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Statistical Evaluation of Water Quality and Meteorological Conditions in Karacaören-II Dam Lake

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Abstract

Karacaören-II Dam Lake is located on Aksu Stream within the borders of Burdur. The lake is planned to be a drinking water supply for Antalya in the near future. Some scientific studies carried out in recent years stated that the lake suffers from eutrophication problem due to the pressures within the basin.

This study examined the relationships between the selected water quality parameters (BOD_5, DO, pH, NH_4-N, NO_2-N, NO_3-N, TKN, TN, o-PO_4, TP and TSS) and the meteorological parameters (temperature, wind speed, precipitation, humidity, pressure, vaporization) measured between the years 2005 and 2014 using correlation analysis. The main factors contributing to the variation in the data set were also determined by principal component analysis and the trends in selected water quality parameters were analyzed using the Mann-Kendall test. The statistical tests indicated that nitrogen, phosphorus, pH, temperature, precipitation, and vaporization are the major parameters influencing the water quality in the dam lake. A very high correlation is found between NO_3-N and DO. Trend analysis showed an upward trend in TN and TP concentrations. The results of this study will be beneficial to decision-makers for better management of water quality and to those who will carry out studies on the lake in the future.

1. Introduction

European Union Water Framework Directive (numbered 2000/60/EC) and Surface Water Quality Regulation state the precautions to be taken to protect and achieve good water status in water resources. The balance between protection and use should be ensured for the sustainable management of water resources [1, 2]. The environmental objectives of Water Framework Directive include prevention of deterioration in the status of surface waters, protection, improvement and restoration of water bodies ensuring good water status in the first management cycle [3]. In order to achieve these environmental goals, it is essential to first determine the pressures by making the basin characterization, reveal the current situation in water quality and the trend in light of previous data, and take the necessary measures to reach the determined environmental goals. Statistical methods are helpful tools to achieve these environmental targets. Correlation analysis, Principal Component Analysis (PCA), and trend analysis are widely used tools for this purpose especially when assessing the quality of surface waters and the relationship between water quality parameters and meteorological conditions [4-7]. They are instrumental in identifying necessary measures to prevent and improve water quality to achieve the environmental objectives.

When the projects and studies related to Karacaören-II Dam Lake were examined, it was seen that there have been limited number of studies that determine the distribution of pollutants in water and sediment. For example, Kır and Tumantozlu (2012) examined the accumulation levels of Fe, Cu, Zn, Mn, Al, Sr, Cr, Pb, Cd, Hg in water, sediment and some carp tissue samples in the lake between April 2009 – March 2010. In the study, it was determined that the metal concentrations increased in spring and summer and decreased in autumn and winter. The most accumulated metal in the sediment was

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mentioned as Fe. According to the results, the metal ratios measured in the sediment were significantly higher than that in water and fish tissues. In the study, the heavy metal amounts detected in water samples and carp tissues were compared with the limit values for aquatic environments. According to the results, both Zn in water, Fe and Zn in sediment exceeded acceptable values in all seasons, while they were below acceptable values in carp tissues [8].

Ardıç (2013) assesed health risk potential caused by nitrate concentrations in drinking water resources of selected provinces in Turkey for 2009. The nitrate data were obtained from Duraliler Well, Aksu Stream, Karacaören II Dam. In the study, it was determined that nitrate values in these three stations do not pose any risk to human health [9].

Apaydın et al. (2019) investigated natural radioactivity levels in sediment of Karacaören II Dam Lake. They collected 12 sediment samples from the lake in May 2016 and measured natural radionuclides like ^{226}Ra, ^{232}Th and ^{40}K. In the study, radium equivalent activities (Ra_{eq}), absorber dose rate (D), internal (H_{in}) and external (H_{ex}) hazard index, annual effective dose rate (AED) and Excess life time cancer risk (ELCR) were calculated and compared with recommended values of international organizations in order to assess the radiological hazards resulting from natural radioactivity. Results indicated that all Raeq, Hex and Hin values were below the criterion values [10].

