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North Atlantic Oscillation Effect on the Water Levels of the Turkish Lakeland with Regard to Meteorological Indicators

Meteorolojik Göstergeler Işığında Kuzey Atlantik Salınımının Göller Bölgesi Su Seviyeleri Üzerindeki Etkisi

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Abstract

The impact of the global climate change and the North Atlantic Oscillation (NAO) on water resources in the geography of Turkey have been revealed as a result of the investigations in recent years. Big climate events have not only a direct effect on the temperature and rainfall but also have an indirect effect on the evaporation, runoff, underground storage, and sea-lake level changes depending on these meteorological parameters.

In this study, it has been investigated how the level variations of the three biggest Turkish lakes (Egirdir, Beysehir and Burdur in Turkish Lakeland) are effected from the global climate change and NAO. This process will be evaluated not only with climate indicators but also with the time variations of the meteorological data. According to the results it is revealed that the meteorological parameters of Turkish Lakeland are not affected strongly from North Atlantic Oscillation. However it is found that the lake levels are affected inversely from North Atlantic Oscillation and evaporation data. Mann-Kendall test has clearly demonstrated a linear variation which is strong and inverse with a coefficient of correlation value as -0.96, between the trends of the NAOI and precipitations for Isparta station. The similar relation was also determined between the trends of NAOI and both Egirdir and Burdur lake levels with a coefficient of correlations as -0.91 and -0.86, respectively. Turning points were also determined by using paired t test in the early 1990s for lake level data sets. By analyzing the dimensionless data it is found that lake levels and precipitations start to decrease after the year 1985.

Keywords: *Meteorological Parameters, Lake Levels, North Atlantic Oscillation, Turkish Lakeland.*

Öz

Küresel iklim değişikliğinin ve Kuzey Atlantik Salınımının (KAS) Türkiye'deki su kaynaklarına olan etkisi son yıllarda gerçekleştirilen çalışmalar ile araştırılmaktadır. Büyük iklim olayları yalnızca sıcaklık ve yağışları değil aynı zamanda buna bağlı olarak buharlaşma, akış, yer altı depolaması ile deniz ve göl seviyelerini de etkilemektedir. Bu çalışma kapsamında Göller Bölgesi'nde yer alan Türkiye'nin üç büyük gölüne ait seviyelerin (Eğirdir, Beyşehir ve Burdur Gölleri) küresel iklim değişikliği ve Kuzey Atlantik Salınımı ile değişimi incelenmiştir. Bu süreçte yalnızca iklim göstergeleri değil aynı zamanda meteorolojik verilerin de zaman içinde değişimi değerlendirilmiştir. Eğilim araştırmaları ve gidişlerin korelasyonları Mann-Kendall tekniği ile boyutsuzlaştırılmış z

istatistikleri yardımıyla gerçekleştirilmiştir. Çalışmanın sonucunda, üç gölün seviye verilerin Kuzey Atlantik Salınımından güçlü ve ters yönlü bir şekilde etkilendiği belirlenmiştir. Bulgular, eşlenik t sınaması ile tespit edilen 1990'ların başındaki dönüm noktaları ile oldukça uyumludur. Boyutsuz verilerin analizi ile göl seviyelerinin ve yağışların 1985'ten sonra düşmeye başladığı bulunmuştur.

Anahtar Kelimeler: *Meteorolojik Parametreler, Göl Seviyeleri, Kuzey Atlantik Salınımı, Göller Bölgesi.*

1. Introduction

Lake levels may be changeable during different periods depending on various variables such as rainfall, recharge, evaporation and outflow etc. Predictable periodic movements occur significant portion of the factors caused short-term changes. Nevertheless, global climate changes and so encountered big climate events have a significant impact on the lake levels in recent years. The North Atlantic Oscillation (NAO) which is a one of the climate events is described as the fluctuations in the difference of atmospheric pressure at sea level between a high-pressure system over the Azores and a low-pressure system over Iceland. The strength of the NAO is described by the North Atlantic Oscillation Index (NAOI) [1, 2] measuring the difference between the normalized sea level pressure recorded in the Atlantic at high (e.g., Reykjavik, or Akurejry, Iceland) and low (e.g., Gibraltar or Lisbon/Ponta Delgada, Portugal) latitudes. The NAO has a significant effect on precipitation, stream flow, temperature and rainfall in Europe and Turkey [1, 3-6]. The variability of lake levels for seven lakes was investigated in Turkey by using winter (DJFM) lake-level and NAOI data and they revealed that a significant correlation between these two time series [7]. In this study, they also indicated that NAO is an important mechanism for the variations of Turkish lake levels. Lake level trends in Turkey was investigated and according to the study they indicated a significant upward trends in lake level at the north coastal region and downward trends at the Midwest region [8]. They also indicated that these results are in agreement with those of the precipitation, stream flow and temperature trend studies in Turkey. The influences of the NAO and the Southern Oscillation (SO) on climatic variability and anomalies in Turkey was invesitgated by [9].

