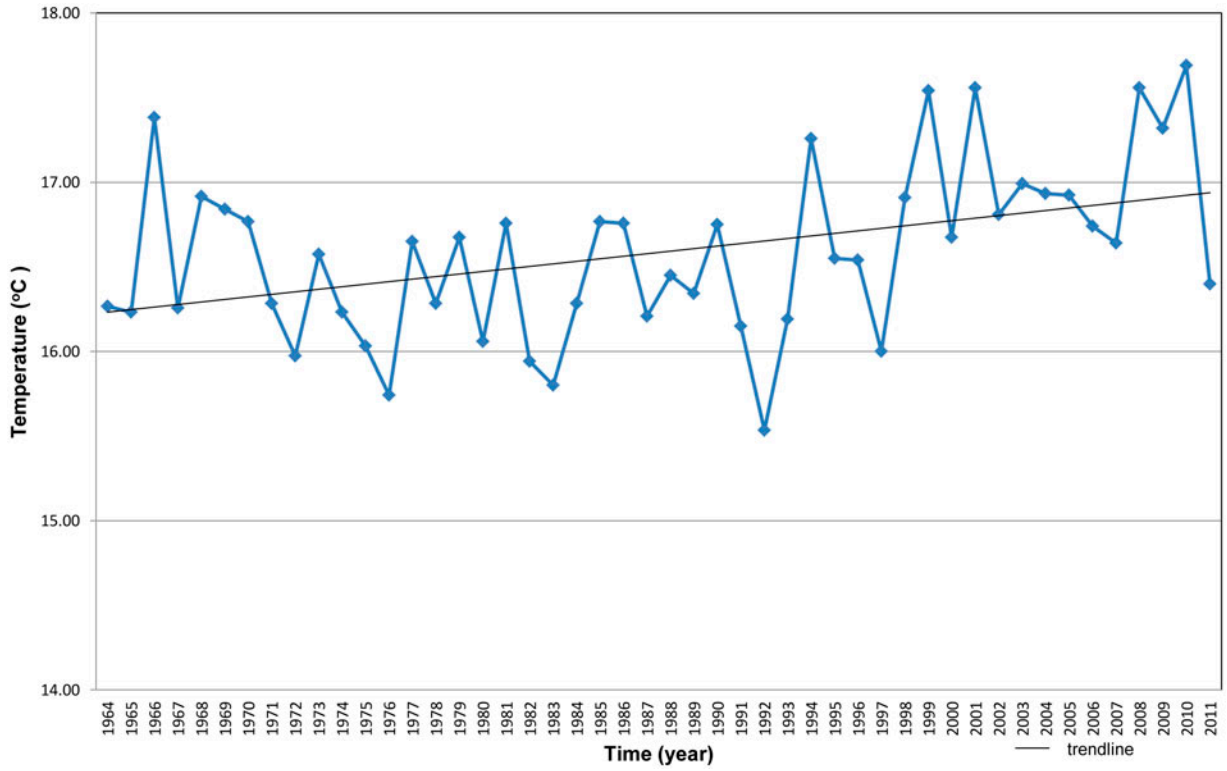

Figure 8. Variation of average annual temperature at Ödemiş meteorological station (1964–2011) with long-term trendline.

