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ORIGINAL ARTICLE

Impacts of climatic variables on water-level variations in two shallow Eastern Mediterranean lakes

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Abstract Variations in temperature and precipitation have direct impacts on the physical, chemical and biological characteristics of the shallow lakes. This paper examines the possible linkages between climate variables and the water levels of shallow interconnected Lakes Mogan and Eymir, located 20 km south of Ankara in Central Anatolia. The variations in the lakes' water levels during 1996–2015 are studied and the impacts of climate variables on the lake levels are assessed to address the long-term consequences. The nonparametric Mann–Kendall test was used to quantify trends in the climate variables and the lakes' level fluctuations between the observation periods 1998–2007 and 2008–2014. Statistical analyses results showed that precipitation and temperature have crucial influence on the variations in the lakes' levels. The projected increase in temperature and decrease in precipitation over the next century may produce substantial decreases in lake levels, with consequent drying of both lakes.

Keywords Climate change · Lake levels · Lakes Mogan and Eymir · Mann–Kendall test

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Introduction

In recent years, the potential impacts of climate change on hydrological cycle and water resources in vulnerable regions have been of interest to many researchers (Chenoweth et al. 2011). The Mediterranean basin is considered to be a global "hot spot" in terms of climate variability and change, as well as in the rate of land transformation processes (Giorgi 2006). His analysis indicates that Turkey is more vulnerable to socio-economic affects than the other Mediterranean countries, especially the expected rapid increase in future population is likely to accelerate the changes in climate. The latest and most advanced sets of global and regional climate model simulations give a collective picture of a substantial drying and warming of the Mediterranean region, especially in the warm season (Giorgi and Lionello 2008).

One of the greatest potential impacts of climate change on human society is through its effect on water resources. The Mediterranean is already a region, experiencing moderate to high water stresses, and climate change has the potential to exacerbate further these stresses. Coupled with climate change impacts, the increase in demand for freshwater due to population growth and economic development puts an additional stress on water resources, reducing the availability of freshwater.

There is a general consensus that global average surface air temperature increased during the twentieth century, and although there is great uncertainty about the magnitude of future increases, most assessments indicate that future warming is "very likely". Freshwater ecosystems and their biodiversity are presently seriously threatened by climate change (Bellard et al. 2012). Lakes are particularly sensitive to variations in climatic parameters. Alterations in air temperature, wind and precipitation directly cause

variations in evaporation, water balance, lake level, ice events, hydrochemical and hydrobiological regimes and entire lake ecosystems. As there is a strong linkage between climate and the hydrological cycle, climate change can also enhance drought with strong implications for water levels. Lakes offer a unique opportunity to detect climate-driven variations (Zhao et al. 2017).

The lake levels are known to be sensitive indicators of changes in climate, and they can play an important role in monitoring current and future climatic changes (Tan et al. 2017). Hence, a study of variations in lake levels and their relation to measured climate variables is crucial not only to understand and monitor the impacts of climate change but also to analyse the impacts on the associated ecosystems (Zhang et al. 2015; Bohn et al. 2016). Shallow lakes are most vulnerable to the impacts of the climate change, especially in arid and semi-arid regions in eastern Mediterranean. The two interconnected shallow lakes located in Central Anatolia suffered significant water-level fluctuations with consequent impacts on eutrophication and expansion of macrophytes. Although twenty years of biological monitoring has been conducted to analyse the impacts of water-level fluctuations on lakes' ecosystem structures as well as on restoration efforts (Beklioğlu et al. 2017), no study has been undertaken to analyse the potential impacts of climatic variables on water-level fluctuations. This paper stems from this point of view and analyses the causes and hydrological consequences of the variations in the water levels of these two shallow inter-connected Lakes Mogan and Eymir, located 20 km south of Ankara in Central Anatolia (Fig. 1).

One of the commonly used tools for detecting changes in climate, hydrology, water quality and other natural time series is trend analysis. Although there are several tests used to assess the significance of trends in time series, the nonparametric Mann–Kendall (Mann 1945; Kendall 1975) test is the most commonly used. The Mann–Kendal test is used for detecting trends in precipitation (Partal and Kahya 2006), temperature (Safari 2012), streamflows (Kahya and Kalaycı 2004), water quality (Zhang et al. 2017), lake levels (Belete et al. 2017) and number of frost days (Erlat and Türkeş 2011). In this study, the nonparametric Mann–Kendall test was used to detect trends in the climate variables and the lakes' level variation to raise awareness for the water authorities responsible for the management of both lakes.

Lakes Mogan and Eymir are important aesthetic, recreational and ecological resources for the city of Ankara and the town of Gölbaşı. Although both lakes and their surroundings mainly fulfil urban housing and recreational needs, the wildlife and biodiversity values of the lakes are high. These lakes, especially Lake Mogan, have wetlands housing to more than 26 mammal species and 231 bird species, of which 76 are breeding. Both lakes are designated as "Specially Protected Areas", and Lake Mogan has been declared an "Important Bird Area" by the Ministry of Environment and Urbanization (Beklioğlu et al. 2017). Because of their values, there is a growing concern about the possible impacts of climate change on the long-term sustainability of these lakes. Thus, the ultimate aim of the paper is to stimulate the interdisciplinary monitoring and cooperation between hydrogeologists, hydrologists, ecologists, water resources managers, etc., which would provide better protection and management of vulnerable and exceptionally valuable Lakes Mogan and Eymir and their aquatic and terrestrial ecosystems.

Description of the study area

Lakes Mogan and Eymir, being located in a closer distance to the metropolitan city of Ankara, mainly serve for recreational purposes for a population of about 4 million people living in Ankara. Upstream Lake Mogan has a surface area of 5.6–8 km^2 and an average depth of 2.4 m. The catchment covers an area of 985 km^2. There are no perennial rivers in the basin. The lakes are fed by several streams, but the majority of these are ephemeral in nature. In general, the basin has a very mild slope. The highest and lowest elevations in the basin are 1560 and 980 m, respectively. The elevation of 62% of the total area is between 1050 and 1250 m (Yagbasan and Yazicigil 2009).

The outflow of the Lake Mogan is regulated and is situated at the north end of the lake. It connects Lake Mogan with Lake Eymir through a canal and a wetland area. Downstream Lake Eymir is smaller than Lake Mogan and has a surface area of 1–1.3 km^2 and an average depth of 3.2 m. The wetland between two lakes and surroundings serve for housing for several different kinds of birds. Other than some limited fish stock in both lakes, they are not used for water supply purposes. The basin can be identified as a semi-arid region in terms of precipitation and as a steppe type in terms of vegetation (Yagbasan 2007). A significant portion (68%) of the catchment area of the lakes consists of agricultural land dominated by non-irrigated crops, mostly wheat. Intensive agricultural activities are among the most significant pressures threatening the water quality of the lakes (Beklioğlu et al. 2017; Özcan et al. 2017).