TÜBİTAK MAM (2013) prepared a basin protection plan for Karacaören-I and Karacaören-II Dam Lakes. For this purpose, the hydrological and hydrogeological water budget of the basin, limnological features, the pollution status of rivers and other water resources, the renewal time of the basin, the geometry of the basin, the point and diffuse pollution sources and the reasons affecting the water quality were evaluated. After that, the effect of the calculated pollution loads on the water quality was determined via water quality modelling study. Pollution maps were also created. Basin protection plan alternatives were created with the help of the modelling study. Then special provisions for the lakes were determined in accordance with the prepared basin protection plan to improve the existing water quality in the basin [11].

Previous studies evaluated distributions of pollutants in sediment and water column of Karacaören Dam Lake but have not conducted any statistical tests. There has been a gap in the statistical evaluation of water quality and meteorological conditions in Karacaören-II Dam Lake. Therefore, correlation between water quality data and meteorological data was examined by correlation analysis in this study. Trend analysis were also performed to evaluate the long-term trends in water quality parameters. Effective parameters in representing the variation in data set were also determined using multivariate principal component analysis.

This study evaluates the long-term trends in Karacaören-2 Dam Lake for selected water quality parameters (BOD_5, DO, pH, NH_4-N, NO_2-N, NO_3-N, TKN, TN, o-PO_4, TP and TSS) using Mann-Kendall trend analysis. The study also determines meteorological variables that significantly affect water quality by correlation analysis, and specifies most deterministic principal components representing variation in data set. In this context, the SPSS program (version 23) was used to conduct correlation analysis, principal component analysis, and trend analysis using data sets belonging to the years 2005-2014. The long-term assessment of the change in water quality with this study will contribute to the protection of Karacaören-II Dam Lake, which has a high potential to be a drinking water source for Antalya in the future.

2. Materials and Methods

2.1. Study Area

Karacaören-II Dam Lake is located at 37^{o}18' north latitude and 30^{o}48' east longitude within the borders of Burdur Province. It was built on Aksu Stream between 1988-1993 for irrigation and energy purposes. It has been used as a recreation and aquaculture area as well. The surface area of the lake is 2.34 km^2. Karacaören-II Dam Lake is fed by Aksu Stream and Koca Stream. Aksu Stream joins with streams such as Dereboğazı Stream, Ağlasun Stream, Kovada Stream, Değirmen Stream, and enters firstly to Karacaören-I Dam Lake and then to Karacaören-II Dam Lake. Then, Aksu Stream outflows from the Karacaören-II Dam Lake and flows into the Mediterranean [12]. Figure 1 shows the locations of Karacaören-II Dam Lake and water quality monitoring stations of State Hydraulic Works.

The dam lake is significant because it is a recreational area used for irrigation, energy, and aquaculture [13]. In addition, it is planned to supply drinking water from the lake to Antalya Province in the future. There are many point and diffuse pollution sources within the basin borders of the lake that adversely affect the water quality. For this reason, determining the change of lake’s water quality in the long term and identifying the significant water quality and meteorological parameters that are effective on the lake’s water quality are extremely important for the management of the lake.

