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Research Article **Araştırma Makalesi**

The Time-Dependent Dynamics of Trophic State Index Related with some Rehabilitation Approaches: Lake Mogan over 30-Year Period

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Abstract: In this study, the temporal changes of the trophic state in Lake Mogan were examined to evaluate the results of various rehabilitation approaches, including dredging, over a 30-year period. Water samples were taken from two different points seasonally between May 2022 and February 2023. The Carlson's Trophic State Index (TSI) was calculated using total phosphorus, Secchi depth and chlorophyll *a* values, and the trophic status of the lake was estimated. Furthermore, TSI was also calculated using data obtained from previous studies conducted in the lake, and a 34-year change was evaluated based on TSI, OECD, and Turkish Surface Water Regulation (SWQR). In this study, the average TSI value was calculated as 52.46, and the trophic status of the lake was determined as eutrophic. Differences in TSI (AVG) values among the months and sampling points were found statistically significant ($p<0.05$). Based on the TSI values calculated using data from previous years, it was determined that the trophic status of the lake still maintained a eutrophic level in a 34-year period despite the rehabilitation efforts. A similarity test (Bray-Curtis Similarity Index) applied to the TSI values obtained for different years showed a strong similarity between the values in 2023 and those in 1989. As a result, preparing precautionary plans against eutrophication of Lake Mogan and monitoring the trophic status via TSI is recommended.

Keywords
- Shallow lake
- Chlorophyll *a*
- Secchi depth
- Total phosphorus
- Water quality

1. INTRODUCTION

The most used approach in the classification of lakes is the trophic state classification, depending on the productivity of the lake due to nutrients. In this classification, lakes are classified on the basis of production, ranging from less productive lakes (oligotrophic) to highly productive lakes (hypertrophic). A change takes place in the trophic state of lakes over time with human-induced (anthropogenic) or natural effects.

The reason for rapid aging in lakes exposed to anthropogenic pollution is due to the increase in the amount of nutrients. This process is called eutrophication. The term eutrophication is the increase in nutrients by artificial and natural means by entering the water environment, the deterioration of water quality because of the increases of phytoplankton and algae in the water sources resulted with the decrease in the recreational value and other usage of the water body. Increased primary production in lakes causes the accumulation of organic detritus formed by the decomposition of organic substances and thus a decrease in the volume of the lake (Tanyolaç, 2009). Eutrophication, climate change and pollution are the biggest threads to the lakes. Consequently, research pertaining to water quality and pollution is of paramount significance for the conservation and

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management of lakes, rivers, and other inland waters (Tundisi & Matsumura-Tundisi, 2008; Tepe, 2009; Mutlu et al., 2014). Lake Mogan is known as an important recreation area due to its proximity to the city of Ankara. Restoration studies and sediment removal applications were carried out in the lake in different years. According to the research studies conducted in Lake Mogan, it is stated that the trophic situation is increasing gradually (Pulatsü & Aydin, 1997; Demir et al., 2014; Manav &Yerli, 2008; Mangit & Yerli, 2010).

Lake Mogan, which is located in Gölbaşı Special Environmental Protection Area is seen to be under intense human-induced urban-industrial pressure. In particular, the discharge of wastes into the lake and the nutrients reaching from the agricultural lands around the lake cause a serious increase in the pollution pressure (Yerli, 2002).

The Carlson's Trophic Status Index (TSI) was defined by using the parameters Secchi depth (SD), chlorophyll *a* (Chl *a*), total phosphorus (TP) to determine the trophic status of lakes and three mathematical equations were created to determine the trophic status (Carlson, 1977). The TSI values in these three equations are logarithmic data-transformed values. Three parameters determined in TSI are correlated with linear regression, and index values are calculated through the correlation between these variables. The limit values used to evaluate the TSI were prepared based on these parameters (Carlson, 1977). The productivity or nutrient level of a lake is determined by TSI and lakes are classified as oligotrophic, mesotrophic, eutrophic and hypertrophic according to their TSI values (Şen et al., 2003; Sezen, 2008; Varol, 2013). The Trophic State Index (TSI) is widely used in the assessment of the trophic status of lakes in Türkiye. For example, it has been applied to Lake Egirdir (Bulut & Kubilay, 2018), Lake Iznik (Yağcı, 2008), Gaga Lake (Candan, 2011), Akgöl Lagoon (Alp et al., 2014), Lake Eber (Mangıt et al., 2017; Gümüş, 2018), Çiğ Lake (Tepe et al., 2018), Balık Lake (Ariman & Koyuncu, 2019), and Balaban Lake (Ertaş et al., 2021). However, these studies are based on data collected over a period of one or two years. Evaluating long-term changes in trophic status using TSI is of great importance for monitoring eutrophication. According to Surface Water Quality Regulation of Türkiye, the trophic status of lakes is assessed using TSI (Table 9 in the Annex 6 of SWQR, 2023).