Analyses of variations in time series of climate variables

The climatological regime in the Lakes Mogan and Eymir basin is analysed with the data measured at Ankara meteorological station for the period 1980–2015. The Ankara
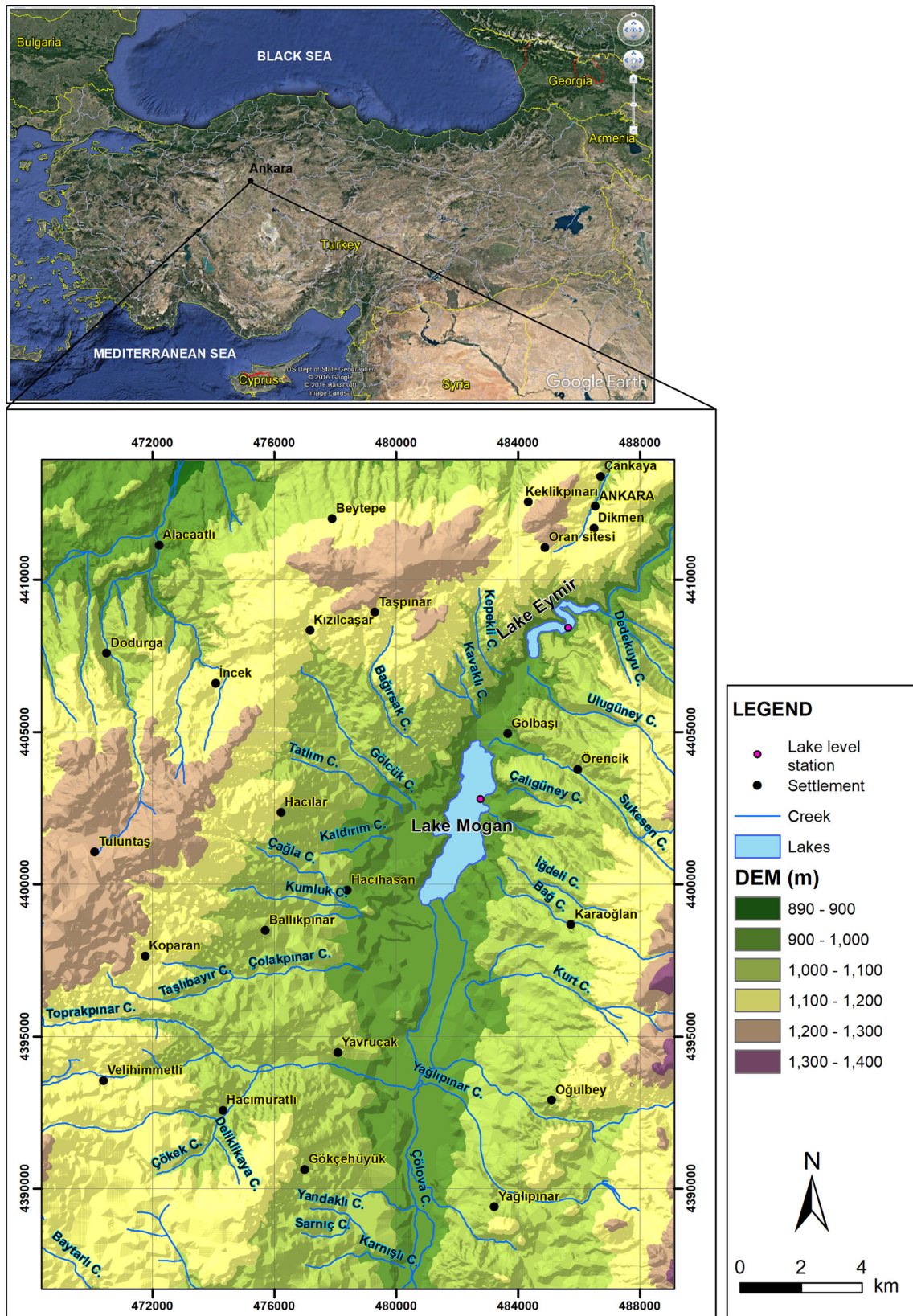
Fig. 1 The study area comprising the Lakes Mogan and Eymir catchment in Central Turkey

meteorological station is located 16 km away from the study area and has the long-term data availability. Precipitation and temperature were measured on a daily basis at the Ankara station. In the following, timewise variations in each of the climate variables and long-term trends have been analysed.
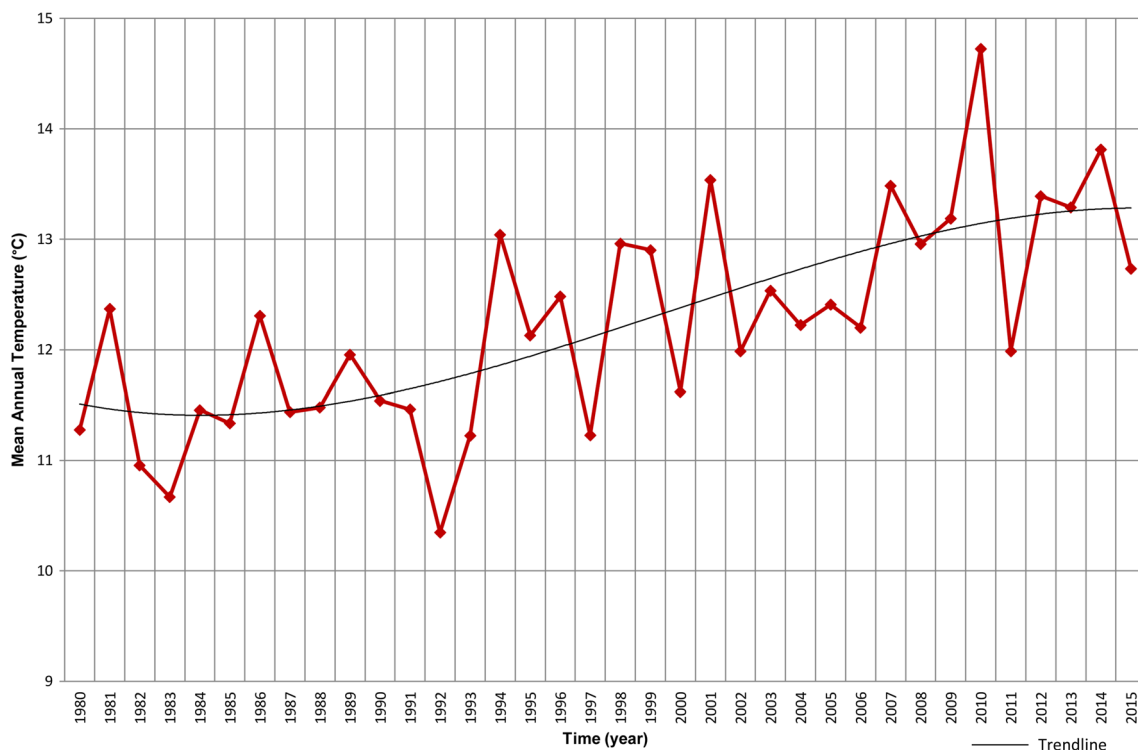
Temperature

