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Water quality trend analysis in Eymir Lake, Ankara

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ABSTRACT

In this study, trends in selected water quality parameters in Eymir Lake over a period of 10 years are analyzed using the Mann–Kendall test. Analyzed water quality parameters are dissolved oxygen (DO), total phosphorus (TP), total suspended solids (TSS), and secchi depth (SD). In addition, trends in the yearly averages of precipitation, lake volume, and ambient temperature are examined. According to Mann–Kendall test results, precipitation, volume and ambient temperature values exhibit decreasing trends in 1998–2008. DO and TSS exhibit increasing trends while TP and SD have decreasing trends in Eymir Lake. The change in the volume of the lake has a significant impact on the trends of DO, TSS, and SD. These results indicate that, besides eutrophic conditions, water balance and drought conditions significantly impact the water quality of Eymir Lake.

1. Introduction

Eymir Lake is a shallow lake located at 20 km south of Ankara, the capital city of Turkey. This lake has been used primarily for recreational purposes, sports and fishing. Unfortunately, the water quality has deteriorated within the last 25 years due to uncontrolled settlements, waste loads and arid conditions. Yet, the lake is still important for being one of the few natural recreational areas in the vicinity of Ankara as well as for its rich ecosystem. Due to these reasons, the lake has been taken under environmental protection since 1990.

In order to follow the status of the water quality and propose management strategies, a number of studies have been conducted in the lake. One of the major studies was carried out by ASKI (Water and Sewage Directorate of Ankara) in coordination with the Middle East Technical University in September 1993 to June 1995 (Altinbilek et al., 1995). According to this study, the lake exhibited eutrophic characteristics with high concentrations of TP, chlorophyll-a (Chl-a), and TSS in ulfiltered samples. Moreover, low SDs were recorded. Phosphorus (P) was determined as the limiting nutrient for the lake. In order to improve the water quality, several management strategies were proposed including minimizing the waste discharges and sediment dredging. During the course of the project, the slaughterhouse that was discharging to an area close to the lake was closed in 1994. The TEIAS residency that was directly discharging to the lake was connected to the sewerage system. In addition, in 1995, 25,833 m of bypass line was put in service by ASKI in order to avoid the discharge of wastewaters of the Golbasi district to the lake. However, since the pumps were not operated continuously, Eymir Lake continued to be a receiving body (Altinbilek et al., 1995). Sediment dredging was not applied.

A biomanipulation project was started in the lake in August 1998. Primary aims of the project were to decrease turbidity and increase SDs in the lake. Following the application of the project, removal of 57% of benthi-planktivorous fish was achieved (Beklioglu et al., 2003). In 2001, the depth of the lake decreased by up to 1 m due to extreme drought conditions. This situation resulted in 90% increase in the coverage of submerged macrophytes. The water level was restored back in 2002 and the coverage of the lake bottom by macrophytes decreased to 63% (Tan and Beklioglu, 2005).

Karakoc et al. (2003) examined the water quality and impact of pollution sources in Eymir Lake. Samples were taken in July 1999, October 1999 and February 2000. Concentrations of TP, chemical oxygen demand (COD) and Kjeldahl-Nitrogen compared well with the quantities reported by Altinbilek et al. (1995). They concluded that pollution loads did not worsen in the time period from 1993 to 1999.

Elahdab (2006) investigated the algae distribution in Eymir Lake using site measurements and remotely sensed data. Furthermore, water quality monitoring was performed. In the study, acceptable levels of correlations were obtained between DO, TSS, SD, and Chl-a. Results once more indicated the highly eutrophic characteristics of the lake.

In the studies mentioned above, water quality of the lake is assessed based on the study period. Some of these studies indicate improvement in some water quality parameters while the others

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report contradicting results. There is no study focusing on a long term systematic trend analysis. Therefore, it is not shown whether there has been any improvement or decline in the water quality following the implementation of management strategies and drought conditions observed in the last years.