In this study, it was aimed to evaluate the trophic status of Lake Mogan according to TSI using TP, Chl *a*, SD parameters. In order to determine the temporal changes caused by the effects of ongoing recreational activities and anthropogenic pressures, TSI was calculated with the data obtained from some studies carried out in previous years and it was aimed to evaluate long term changes in the trophic status of Lake Mogan.

2. MATERIAL and METHODS

2.1. Study site

This study was carried out in the Lake Mogan (Figure 1). Lake Mogan is located 20 km south from the center of Ankara. Lake Mogan, which is an alluvial set lake between 39˚44'45" and 39˚47'45" northern latitudes and 32˚46'30" and 32˚49'30" east longitudes, is 972 m above sea level and it has a 5.4 km² lake area. With an average depth of 2.8 m, the deepest part of this lake was determined as 4 m. The width of the lake has been determined as 900-1100 m and its length as 6000 m (Akbulut, 1998; Pulatsü et al., 2008).



Figure 1. Lake Mogan and sampling stations.

2.2. Sampling, physical and chemical water analysis

In this study, water samples were taken from two sampling sites—Station 1 (39° 46′ 50.04″ N, 37° 47′ 40.50″ E) and Station 2 (39° 46′ 2.88″ N, 37° 47′ 16.92″ E)—on 13 May, 09 August, 05 November 2022, and 25 February 2023. Temperature, pH, EC (electrical conductivity), DO (dissolved oxygen), OS (oxygen saturation), TDS values were measured *in situ* by YSI ProPlus 20 multiparameter instrument. SD was determined as the depth at which the Secchi disc could not be seen in the water. Chl *a* was extracted by 96% ethanol and optical density of extract was measured spectrophotometrically (APHA, 1995). Alkalinity and TP values were determined according to APHA (1995).

2.3. Determination of the trophic state

SD, TP and Chl *a* parameters were used to determine the trophic status in Lake Mogan. TSI of these three variables was calculated according to the equations below (Carlson, 1977).

$$TSI(CHL) = 9.81 \ln(CHL) + 30.6 \quad (1)$$

$$TSI(SD) = 60 - 14.41 \ln(SD) \quad (2)$$

$$TSI(TP) = 14.43 \ln(TP) + 4.15 \quad (3)$$

$$TSI(AVG) = (TSI(SD) + TSI(CHL) + TSI(TP)) / 3 \quad (4)$$

Under the TSI scale (Carlson, 1977), the trophic level of water bodies is classified as oligotrophic (values between 0-40), mesotrophic (values between 40 and 50), eutrophic (values between 50 and 70) and hypertrophic (values 70-100). TSI (SD), TSI (CHL), TSI (TP), TSI (AVG) values were calculated according to the data obtained from the studies conducted by Bakan (1990) in 1989, by Pulatsü (1995) in 1994, by Demir et al. (2014) in 2006 and by Sanal and Demir (2018) in 2013. The calculated TSI values were taken from the studies conducted by Manav (2003) and Manav and Yerli (2008) in 2003.

2.4. Statistical analysis

The differences in the changes of temperature, SD, pH, EC, DO, OS, TDS, alkalinity, Chl *a*, TP, SD, TSI (TP), TSI (CHL), TSI (SD), TSI (AVG) values to months and sampling sites in Lake Mogan were determined by one-way ANOVA and Tukey test using SPSS (Statistical Package for the Social Sciences) 17.0 version statistical program. The similarities of TSI (AVG) results with other TSI (AVG) obtained in different from several studies in the lake were evaluated. To determine this, hierarchical clustering analysis was performed in PAST v4.09 software according to the Bray-Curtis method. A similarity matrix was created by calculating the similarity coefficients between the years (Hammer et al., 2001).