According to the IPCC's (Intergovernmental Panel on Climate Change) SRES (Special Report on Emission Scenarios) high-emission A2 scenario simulation, the temperatures in Turkey are projected to increase between 1.0 and 2.5 °C by the mid-twenty-first century and between 2.5 and 5.0 °C by the end of the century (IPCC 2013). The changes are not uniformly distributed. Temperatures will increase ubiquitously in all seasons, but the increases will be higher in summer than in winter. Future temperature changes are projected as 1.5–2 and 3.5–4 °C for the hotspot city of Ankara for 2041–2071 and 2071–2099 periods, respectively (Şen 2013). Thus, temperatures are expected to be one of the most critical climate variables that will impact the hydrological regime of the basin in the future.

Figure 2 depicts a time series of mean annual temperature for the Ankara meteorological station for the 1980–2015 period with a fitted polynomial third order. The examination of the figure shows three distinct periods where the mean annual air temperatures either stayed

almost uniform or increased significantly. During the first period between 1980 and 1993, mean annual temperatures stayed almost uniform with an average value of 11.4 °C. The second period between 1994 and 2008 experienced a linear increase in mean annual air temperature from a value of about 11.4 °C in 1993 to a value of about 13.0 °C in 2008. The third period between 2009 and 2015 observed almost a uniform trend in mean annual temperatures with an average value of about 13.3 °C. The period between 1994 and 2008 during which the trend for mean annual temperatures almost increased linearly with a value of more than 1.5 °C had directly influenced the lakes' hydrological regimes with critically low lake levels. Considering the future predictions made by Şen (2013) for the Ankara region, it is obvious that these shallow lakes are expected to disappear due to expected significant increase in temperatures.

Precipitation

Precipitation is the main driver of the hydrological system over land. Therefore, any change in the long-term trends of precipitation will have direct impact on water resources, especially on lake levels. Recent climatic studies showed a decreasing precipitation trend in most of the eastern Mediterranean (Alpert et al. 2004). Many studies reported general decreasing precipitation trend over western and southern parts of Turkey that are dominated by the

Fig. 2 Variation of mean annual temperature at Ankara meteorological station (1980–2015) with long-term trendline

Mediterranean climate. Some researchers also indicated a decreasing precipitation trend in the south-eastern and north-western parts which are partly influenced by the Mediterranean climate (Partal and Kahya 2006; Turkes et al. 2009). In contrast, in northern parts along the Black Sea coast, precipitation trend has been in the increasing direction (Partal and Kahya 2006; Tayanc et al. 2009). The study area located in Central Turkey, however, did not experience either decreasing or increasing long-term trend in the past 35 years.
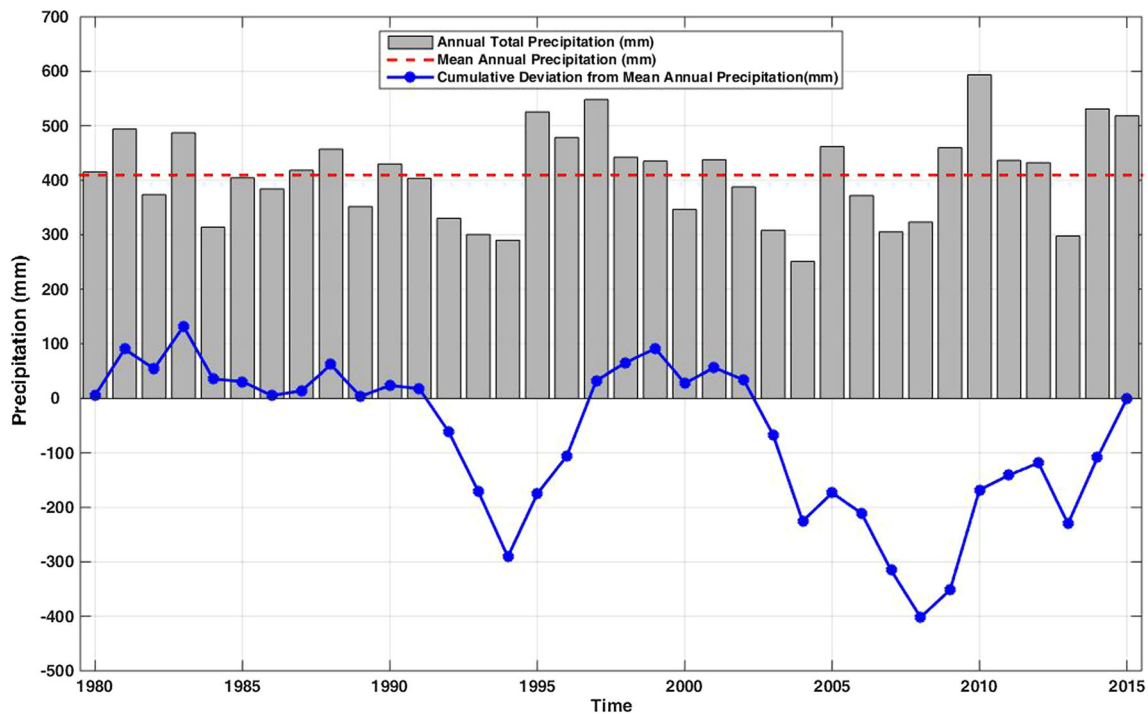
Figure 3 depicts annual precipitation, mean annual precipitation and cumulative deviation from mean annual precipitation calculated at Ankara meteorological station for the 1980–2015 period. The average annual precipitation measured at Ankara meteorological station for the period 1980–2015 was 410 mm. The examination of the figure displays three distinct periods where the trends of mean annual precipitations either decreased, increased or with no significant trend. The first period between 1980 and 1991 corresponds to the period when the annual precipitations did not change significantly from the long-term mean annual value. The mean annual precipitation measured during this period was 411 mm. The second trend constitutes a decreasing trend observed between 1991–1994 and 1999–2008. The mean of annual precipitations observed during these periods was 19.2% (79 mm/year) and 13.4% (55 mm/year) lower than the long-term mean annual precipitation of 410 mm, respectively. The increasing trends in the annual precipitation series were noted between 1995–1999 and 2009–2015. The mean of annual precipitations observed between 1995–1999 and 2009–2015 was, respectively, 18.5% (76 mm/year) and 13.9% (57 mm/year) greater than the long-term mean annual precipitation. The observed dry and wet periods corresponding to decreasing and increasing trends in annual precipitations in short-term had a significant impact on the observed lake levels (Figs. 4, 5).