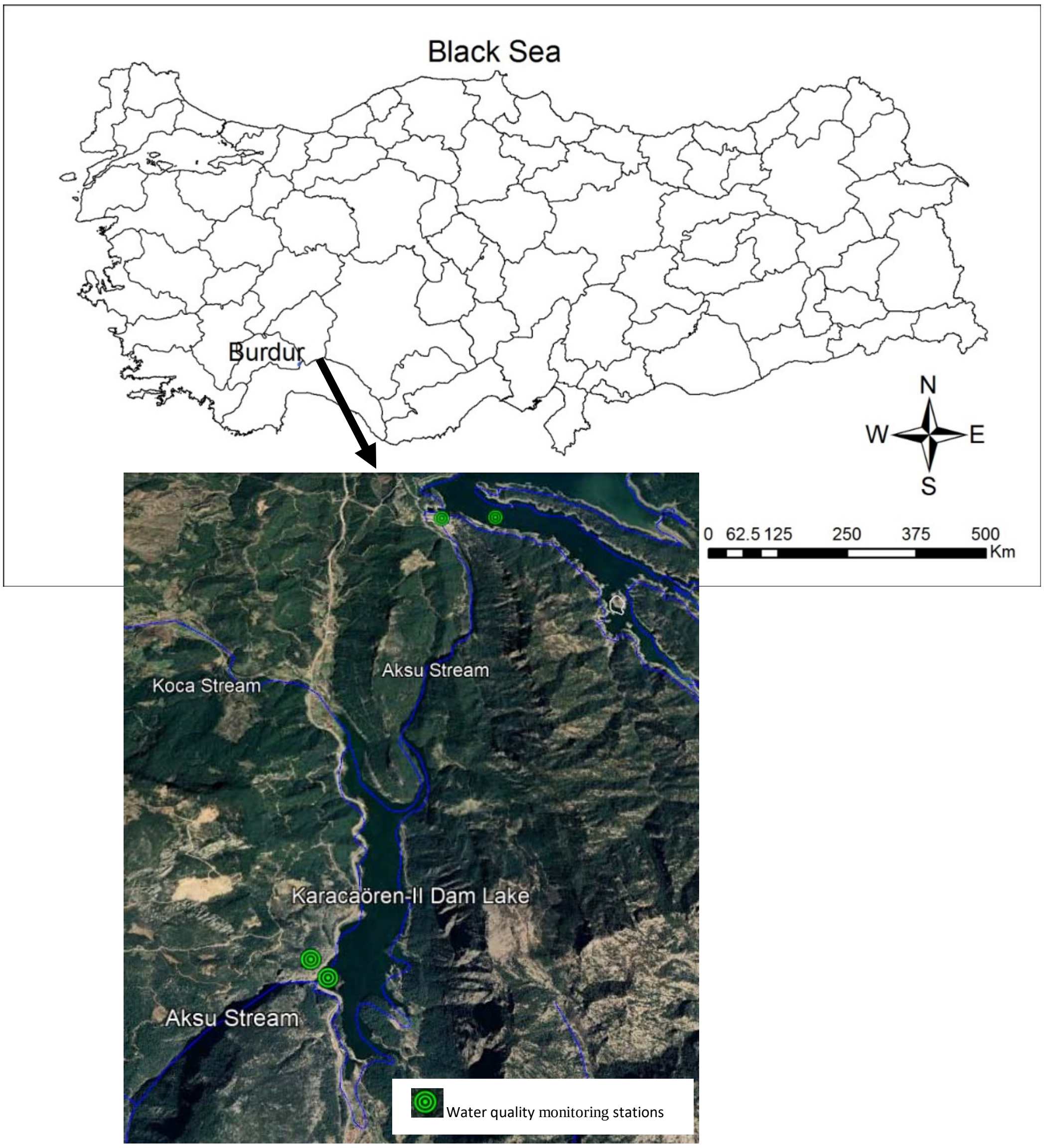

Figure 1. Karacaören-II Dam Lake and water quality monitoring stations

2.2. Methods

In this study, the relationship between water quality parameters and meteorological variables were examined by correlation analysis and principal component analysis. Thus, the most correlated and prominent parameters in explaining the change in the data set for 2005-2014 were determined. SPSS program (version 23) developed by IBM was used to perform correlation analysis and principal component analysis. As a first step, Pearson Correlation Coefficients were calculated to determine the degree and direction of the relationship between water quality parameters and meteorological data. The correlation values were tested within the 95% confidence limits to decide whether the relations between the variables were acceptable or not. The results obtained from the reliable correlations were discussed. The Pearson correlation coefficient is always between -1 and +1, and the closer the coefficient is to -/+1, the closer to perfect correlation. Pearson correlation coefficient indicates a very high correlation above 0.8, a high correlation between 0.6-0.8, a moderate correlation between 0.4-0.6, a weak correlation between 0.2-0.4, and a very weak relationship below 0.2. If the correlation coefficient is negative, there is an inverse relationship between the two parameters, indicating that if one of the parameters increases, the other decreases. If the correlation coefficient is positive, there is a positive relationship in which one of the parameters increases as the other increases [14].

After the correlation analysis, the main components that can explain the change in the data set consisting of water quality and meteorological parameters were determined. Principal component analysis mathematically consists of five steps: (1) Standardization of the measurements to ensure that all variables are equally weighted in the analysis, that is, coding the variables as X_1,

X_2, …, X_p with zero mean and unit variance, (2) calculation of covariance matrix (C), (3) finding the eigenvalues (λ_1, λ_2,......, λ_p) and corresponding eigenvectors (a_1, a_2, …, a_p), (4) discarding components that makeup only a small part of the variation in the data set, and (5) developing the factor loading matrix and determining the principal components [15]. By following these steps, the main components that explain the change in the data set for the period 2005-2014 in Karacaören-II Dam Lake and the parameters that make up these components were determined using the SPSS program.

In the next step, the Mann-Kendall Trend Analysis test was applied to determine trends in DO, BOD_5, TN, TP, pH, and TSS parameters. A trend is defined as the long-term increase or decrease of a variable observed over time or space. Trend analysis helps to statistically determine whether the values of a random variable are decreasing or increasing over a period of time. A non-parametric Mann-Kendall test was choosen as it is not affected by the distribution of variables and is based on the calculation of the Kendall correlation coefficient. In addition, a