3. RESULTS

3.1. Physical and chemical results

During the study period (2022-2023) at Lake Mogan, the average water temperature was 15.34 °C, with seasonal extremes ranging from a high of 26.4 °C in August to a low of 5.45 °C in February (Table 1). The lake's shallow depth prevented thermal stratification, as evidenced by consistent temperatures from surface to bottom. The average dissolved oxygen (DO) concentration was recorded at 7.16 mg/L, peaking at 10.21 mg/L in February and reaching its lowest at 5.23 mg/L in May (Table 1). DO levels showed a seasonal increase from May to February. Oxygen saturation (OS) averaged 77.02%, with values ranging from a high of 92.85% in February to a low of 62.97% in May, similarly increasing from May to February (Table 1).

SD averaged 2.1 meters, with the maximum clarity of 3 meters observed in May and a minimum of 1.1 meters in August, indicating reduced visibility during warmer months. Following the low value in August, visibility increased in subsequent samplings. The average pH level of 8.56 exhibited minor seasonal fluctuations, with the highest reading of 8.83 in February and the lowest of 8.31 in May. Conductivity (EC) averaged 4053 µS/cm, increasing from 3314 µS/cm in May to a peak of 4498 µS/cm in February. Total dissolved solids (TDS) averaged 2722 mg/l, showing a similar seasonal trend, with the highest value of 2722 mg/l in February and the lowest at 2505 mg/l in May (Table 1). Alkalinity levels averaged 3.1 meq/l with seasonal variations peaking at 4.8 meq/l in February and dropping to 2.4 meq/l in May and November (Table 1). Chl *a* averaged 7.24 mg/m³, with a peak of 17.61 mg/m³ in August and a minimum of 0.8 mg/m³ in May (Table 1). TP concentration was 43.3 mg/m³, peaking at 70.67 mg/m³ in November and reaching a low of 18.22 mg/m³ in May. TP levels increased from May to February, with a subsequent decline by February (Table 1).

Table 1. The changes of the parameters according to the months and stations in Lake Mogan between May 2022 and February 2023).