Analyses of variations in lakes' levels

Shallow lakes in semi-arid and arid climate regions, including the Mediterranean, are subjected to large water-level fluctuations, on both a seasonal and an annual scale (Beklioğlu et al. 2007). Water levels in shallow lakes naturally fluctuate intra- and interannually depending on regional climatic conditions (Beklioğlu et al. 2001). Furthermore, the results of a groundwater–lake system mathematical model developed for the study area showed that very small, but long-term changes to temperature and precipitation have the potential to cause significant declines in lake levels and temporary drying of the lakes in the long term (Yagbasan and Yazicigil 2012).

The water levels of Lakes Mogan and Eymir were monitored by the Turkish General Directorate of Electrical and Survey Works (EIEI) until 2010 at monthly intervals in two stations, the locations of which are shown in Fig. 1. After 2011, the hydrological monitoring was transferred to

Fig. 3 Annual precipitation, mean annual precipitation and cumulative deviation from mean annual precipitation for 1980–2015
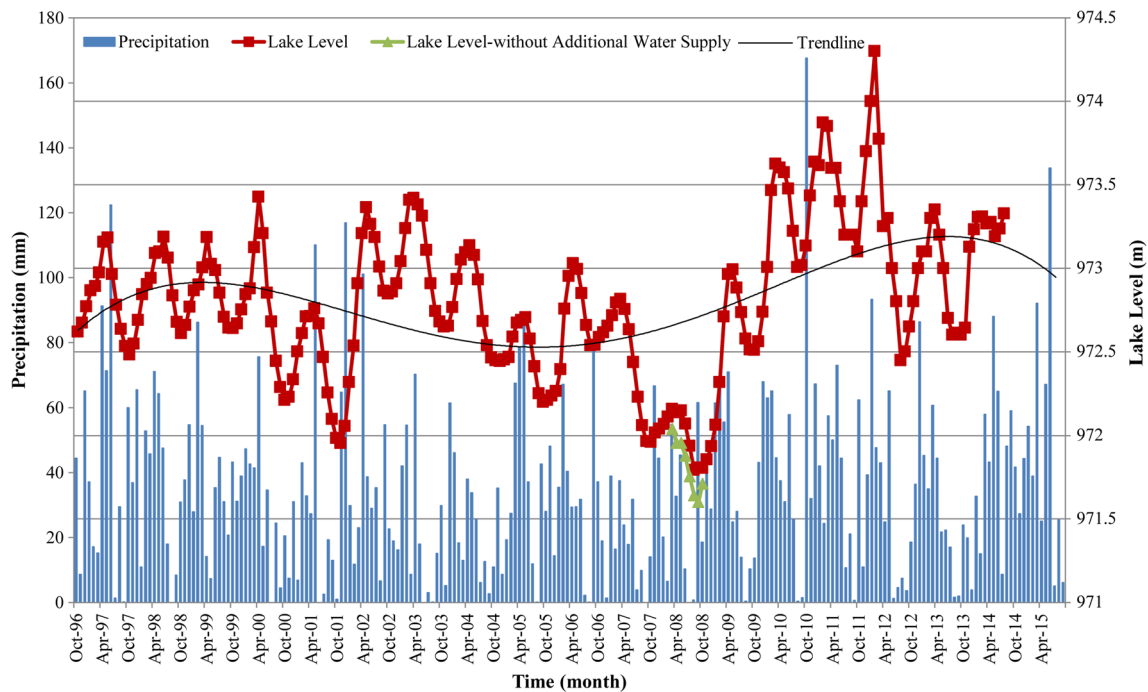
Fig. 4 Time data series of Lake Mogan's average monthly levels for the period 1996–2015
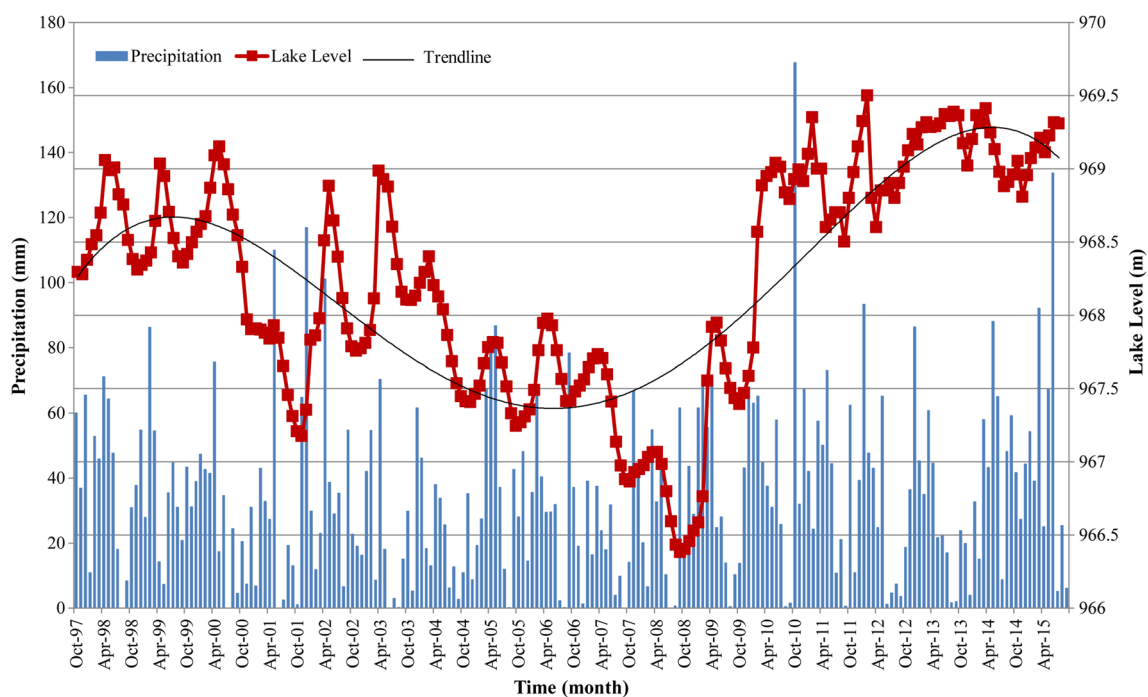
Fig. 5 Time data series of Lake Eymir's average monthly levels for the period 1997–2015

the authority of the General Directorate of State Hydraulic Works (DSI). The monthly monitored water levels between October 1996 and September 2014 for Lake Mogan and between October 1997 and September 2015 for Lake Eymir are displayed with the monthly precipitation data in Figs. 4 and 5, respectively.