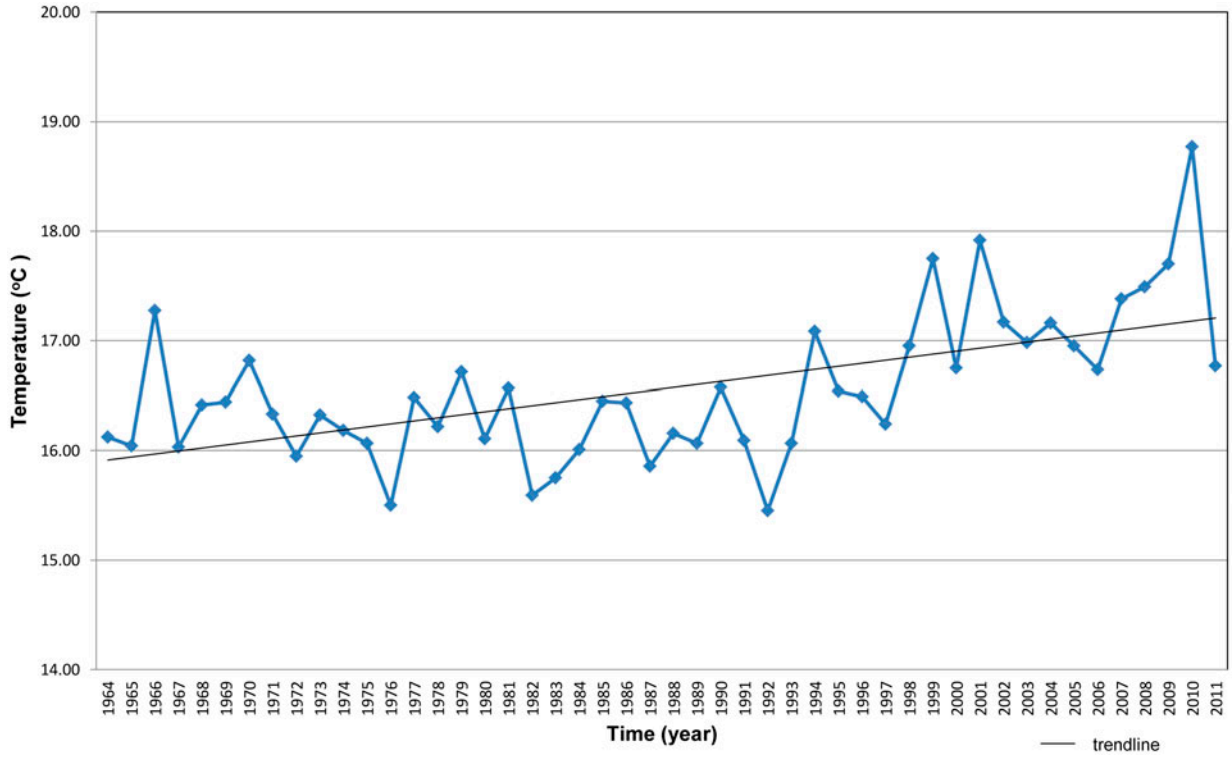

Figure 9. Variation of average annual temperature at Selçuk meteorological station (1964–2011) with long-term trendline.

during which irrigated area increased from 15,820 hectares to 42,335 hectares. The groundwater pumped for drinking and domestic use as well as industrial use constitute only a small portion (about 13.2%) of the total