Parameters	May		August		November		February	
	Station 1	Station 2	Station 1	Station 2	Station 1	Station 2	Station 1	Station 2
Temperature (°C)	17.55 ± 0.07^{dB}	18.05 ± 0.07^{cB}	25 ± 0.07^{bA}	26.4 ± 0.07^{aA}	12.3 ± 0.14^{eC}	11.7 ± 0.14^{fC}	6.3 ± 0.14^{gD}	5.45 ± 0.07^{hD}
DO (mg/l)	5.12 ± 0.02^{eD}	5.35 ± 0.02^{eD}	6.63 ± 0.28^{cB}	6.54 ± 0.08^{cC}	5.8 ± 0.01^{dC}	7.43 ± 0.02^{bB}	10.16 ± 0.08^{aA}	10.27 ± 0.01^{aA}
OS (%)	61.1 ± 1.41^{cC}	64.85 ± 1.62^{cC}	75.6 ± 3.39^{bB}	89.5 ± 0.7^{aA}	61.15 ± 1.62^{cC}	78.3 ± 1.83^{bB}	93.75 ± 1.06^{aA}	91.95 ± 0.99^{aA}
EC (µS/cm)	3289 ± 0.07^{hD}	3340 ± 0.01^{gD}	3916 ± 0.7^{fC}	3945 ± 0.7^{eC}	4457 ± 0.7^{dB}	4482 ± 1.41^{cB}	4492 ± 1.41^{bA}	4505 ± 1.41^{aA}
pH	8.23 ± 0.01^{eD}	8.4 ± 0.01^{dC}	8.5 ± 0.07^{cdC}	8.49 ± 0.01^{cdB}	8.7 ± 0.01^{bB}	8.54 ± 0.01^{cB}	8.85 ± 0.01^{aA}	8.82 ± 0.02^{aA}
TDS (mg/l)	2502 ± 0.01^{hD}	2509 ± 0.01^{gD}	2548 ± 0.01^{fC}	2565 ± 2.12^{eC}	2899 ± 2.11^{dB}	2912 ± 0.7^{cB}	2918 ± 0.01^{bA}	2925 ± 0.01^{aA}
Alkalinity (meq/l)	2.4 ± 0.14^{cB}	2.4 ± 0.14^{cC}	2.4 ± 0.14^{cB}	4.0 ± 0.14^{bB}	2.4 ± 0.14^{cB}	2.4 ± 0.14^{cC}	4.0 ± 0.14^{bA}	4.8 ± 0.14^{aA}
TP (mg/m^3)	18.85 ± 0.49^{dC}	17.6 ± 0.56^{dC}	44.99 ± 4.5^{bB}	44.54 ± 0.01^{bB}	69.54 ± 3.2^{aA}	71.81 ± 2.56^{aA}	29.09 ± 1.28^{cC}	49.99 ± 2.56^{bB}
Chl *a* (mg/m^3)	0.66 ± 0.1^{dC}	1.03 ± 0.2^{cdD}	18.65 ± 1.25^{aA}	16.57 ± 2.51^{aA}	3.17 ± 0.8^{cdBC}	7.72 ± 0.5^{bB}	5.15 ± 0.08^{bcB}	4.97 ± 0.08^{bcBC}
SD (m)	3.0 ± 0.14^{aA}	3.0 ± 0.14^{aA}	1.0 ± 0.14^{dC}	1.2 ± 0.14^{dD}	1.8 ± 0.14^{cB}	1.8 ± 0.14^{cC}	2.6 ± 0.14^{bA}	2.4 ± 0.14^{bB}
TSI (TP)	45.12 ± 0.01^{gD}	44.13 ± 0.01^{hD}	59.05 ± 0.007^{dB}	58.9 ± 0.01^{eC}	65.32 ± 0.01^{bA}	65.78 ± 0.01^{aA}	52.75 ± 0.01^{fC}	60.56 ± 0.01^{cB}
TSI (CHL)	26.53 ± 1.57^{dC}	30.84 ± 1.95^{dC}	59.29 ± 0.66^{aA}	58.08 ± 1.49^{aA}	41.72 ± 2.74^{bB}	50.64 ± 0.69^{bB}	46.67 ± 0.16^{bcB}	46.32 ± 0.16^{bcB}
TSI (SD)	44.17 ± 0.01^{fD}	44.17 ± 0.01^{fD}	60.0 ± 0.01^{aA}	57.37 ± 0.01^{bA}	51.53 ± 0.01^{cB}	51.53 ± 0.01^{cB}	46.23 ± 0.01^{eC}	47.38 ± 0.01^{dC}
TSI (AVG)	38.48 ± 0.01^{hD}	39.67 ± 0.01^{gD}	59.52 ± 0.01^{aA}	58.37 ± 0.01^{bA}	52.68 ± 0.01^{dB}	56.36 ± 0.01^{cB}	47.42 ± 0.01^{fC}	50.81 ± 0.01^{eC}

^{abcdefgh} The difference between the means with different letters in the same line is statistically significant ($p<0.05$).

^{ABCD} The difference between the mean with different exponents for each station on the same line according to months is statistically significant ($p<0.05$).

3.2. TSI

In this study, the mean values of TSI (AVG) were determined as 52.46, and according to this value, it was concluded that Lake Mogan is a eutrophic lake (Carlson, 1977; Carlson & Havens, 2005).

The monthly change of TSI values calculated according to TP, Chl *a* and SD in May, August, November and February for the sampling period is shown in Figure 2.