Lake Beysehir and Egirdir are two biggest freshwater lakes of Turkey. These lakes are used for domestic use, irrigation, fishery and recreation purposes. Even though Lake Burdur is a salty lake it is also considered since it is one of the deepest lakes of Turkey and it is used as sodium sulfate source in industry. The demand for freshwater has gradually increased in the world and so in Turkey caused by population growth and the depletion of the freshwater sources. Lakes Egirdir, Beysehir and Burdur are important water resources for Turkey hence, a comprehensive and sustainable water resources management is required for the study area.

In this study relation between meteorological parameters, NAOI and lake levels of Egirdir, Beysehir and Burdur were investigated. The annual index of the NAO provided by Hurrell based on the difference of normalized sea level pressures (SLP) between Ponta Delgada, Azores and Stykkisholmur/Reykjavik, Iceland was used [10].

2. Study Area and Data

The study area is named as Turkish Lakeland which is a region with a series of lakes in Southwestern part of Anatolia, Turkey. Lakeland consists of seven lakes and the major ones are Egirdir, Beysehir and Burdur Lakes. The characteristics of the selected lakes are summarized in Table 1.

In this study, annual mean temperatures, annual total precipitations and evaporations data compiled by the Turkish State Meteorological Service (DMI) at 3 stations and annual mean lake levels data compiled by the General Directorate of Electrical Power Resources Survey and Development Administration (EIEI) at 3 main stations were used. All of the meteorology stations and lake tide-gauges have continuous observations. The location of the studied area and the stations are shown in Figure 1.

The meteorology stations were selected in a manner to represent the tide-gauges properly. So, 17238 Burdur, 17240 Isparta and 17244 Konya stations data were used to associate the tide-gauges 1012 Burdur, 905 Egirdir and 1624 Beysehir, respectively. The details are given in Table 2.

Table 1. The features of the studied lakes.

Lakes	Location (Basin)	Mean Elevation (m)	Mean Surface Area (km^2)	Drainage Area (km^2)	Purpose of usage
Egirdir	Discrete Middle Mediterranean Waters	915	468	3351	Domestic, irrigation, fishery and recreation use
Burdur	Burdur Lake Closed	845	153	4512	Recreation use
Beysehir	Middle Anatolia Closed	1121	656	3095	Domestic, irrigation, fishery and recreation use

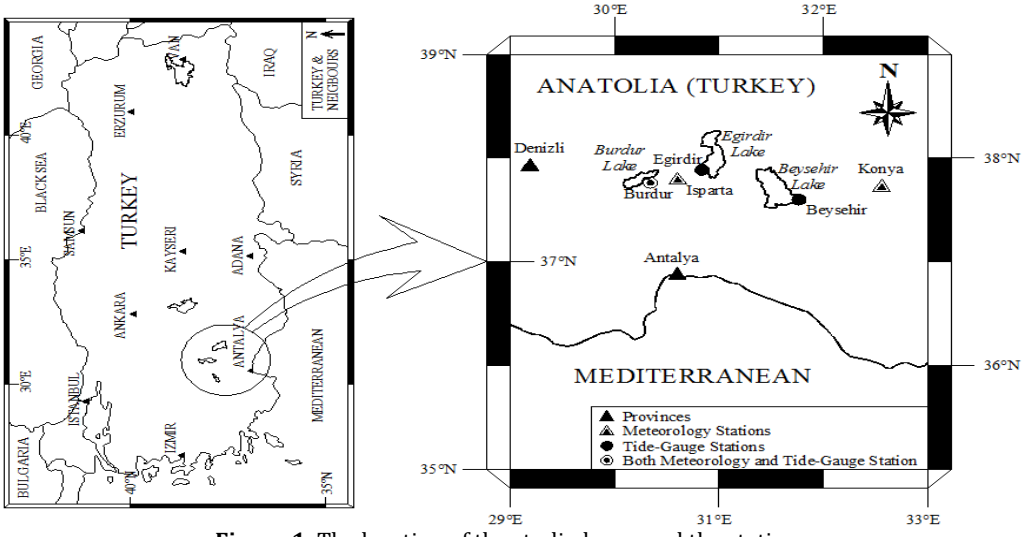

Figure 1. The location of the studied area and the stations

Table 2. Meteorology and lake tide-gauge stations used in this study.