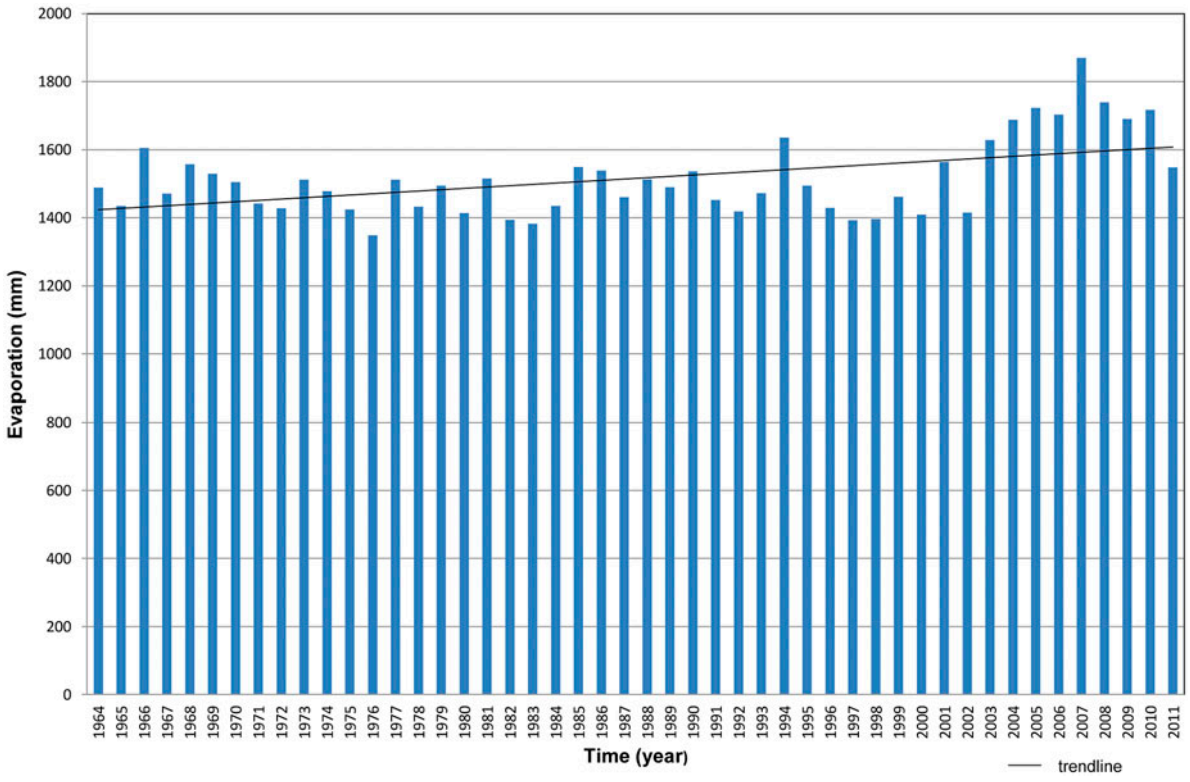

Figure 10. Variation of annual evaporation at Ödemiş meteorological station (1964–2011) with long-term trendline.

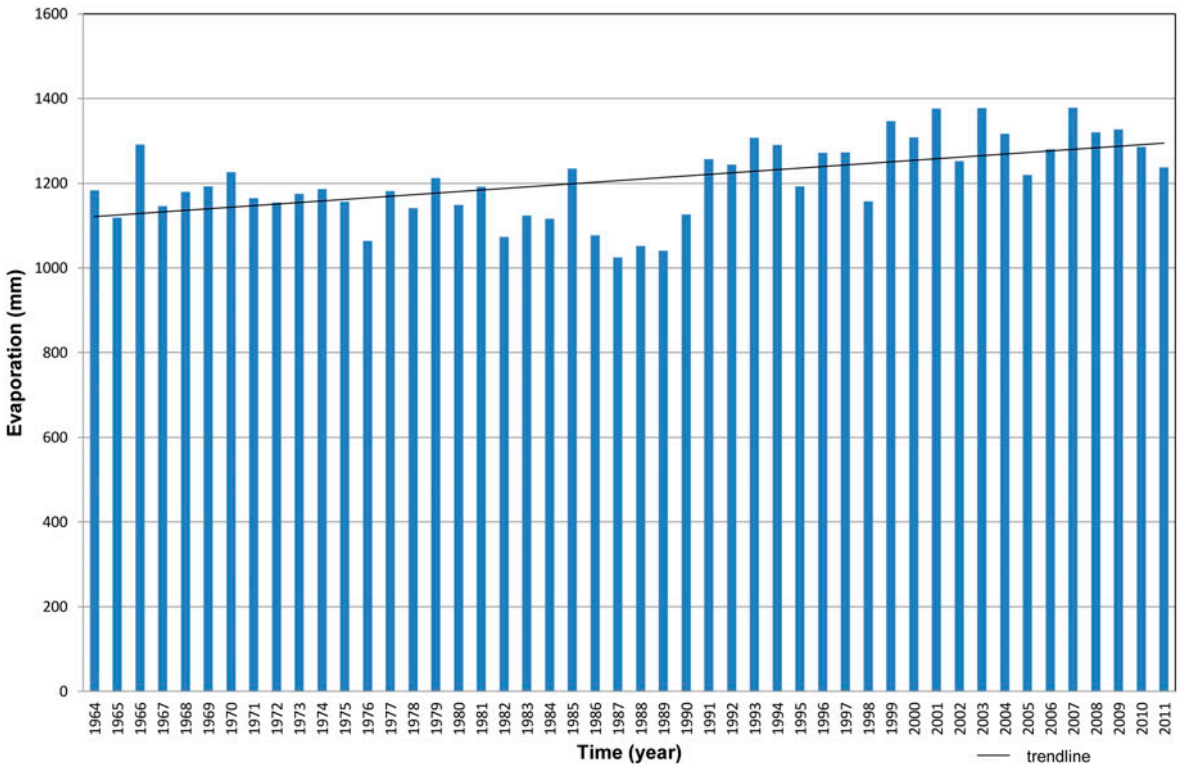

Figure 11. Variation of annual evaporation at Selçuk meteorological station (1964–2011) with long-term trendline.

water use which was estimated to be 273.3 Mm^3/year in 1998. Although a regulation (Regulation No. 27957 printed in Official Gazette dated 07.06.2011) which enforces each farmer to install water metres on their