The aim of this study is to carry out a comprehensive data analysis for detecting the trends in DO, TP, TSS, SD, precipitation, ambient temperature and lake volume in the last decade (1998–2008). Analysis is conducted only for a limited number of water quality parameters due to limitations in data availability. To test a range of hypotheses regarding the statistical properties of the time-series, Mann–Kendall test, a nonparametric statistical technique, is employed. Mann–Kendall test is a common test that has been used in hydrological and water quality studies (Lettenmaier, 1988; Zhang et al., 2001; Libiseller and Grimvall, 2002; Karabork, 2007). It is particularly useful for discovering the trends in time-series data. The trend analysis helps to determine statistically whether the values of a random variable are decreasing or increasing over some period of time. The test is simple, robust and able to cope with the missing data. Since its first proposal by Mann (1945) and Kendall (1975), several enhancements have been introduced in the test. Derivation of covariances between Mann–Kendall statistics of multivariates are proposed by Dietz and Killeen (1981). The test is extended to include seasonality (Hirsch et al., 1982), multiple monitoring sites (Lettenmaier, 1988) and covariates representing the natural fluctuations (Libiseller and Grimvall, 2002).

In this study, data sets belonging to 1998–2008 are used. Data sets are obtained from Ozen (2006) and the Ministry of Environment and Forestry, Environmental Protection Agency for Special Areas (EPASA). In order to get useful information from the available data, exploratory data analysis stages are applied. In addition, the impact of drought conditions, represented by the variation in precipitation and lake volume, as well as ambient temperature, on water quality is examined.

2. Materials and methods

2.1. Study area

Eymir Lake, as shown in Fig. 1, is mainly fed by Mogan Lake. Kıslakcı Stream and groundwater sources are the other inflows. The excess water of the lake drains into İmrahor Creek at north (Altinbilek et al., 1995). The lake has an average depth of about 3 m and a catchment area of 971 km^2. The surface area of the lake is reported to change between 1.05 and 1.25 km^2 depending on the depth of water (Tan and Beklioglu, 2005).

For years, Mogan Lake provided the major inflow to Eymir Lake. A sluice gate was installed in 1974 to control the incoming flow from Mogan Lake to Eymir Lake. However, it has been kept closed in the last years to control the declining water depth in Mogan Lake as a result of drought conditions. In return, the volume of water in Eymir Lake has decreased. Moreover, the lake has continued to be a receiving body for the wastewaters of the Golbasi district. Therefore, conditions in Eymir Lake have enhanced eutrophication (Elahdab, 2006).

2.2. Mann–Kendall test

In order to define the trends in DO, TP, TSS, and SD, as well as precipitation, lake volume and ambient temperature, Mann–Kendall test is applied. The null hypothesis for the Mann–Kendall test is that there is no change in the probability distribution of a random variable with time. The test assumes that the random variables are independent and their values are from the same type of statistical distribution (normal, lognormal, etc.). The test makes all possible pair-wise comparisons between the variables in the form of time-series. If a value of a given variable in a given time is larger than the preceding one, a plus sign is recorded. If it is smaller, a minus sign is attained. The test statistic is computed as the difference between the total number of plus signs (representing increase in time) and the total number of minus signs (representing decrease in time) in the study period. A test statistic of zero would indicate no change over time (acceptance of the null hypothesis). As the deviation of the test statistic from zero becomes larger, the likelihood of observing a trend in the data is greater, and the rejection of the null hypothesis is more likely.