The fitted polynomials to the lake levels are also shown in Figs. 4 and 5. The average lake levels for the past 18 years of data were 972.81 m for Lake Mogan and 968.24 m for Lake Eymir. The data showed significant declines in measured lake levels between 1999 and 2008 for both lakes. The Lake Mogan's levels decreased from 972.64 to 971.79 m from

September 1999 to September 2008. Similarly, Lake Eymir's water levels decreased from 968.35 m in September 1999 to 966.43 m in September 2008. The resulting declines were 0.85 m for Lake Mogan and 1.92 m for Lake Eymir (Fig. 4). The greater decline observed in Lake Eymir's water level is due to the reduced release of water from the upstream Lake Mogan. In order to alleviate the decreased lake level for Mogan, 6,260,000 m^3 of water was supplied from Kesikköprü Dam on Kızılırmak River by General Directorate of Ankara Water and Sewerage Authority from April 2008 through November 2008. The expected Lake Mogan's water levels without this additional water supply were calculated and displayed with triangle marker in Fig. 4. A comparison of the variations in lake levels shown in Figs. 4 and 5 with the mean annual temperature and precipitation series shown in Figs. 2 and 3 for the same period correlates well with a significant increase in temperature and decrease in precipitation. During 1999 and 2008 period, the annual precipitation was 55 mm/year lower than the long-term mean annual precipitation and the increase in annual temperature was more than 0.7 °C, producing significant declines in both lakes' levels.

The lake levels responded well to the variations in climatological variables, such as temperature and precipitation. Following the lowest levels observed in September 2008, the water levels in both lakes started to increase in parallel to the increased annual precipitation and slight decrease in temperature. The Lake Mogan's levels increased from 971.79 to 973.33 m from September 1999 to September 2014. Similarly, Lake Eymir's water levels increased from 966.43 m in September 2008 to 968.88 m in September 2014. The resulting rise in lake levels was 0.52 m for Lake Mogan and 0.63 m for Lake Eymir from the long-term mean lake levels. During this period, the mean of the observed annual precipitation was 57 mm/year greater than the long-term mean annual precipitation.

According to comprehensive analyses of the meteorological and hydrological data, lakes' levels have changed significantly under the impacts of the climatological variation in the basin. Both lakes' levels response in the same manner with the climatic variables' variations. The variations in the mean annual precipitation and air temperature were closely correlated with the water-level variations of Lakes Mogan and Eymir. So, the periodicity of fluctuations in the water levels of the lakes can be determined by the periodicity of the rate of precipitation and the thermal regime of the region.

Mann–Kendall test method

Changes in various climatological and hydrological parameters such as temperature and precipitation and their impacts on fluctuations in Lakes Mogan and Eymir's water levels during the observation period were the most important objective of this study. For this purpose, variations in these parameters were also evaluated statistically by nonparametric Mann–Kendall (Mann 1945; Kendall 1975) test method. The Mann–Kendall test was used to quantify trends in the climate variables and the lakes' level fluctuations between the observation periods 1998–2007 and 2008–2014. The observation periods were selected by applying Mann–Kendall rank statistic test to temperature, precipitation and lake levels. This test was used for determining the approximate year of the beginning of the significant trends at significance levels of 0.05 and 0.1. The results have shown that there has been statistically significant change in the trends of the data in 2008. Consequently, the trends have been analysed between 1998–2007 and 2008–2014.

Mann–Kendall test method is one of the nonparametric tests to catch trend in a time series especially in meteorological and hydrological time series. The Mann–Kendall test statistic S is calculated by using Eq. 1 (Mann 1945; Kendall 1975).

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} \text{sgn}(x_j - x_i) \tag{1}$$

In Eq. (1), n is the number of data points and x_i and x_j are the data values in time series i and j, respectively, and in Eq. 2, sgn $(x_j - x_i)$ is the sign function as:

$$\text{sgn}(x_j - x_i) = \begin{cases} 1; & \text{if } x_j > x_i \\ 0; & \text{if } x_j = x_i \\ -1 & \text{if } x_j < x_i \end{cases} \tag{2}$$

The variance is computed by Eq. 3;

$$\text{Var}(S) = \frac{n(n-1)(2n+5) - \sum_{i=1}^{P} t_i(t_i-1)(2t_i+5)}{18} \tag{3}$$

In Eq. 3, n refers to number of data, P shows the number of tied groups, and t_i indicates the number of ties of extent i. A tied group is a set of sample data and has the same value. In cases of sample size $n > 10$, the standard normal test statistic Z is calculated using Eq. 4.

In Eq. 3, P shows the number of tied groups (equal data in time series), and summary sign ($\sum$) indicates the summation over all tied groups. t_i is the number of data values in Pth group. If tied groups do not exist, this summary process is ignored for this equation. After computing variance of time series with Eq. 3, standard Z value is computed using the following equation.

$$Z = \begin{cases} \dfrac{S-1}{\sqrt{\text{Var}(S)}}; & \text{if } S > 0 \\ 0; & \text{if } S = 0 \\ \dfrac{S+1}{\sqrt{\text{Var}(S)}} & \text{if } S < 0 \end{cases} \tag{4}$$

The computed standard Z value is compared with standard normal distribution according to the two-tailed confidence intervals ($\alpha = 10\%$, $\alpha = 5\%$). If the computed Z value is greater than $|Z| > |Z_{1-\alpha/2}|$, null hypothesis (H_0) is rejected and thus H_1 hypothesis is accepted. Otherwise, the H_0 hypothesis is accepted, and this means that the trend is not statistically significant.

In this study, two-tailed confidence intervals ($\alpha = 10\%$ and $\alpha = 5\%$) were used for the Mann–Kendall trend test. The water-level fluctuations in Mogan and Eymir lakes were examined with monthly total precipitation and monthly mean temperature data between 1998 and 2014 (17 years × 12 months = 204 months, which is considered to be long enough for a valid meaningful statistics). Mann–Kendall test results are given in Table 1, and the variations and trends of the parameters are illustrated in Figs. 6, 7 and 8. In Table 1, negative and positive values indicate declining and increasing trends, respectively.