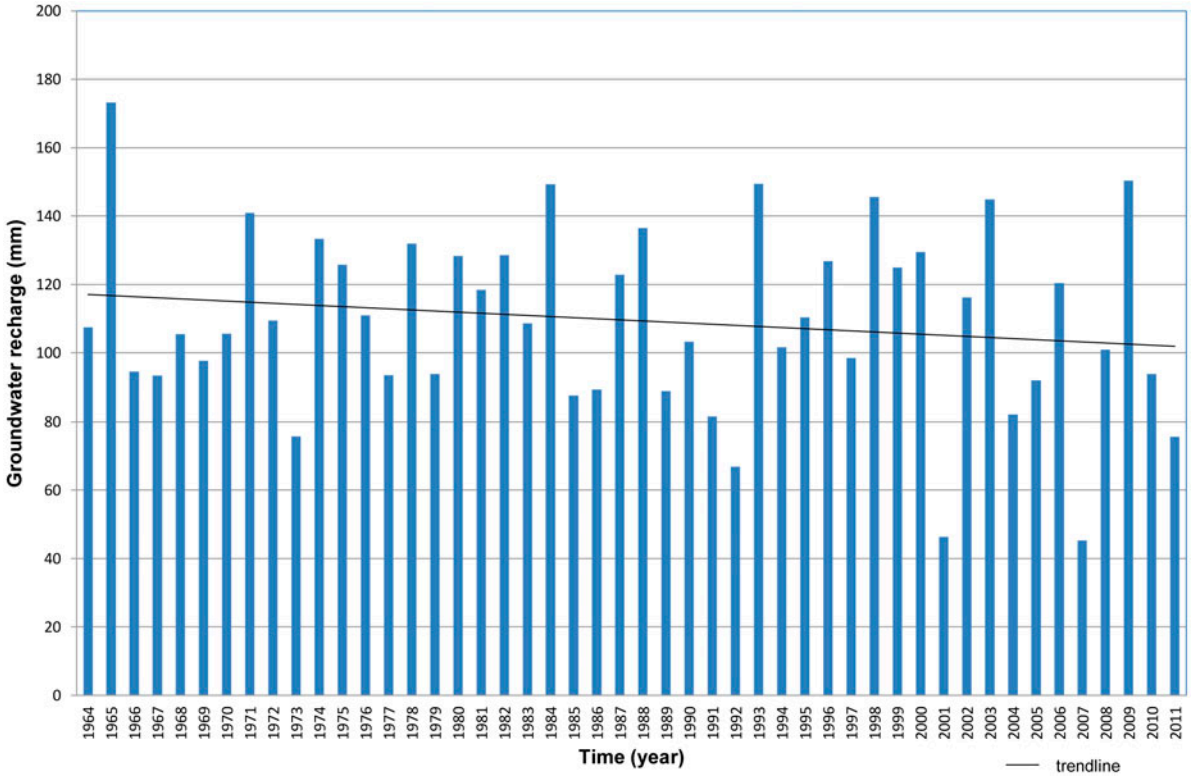

Figure 12. Variation of annual groundwater recharge calculated for Ödemiş-Tire sub-basin (1964–2011) with long-term trendline.