In this study, two different Mann–Kendall tests are employed. The first one is the univariate–multivariate Mann–Kendall test and the second one is the partial Mann–Kendall test. In order to determine the univariate–multivariate Mann–Kendall test statistic (MK) for a time-series $x_i\,\{x_i, i = 1, 2, \ldots, n\}$, first the variations in the successive quantities are evaluated. The variations in the time-series data is defined by

$$\mathrm{sign}(x_j - x_i) = \begin{cases} 1; & x_j > x_i \\ 0; & x_j = x_i \\ -1; & x_j < x_i \end{cases} \quad (1)$$

In above equation, x_i is the data set belonging to a variable of concern (i.e. DO, TSS, precipitation, etc.) where i is ordered as $i = 1, 2, \ldots, n-1$. x_j is the dataset where $j = i+1, i+2, \ldots, n$. Then, the total numbers of negatively and positively signed values are determined and substituted into the equation given below in order to determine

$$\mathrm{MK} = \frac{2(P-N)}{n(n-1)} \quad (2)$$

where P is the total number of positively signed values, N is the total number of negatively signed values and n is the total number of observation (Sen, 2002).

Univariate–multivariate Mann–Kendall test is applied to detect the trends in the individual variables considered in this study. Partial Mann–Kendall test is applied to detect the trends in a variable that is dependent to independent variables. One or several covariates (e.g. time-series representing meteorological or hydrological influences) can be included in the analysis. This would yield MK for the variable of concern computed conditional on MK of the covariates.

2.3. Approach

Trends in time-series data of selected variables are evaluated using the Mann–Kendall test in order to test whether there has been improvement for the variables of concern within the last decade. For this purpose, data belonging to the period of 1998–2008 are gathered. Analyzed water quality parameters are selected based on the availability and continuity in the data as well as its importance for the lake. The biomanipulation project carried on in the lake primarily aims at decreasing the turbidity in the lake. In order to determine the change in turbidity in the last decade, TSS and SD are good indicator parameters. Furthermore, DO is considered as the main water quality parameter. DO has major influence on the survival of most aquatic species and it is greatly impacted by the eutrophic state (Thomann and Mueller, 1987). Since the lake is phosphorus limited, TP is another water quality parameter examined.

Water quality data including DO, TP, TSS, and SD measurements is obtained from Ozen (2006) for 1998–2005. For 2006–2008, the water quality data is received from the Ministry of Environment and Forestry, Environmental Protection Agency for Special Areas (EPASA). In these studies, the same standard analysis methods

