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ARAŞTIRMA MAKALESİ RESEARCH PAPER

Assessment of Ecological Status of Damsa Dam (Nevşehir, Türkiye) Using Trophic Classification Indexes, Geospatial and Statistical Techniques

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Abstract: In this study, the water quality and trophic status of Damsa reservoir were evaluated using spatial and multivariate statistical analysis. When the thematic spatial distribution maps created for each parameter were analysed, it was determined that the water quality of Damsa Dam was class I water (very good) in terms of temperature, pH and dissolved oxygen and class III water (moderate) in terms of total N concentration. In the study, the changes on eutrophic status were analysed by global index categorisations and it was determined that Carlson trophic status index was CTSI=66.6, Burns trophic level index was BTLI=6.2 and Shu trophic status index was STSI=64.7. The results showed that Damsa Reservoir can reach the limits of 'eutrophic' according to CTSI classification scale, 'eutrophic' according to STSI classification scale and 'hypereutrophic' according to TLI classification scale. For this reason, the water quality of Damsa reservoir should be monitored continuously in certain periods and necessary interventions should be made in case of pollution.

Keywords: Damsa dam, physico-chemical pollution, spatial analysis, trophic index.

Damsa Barajı'nın (Nevşehir, Türkiye) Ekolojik Durumunun Trofik Sınıflandırma İndeksleri, Mekansal ve İstatistiksel Teknikler Kullanılarak Değerlendirilmesi

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Öz: Yapılan bu çalışmada; Damsa baraj gölü su kalitesi ve trofik durumu mekansal ve çok değişkenli istatistiksel analiz kullanılarak değerlendirilmiştir. Her bir parametre için oluşturulan tematik mekânsal dağılım haritaları incelendiğinde, Damsa Barajının sıcaklık, pH ve çözünmüş oksijen yönünden su kalitesinin I. sınıf su (çok iyi), toplam N konsantrasyonu bakımından III. sınıf su (orta) olduğu belirlenmiştir. Araştırmada, ötrofik durum üzerindeki değişiklikler, küresel indeks kategorilendirmeleriyle incelenmiş olup Carlson trofik durum indeksi'nin CTSI=66.6, Burns trofik seviye indeksi'nin BTLI=6.2 ve Shu trofik durum indeksi'nin STSI=64.7 olduğu belirlenmiştir. Sonuçlar; Damsa Baraj gölünün CTSI sınıflandırma ölçeğine göre "ötrofik", STSI sınıflandırma ölçeğine göre "ötrofik", TLI sınıflandırma ölçeğine göre "hipereutrofik" sınırlarına ulaşabileceğini göstermiştir. Bu nedenle, damsa baraj gölünde belirli dönemlerde tekrarlanmak suretiyle su kaliteleri sürekli olarak izlenmeli ve kirlenme durumunda gerekli müdahalelerin yapılması sağlanmalıdır.

Anahtar kelimeler: Damsa barajı, fiziko-kimyasal kirlilik, mekansal analiz, trofik indeks.