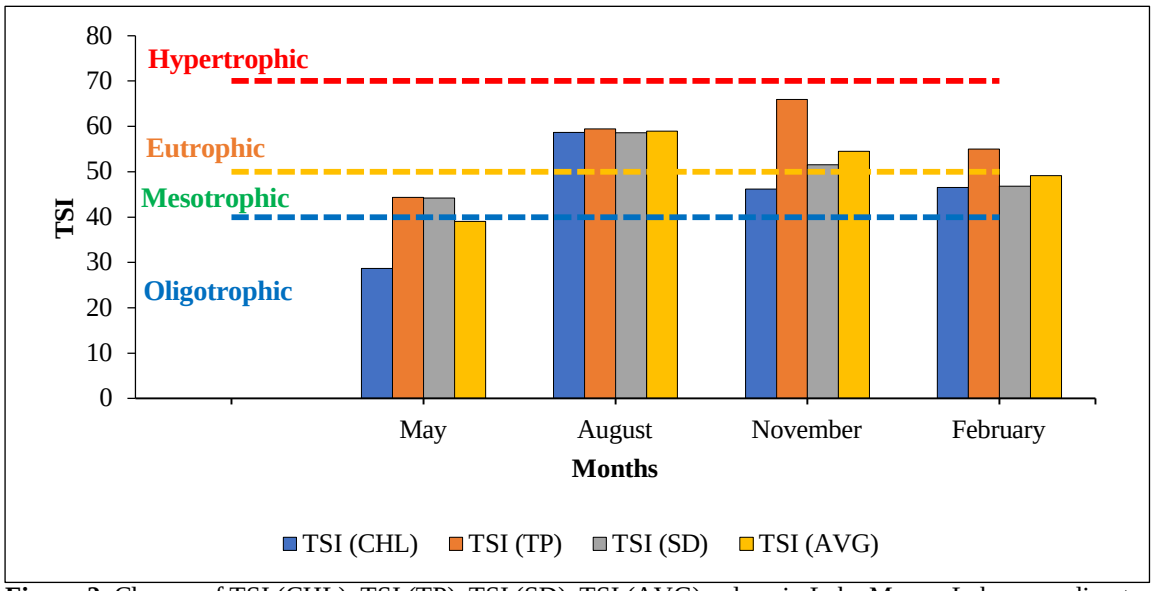

Figure 2. Change of TSI (CHL), TSI (TP), TSI (SD), TSI (AVG) values in Lake Mogan Lake according to months in 2022-2023.

TSI (SD), TSI (CHL), TSI (TP), TSI (AVG) values were calculated according to the data obtained from the studies conducted by Bakan (1990) in 1989, by Pulatsü (1995) in 1994, by Demir et al. (2014) in 2006 and by Sanal and Demir (2018) in 2013. The same parameter values were taken from the study conducted by Manav (2003) and Manav and Yerli (2008) in 2003 and are shown in Figure 3. The trophic status of the lake changed between mesotrophic and eutrophic. TSI (AVG) values are similar to this study and the study conducted by Bakan (1990) in 1989 according to Bray-Curtis similarity test (Fig. 4).

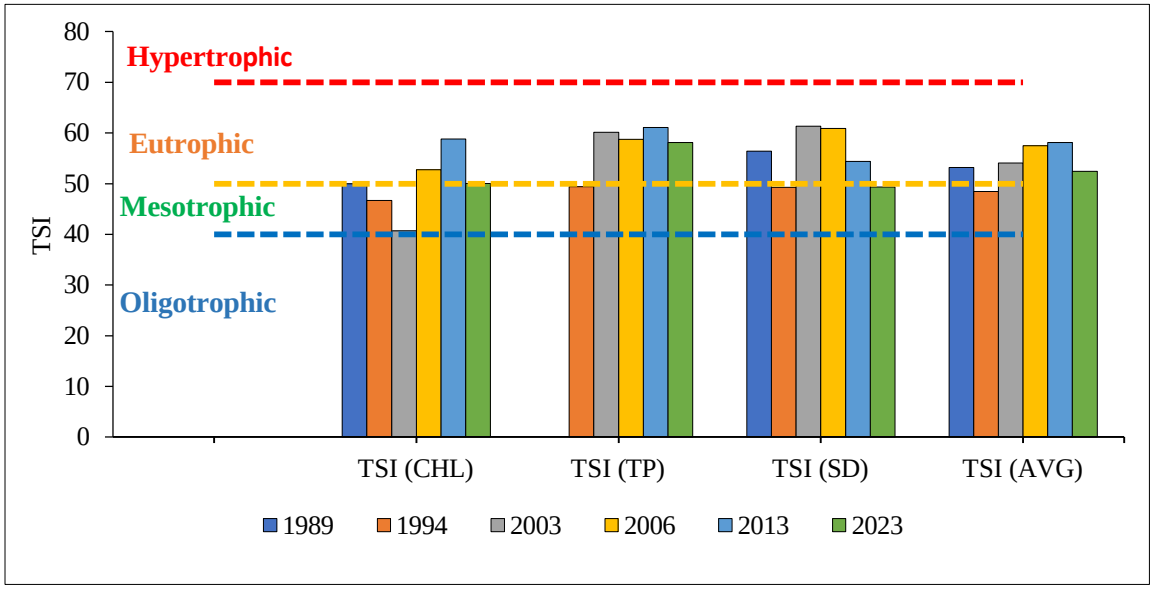

Figure 3. Change of TSI (CHL), TSI (TP), TSI (SD), TSI (AVG) values in Lake Mogan in 1989, 1994, 2003, 2006, 2013 and 2023.