Station Type	Station ID	Station Name	Record Period			Latitude (N)	Longitude (E)	Altitude (m)
			Preci.	Tempe.	Evapo.			
Meteorology Stations	17238	Burdur	1953-2005	1953-2005	1979-2005	37° 43′	30° 18′	957
	17240	Isparta				37° 45′	30° 33′	997
	17244	Konya				37° 52′	32° 28′	1029
Lake Levels								
Lake Tide-Gauges	905	Egirdir	1953-2005			37° 52′	30° 50′	915
	1012	Burdur	1969-2005			37° 48′	30° 17′	845
	1624	Beysehir	1953-2005			37° 41′	31° 44′	1121

3. Methods

In this study, first, the Mann-Kendall test that is a nonparametric statistical test was used to assess trends in the time series of lake levels, meteorological parameters and NAO indices. Prewhitening process was applied to remove serial correlations from the time series to obtain stationary series. Then, the paired *t*-test was used to investigate the presence of possible turning points at the time series of lake levels and meteorological parameters. After these processes, linear correlations were investigated between related time series to reveal the effects of the NAO and meteorological parameters on the lake levels.

3.1 The Mann-Kendall Test

This nonparametric method, based on the Kendall tau statistic, τ, has been properly used to test for randomness against trends, especially in hydro-climatologic time series [11]. In this method, the null hypothesis H0 states that the deseasonalized data (x1, x2, ..., xn) are a sample of n independent and identically distributed random variables [12]. The alternative hypothesis, H1, of a two-tailed test is that the distribution of xk and xj are not identical for all k,j≤n with k≠j. The test statistic, S, is asymptotically normal [13] and can be calculated with the help of Eqs. (1) and (2):

$$S = \sum_{k=1}^{n-1} \sum_{j=k+1}^{n} sgn(x_j - x_k) \quad (1)$$

$$sgn(x_j - x_k) = \begin{cases} +1\,;\ (x_j - x_k) > 0 \\ 0\,;\ (x_j - x_k) = 0 \\ -1\,;\ (x_j - x_k) < 0 \end{cases} \quad (2)$$

where S has a mean of zero, and the variance of S can be computed using Eq. (3):

$$Var(S) = [n(n-1)(2n+5) - \sum_t t(t-1)(2t+5)]/18 \quad (3)$$

where t is the extent of any given time, and ∑t denotes the summation over all times. For the cases where n is greater than 10, the standard deviate z can be calculated using Eq. 4 [13].

$$z = \begin{cases} \frac{S-1}{\sqrt{Var(S)}};\ S > 0 \\ 0\ \ ;\ S = 0 \\ \frac{S+1}{\sqrt{Var(S)}};\ S < 0 \end{cases} \quad (4)$$

If |z|>zα/2 at the significance level of α (5% for this study), then a significant trend exists in the time series and the sign of z indicates the direction of the trend.

3.2 Paired t-test

With this method, one can test the difference between the means of the data in the periods before and after the possible turning point (each point represents one year for this study). Hence, test statistic t can be determined as follows:

$$t = \frac{\bar{y} - \bar{x}}{\sqrt{\frac{(n_x - 1)S_x{}^2 + (n_y - 1)S_y{}^2}{n_x + n_y - 2}}\sqrt{\frac{1}{n_x} + \frac{1}{n_y}}} \quad (5)$$

where is the arithmetic mean, is the standard deviation and is the length of the data in the period before the turning point (beginning to turning point); and , and are the parameters in the period after the turning point (turning point to the end).

It is known that the sampling distribution of test statistic t has a t-distribution with nx+ny-2 degrees of freedom, where (nx+ny) is the number of elements in the entire data period. The t-statistic is employed to check the H0: = 0 hypothesis, against H1: ≠ 0. If the t-values, computed from Eq. (5), are within the confidence interval corresponding to the selected significance level, the null hypothesis will be accepted; else, the null hypothesis will be rejected and the alternate hypothesis will be accepted.

In the Mann-Kendall test, the critical value was determined to be ±1.96 for a 5% significance level, which is also known as the standardized normal deviate with non-exceedance probability of 0.025.

Backward propagated sequential Mann-Kendall tests were used to investigate the trends in the lake levels and meteorological indicators (temperature, precipitation, evaporation and NAOI) depending on data length. In this test, the beginning year keeps constant while the ending year decreases one by one. For example for Egirdir Lake levels, the length of the first data set was fifty three years (1953-2005) and the length of the last data set was thirteen years (1953-1965).

4. Results and Discussions

The results of the Mann-Kendall test for lake levels are given in Figure 2.