INTRODUCTION

Today, increasing water demand with rapid population growth, global warming, increasing pollution load with the development of industry and differentiation of waste composition discharged to the ecosystem adversely affect the quality of water resources. Pollutants arising from domestic, industrial and agricultural activities firstly mix into rivers and reach lakes, dams and even seas through rivers. Since reservoirs are continuous receiving environments, they are affected by environmental pollution at the first degree. The parameters constituting the physicochemical structure of waters vary from source to source depending on the geological structure of the water bed and the anthropogenic activities affecting the source. For this reason, each water source requires effective monitoring within itself and the quality of water is of great importance as well as the existence of water in order to ensure the continuity of ecological balance (Karadavut et al., 2011; Karadavut et al., 2012; Mdee et al., 2024; Mutlu & Güzel, 2024; Yılmaz, 2004). As of 2021, 861 dams are operating in our country and these dams may experience more pollution problems depending on their morphological structures, short water retention period and the quality and quantity of the water discharged into the lake (Küçükönder et al., 2022). Pollution observed in surface waters is divided into two as point and diffuse. Point source pollution occurs when wastewater is discharged from a single point. Diffuse pollution is the type of pollution caused by pollutants that reach the receiving environment by passing through large areas in different time periods depending on meteorological events and the structure of the land. Since the structure of the waters forming diffuse pollution depends on climate, surface shape, hydrology, land use and soil structure, detection and control of diffuse pollution is much more difficult (Yıldız & Karakuş, 2018). Rapid pollution and depletion of water resources have led people to find new water resources. Therefore, artificial ponds are constructed in many river basins and ponds are tried to be filled by utilising both surface runoff and rainfall from the atmospheric water cycle. However, these artificial ponds should also provide water quality for drinking and irrigation (Cüce et al., 2020). Physical and chemical evaluation of water quality is very important in terms of providing information about the current status of water in the studies to determine the pollution and its effects (Bağdatlı et al., 2017). For this reason; in recent years, the importance and number of studies on pollution parameters affecting water quality and ecological health risk assessment in aquatic environments have been increasing (Cüce et al., 2022a; Cüce et al., 2022b; Fındık & Aras, 2023; Ustaoğlu et al, 2020). In order to ensure the continuity of ecological balance and to benefit from water resources efficiently, water quality should be monitored repeatedly in certain periods, important factors affecting pollution should be determined and appropriate measures should be taken. In particular, point and non-point pollutant sources around the dams used as drinking and utility water should be taken under control (Kalıpcı et al., 2020). In this context, a proper assessment and prediction of possible changes in water quality is necessary. The first step towards this goal is to analyse the dam lakes determination of trophic levels. Trophic status of water in reservoirs, biological It is used as an important indicator in terms of productivity, pollution protection, eutrophication risk. Determination of the trophic level will also enable the classification of the lakes and the making of healthy and valid plans for fisheries (Ayvaz et al., 2011; Aslantürk & Çetinkaya, 2022). This study is important in terms of providing data for the proper use of water and protection of water quality. Therefore, in this study, the physicochemical parameters of Damsa dam, which is used as drinking and irrigation water, were determined and the trophic status of the dam lake was evaluated according to different indices by multivariate statistical analysis and geographic information systems (GIS).

MATERIAL AND METHOD

This study was carried out in Damsa Dam Lake, which was constructed within the borders of Nevşehir province. In this comprehensive study, monitoring and evaluation studies were carried out in three stages in order to determine the trophic water quality in the central part of Anatolia where the effects of water pollution, drought and agricultural drainage waters are intense. Firstly, multidimensional statistical analyses (clustering, correlation, PCA) were performed on all results and the periodic dimension of physico-chemical pollution in water was addressed. Secondly, the trophic status of the reservoir water was calculated using various ecological status indices (Burns et al., 1999; Carlson, 1977; Shu, 1993). Thirdly, the trophic status of the reservoirs was assessed through spatial analysis using geographic information systems (ArcGIS).

Study Area and Sampling: Damsa Dam, which was selected as the study area, was constructed between 1965 and 1971 for irrigation purposes on Damsa Stream in Ürgüp district of Nevşehir province (Figure 1). The dam has a body volume of 862000 m^3, a lake volume of 7.12 hm^3 at normal water level and a lake area of 0.82 km^2 at normal water level. The dam provides irrigation service to an area of 1390 hectares and 1 hm^3 of drinking-utility water per year. At the same time, the dam is also used as a picnic area with its appearance and forested surroundings. It is 30 km to the city centre and 9 km to the district centre (Ürgüp). The coordinates of Damsa Dam, which was determined as the study area, are 38° 32‘North latitude and 34° 55’ East longitude, and the province of Nevşehir in the Central Anatolia Region has a continental climate and the average water height is 32.50 metres. It has been revealed that temperatures are in an increasing trend due to global climate change around Nevşehir Damsa Dam and precipitation is gradually decreasing in the region, which triggers the decrease in the water amount of Damsa Dam (Bağdatlı et al., 2015; Kalıpcı et al., 2017).

Sampling was carried out during the spring mixing period (March, April, May) in 2020. Surface water samples were collected from 12 stations at Damsa Dam using Nansen bottle in plexiglass sample containers (Figure 1). The coordinates of the sampling stations were taken with a

Magellan Exp710 GPS device. Real-time field measurements of water quality parameters such as temperature, pH, dissolved oxygen (DO), total suspended solids (TSS) and electrical conductivity (EC) were performed using a portable Hach 40dQ multi-meter probe. In addition, fluorometric analysis was performed to determine chlorophyll-a concentrations in surface water samples. Concentrations of anionic surfactant, TP, TN and Cl- in samples stored at +4 ˚C were quantitatively determined using laboratory test kits (Hach-Lange) and conventional procedures (APHA, AWWA, WEF, 2012). In all experimental studies carried out in the laboratory, pure chemicals of Merck and Sigma Aldrich brand quality were used and all sets were carried out in three replicates. Spectrophotometric measurements were performed in the laboratory using a Hach Lange DR3900 thermo-reactor.