Mann–Kendall test method was employed for the observed data analysis to demonstrate any existence of possible trends (confidence intervals, $\alpha = 10\%$ and $\alpha = 5\%$). The main findings of the study indicated that the mean temperature had significant increasing and decreasing trends in the observation periods 1998–2007 and 2008–2014, respectively (Fig. 6). For the precipitation data, the Mann–Kendall test demonstrated significant decreasing and increasing trends in the observation periods 1998–2007 and 2008–2014, respectively (Fig. 7). Moreover, Mann–Kendall test of the 17 years showed both significant decreasing and increasing trends in the water levels of Lakes Mogan and Eymir in the observation periods 1998–2007 and 2008–2014, respectively (Fig. 8). Increasing temperature and decreasing precipitation trends observed in 1998–2007 caused severe water-level declines in Lakes Mogan and Eymir. On the contrary, decreasing temperature and increasing precipitation trends observed in 2008–2014 ensured an increase in water levels of both lakes. The decreasing and increasing trends determined in Lake Eymir are more substantial than Lake Mogan's (Fig. 8) due to its relatively smaller water volume. Mann–Kendall test results showed that temperature and precipitation have crucial influence on the variations in Lakes Mogan and Eymir water levels.

Results and discussion

The main objective of this research was to identify the causes and processes for the variations in Lakes Mogan and Eymir's water levels. It is necessary to investigate climatic contribution to the variations in Lakes Mogan and Eymir's water levels observed over 1996–2015. The study addresses the question of whether any trend in the long-term monthly series of temperature, precipitation and lake levels already appears at the scale of the region. To ascertain the fact of the changing climate, the water-level fluctuations in Mogan and Eymir lakes were examined with monthly total precipitation and monthly mean temperature data between 1998 and 2014 using the Mann–Kendall test. The statistical test results showed that temperature and precipitation have crucial influence on the variations in Lakes Mogan and Eymir water levels and significant trends in parameters were indicated.

According to comprehensive analyses of the meteorological data, the lakes' water levels have changed in harmony with the impacts of the climatological variation in the Lakes Mogan and Eymir basin. Analyses of the meteorological data showed that precipitation and temperature have crucial influence on the variations in the lakes' levels. The calculated water budget for both lakes by Yagbasan and Yazicigil (2009) for the period of 1998–2004 showed that the run-off from streams constitutes 77 and 89% of inflows for Lakes Mogan and Eymir, respectively. Thus, the increase or decrease in run-off, mainly controlled by the respective increase or decrease in precipitation, will have a greater impact on the lake levels as compared to increase or decrease in temperature. The calculated water budget for both lakes also showed that the temperature-driven evaporation losses made about 53 and 20% of the total outflow from Lakes Mogan and Eymir, respectively. The remaining outflows were mainly produced by the release of water from the lakes as contributions of groundwater outflow which were insignificant with percentages of 4 and 3, respectively. Although the run-off as well as withdrawal data for the entire data period for both lakes are unavailable, one can conclude that the increase or decrease in precipitation causes increase or decrease in surface run-off with a consequent change in lake levels due to their significant proportion in inflows. In addition, the

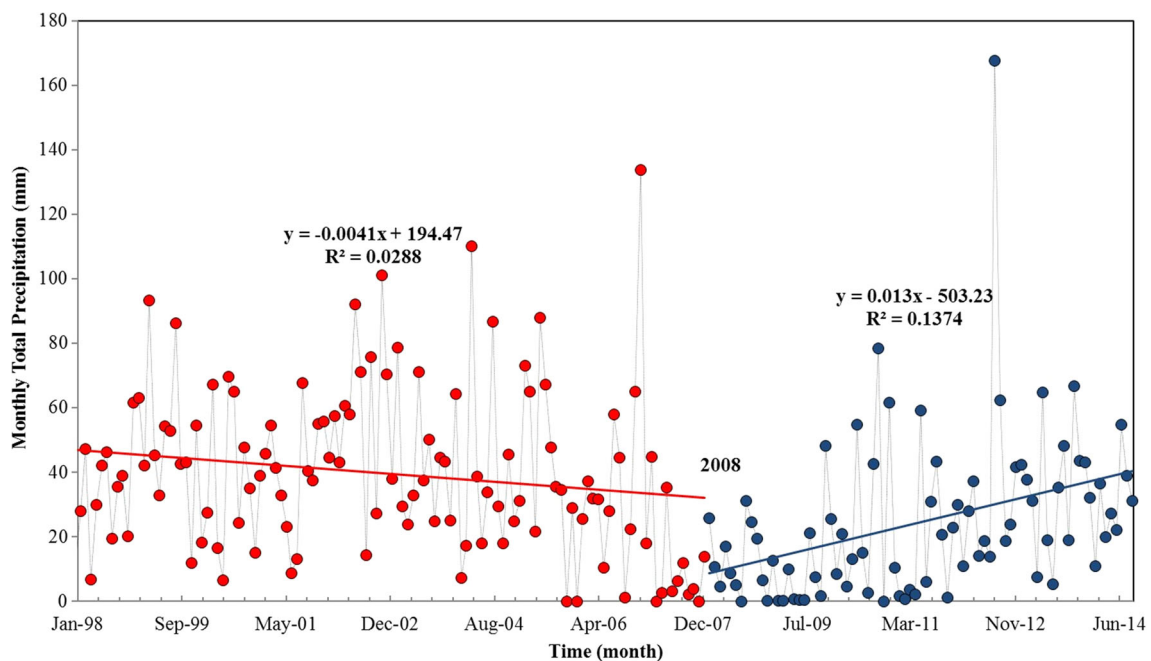**Table 1** Mann–Kendall test Z values results for the period 1998–2014

Period (years)	Parameters			
	Precipitation (mm)	Temperature (°C)	Mogan lake levels (m)	Eymir lake levels (m)
1998–2007	−2.358[a]	13.371[a]	−3.601[a]	−8.614[a]
2008–2014	4.237[a]	−9.967[a]	4.176[a]	8.523[a]