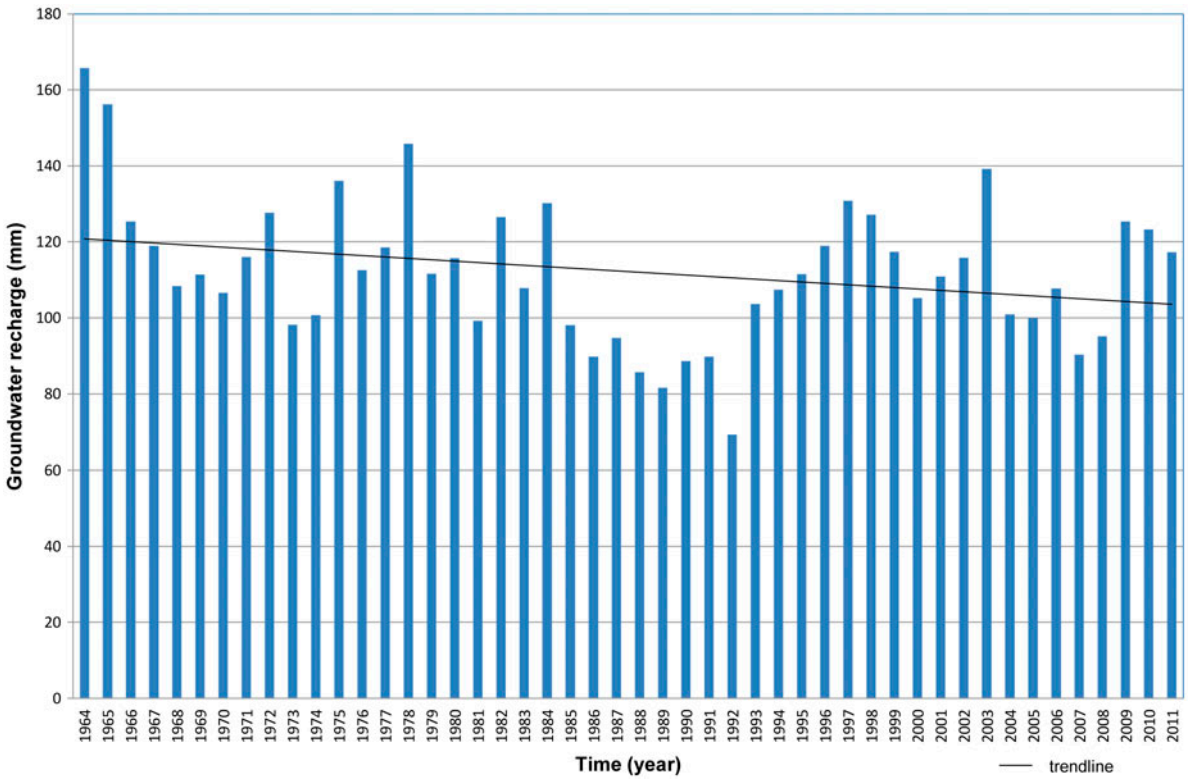

Figure 13. Variation of annual groundwater recharge calculated for Selçuk sub-basin (1964–2011) with long-term trendline.

wells was issued by the Ministry of Forest and Water, except for the industrial use, the application of the regulation was postponed until April 2016. Currently, it is not known for certainty how much groundwater is

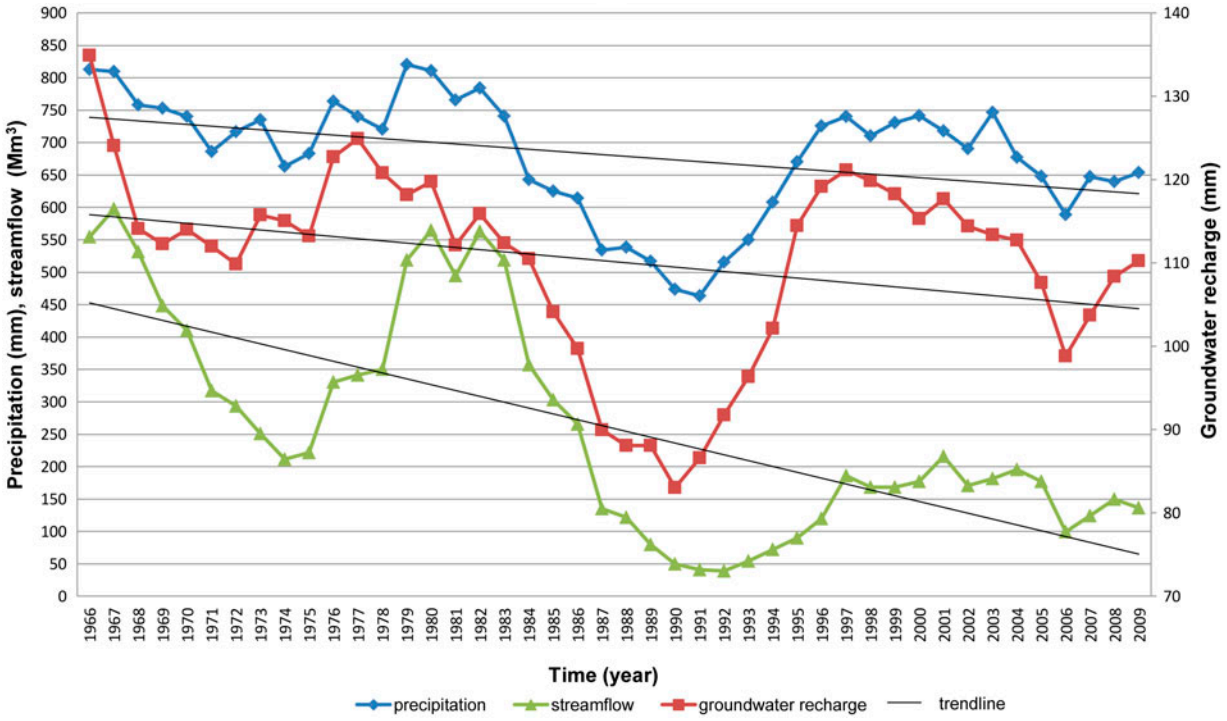

Figure 14. 5-year moving averages graph of annual precipitation (Selçuk Meteorological Station), yearly streamflow and annual groundwater recharge with long-term trendlines.