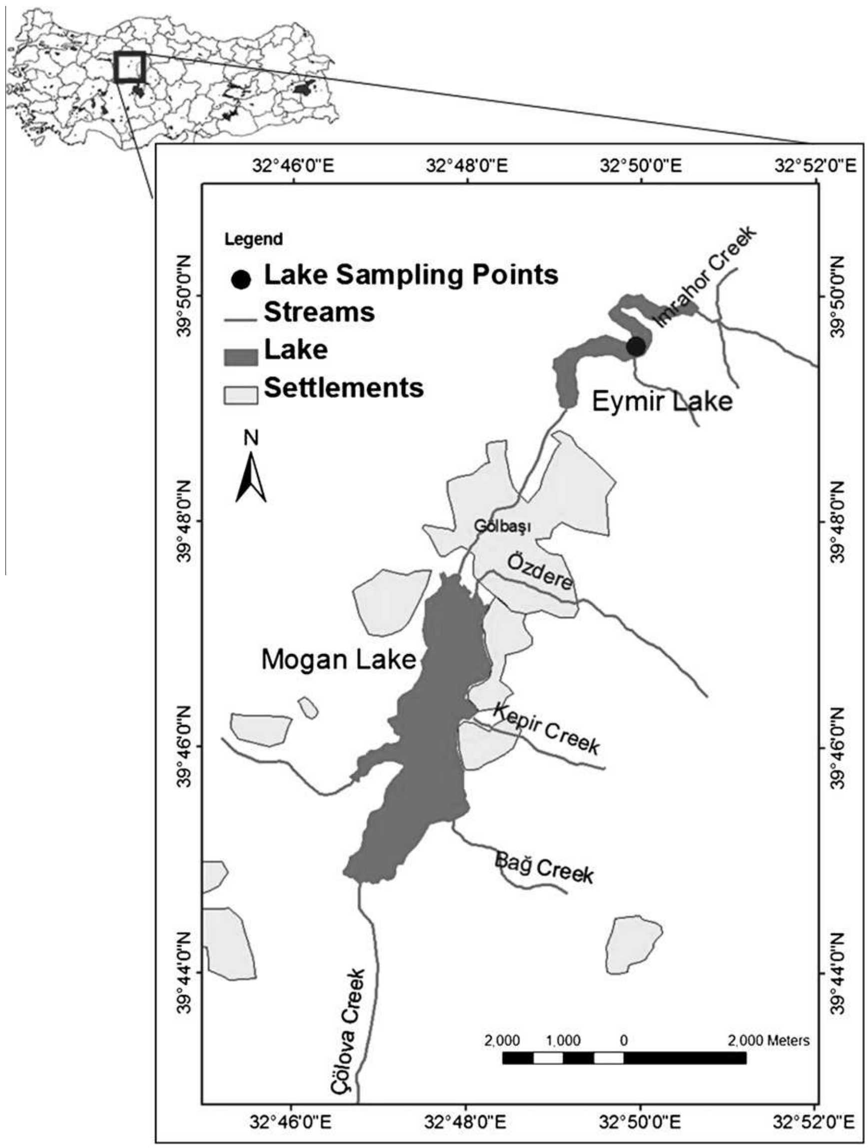

Fig. 1. Locations of Eymir Lake and Mogan Lake.

are utilized for the measurement of the water quality parameters considered in this study. The data belong to the same sampling point in the lake as depicted in Fig. 1. Mann–Kendall test is applied on the yearly average quantities which are calculated by taking the averages of the monthly average data (Ozen, 2006).

The meteorological data constituting of ambient temperature and precipitation are acquired from the Turkish State Meteorological Service. Data belonging to the Central Ankara Monitoring Station is utilized. Data on the volume of the lake is obtained from the General Directorate of Electrical Power Resources Survey and Development Administration. Since Mogan Lake is the primary source of inflow to Eymir Lake when sluice gate is open, variation in the volume of the Mogan Lake is also analyzed.

A potentially serious limitation of the Mann–Kendall test occurs when serial correlation exists. The existence of positive serial correlation increases the probability that the Mann–Kendall detects a trend when no trend exists (Cox and Stuart, 1955; Von Storch, 1995). This leads to rejection of the null hypothesis, although the null hypothesis is actually true. Therefore, presence of serial correlation between variables should be checked out prior to application of the Mann–Kendall test. Kulkarni and von Storch (1995), and Von Storch (1995) proposed application of ''pre-whitening'' to eliminate the influence of the serial correlation. Following ''pre-whitening'' the trend analysis can be proceeded using the Mann–Kendall test (Zhang et al., 2001).

As given by Zhang et al. (2001), the serial correlation coefficient ''r_1'', which is also called as the lag-one serial correlation, can be computed as

$$r_1 = \frac{\sum_{i=1}^{n}(x_i - \bar{x})(x_{i+1} - \bar{x})}{\sum_{i=1}^{n}(x_i - \bar{x})^2} \tag{3}$$

where x_i and x_{i+1} are the ith and $i+1$th observations and $\bar{x}$ is the mean of the n observations within the observation period. If r_1 is less than 0.1, then Mann–Kendall test is applied on the time-series given as $(x_1, x_2, x_3, \ldots, x_n)$. Otherwise, the test is applied on the time-series given as $(x_2 - r_1x_1, x_3 - r_1x_2, \ldots, x_n - r_1x_{n-1})$. In this study, pre-whitening procedure is applied to remove the serial correlations in the water quality parameters, volume of the lake, ambient temperature and precipitation. Then, partial and univariate–multivariate Mann–Kendall tests are applied to determine the trends in the time-series data. For this purpose a macro was created in Microsoft Excel. The algorithm of the macro is depicted in Fig. 2.