[a] Confidence intervals, $\alpha = 10\%$ (±1.645), $\alpha = 5\%$ (±1.96)
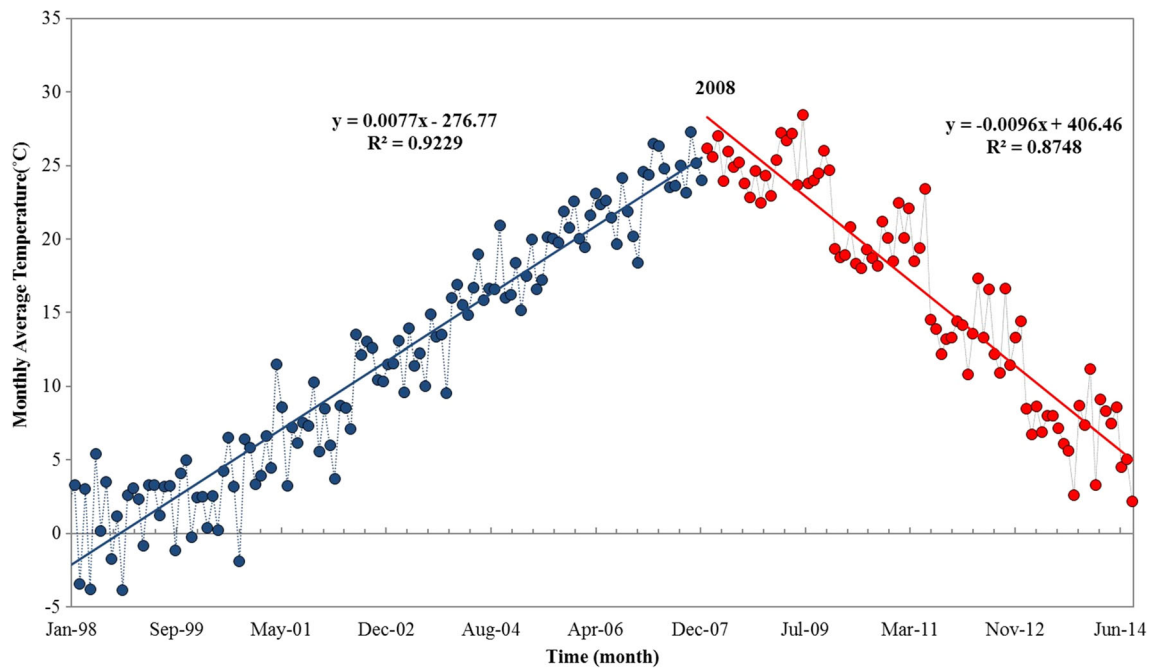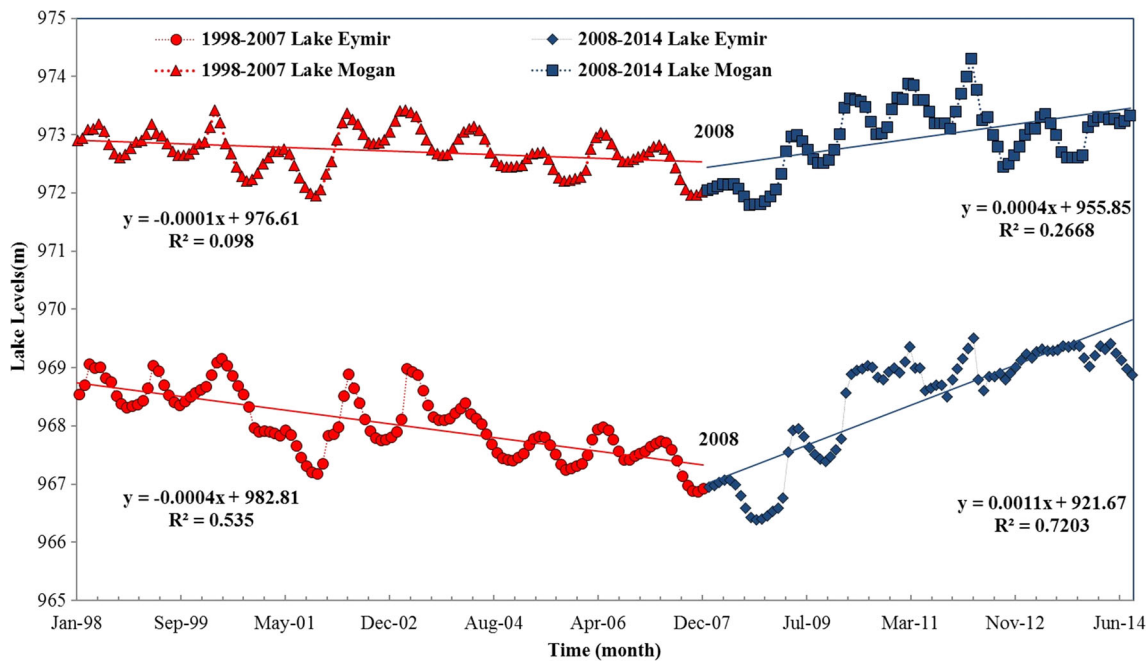
Fig. 6 Variations and trends of monthly mean temperature for the period 1998–2014

Fig. 7 Variations and trends of monthly total precipitation for the period 1998–2014

release of water from both lakes constitutes a significant portion of the outflow. Hence, the budget of these natural lakes is impacted by the controlled release of water in addition to the hydrological and climatic factors. Thus, it is of crucial importance and highest priority to initiate the monitoring of run-off and management of release of water from both lakes to sustain their hydrological and ecologic status in the long term.

Increasing the resilience of watershed systems can be an effective strategy to adapt to climatic impacts. It is essential to develop mix of strategies that includes mitigation, adaptation and research. To better assess the evolving impacts of climate change on—both quality and quantity of—water resources, basin-scale impact assessment studies are needed that utilize coupled land surface and regional climate model outputs together with a method for

Fig. 8 Variations and trends of monthly lake level fluctuations for the period 1998–2014

Conclusions

The temperature and precipitation variations can cause significant changes in the hydrological regime. Based on this study, it is considered as Lakes Mogan and Eymir water levels are very sensitive to variations in temperature and precipitation. Both lakes' levels response in the same manner with the climatic variables' variations as described in the previous sections. The nature of watershed ecohydrology of the lake systems makes them highly vulnerable to climate change. According to the IPCC's SRES high-emission A2 scenario simulation, the temperatures in Ankara are projected to increase between 1.5 and 2 °C for 2041–2071 and between 3.5 and 4.0 °C for 2071–2099 periods. The precipitation is projected to decrease 10% for 2041–2071 and 2071–2099 periods (Şen 2013). Unfortunately, the projected changes in both temperature and precipitation may produce substantial decreases in lake levels in the long term, with consequent drying of both lakes. Climate change mitigation and water-related disasters need a proactive approach concerning the freshwater resources in a timely, coordinated and effective manner during extended drought conditions.

Successful integrated management of water resources stored in the Lakes Mogan and Eymir basin is one of key prerequisite for sustainable ecological, economic and social development, effective protection of the environment and safeguard of vulnerable and valuable biological diversity. In order to fulfil these goals, it is necessary to establish a monitoring programme that not only measures the lake levels but also the other components of the water balance for both lakes. In addition, truly interdisciplinary cooperation between different scientific disciplines (hydrogeology, hydrology, climatology, biology, ecology, etc.) and different governmental, regional and local participants is mandatory to achieve these goals.