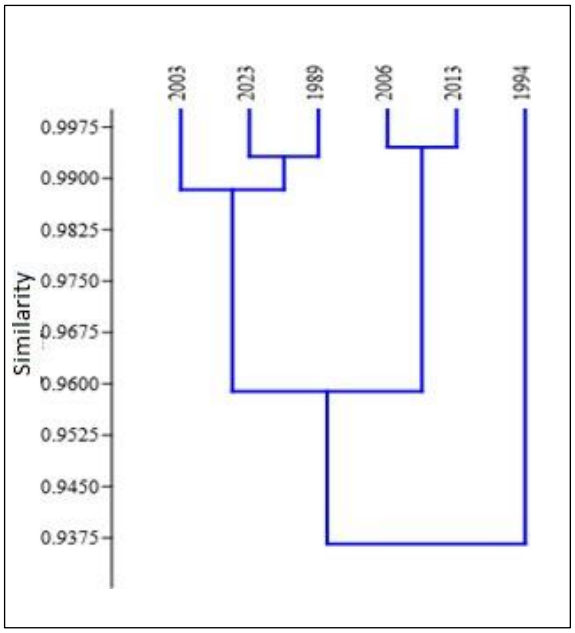

Figure 4. Bray-Curtis similarity test results between TSI (AVG) values obtained in this study and values obtained in previous years.

3.3. Trophic status of the lake

Chl *a*, TP and SD values obtained in some studies carried out in the lake in order to make a comparison on a yearly basis in the change of trophic status in Lake Mogan were examined according to the value limits determined by OECD (1982) (Table 2). Trophic status of the lake varied from mesotrophic to hypertrophic according to several research conducted in the lake between 1989 and 2023.

Table 2. According to various research conducted in Lake Mogan, evaluation of chlorophyll *a* (Chl *a*), TP (total phosphorus), SD (Secchi depth) parameters on a yearly basis according to OECD (1982).

References and years	Parameters	Values	Trophic status OECD (1982)	OECD (1982) limit values (range)
Bakan (1990) 1989	Chl *a* (mg/m^3)	7.18	Mesotrophic	2.5-8.0
	SD (m)	1.28	Hypertrophic	<1.5
Pulatsü (1995) 1994	Chl *a* (mg/m^3)	5.14	Mesotrophic	2.5-8.0
	TP (mg/m^3)	23.07	Mesotrophic	10.0-35.0
	SD (m)	2.1	Eutrophic	1.5-3.0
Manav (2003); Manav and Yerli (2008) 2003	Chl *a* (mg/m^3)	2.79	Mesotrophic	2.5-8.0
	TP (mg/m^3)	48.66	Eutrophic	35.0-100.0
	SD (m)	0.91	Hypertrophic	<1.5
Demir et al. (2014) 2006	Chl *a* (mg/m^3)	8.87	Eutrophic	8.0-25.0
	TP (mg/m^3)	47.74	Eutrophic	35.0-100.0
	SD (m)	1.21	Hypertrophic	<1.5
Sanal and Demir (2018) 2013	Chl *a* (mg/m^3)	21,03	Eutrophic	8.0-25.0
	TP (mg/m^3)	54.54	Eutrophic	35.0-40.0
	SD (m)	1.39	Hypertrophic	<1.5
Eldarov (2023) 2022-2023	Chl *a* (mg/m^3)	7.24	Mesotrophic	2.5-8.0
	TP (mg/m^3)	42.27	Eutrophic	35.0-40.0
	SD (m)	2.1	Eutrophic	1.5-3.0

4. DISCUSSION

In this study, the TSI (CHL), TSI (TP), TSI (SD), TSI (AVG) values of Lake Mogan were examined and these values were compared with the data obtained and calculated by us from the study conducted by Bakan (1990) in 1989, by Pulatsü (1995) in 1994, by Demir et al. (2014) in 2006 and by Sanal and Demir (2018) in 2013, and with the data obtained from the study conducted by Manav (2003) and Manav and

Yerli (2008) in 2003, and the change in the trophic status of the lake in the 34-year period was evaluated.