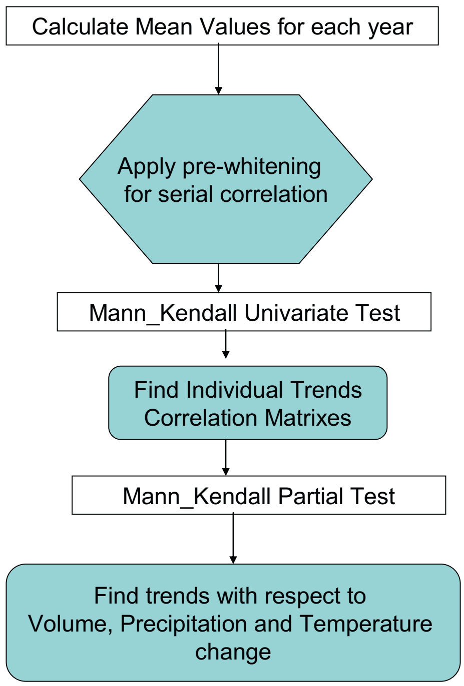

Fig. 2. Flow diagram of the steps followed in the trend analysis.

3. Results and discussion

Fig. 3 depicts the change in the monthly average volumes of Mogan and Eymir Lakes with respect to time. Precipitation values are also presented in the same figure. On the average, the volume of Mogan Lake is about 2.5 times larger than Eymir Lake. The tracks of drought conditions can be easily seen in 2001 and 2007 for both lakes. In these years, lower volumes are recorded. This is due to decreased precipitation in 2001 and 2007, especially in summer months. The average summer precipitation is about 124 mm for the basin for the years 1997–2007. In 2001 and 2007 summers, these values decreased to 75 and 55 mm, respectively. In addition, the sluice gate being kept closed and evaporation might have further impacted the water volumes in the lakes. Even visually, it is obvious that there is a decreasing trend in the volume of Eymir Lake after 2004 in Fig. 3. The decreasing trends in the volumes of the lakes are also validated with MK values, as will be discussed.

Since Eymir and Mogan Lakes have different volumes, in order to better observe and compare the relationships between precipitation and the volumes of the lakes, volume and precipitation values are normalized with respect to the corresponding average values for the whole observation period. The average values are determined on a yearly basis. Therefore, the average data set is formed in rolling 12 month averages of the relevant variables. The probability of obtaining a given variable value is determined with a mean of zero and a standard deviation of unity with normal distribution function properties (McKee et al., 1993). The resultant relationships are depicted in Fig. 4. In this figure, the precipitation is above normal value (mean of 0) between 1997–2000 and 2006–2007. In the other years, the precipitation is near or below normal which states that there is a precipitation deficit in the basin. Both of the lakes show similar volume change trends between 1997 and 2002. However, the condition in Eymir Lake is better in terms of the volume of water with respect to the average value of the period 1997–2001. Starting from 2002, the situation gets worse for Eymir Lake. For Mogan Lake the opposite is true such that condition is better after 2002. These outcomes support the impact of the sluice gate on the water balance of both lakes. Since there is no outflow from Mogan Lake to Eymir Lake, Mogan Lake exhibits an increase in the volume in 2003 despite the decrease in precipitation with respect to the previous years. In 2005, although there is an increase in precipitation, the lakes can not recover and the volumes stay below their mean values. This may be due to the declined input from groundwater as a result of lower water table levels. In overall, Fig. 4 indicates that there are decreasing trends in precipitation and volumes of the lakes. The validation of these outcomes will also be presented through MK values.