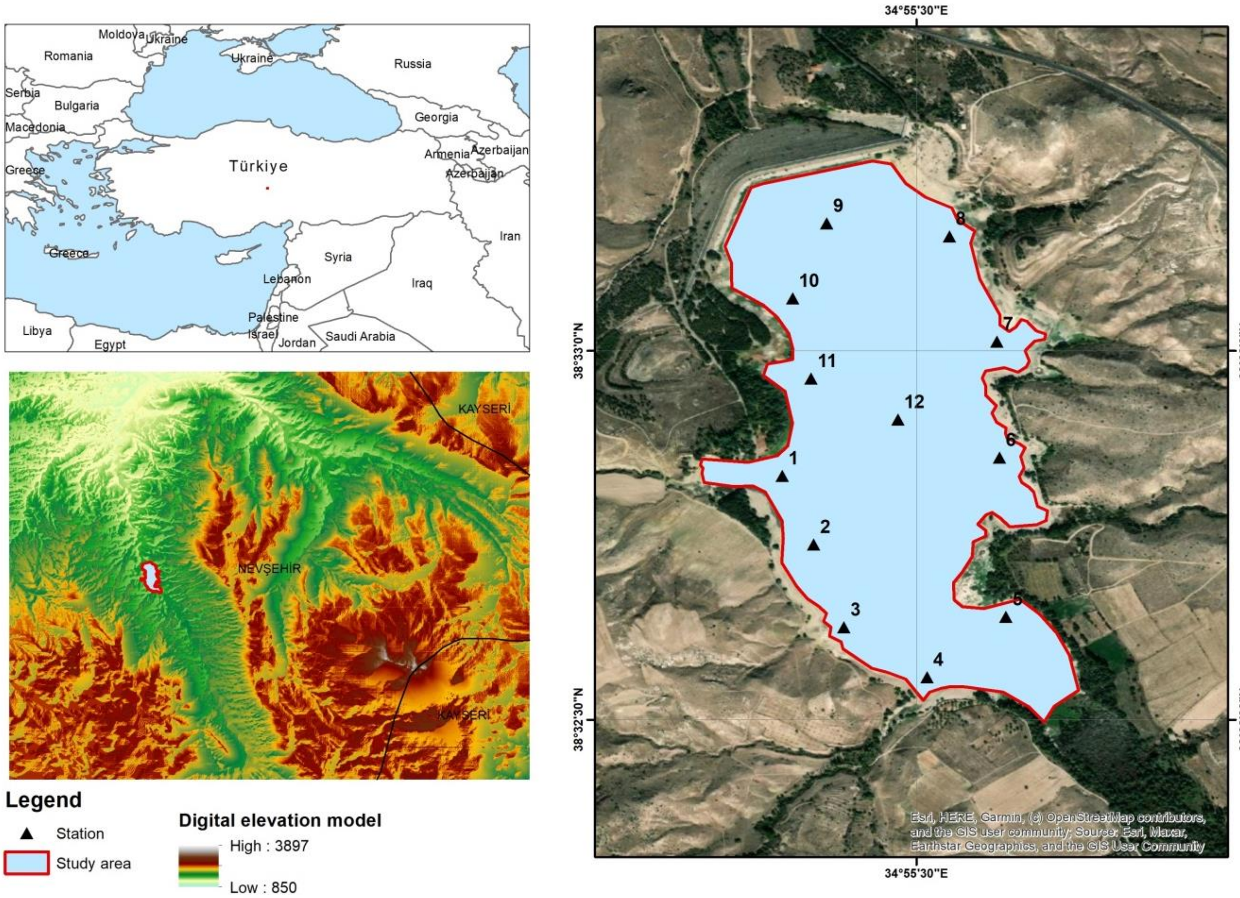

Figure 1. Sampling points in the Damsa dam lake.

Eutrophical Assessment: In this research, Carlson Trophic Status Index, CTSI (Carlson, 1977), Burns Trophic Level Index, BTLI (Burns et al., 1999) and Shu Trophic State Index, STSI (Shu, 1993) values were computed to assess the periodical change in th e trophic status of the dam surface water. The Carlson index is widely used by government officials and researchers to indirectly estimate algal biomass and a key indicator of the health of aquatic ecosystems for the extent of lentic system eutrophication (Jeppesen et al., 2000). It is calculated mathematically based on the relevant equations for three parameters (chlorophyll-a, Secchi depth, and total P). In this study, Carlson Trophic Status Index was obtained from periodic Chl-a values. Equation 1 is as follows:

$$TSI(Chla) = 10\left(6 - \frac{2.04 - 0.68 \ln Chla}{ln2}\right) \qquad (1)$$

Carlson trophic state index (CTSI) value; A value below 40 indicates an oligotrophic water quality, between 40 and 60 a mesotrophic quality, between 60 and 70 an eutrophic quality, and a value above 70 an hypertrophic quality (Carlson & Havens, 2005). Burns et al. (Burns et al., 1999) developed the Burns Trophic Level Index, BTLI to determine the trophic status of lakes in New Zealand. This required changing the Carlson TSI, which meant getting rid of the TN parameter. In this study, the seasonal trophic level in the dam lakes were based on the average value parameter of Chl-a for the BTLI. Burns Trophic Level Index (BTLI) value; The classification of water quality levels is as follows: levels below 3 are oligotrophic, 3–4 are mesotrophic, 4–5 are eutrophic, 5–6 are super-oligotrophic, and levels above 7 are hypertrophic (Burns et al, 2005).

$$TLI(Chl_a) = 2.22 + 2.54\log(Chl_a) \quad (2)$$

The method developed by Shu (Shu, 1993) to assess the periodic eutrophication of lakes, defined as the Shu model, calculates index values reflecting the current trophic state of the lake based on the algorithm defined below (equation 3), focusing on chlorophyll-a concentration. The unit of chlorophyll a concentration is µg/L. Shu Trophic State Index (STSI) value; ≤20 indicates oligotrophic, ≤40 mesotrophic, ≤70 eutrophic, ≤80 hypertrophic and ≤100 extremely hypertrophic water quality (Shu, 1993).

$$TSI(Chl - a) = 10(2.46 + \frac{\ln(chl-a)}{\ln(2.5)} \quad (3)$$

The trophic status of the Damsa dam lake was constructed in accordance with the relevant legislation of Türkiye. This ordinance, "Surface Water Quality Management Regulations (SWQR)" was reported in the Official Gazette of the Republic of Türkiye (2012 / 28483). Table 1 shows the SWQR trophic classes (SWQR, 2012). However, by using the trophic status classification of lakes and ponds determined by the National SWQ regulations of Türkiye, the trophic level of the irrigation/energy dam with CTSI, BTLI and STSI values has been revealed.

Table 1. Trophic classifications based on SWQR according to the legislation of Türkiye (SWQR, 2012).

Trophic Classes	TP (µg/L)	TN (µg/L)	Chl_*a* (µg/L)	Secchi Depht (m)	DO (mg/L)
Oligotrophic	<10	<350	<3.5	>4	>7
Mesotrophic	30-50	650-1000	9-15	2.0-1.5	6-4
Eutrophic	100	1500	25	1	3
Hypereutrophic	>100	>1500	>25	<1	<3

Statistical and Geospatial Analyses: All data calculations and statistical analyses used in the research were calculated using SPSS 22 software. Thematic geospatial analyses were performed using ArcGIS 10.8 software. Tercan & Dereli (2020) stated that the IDW (Inverse Distance Weighted) method allows the evaluation of the effect of each point on the other based on the inverse of the distance between the points. For this reason, the maps produced to compare the effects of Damsa reservoir on trophic/water quality were created using the IDW (Inverse Distance Weighted) distance-weighted interpolation technique.

RESULTS AND DISCUSSION

Damsa Dam Lake water's physical and chemical results: The average concentrations of physicochemical pollution parameters determined as a result of in-situ and laboratory measurements in Damsa Dam surface water during the three-month sampling period are shown in Figure 2, and the geo-spatial distribution maps of surface water quality are shown in Figure 3. Thematic geospatial maps prepared with geographical information system offer important opportunities in positioning and water quality analysis studies related to surface waters. They represent a fast and effective approach in the assessment of water quality. Due to the geological structure of Damsa reservoir environment, conductivity was determined as 419 µS/cm on average (Figure 2). The lowest EC values were determined at the measurement station no. 6 (394 µS/cm) and it was evaluated that it reached the highest value (445 µS/cm) as it approached the northern parts of the dam. According to the Turkish SWQ Regulation (SWQR, 2012), Damsa Dam has ‘very good’ category water quality in terms of EC. In addition, in terms of irrigation water, the dam pond is in the category of “water suitable for use as irrigation water and where no harmful effect will be noticed” and it was determined that it has permissible water quality. As seen in Figure 3, the pH value (<9) reached the highest level (8.51) in the southern parts of the dam. The water quality in terms of pH was determined as Class I water (very good). The temperature parameter, which is among the quality elements that should be monitored in surface waters, was excluded from the Turkish SWQ Regulation. However, during this study, the temperature value was measured in all samplings and monitored to evaluate the inter-station variation in the dissolved oxygen level in the lake and the stability of the trophic state of the reservoir.