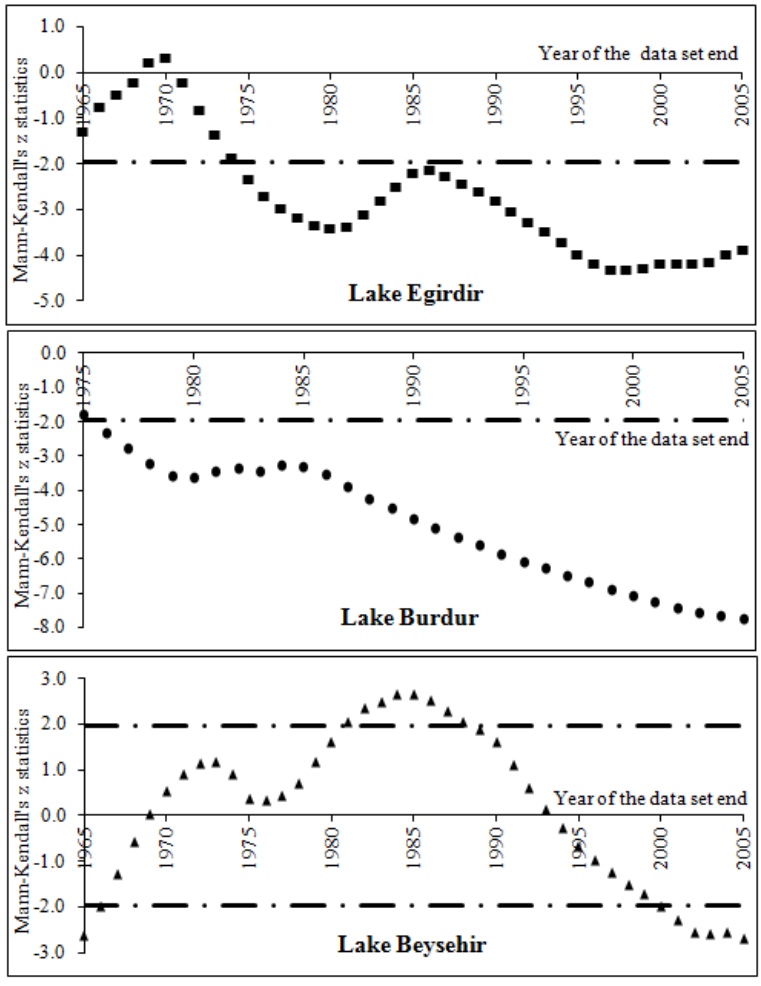

Figure 2. The results of backward propagated sequential Mann-Kendall test for lake levels (▬ · ▬ limits of significance at the 5% level).

According to Mann-Kendall test results for lake levels, significant negative trends were determined for whole data periods (1953-2005 for Egirdir and Beysehir Lakes, 1969-2005 for Burdur Lake). The Mann-Kendall's z statistics values for whole data periods are -3.9, -7.5 and -2.7 for Lakes Egirdir, Burdur and Beysehir, respectively. Following the results in Figure 2, decreasing in trends was observed for all of the lake levels after the year 1985.

For Lake Egirdir, Mann-Kendall's z statistics fluctuate around the value of -2, between 1965 and 1985 which are the years of the data set end. However, these statistics tend to decrease after the year 1985.

In the light of the Figure 2, while the tendency of trends is stationary up to 1985, after this point decreasing tendency is observed from the value of -3.0 to -7.5, for Lake Burdur.

According to backward propagated sequential Mann-Kendall test results for the lake levels of Beysehir, although an increasing tendency is observed until 1985, decreasing in trends is determined after 1985 as the case of Lakes Egirdir and Burdur.

After determining the z statistics for the lake levels, the backward propagated sequential Mann-Kendall test was applied for meteorological parameters and the results are given in Figure 3.