The trend analysis via Mann–Kendall test has been carried out in two phases. Firstly the individual trends for each variable (DO, TP, TSS, SD, volume, precipitation and ambient temperature) are

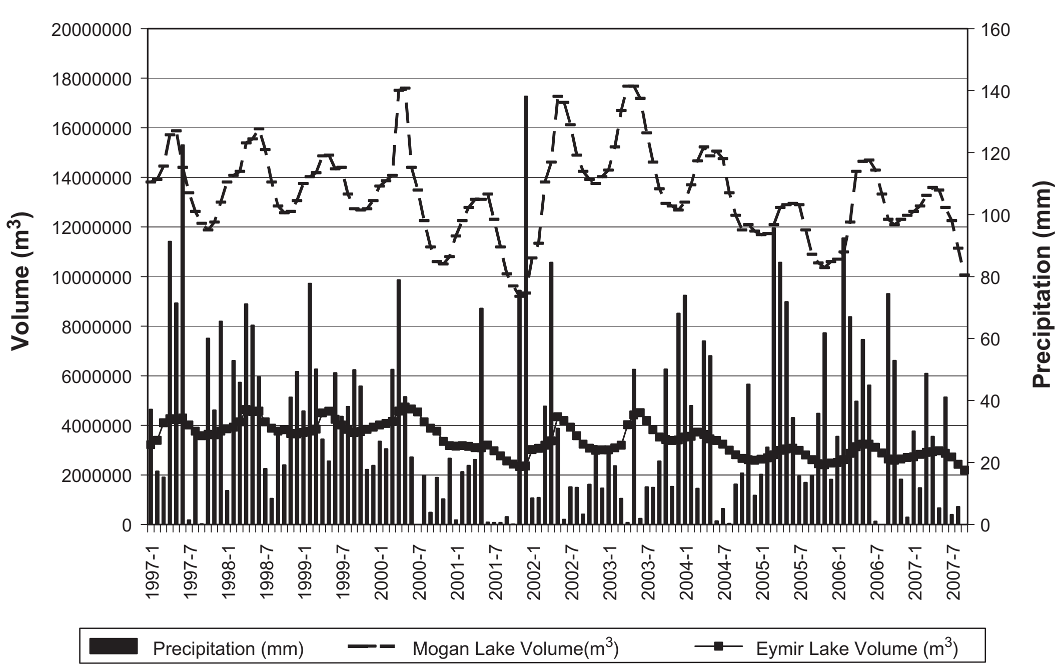

Fig. 3. Records of precipitation and volumes of Eymir and Mogan Lakes in 1997–2007.

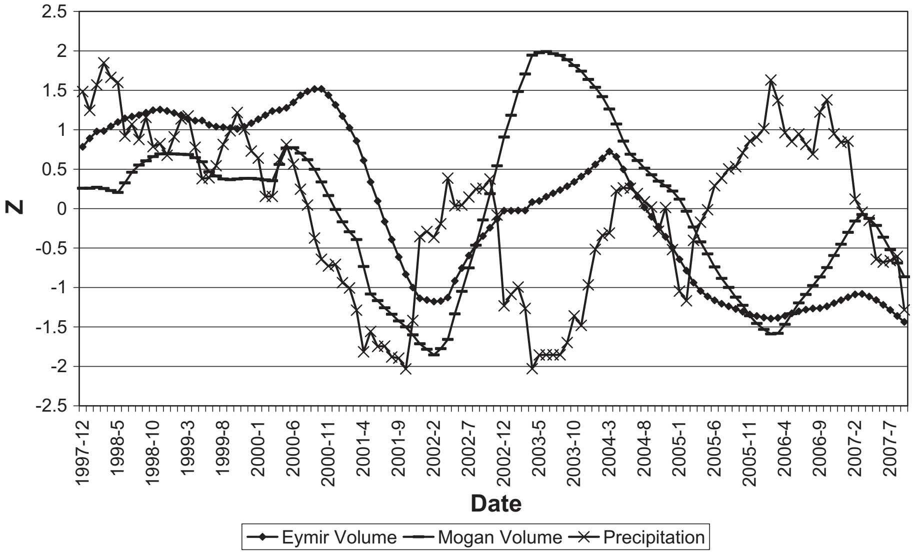

Fig. 4. Normalized precipitation and volume quantities for Mogan and Eymir Lakes.

assessed. Then, DO, TP, TSS, and SD are treated as dependent variables and the trends in these water quality variables are calculated in relation to the environmental variables (precipitation, ambient temperature and volume) that may impact the water balance in the lake. The Spearman's correlation coefficients between the dependent and independent variables are determined and the results are summarized in Table 1.