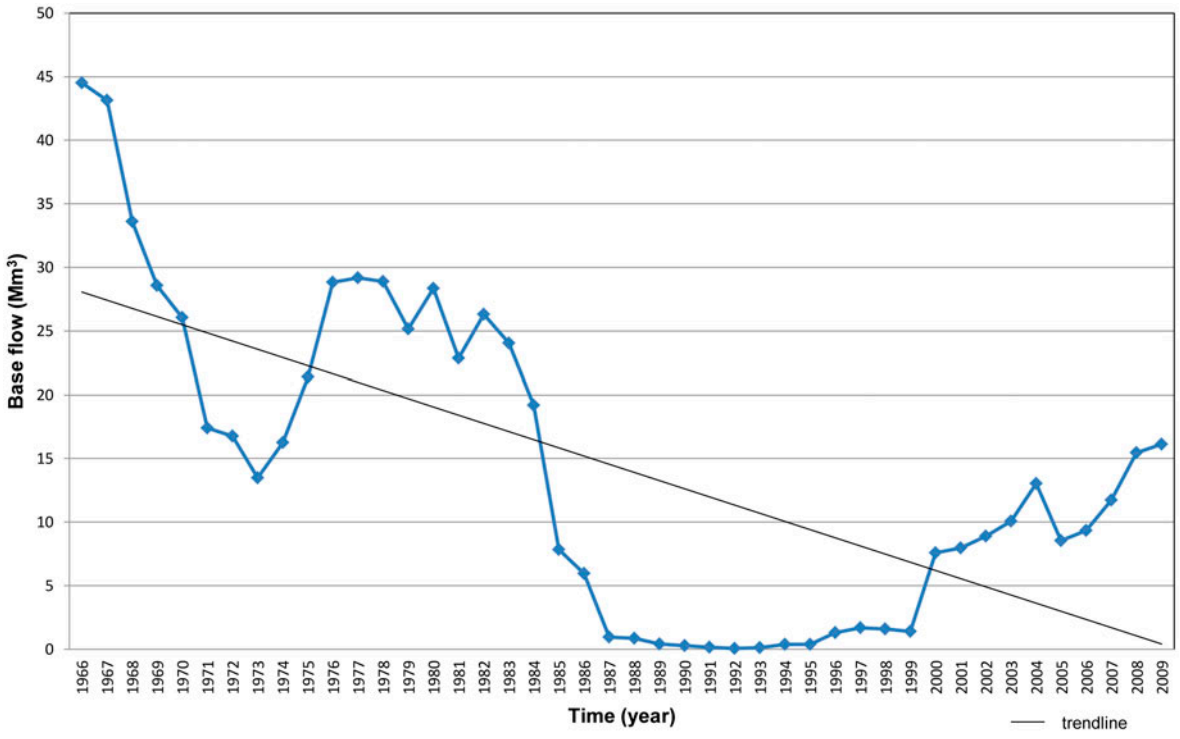

Figure 15. 5-year moving averages graph of the Küçük Menderes River's annual base flow with long-term trendline.

extracted from the basin, but an estimation can be made using the land use capability maps suitable for irrigation and plant water needs, current population and per capita water use and industrial water use. The estimations show that currently 335.6 Mm^3/year of groundwater is extracted from the basin, of which 279.5 Mm^3/year is pumped for irrigating 55,900 hectares, 35.1 Mm^3/year is used for drinking and domestic needs of about