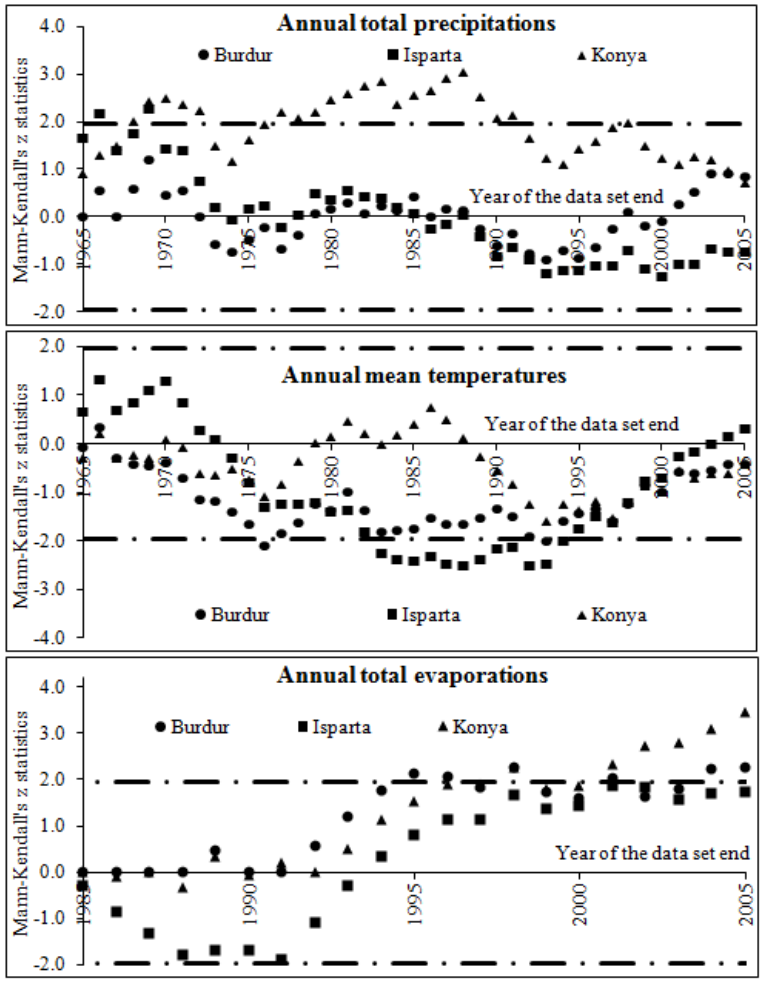

Figure 3. The results of backward propagated sequential Mann-Kendall test for precipitations, temperatures and evaporations (▬ · ▬ limits of significance at the 5% level).

According to Figure 3, the tendency of trends in precipitations and temperatures at Burdur and Isparta stations are stationary and do not have significant trends since the Mann-Kendall's z statistics values are between ±1.96. However for Konya station the run of trends are different from the other stations and significant trends were observed between 1980 and 1990 for precipitations. The trends in evaporations increase after the early 1990s for all stations.

The decreasing trends in Egirdir lake levels observed after 1970s are compatible with those observed for precipitation trends for Isparta station. Moreover at early 1990s, the decreasing trends in Egirdir lake levels are also compatible with increasing trends in temperatures and evaporations for Isparta station. The decreasing trends in Burdur lake levels observed after 1985 are compatible with increasing trends in temperatures and evaporations for Burdur station. The decreasing trends in Beysehir lake levels observed after 1985 are compatible with those observed for precipitation trends for Konya station. The decreasing trends in Konya lake levels are also compatible with increasing trends in evaporations for Konya station.

Paired t test was performed to determine significant turning years in data period. The results are given in Figures 4 and 5 for lake levels and for precipitations-temperatures-evaporations, respectively.