non-parametric method was preferred in order not to be affected by situations such as not measuring water quality data at regular time intervals, missing data, not knowing the exact value of some values, expressing them as lower or higher than the lower and upper limit values [16-17]. The MK test is a widely used method for determining hydro-meteorological time series and water quality trends [18-19]. The null hypothesis for the Mann-Kendall test is that there is no change in the probability distribution of a random variable over time. In other words, the null hypothesis is that there is no trend in the data series. 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 pairwise comparisons between variables in a time-series format. If the value of a particular variable is greater than the previous one at a given time, the plus sign is recorded (Equation (1)). If it is smaller, a minus sign is assigned. The test statistic is calculated as the difference between the total number of plus signs (representing the time increase) in the run time and the total number of minus signs (representing the time decrease). The zero test statistic shows no change over time (accepting the null hypothesis). The larger the deviation of the test statistic from zero, the more likely it is to observe a trend in the data and the more likely it is to reject the null hypothesis.

MK test statistic was calculated using Equation (2). In Equation (2), P is the total number of values marked positive, N is the total number of values marked as negative, and n is the total number of observations [16-20].

$$\text{sgn}(X_j - X_k) = \begin{cases} +1 & \text{If } (X_j - X_k) > 0 \\ 0 & \text{If } (X_j - X_k) = 0 \\ -1 & \text{If } (X_j - X_k) < 0 \end{cases} \quad (1)$$

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

To perform trend and correlation analysis, water quality data between 2005 and 2014 years were obtained from the 13th Regional Directorate of DSI, and meteorological data from the 4th Regional Directorate of Meteorology. The 13th Regional Directorate of DSI has an accredited testing laboratory for water quality. Although the data obtained from the laboratory was accurate and reliable, it was also preprocessed before using in the statistical analysis. The units of water quality parameters were checked, and spikes were removed from the data. Water quality parameters with sufficient data were selected for trend analysis. BOD_5, DO, pH, NH_4-N, NO_2-N, NO_3-N, TKN, TN, o-PO_4, TP and TSS were the selected water quality parameters in this study. These parameters are the good indicators of productivity and water quality in lakes. They are commonly utilized in the determination of trophic status and pollution loads in lakes and reservoirs. Temperature, wind speed, humidity, pressure and vaporization are the meteorological parameters used in the study. These parameters have significant impact on productivity and water budget of lakes. In this study, annual average values were calculated for water quality and meteorological data, and correlation analysis, principal component analysis, and MK trend analysis were performed using these values.