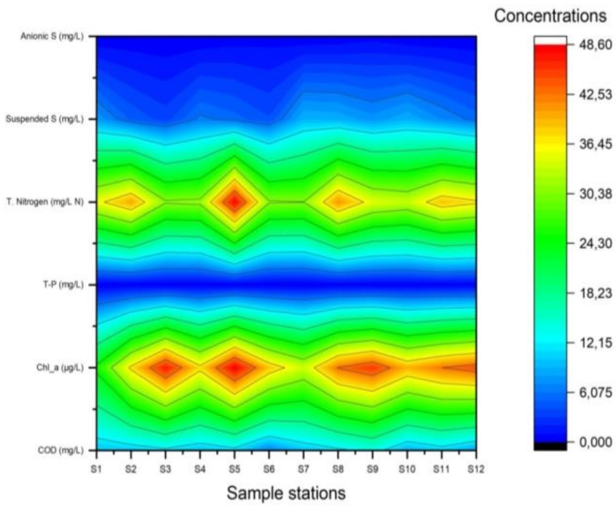

Figure 2. The distribution of average physico-chemical parameters according to sampling stations.

The mean variation of surface water temperature values according to the stations is between 12.5 - 13.03 °C. The lowest temperature recorded for surface water in the reservoir was 12.5 °C (at station no. 5 during the rainy season) and the highest temperature recorded for surface water was 13.03 °C (at station no. 12). Although there was a low temperature in the north-eastern part of the reservoir, the temperature value was found to increase in the southern parts (Figure 3).

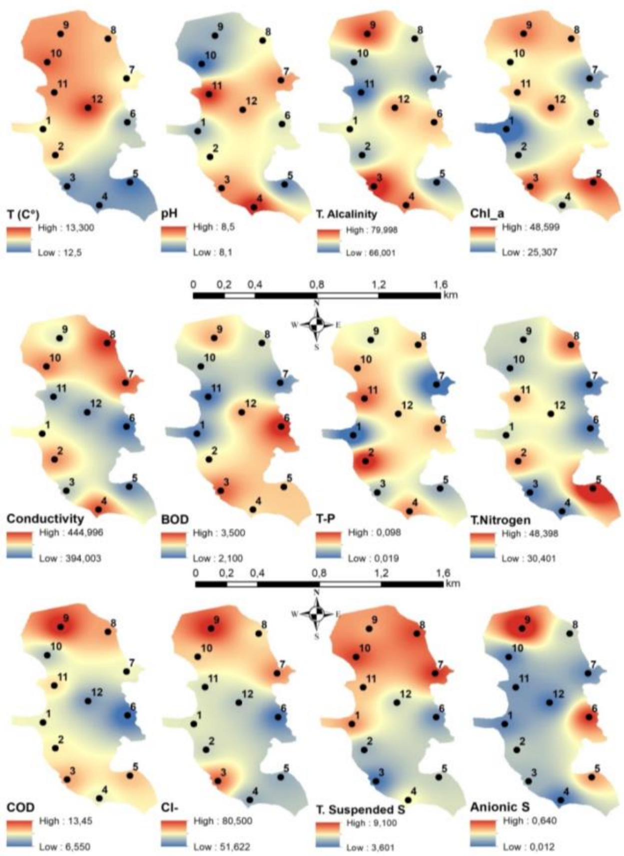

Figure 3. Geo-spatial distribution maps of surface water quality parameters (T, pH, EC, BOD, COD, Cl^-, DO, TA, Chl_*a*, TP, TN, TSS, AS).

It was determined that the average suspended solids (TSS) concentration in the measurement stations of the lake was 6.6 mg/L and the highest values were found in stations 7, 8 and 10. It is hypothesised that TSS load is caused by agricultural drainage and erosion of upper soil layers into the water environment. According to the average dissolved oxygen (DO) concentrations obtained from 12 measurement stations; the lowest DO concentration in the dam lake was 8.1 mg O2/L (at sample station 4) and the highest DO concentration was 9.2 mg O2/L (at sample stations 11 and 12). Damsa Dam is used for irrigation purposes and aquaculture activities are also carried out in the dam. Dissolved oxygen concentration in the water should be 4-5 mg O2/L for the continuation of living activities. During the analyses conducted at 12 measurement stations, no dissolved oxygen (DO) concentration below 4 mg O2/L was found. According to the Turkish SWQ Regulation (SWQR, 2012), the quality of waters with dissolved oxygen concentration greater than 8 mg/L is stated as Class I. Since the dissolved oxygen concentration in 12 stations measured in the dam surface water was greater than 8 mg/L, it was determined that this value was sufficient for the survival of aquatic organisms in the dam and this value was determined to be in the 'very good' class waters in terms of quality criteria according to the Turkish SWQ Regulation. The results of EC, pH, temperature and DO determined in this study were similar to the results of the previous study by Kalıpcı et al. (2017).