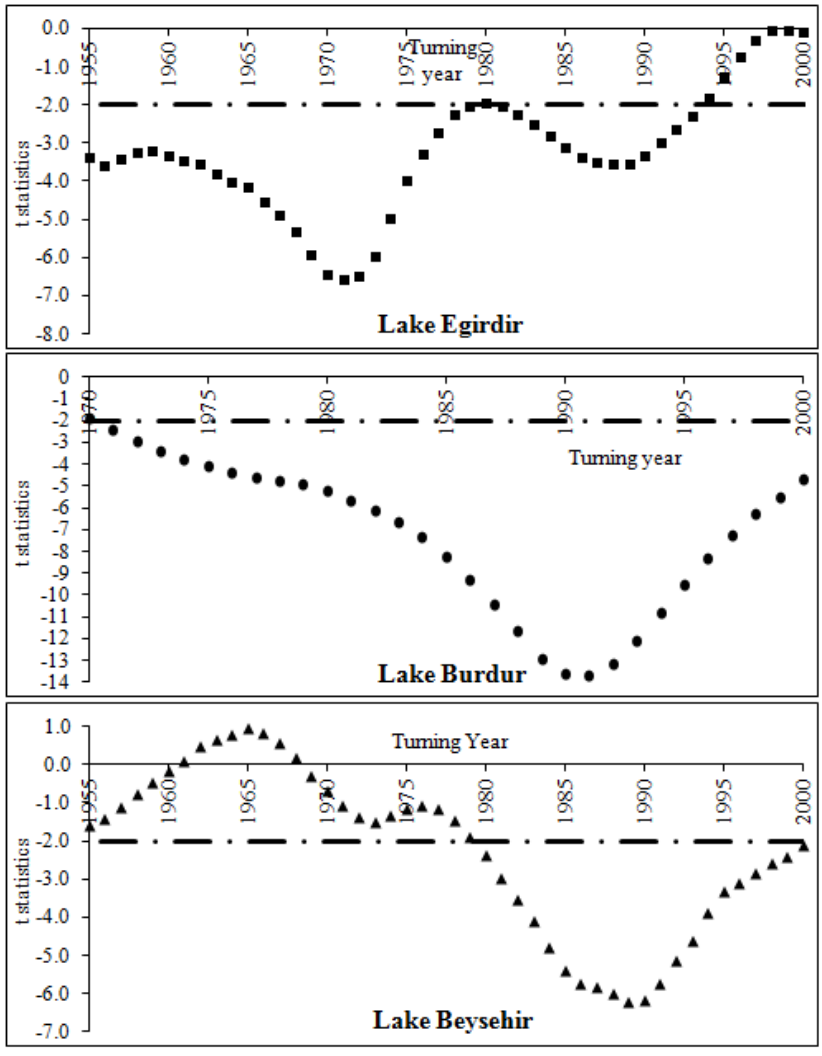

Figure 4. The results of paired t test for lake levels
(▬ · ▬ limits of significance at the 5% level).

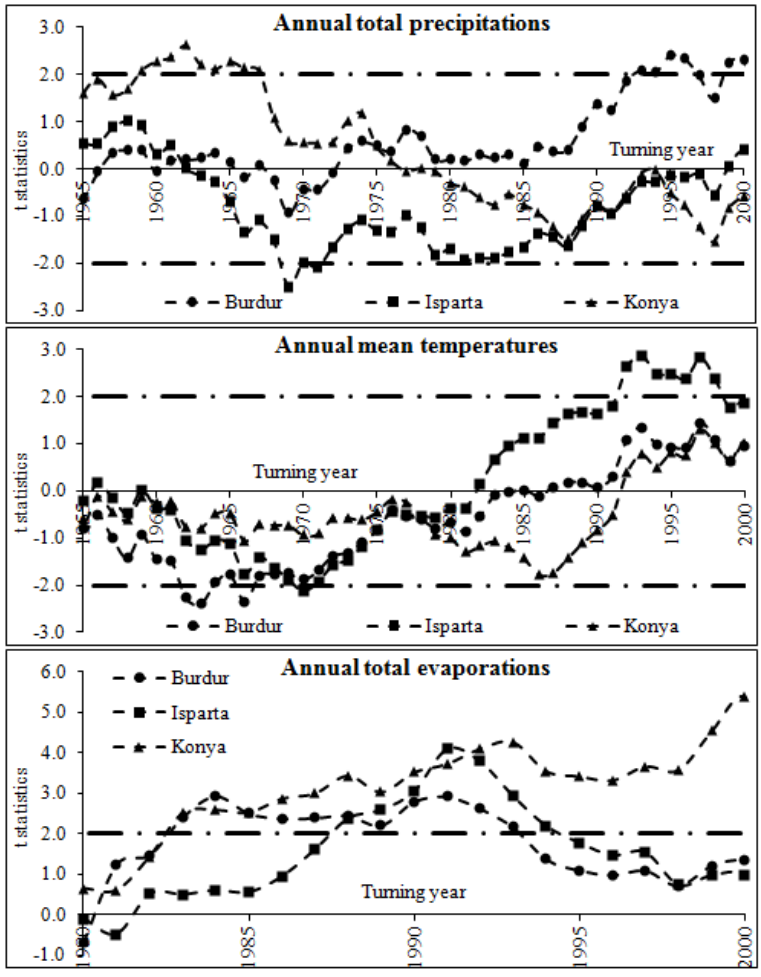

Figure 5. The results of paired t test for precipitations, temperatures and evaporations (▬ · ▬ limits of significance at the 5% level).

t statistics values reach their peak values in 1990 as -13.9 and -6.3 for Burdur and Beysehir lakes, respectively. This means that, the average of the lake levels after the year 1990 is significantly less than that before the year 1990. Furthermore, according to paired t test results for Egirdir Lake, two peaks were observed in 1970 and 1990.

The results of the paired t tests, performed for precipitations, temperatures and evaporations, are similar especially for Isparta and Burdur stations.

For precipitation data, t statistics value is determined as -2.5 at the late 1960s for Isparta, 2.7 at the early 1960s for Konya and 2.4 at the mid 1990s for Burdur. These values indicate potential turning years for precipitation data.