3. Results and Discussion

The Pearson correlation coefficients calculated to show the degree and direction of the correlation between water quality parameters and meteorological data are given in Table 1. The correlation coefficient can be positive or negative, as seen in the table. When Table 1 is examined, it is seen that there is a very high positive correlation between nitrate nitrogen (NO_3-N) and dissolved oxygen (DO) with a correlation coefficient of 0.868, which is significant at the 0.01 level. The very high positive relationship between nitrate nitrogen and dissolved oxygen can be explained by the dependence of the nitrification process on oxygen supply [21]. Total Kjeldahl nitrogen (TKN) also represents high positive correlations significant at the 0.05 level with dissolved oxygen (DO), nitrate-nitrogen (NO_3-N), and total nitrogen (TN). Total Kjeldahl nitrogen is the sum of organic nitrogen and NH_4-N. So, it determines both the organic and the inorganic forms of nitrogen. High positive correlation between TKN and NO_3-N can be attributed to the oxidation of the TKN (organic and inorganic nitrogen) to nitrate nitrogen by the nitrification process. Furthermore, total nitrogen has a high positive correlation with pH and temperature with correlation coefficients of 0.665 and 0.695, respectively. The positive relationships between TN, pH, and temperature can be readily explained by photosynthesis, since CO_2 assimilation increases pH values [21-22]. In addition, Total Suspended Solids (TSS) with a 0.707 correlation coefficient shows a significant positive correlation with total phosphorus (TP). This may be due to the fact that precipitation introduces TP to the lake via surface runoff [7]. The moderate correlations of TP and TSS with precipitation confirm this statement. However, BOD_5 has high negative correlations with dissolved oxygen and nitrate nitrogen (NO_3-N). BOD_5 represents the amount of oxygen consumed by microorganisms during decomposition of organic matter. While BOD_5 increases in lake, the decrease of DO and NO_3-N are expected [23]. Ammonium nitrogen (NH_4-N) give also high negative correlations with total Kjeldahl nitrogen (TKN), pH, total nitrogen (TN), total suspended solids (TSS), and total open surface vaporization with the varying correlation coefficients between -0.6 and -0.784. Nitrogen is usually removed from lakes by NO_3-N denitrification simultaneously with the oxidation of organic matter. On the other hand, high pH would favor N release to the atmosphere as NH_3 in highly productive surface waters [24]. This mechanism explains high negative correlation between NH_4-N and pH. The release of nitrogen to the atmosphere as ammonia (NH_3) also decreases NH_4-N, TKN and TN concentrations within lake. High negative correlation between open surface vaporization and NH_4-N can be as a result of the lost of ammonia (NH_3) nitrogen by volatilization.

Only temperature within meteorological parameters exhibited high correlation with TN. Temperature affects directly the growth rate of algae. Increase in temperature up to a certain level increases algal growth rates [25]. This can cause the increase of TN in lakes.