The results show that there has been a high negative correlation between volume and DO in Eymir Lake (Table 1) in the last decade. Change in DO may depend on several factors. Lower lake volume can be one of them. Low volume may enhance the conditions for eutrophication due to higher water temperatures. Since field measurements are performed in daylight, it is not surprising to observe high DO values in an eutrophic lake in daytime. In addition, lower water depth may enhance the impact of macrophytes in the DO balance. Nevertheless, it is seen that daytime DO values in the lake have improved in the last 10 years. In order to make a conclusion about the state of DO in the lake, nighttime measurements should be performed as well.

As given in Table 1, the relationship between TP and volume is negligible. However, it is in the negative direction. Enhanced eutrophication with lower lake volume may result in an increase in TP due to algal biomass. Although not strong, TSS and SD exhibit some relationship with volume. As volume increases TSS decreases and SD increases. Elahdab (2006) showed that there is a strong positive correlation between algal production (i.e. increased chlorophyll-a concentrations) and TSS in Eymir Lake. In the same study, SD exhibited strong negative correlation with chlorophyll-a. Therefore, the results obtained in this study are in line with Elahdab's (2006). It should also be pointed out that lower lake volume enhances the impact of wind induced mixing of the lake and resuspension of the sediment, which may lead to increased TSS and lower SD values.

DO and TSS exhibit insignificant relationships with precipitation (Table 1). There has been a weak positive relationship between TP and precipitation. Although the relationship is weak, it is possible that precipitation introduces TP to the lake via surface runoff. Since the lake is P limited, TP introduction may provide additional nutrients for algal growth. Surface runoff may also result in increased TSS values. However, this may not be significant due to the existing turbidity. Although not strong, there exists some positive correlation between SD and precipitation. This may be due to the fact that precipitation is mostly observed in winter and spring. In the wet seasons, water temperature is lower, and therefore, algal production is lower. As a result, SD values are higher. Since strong correlation has been observed between algal production and SD in Eymir Lake (Elahdab, 2006), these results are not surprising.

Although not strong, ambient temperature exhibits some correlation with TSS as given in Table 1. For DO and SD, the correlations are insignificant. In addition, the correlation between temperature and TP is weak but positive. As ambient air temperature increases, algal production, therefore TSS and TP increases.

The univariate–multivariate Mann–Kendall test trend statistics for volume, precipitation, temperature and water quality variables are depicted in Fig. 5. Decreasing trends are observed for all examined variables except DO and TSS. It is clear that DO concentrations

Table 1
Correlation of water quality parameters (DO, TP, TSS, and SD) with lake volume, precipitation and ambient temperature.

Independent variables	Spearman's correlation coefficients			
	DO	TP	TSS	SD
Volume	−0.75	−0.14	−0.31	0.31
Precipitation	−0.07	0.34	0.07	0.30
Temperature	0.06	0.24	0.54	0.13

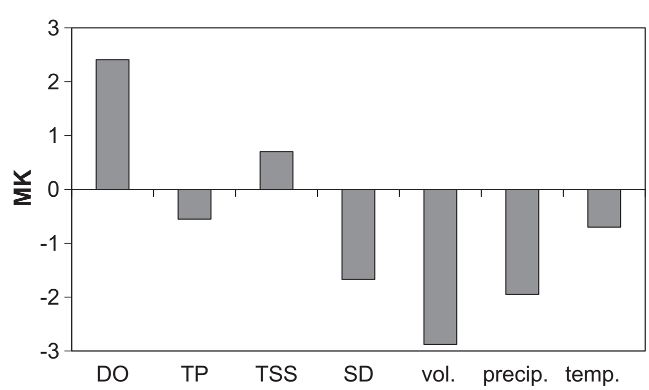

Fig. 5. Univariate–multivariate Mann–Kendall test results.