A significant negative turning year was detected at early 1960s for the temperatures measured at Burdur station. However, paired t test put forth positive turning years at the early 1990s in Isparta station. Any significant turning year was not observed in Konya station.

Significant t statistic values for evaporations data are observed at early 1980s for Burdur and Konya stations. In addition the test shows a specific change of the tendencies in evaporations data for Isparta at the late of 1980s.

The determined turning points for lake levels are compatible with the tendency of trends which is detected by means of Mann-Kendall's test, as expected. Furthermore two turning points which were determined for Egirdir Lake

in 1970 and 1990 were also determined for the precipitation and temperature data belong to Isparta station. Similarly the detected turning years for Beysehir and Burdur lakes are compatible with those detected for precipitation and temperature data.

Backward propagated Mann-Kendall tests were also performed for NAOI values. The results were associated to lake levels and meteorological parameters. Coefficients of correlation for Mann-Kendall tests results are given in Table 3.

Table 3. Coefficients of correlation between NAOI and Lake levels–meteorological parameters for Mann-Kendall tests results.

Station Type	Station	Data	r*	r**
Meteorology Stations	17238 Burdur	Precipitation	-0.35	-0.26
		Temperature	-0.42	-0.72
		Evaporation	0.74	-0.89
	17240 Isparta	Precipitation	-0.96	0.87
		Temperature	-0.60	0.52
		Evaporation	0.61	-0.87
	17244 Konya	Precipitation	-0.33	0.83
		Temperature	-0.52	0.51
		Evaporation	0.58	-0.95
Lake Tide-Gauges	905 Egirdir	Lake levels	-0.91	1
	1012 Burdur		-0.86	1
	1624 Beysehir		-0.20	1

* Coefficients of correlation between the trends of the NAOI and the other data sets

** Coefficients of correlation between the trends of the lake levels and related meteorological parameters:

(1012 Burdur ↔ 17328 Burdur; 905 Egirdir ↔ 17240 Isparta; 1624 Beysehir ↔ 17244 Konya)

In this study the relation between the trends of NAOI and both meteorological indicators and lake levels were investigated. Mann-Kendall test has clearly demonstrated a linear variation which is strong and inverse with a coefficient of correlation value as -0.96, between the trends of the NAOI and precipitations for Isparta station. The similar relation was also determined between the trends of NAOI and both Egirdir and Burdur lake levels with a coefficient of correlations as -0.91 and -0.86, respectively.

After the analysis, it is revealed that there is a strong and inverse linear relation between the trends of the lake levels and evaporations as shown in Table 2. The calculated coefficients of correlations between the lake levels and precipitations for Konya and Isparta are 0.83 and 0.87, which indicates a strong and positive relation. [9] indicated that a significant negative correlations between NAOI and both precipitations and temperatures in Turkey. These results are compatible with those of obtained from present study.

[7] revealed that an influence of the NAO on lake levels of Beysehir and Egirdir by using time scale analysis.

The relations of the lake levels between each other have also been investigated and the results are given in the Table 4. According to the values of correlation coefficients, one can say that climate parameters affect lake levels in a similar way.

The tendency of trends in the lake-levels and meteorological parameters for each lake and meteorology stations are given in Figure 6. The courses of lake levels and precipitations start to decrease after the year 1985 while temperatures and evaporations increase after that year as shown in Figure 6.

Table 4. The correlation coefficients between lake levels for Mann-Kendall test results.

Station	Egirdir	Burdur	Beysehir
Egirdir	1	0.83	0.86
Burdur	0.83	1	0.84
Beysehir	0.86	0.84	1