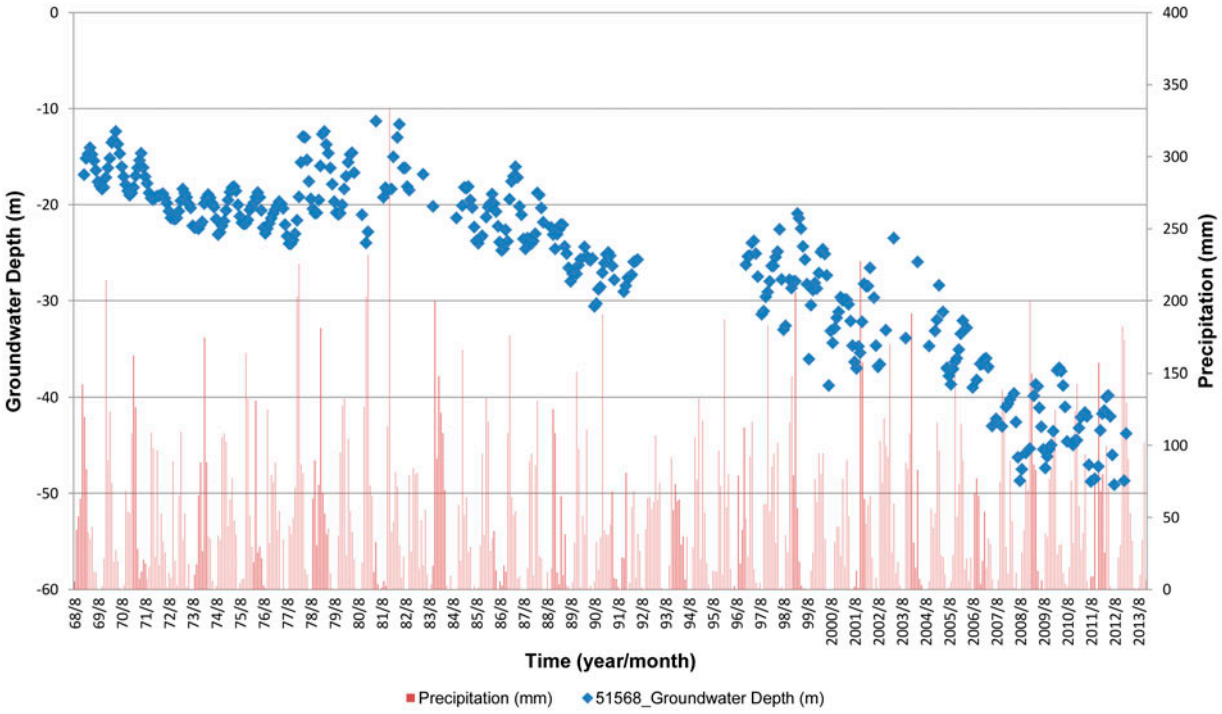

Figure 16. Groundwater depth versus precipitation versus time graph of monitoring well No. 51568.

450,000 people in the basin and 21 Mm^3/year is consumed by the industry. As a result of over-pumping in the basin, significant declines in groundwater levels were observed along the southern and northern margins of the plain with values ranging between 30 and 40 m, followed by smaller declines towards the centre with values ranging between 10 and 15 m (Sakiyan & Yazicigil, 2004).

The combined effect of the long-term declining trend in precipitation and over-pumping of the groundwater