During this research, the concentrations of TP and TN levels in the reservoir according to the measurement stations and the chlorophyll-a value in all samplings were measured to evaluate the stability of the trophic state of the reservoir. The highest mean chlorophyll-a (Chl_a) concentration in the reservoir was determined at the measurement station 5 (48.6 µg/L), while the lowest (25.3 µg/L) was determined at the measurement station 1 (Figure 3).

Many factors in the lake environment affect the changes in total nitrogen and phosphorus concentrations. In the dam water, where the highest total N concentration was detected at station 5 (48.4 mg/L N), the increase in nutrient input is considered to be the most important factor affecting the trophic status of the lake. Since Total N > 11.5 mg/L N determined in all measurement stations, Damsa dam water was determined to be in 'medium' class waters according to Turkish SWQ Regulation (SWQR, 2012). The highest total phosphorus was observed at stations 2 (0.098 mg/L) and 11 (0.085 mg/L), respectively (Figure 3). It is suggested that the cause of this pollution is caused by sewage discharge, garbage and solid wastes, wastes of industrial facilities in the region. Since the total phosphorus concentration in the dam lake is < 0.08 except for measurement stations 2 and 11, Damsa dam water is classified as 'very good' according to the Turkish SWQ Regulation (SWQR, 2012). The sudden increase in the levels recorded at the measurement stations 2 and 11 in the dam is thought to be caused by the leaching of phosphate fertilisers into the water.

The highest alkalinity was determined at measuring station 3 (80 mg/L) and the lowest alkalinity was determined at measuring station 11 (66 mg/L) (Figure 3). Especially in the central-northern parts of the lake, Chemical Oxygen Demand (COD) values are extremely high for an irrigation dam and indicate an interference. According to the classification standards of continental surface water resources (SWQR, 2012), the surface water quality of the lake can be classified as 'very good' class water quality when evaluated in terms of COD and Biochemical Oxygen Demand (BOD).

Evaluation of the trophic status of the Damsa dam lake: Eutrophication is a very common water quality problem seen all over the world. Since it is a problem in both developing and developed countries, it is very important to detect, rank and determine the course of eutrophication. In order to evaluate the risk of eutrophication, trophic status should be determined as an important indicator (Akyüz, 2016; Aslantürk & Çetinkaya, 2022). The eutrophication index is an important criterion in the assessment of lake water quality and indicates a significant degree of pollution in the lake by showing a significant change in trophic levels throughout the year. The definition of the Carlson Trophic Status Index (CTSI) classification scale ranges from 0 to 100 and the findings of this regional study show that the mean CTSI for periodic Chl_a is 66.6. According to this result, Damsa reservoir is classified as 'eutrophic'.

Burns Trophic Level Index (TLI) classification hierarchy ranges from 0 to 7. According to the results of this regional study, the average TLI for Chl_a was calculated as 6.28. This result indicates that the lake may reach the regional hypereutrophic limits (Figure 4).

The Shu Trophic State Index (STSI) classification scale ranges from 0 to 100, and according to the findings of this regional study, the average STSI for periodic Chl_a was calculated as 64.78. According to these results, the lake is becoming eutrophic. Overall, the index values (CTSI, BTLI and STSI) indicate that Damsa Reservoir is hypereutrophic, which is evidenced by the high amount of phosphorus (P) and nitrogen (N) in the surface water.