Table1. Correlations between water quality parameters and meteorological parameters

Parameter	BOD_5	DO	pH	NH_4-N	NO_2-N	NO_3-N	TKN	TN	o-PO_4	TP	TSS
BOD_5	1.000	-.653*	-.311	.032	.226	-.787**	-.416	-.189	.231	-.298	.291
DO	-.653*	1.000	.059	-.173	-.211	.868**	.710*	.178	-.314	.002	-.078
NH_4-N	.032	-.173	-.750*	1.000	.188	-.369	-.732*	-.784**	-.067	-.507	-.600*
NO_2-N	.226	-.211	-.071	.188	1.000	-.369	-.344	-.537	-.087	-.306	-.241
NO_3-N	-.787**	.868**	.317	-.369	-.369	1.000	.764*	.456	-.205	.371	.097
o-PO_4	.231	-.314	-.092	-.067	-.087	-.205	-.338	.144	1.000	-.272	-.015
TKN	-.416	.710*	.517	-.732*	-.344	.764*	1.000	.713*	-.338	.445	.396
pH	-.311	.059	1.000	-.750*	-.071	.317	.517	.665*	-.092	.398	.068
TSS	.291	-.078	.068	-.600*	-.241	.097	.396	.442	-.015	.707*	1.000
TN	-.189	.178	.665*	-.784**	-.537	.456	.713*	1.000	.144	.529	.442
TP	-.298	.002	.398	-.507	-.306	.371	.445	.529	-.272	1.000	.707*
Temperature	-.304	.199	.578	-.344	-.490	.373	.437	.695*	.118	.002	-.255
Wind Speed	-.092	-.110	.287	.072	-.467	-.006	-.080	.276	.246	-.316	-.525
Precipitation	-.012	.124	-.097	.016	-.317	.248	.332	.295	-.544	.502	0.400
Humidity	-.186	.216	-.525	.529	.251	.067	-.085	-.561	-.575	.008	-.131
Pressure	-.304	.196	-.260	.149	.291	.165	-.213	-.266	.567	-.188	-.151
Total Open Surface Vaporization	.139	.016	.477	-.600	-.199	.015	.203	.373	.478	-.153	.108

*Correlation is significant at 0.05 level.
** Correlation is significant at 0.01 level.

Except tempretaure, all other meteorological parameters exhibited moderate, weak and very weak correlations with water quality prameters. For example, total open surface vaporization has a moderate positive correlation with orthophosphate phosphorus and pH with 0.478 and 0.477 correlation coefficients, respectively. As the total open surface vaporization increases, it means that the orthophosphate phosphorus and pH in the lake also increase. This can be attributed to the fact that vaporization enhance the conditions for eutrophication and increase algal productivity due to low lake volume. The increase in algal productivity rates increases water pH, as well.

After the correlation analysis, Principal Component Analysis (PCA) is performed. Principal components obtained from PCA analysis are depicted in Figure 2. Moreover, the variance in the data set explained by each principal component is given in Table 2. According to Table 2, the first component explains 31.768 % of the variance in the examined data set. In the first component, mostly nitrogen species such as NH_4-N, NO_3-N, TKN, and TN are present. pH and average temperature are also included in the first component. The TN: TP ratio indicates which nutrient limits growth in the lakes. If the ratio is less than 10, nitrogen is the limiting nutrient. If it is higher than 17, P is the limiting nutrient. If the ratio is between 10 and 17, this means that both N and P can limit the growth [26]. When TN: TP ratio is calculated based on the mean TN and TP concentrations given in Table 3, it is found as 15.86. This means nitrogen or phosphorus can be limiting nutrients for growth separately or together. Figure 2 confirms this statement because nitrogen locates in the first component and phosphorus in the second component. Both of them are very crucial for the lake's water quality.

The second component includes o-PO_4 and meteorological parameters like precipitation and open surface vaporization. The second principal component explains a 21.21% change in the data set in addition to the first component. The last component explaining 15.54% of the variance is composed of BOD_5, DO, and TSS. The three key components listed in Figure 2 describe 68.52 % of the variance in the examined data set.