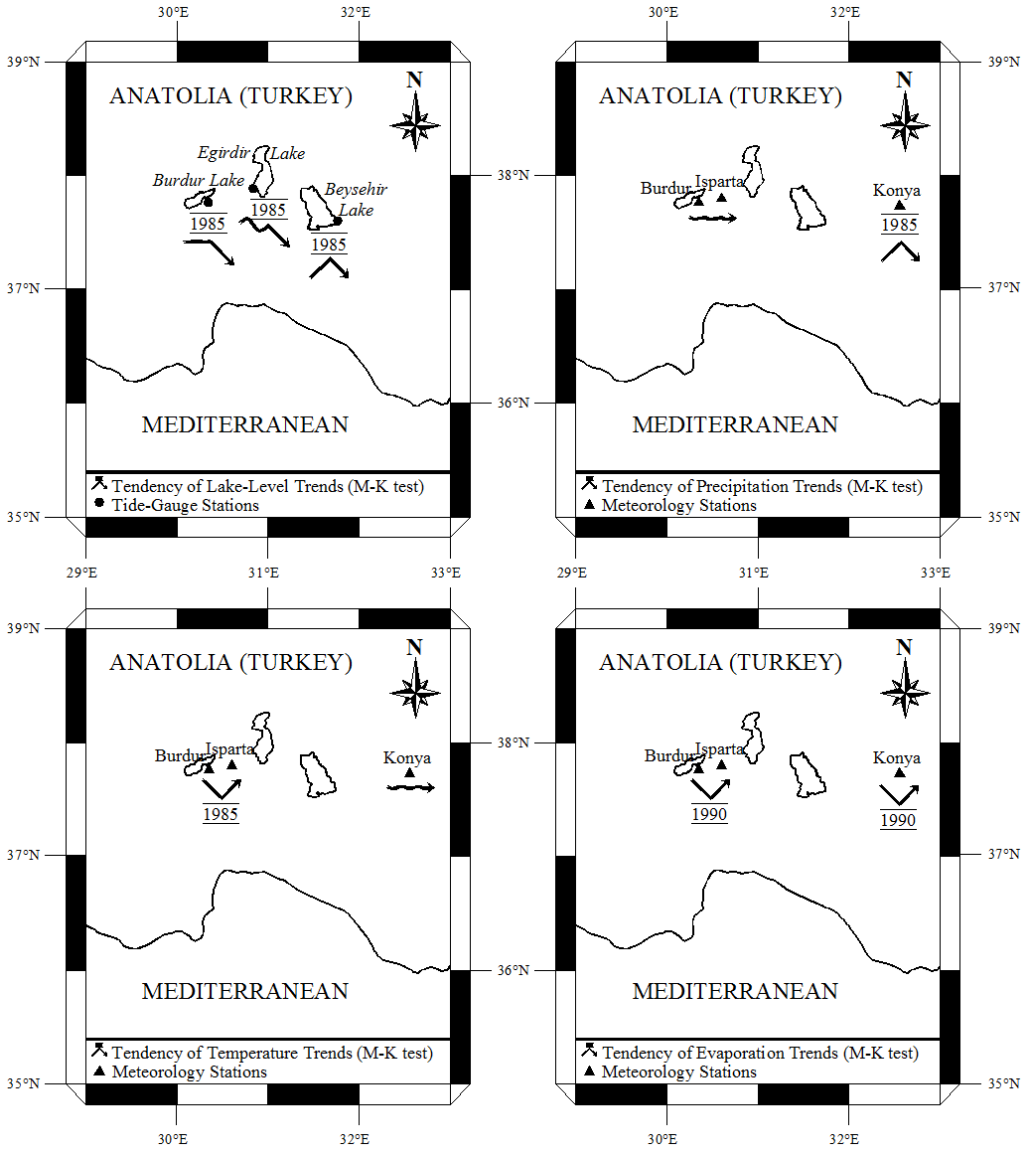

Figure 6. Tendency of trends in lake-levels and meteorological parameters.

The inverse linear relation was detected between the lake levels and evaporations which indicate an increase in evaporation while decrease in lake levels. According to the analysis results positive linear relation was deduced between the lake levels and precipitations as expected.

Turning points were determined by using paired *t* test in the early 1990s for lake level data sets. Henceforth whole data period can be considered as two parts (the periods before and after 1990). This indicates that the means of lake levels before the year of 1990 are significantly lower than the means of those observed after the year 1990.

5. Conclusions

In this study, the relationship between meteorological parameters, North Atlantic Oscillation (NAO) and trends of Egirdir, Beysehir and Burdur lake levels has been investigated. According to the Mann-Kendall test results one can say that the meteorological parameters of Turkish Lakeland are not affected strongly from North Atlantic Oscillation, except precipitations observed at Isparta station. It is also revealed that the levels of Egirdir, Burdur and Beysehir lakes are affected inversely from North Atlantic Oscillation.

Even though there are lots of studies which investigate the relation between the NAOI values and the meteorological parameters, the results of this study cannot be compared directly with current literature since in the present study this relation was investigated by using the Mann-Kendall's dimensionless z statistics of NAOI and meteorological parameters instead of their values. This case provides us to analyze various parameters in different units, with a dimensionless approach.

The one of the most important vital resource is water for sustainable development. The demand of water increases six times while the population increases three times in the world. An efficient water resources management is very important for whole world countries. As a result of inefficient management of water resources in Turkey approximately 1300 thousand hectares of wetlands gradually fade away. The results of the present study can be used in water resources planning studies for the region and provide a basis for a model established to predict lake levels in terms of climatic indices.

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