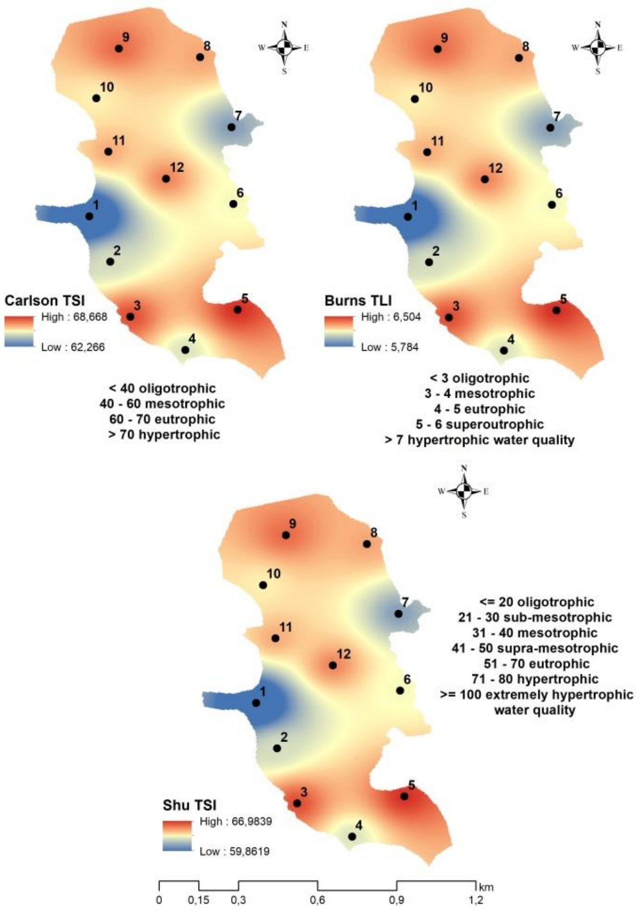

Figure 4. Geographical analysis of trophic status index values in the Damsa dam lake.

Statistical observations: The Spearman correlation analysis of the content of physicochemical pollution parameters in the surface water of the dam lake spring mix season is shown in Figure 5. While Chl_a values have a weak relationship with the temperature and pH, it was observed that there was a relatively high correlation between BOD, COD and total alkalinity. The significant correlation suggests that the majority of these organic compounds may have a common pollution source at the surface of the lake water. There is a positive correlation between this variable and TN, COD and Chl_a, while the relationship with TP is relatively limited. However, the water environment is in a state of constant change due to the activities of animals and plants and human intervention, which can result in greater variability in the stability of nutrient content in surface water environments during the mixing period.

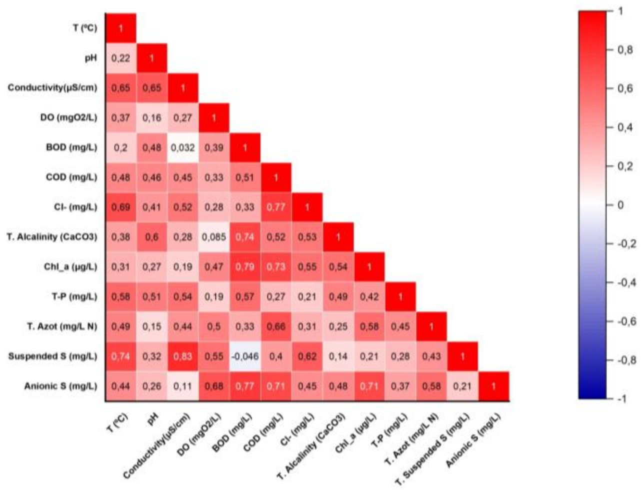

Figure 5. Spearman's correlation between physicochemical parameters.

Principal component analysis (PCA) was employed to investigate the potential sources of organic/chemical contamination. The concentration of high -level nutrients and surfactants in water is an indication of the current pollution state. For the water columns, the two principal components extracted accounted for 46.5% of the total variance (Figure 6).

The principal component was predominantly characterised by EC, TSS, COD and TA. There is a notable positive correlation between physiochemical parameters and oxygen consumption rate and chloride content in the lake, which suggests that they may have a common origin. In particular, COD plays a pivotal role in the functioning of pesticides, while TA and Cl^- serves as a vital indicator of domestic pollution. It can therefore be concluded that PC1 is indicative of pollution resulting from the domestical and chemical industries. The principal component 2 (PC2) is characterised by elevated levels of AS, BOD and TP/TN. The concentration of Chl_a is regarded as an indicator of excessive nutrient input. As a result, PC2 can be attributed to chemical industry and agricultural pollution.

The same data used in PCA were analysed to understand the similarities. The results of the double clustering analysis demonstrate the formation of two fundamental fixed clusters between the conductivity value and other physical/chemical parameters based on the variance weighted distance lines between the cluster centre points. Among the measured chemical parameters are TA – Cl^- and Chl_a - TN, which form a cluster among themselves, while the remaining parameters form a pile cluster. Upon examination of the subsets of the two main groups between the stations, S3-S4-S7 and S1-S9 and S3-S9 cluster between S1-S1-S7 and S11-12 and S5 (Figure 7).