References

Alpert P, Osetinsky I, Zivb B, Shafir H (2004) Semi-objective classification for daily synoptic systems: application to the Eastern Mediterranean climate change. Int J Climatol 24:1001–1011

Beklioglu M, Altinayar G, Tan CO (2001) Role of water level fluctuations, nutrients and fish in determining the macrophyte dominated clear water states in five Turkish shallow lakes. In: Shallow lake wetlands: ecology, eutrophication and restoration, international workshop, 28–30 October 2001, Ankara, Turkey

Beklioğlu M, Romo S, Kagalou I, Quintana X, Becares E (2007) State of the art in the functioning of shallow Mediterranean lakes: workshop conclusions. Hydrobiologia 584(1):317–326

Beklioğlu M, Bucak T, Coppens J, Bezirci G, Tavşanoğlu ÜN, Çakıroğlu Aİ, Levi EE, Erdoğan Ş, Filiz N, Özkan K, Özen A

(2017) Restoration of eutrophic lakes with fluctuating water levels: a 20-year monitoring study of two inter-connected lakes. Water 9(127):1–22. doi:10.3390/w9020127

Belete MD, Diekkrüger B, Roehrig J (2017) Linkage between water level dynamics and climate variability: the case of Lake Hawassa hydrology and ENSO phenomena. Climate 5(21):1–14. doi:10.3390/cli5010021

Bellard C, Bertelsmeier C, Leadley P, Thuiller W, Courchamp F (2012) Impacts of climate change on the future of biodiversity. Ecol Lett 15:365–377

Bohn VY, Delgado AL, Piccolo MC, Perillo GME (2016) Assessment of climate variability and land use effect on shallow lakes in temperate plains of Argentina. Environ Earth Sci 75:818. doi:10.1007/s12665-016-5569-6

Chenoweth J, Hadjinicolaou P, Bruggeman A, Lelieveld J, Levin Z, Lange MA, Xoplaki E, Hadjikakou M (2011) Impact of climate change on the water resources of the eastern Mediterranean and Middle East region: modeled 21st century changes and implications. Water Resour Res 47:W06506. doi:10.1029/2010WR010269

Erlat E, Türkeş M (2011) Analysis of observed variability and trends in numbers of frost days in Turkey for the period 1950–2010. Int J Climatol 32:1889–1898. doi:10.1002/joc.2403

Giorgi F (2006) Climate change hot-spot. Geophys Res Lett 33:L08707. doi:10.1029/2006GL025734

Giorgi F, Lionello FP (2008) Climate change projections for the Mediterranean region. Glob Planet Change 63(2–3):90–104. doi:10.1016/j.gloplacha.2007.09.005

IPCC (2013) Intergovernmental Panel on Climate Change. The contribution of working group I to the fifth assessment report of the intergovernmental panel on climate change. In: Stocker TF, Qin D, Plattner G-K, Tignor MMB, Allen SK, Boschung J, Nauels A, Xia Y, Bex V, Midgle PM (eds), Climate Change 2013: The physical science basis summary for policymakers. pp 3–30. ISBN 978-1-107-66182-0. Cambridge University Press, Cambridge

Kahya E, Kalaycı S (2004) Trend analysis of streamflow in Turkey. J Hydrol 289:128–144. doi:10.1016/j.jhydrol.2003.11.006

Kendall MG (1975) Rank correlation methods. Charles Griffin Publishing, London, p 160

Mann HB (1945) Nonparametric tests against trend. Econometrica 13(3):245–259

Özcan Z, Başkan O, Düzgün HŞ, Kentel E, Alp E (2017) A pollution fate and transport model application in a semi-arid region: is some number better than no number? Sci Total Environ 595:425–440

Partal T, Kahya E (2006) Trend analysis in Turkish precipitation data. Hydrol Process 20(9):2011–2026. doi:10.1002/hyp.5993

Safari B (2012) Trend analysis of the mean annual temperature in Rwanda during the last fifty two years. J Environ Prot 3:538–551

Şen ÖL (2013) A holistic view of climate change and its impacts in Turkey. Istanbul Policy Center, Sabancı University, Stiftung Mercator Initiative, İstanbul. ISBN 978-605-4348-65-7

Tan C, Ma M, Kuang H (2017) Spatial-temporal characteristics and climatic responses of water level fluctuations of global major lakes from 2002 to 2010. Remote Sens 9(150):1–15. doi:10.3390/rs9020150

Tayanc M, Im U, Dogruel M, Karaca M (2009) Climate change in Turkey for the last half century. Clim Change 94(3):483–502. doi:10.1007/s10584-008-9511-0

Turkes M, Koc T, Saris F (2009) Spatiotemporal variability of precipitation total series over Turkey. Int J Climatol 29:1056–1074. doi:10.1002/joc.1768

Yagbasan O (2007) Modelling of Mogan and Eymir lakes aquifer system. Ph.D. thesis, Middle East Technical University, Graduate School of Natural and Applied Sciences, p 184, Ankara, Turkey

Yagbasan O, Yazicigil H (2009) Sustainable management of Mogan and Eymir Lakes in central Turkey. Environ Geol 56(6):1029–1040. doi:10.1007/s00254-008-1203-6

Yagbasan O, Yazicigil H (2012) Assessing the impact of climate change on Mogan and Eymir Lakes' levels in Central Turkey. Environ Earth Sci 66:83–96. doi:10.1007/s12665-011-1209-3

Yilmaz KK, Yazicigil H (2011) Potential impacts of climate change on Turkish water resources: a review. In: Baba A, Tayfur G, Gunduz O, Howard KWF, Friedel MJ, Chambel, A (eds), Issues of National and Global Security Series: NATO Science for Peace and Security Series C: Environmental Security, Vol 3, Springer, Dordrecht, The Netherlands, 1st edn. p 318, Hardcover. ISBN: 978-94-007-1142-6

Zhang C, Lai S, Gao X, Xu L (2015) Potential impacts of climate change on water quality in a shallow reservoir in China. Environ Sci Pollut Res 22:14971–14982. doi:10.1007/s11356-015-4706-1

Zhang C, Zhang W, Liu H, Gao X, Huang Y (2017) A quantitative assessment of the contributions of climatic indicators to changes in nutrients and oxygen levels in a shallow reservoir in China. Theor Appl Climatol. doi:10.1007/s00704-017-2165-y

Zhao Z, Liu F, Zhang Y, Liu L, Qi W (2017) The dynamic response of lakes in the Tuohepingco Basin of the Tibetan Plateau to climate change. Environ Earth Sci 76:137. doi:10.1007/s12665-017-6446-7