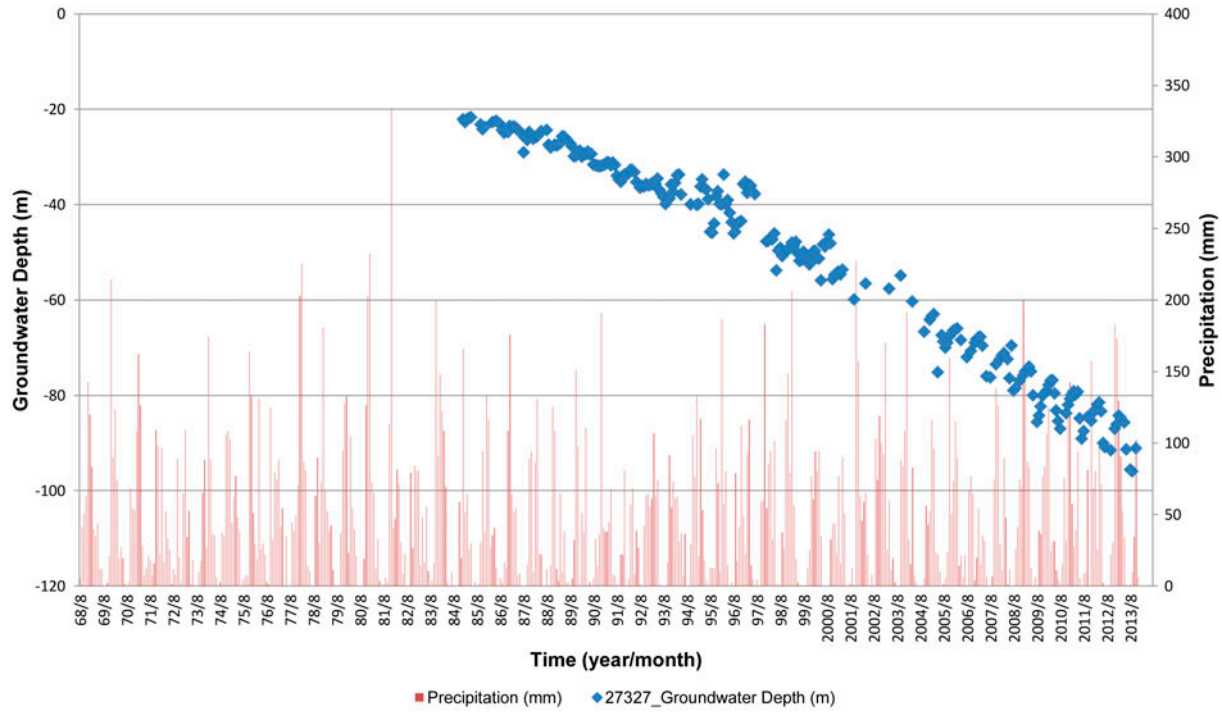

Figure 17. Groundwater depth versus precipitation versus time graph of monitoring well No. 27327.

directly influenced groundwater resources in the basin. The groundwater levels in monitoring wells declined noticeably after 1981 in conjunction with the drought observed between 1981 and 1995 and increased pumping of the groundwater since early 1980s (Figures 16 and 17). It is difficult to separate the individual impacts of declining precipitation and over-pumping of groundwater from these graphs, but the examination of both graphs shows a more rapid decline in groundwater levels after 2001 during which precipitation did not change significantly. This could be attributed to the over extraction of the groundwater system. Thus, the groundwater extracted for various purposes should be measured in order to develop sustainable groundwater management policies for the basin. Hence, the enforcement of the regulation number 27957 article 5 requiring the installation of water metres on each well should not be postponed any further.

6. Conclusions

The consequences of climate change on groundwater recharge in the Küçük Menderes River Basin in western Turkey, based on precipitation, temperature and evaporation data from the past 48 years (1964–2011) were investigated. The analysis of precipitation in the Küçük Menderes River Basin showed a decreasing trend. However, analysis of temperature and evaporation time series revealed that the temperature and evaporation exhibited increasing trends during the study period. Under natural conditions, long-term trends depend on net groundwater recharge, which is a function of total precipitation, temperature and evapotranspiration. The results of the hydrologic simulation of the Ödemiş-Tire and Selçuk sub-basins for the observation period demonstrated an approximately 15% decline in groundwater recharge of the unconfined alluvium aquifer, one of the largest freshwater aquifers in Turkey.

Predicting the impacts of climate change, effective mitigation and developing adaptation strategies is essential for ensuring sustainable groundwater management. The driving force for climate change is the emission of greenhouse gases. Thus, greater efforts in mitigating climate change should be undertaken to reduce emissions and to develop new technologies. Groundwater needs to be protected, and its use and maintenance adapted to climate change. A very important alternative or supplement to the preservation or restoration of natural infiltration conditions is artificial groundwater recharge. The potential for artificial aquifer recharge in the Küçük Menderes River Basin, as assessed by Peksezer Sayit and Yazicigil (2012), is significant and possibly the most viable approach to mitigate the negative impacts of overdraft.

Besides the direct impacts of climate change on the natural processes of the global hydrological cycle, it is crucial to also consider the indirect impacts. The management of groundwater resources under the coupled pressures of climate change and human activity is an important task that must be considered. Effective, long-term adaptation to climate change and hydrologic variability requires measures which protect groundwater recharge and manage water demand. Adaptation needs to be informed by an understanding of the local dynamics and dominant drivers on groundwater resources in future. Adaptations are essentially management responses to risks associated with climate variability and climate change. Adaptations to climate change and variability must also complement adaptations to non-climate pressures that may affect the hydrologic system.

Since agricultural sector is the main user of water in the basin, further investigations for the possibility of switching to more efficient irrigation methods and to less water demanding crops are recommended in conjunction with the installation of water metres on individual wells. Decision-makers should develop an early warning system that monitors changing climatic conditions and triggers contingency plans at the first sign of water shortage, offering water managers and farmers the best chances of avoiding crop failure. Efficient water use must be the main objective in agriculture, and the cultivation of drought resistant plants is suggested. Rainwater harvesting should be increased by catching run-off in basins or by infiltration wells. Water resources managers and politicians should notice the important role of groundwater resources in meeting the demands for agricultural and industrial activities, domestic uses and sustainable ecosystems, as well as in the adaptation to and mitigation of the impacts of climate change coupled with human activity.

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Disclosure statement

No potential conflict of interest was reported by the author.

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