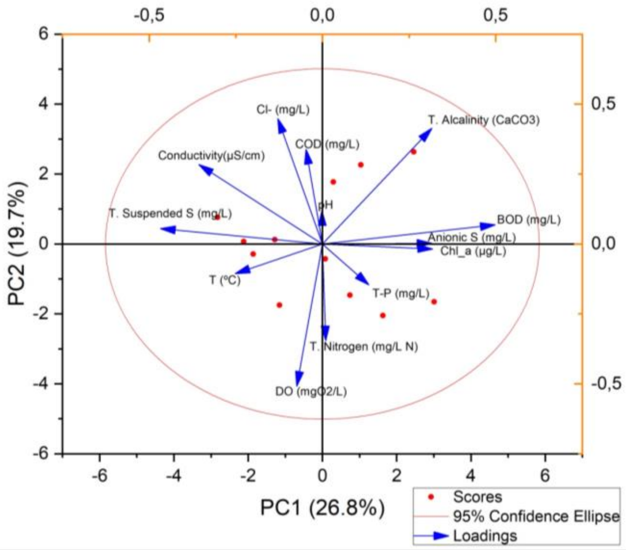

Figure 6. PCA/FA of measured physico-chemical parameters.

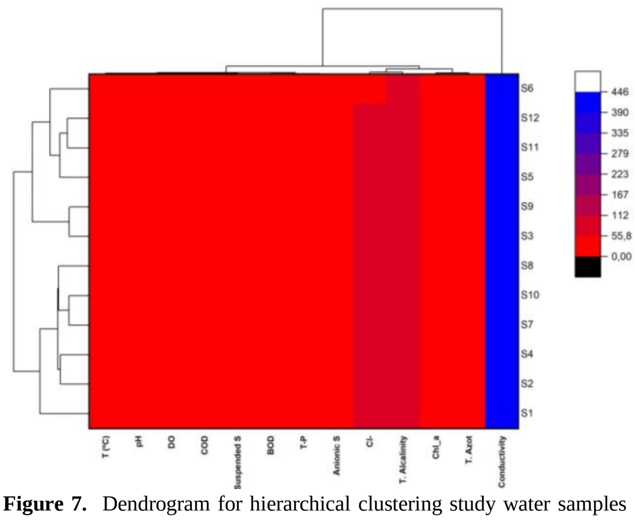
Figure 7. Dendrogram for hierarchical clustering study water samples from the Damsa Dam.

CONCLUSION

In this study, the eutrophication status of Damsa reservoir, which is subjected to the intense pressure of global warming and the possibility of agricultural drainage, and the changes in water quality according to the measuring stations were evaluated by statistical, ecological indices and thematic geo-spatial analyses. The results show that Damsa reservoir is hypereutrophic and the results of thematic maps and multiple statistical analyses indicate that extreme fluctuations in nutrients can be caused by agricultural irrigation discharges, which directly affect the eutrophication of lakes. The most important finding indicating eutrophication in the dam was the minimum and maximum values of chlorophyll-a (Chl_a), which ranged from a minimum of 25.3 µg/L to a maximum of 48.6 µg/L. Although this study reflects the current situation in the dam lake, it is necessary to increase the number of measured parameters in future comprehensive studies and seasonal monitoring of the change in the trophic state of the lake together with ecological evaluation should be carried out at certain period intervals. It is of utmost importance to carry out detailed research on the determination of the concentrations of potentially toxic elements that may accumulate in fish due to freshwater fishing in Damsa Dam. It should be ensured that the pollution in water quality is prevented by switching to good agricultural practices by ensuring the controlled use of chemical-based pesticides used intensively in the region. It is also recommended to take measures in accordance with the protection status to restrict the discharge of solid wastes, domestic and industrial wastewater into the reservoir. It is clear that improved pollution control in the reservoir system is essential to achieve optimum chemical and ecological status. This can be achieved by implementing wastewater treatment facilities while maintaining a minimum level of agricultural pollution within the system. Therefore, it is necessary to prevent sewage and solid wastes from entering the rivers through effective removal and control techniques, thus preventing potential pollutants from entering the reservoir. As a result, the findings obtained in this study will guide future studies within the framework of the sustainability of the reservoir for energy, fish farming and irrigation. It is essential to carry out anti-pollution training studies in order to use Damsa Dam Lake, which is located in the Central Anatolia region where the effect of global warming is intensely experienced, for agricultural irrigation purposes and to continue freshwater fishery in the lake area.

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