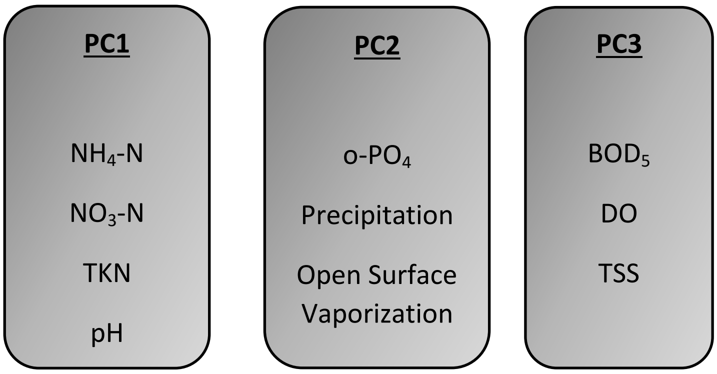

Figure 2. Principal Components

Table2. Total Variance Explained by each principal component

Principal Components	% of Variance	Cumulative %
1	31.768	31.768
2	21.211	52.979
3	15.543	68.522

Following principal component analysis, trend analysis was carried out to examine the changes in water quality of Karacaören-II Dam Lake during the 2005-2014 period. Mann Kendall test is used to determine the trends for TN, TP, DO, BOD_5, pH and TSS. Statistical data of water quality parameters and results obtained from trend analysis are given in Table 3. The H_0 hypothesis in the Mann-Kendall analysis is that there is no trend in the series. If the p-value calculated from the trend analysis is greater than the confidence level alpha value, the H_0 hypothesis is accepted. This indicates no trend in the water quality series in question. If the p-value is less than the alpha value, the trend is present in the water quality series studied [15]. Because the p values of the dissolved oxygen, BOD_5, pH, and total suspended solids parameters are greater than the alpha values, they do not show any trend between the 2005 and 2014 years. Whereas, the total nitrogen and total phosphorus parameters with the p values which are smaller than the alpha value show a positive increasing trend. NO_3-N: NH_4-N ratio is directly related to the TN: TP ratio for lakes [24]. So, the increase of TN and TP in the dam lake may cause the change in the concentrations of NO_3-N and NH_4-N, as well. As a result, lake trophic state can change. Therefore, some measures must be taken to reduce the total nitrogen and total phosphorus loads coming into Karacaören-II Dam Lake to improve the trophic level in the lake and to prevent possible eutrophication problems in the near future.

Table3. Mann-Kendall trend analysis results for water quality parameters

Parameter	Min	Maximum	Mean	Std. Deviation	p-value	alpha	Trend
TP (mg/L)	0.000	0.205	0.052	0.068	0.032	0.05	↑
TN (mg/L)	0.000	1.430	0.825	0.541	0.008	0.05	↑
DO (mg/L)	7.000	10.650	8.293	1.034	0.242	0.05	-
BOD_5 (mg/L)	0.500	9.075	5.108	2.383	0.569	0.05	-
pH	7.663	8.375	8.022	0.223	0.122	0.05	-
TSS (mg/L)	1.500	15.750	5.902	4.542	0.054	0.05	-

4. Conclusions

The results obtained in this study show that the highest positive correlation is observed between nitrate nitrogen and dissolved oxygen. Additionally, the temperature is the most effective meteorological parameter on the lake water quality for the study period. The results of the principal component analysis indicate that nitrogen, phosphorus, pH, temperature, precipitation, and vaporization are the key variables effecting the water quality of the Karacaören-II Dam Lake.

It can be concluded from the study that the TN and TP indicate positive increasing trends at statistical significance. The increasing trends of these parameters can lead to water quality problems in the future, such as not achieving good water status and having high trophic status. Therefore, some precautions including improvements in current wastewater treatment plants discharging into streams flowing into the Dam Lake, modifications in the current irrigation technologies to reduce the loads coming from agricultural lands to the lake can be taken. Changes in the product pattern within agricultural areas located in the watershed of the lake may also contribute to the reduction of the total nitrogen and phosphorus loads reaching to the lake.

Declaration of Ethical Standards

The author of this article declares that the materials and methods used in this study do not require ethical committee permission and/or legal-special permission.

Conflict of Interest

The author declares that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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