Table 2
Partial Mann–Kendall test results for water quality parameters.

	DO	TP	TSS	SD
Volume	0.37	−0.97	−0.19	−0.82
Precipitation	2.27	0.13	0.83	−1.14
Temperature	2.50	−0.39	1.30	−1.59

have increased in the last decade. Although, to a lower extent compared to DO, TSS values in 1998–2008 exhibited an increasing trend as well. Although the biomanipulation project conducted in the lake aims at reducing the TSS concentrations (Beklioglu et al., 2003), the trends in TSS and SD show that it has not been possible to achieve the improvement in these parameters. This is probably due to hydrological conditions in the last 10 years. The volume of the lake and precipitation exhibited significant decreasing trends. In addition, in the last years, inflows from Mogan Lake and groundwater declined. Since water balance has a major impact on water quality parameters, the drought conditions impacted the status in the lake. As well as algal production and eutrophic conditions, easier resuspension of the sediments due to decreased volume and depth may negatively impact the TSS and SD values.

The partial Mann–Kendall test results are tabulated in Table 2. These results indicate the impact of the independent variables on the trend of the dependent variables. When the trend in DO is examined in relation to the dependencies to volume, precipitation and ambient temperature, it is seen that the significant increasing trend for DO decreases when volume changes. For example when the trend in DO is examined independently, MK is calculated as 2.41 (Fig. 5). However, when the impact of volume on DO is taken into account, partial MK is 0.37 (Table 2). Therefore, volume of the lake has negatively impacted the significantly increasing trend in DO. This result confirms the results obtained in Table 1 such that there is a strong negative correlation between lake volume and DO. The change in precipitation and temperature is not effective on the trend of DO compared to the impact of volume change.

For TP, the effect of volume change is inverse, stating that the decreasing trend in TP will be enhanced as the volume effect is included. When the volume of the lake decreases, TP concentrations increase in the water body due to decreased dilution. In addition, lower volume may enhance algal growth in shallow waters due to higher temperatures. In fact, temperature positively impacts the trend such that TP increases as temperature increases. The trend in TP is also impacted by precipitation. Individually MK is −0.55 for TP. However, when the effect of precipitation is considered, partial MK value is observed as 0.13. Therefore, as also indicated by the Spearman's correlation, precipitation increases TP. This may be due to the introduction of TP or nutrients to the lake via surface runoff. Among precipitation, lake volume and ambient temperature, precipitation has the highest impact on the trend of TP in the last 10 years.

When the results obtained for TSS and SD in univariate–multivariate Mann–Kendall test and partial Mann–Kendall test are compared, it is observed that among the independent parameters, lake volume has the highest impact on the trends of TSS and SD in the last 10 years. The TSS has a positive trend and this trend is signified when precipitation and temperature is included in the analysis. As discussed before, this situation can be as a result of TSS transport from the watershed via precipitation and increased algal production due to increased temperatures. The negative trend for SD becomes weaker as the volume change effect is included.

4. Conclusions

The results obtained from Mann–Kendall tests indicate that the volume, precipitation, and ambient temperature in Eymir Lake have decreased in the last 10 years when yearly averaged data is considered. This decrease is especially significant for the volume of water in Eymir Lake. When the trends in DO, TP, TSS, and SD are examined, it is seen that DO and TSS in Eymir Lake exhibit increasing trends while TP and SD decreasing trends. However, the change in the volume of the lake has a significant impact on the trends of these water quality parameters, especially for DO, TSS, and SD. If similar conditions prevail, it is expected that the volume of the lake and precipitation in the basin will continue to decline. In that case water quality in Eymir Lake may get worse. In overall, the results indicate that, as well as eutrophication, water budget and drought conditions have primary importance in the quality of the lake.

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