According to the TSI data obtained in this study, the TSI (TP) value in May is equal to the TSI (SD) value and the TSI (CHL) value is smaller. According to Carlson (1977) and Carlson and Havens (2005), in this case, dissolved particles that do not contain algae may dominate the water and a decrease in light intensity may be observed. The fact that all TSI values are equal in August may indicate that phosphorus has a key limiting role in algal growth. In November, as in May, the TSI (CHL) value is lower than other values, and if TSI (SD) and TSI (TP) are equal, it can be said that dissolved particles that do not contain algae may dominate the water and the light intensity is low. In February, the TSI (SD) and TSI (CHL) values are equal and the TSI (TP) value is high, indicating that the key limiter for algae growth may be environmental factors such as temperature or nitrogen instead of phosphorus.

TSI values for Lake Mogan indicate eutrophic status, with an average of 52.46 in 2023 according to Carlson (1977) and SWQR (Table 9 in the Annex 6 of SWQR, 2023). Earlier studies showed a range of classifications: the average of TSI (CHL) and TSI (SD) was calculated as 53.18 for 1989 pointed out eutrophic conditions while it was found as a mesotrophic status of 48.45 for 1994. Manav (2003) and Manav and Yerli (2008) noted eutrophic with a TSI of 54.06 in 2003. A TSI of 57.48 was calculated for 2006 and 58.11 for 2013, using data from Demir et al. (2014) and Sanal and Demir (2018), respectively. As can be seen from the Bray-Curtis similarity test results shown in Figure 4, TSI (AVG) values are similar to this study and the study conducted by Bakan (1990) in 1989. It is thought that the similarity between the data of 1989 and the data of 2023 indicates that various rehabilitation works in the lake and the bottom mud dredging work carried out in two stages in 2016-2018 and 2020-2022 (Gölbaşı Municipality, 2021) may have a positive impact on preserving the trophic status in the lake. The results indicate that although there were increases and decreases in TSI (AVG) values in some years, but the lake generally maintained its eutrophic state over a 34-year period.

Based on TSI (SD) values, Lake Mogan is classified as a mesotrophic lake with a TSI value of 49.31, according to Carlson (1977) and SWQR (2023). Using the dataset provided by Bakan (1990), a eutrophic TSI of 56.42 was calculated for 1989, whereas data from Pulatsü (1995) yielded a mesotrophic status of 49.28 for 1994. Further studies by Manav (2003) and Manav and Yerli (2008) indicated eutrophic conditions with a value of 61.35, while analysis of the 2006 dataset presented by Demir et al. (2014) yields a TSI of 60.9, placing the lake firmly in the eutrophic range. Lastly, using the 2013 dataset reported by Sanal and Demir (2018), a TSI of 54.42 was calculated here, placing the lake in the eutrophic range.

Regarding the average TSI values based on chlorophyll *a* (TSI CHL), Lake Mogan was classified as eutrophic with a value of 50.02 in 2023 according to Carlson (1977). In previous assessments, a TSI (CHL) of 49.95 was calculated for 1989 from the nutrient data provided by Bakan (1990), whereas a value of 46.66 - also indicative of mesotrophic conditions - was obtained for 1994 from the dataset reported by Pulatsü (1995). Further studies by Manav (2003) and Manav and Yerli (2008) classified the lake as mesotrophic with a value of 40.66. A TSI (CHL) of 52.76 was obtained for 2006 from the dataset provided by Demir et al. (2014), whereas analysis of the 2013 data reported by Sanal and Demir (2018) pointed out an eutrophic value of 58.81.

In terms of average TSI values based on total phosphorus (TSI TP) in 2023, Lake Mogan was classified as eutrophic, with a value of 58.14 according to Carlson (1977) and SWQR (2023). However, TSI (TP) values were not available for Bakan's (1990) study from 1989 as total phosphorus was not measured. Derived from the 1994 dataset published by Pulatsü (1995), a TSI (TP) of 49.41 was calculated, indicating mesotrophic conditions. Subsequent studies by Manav (2003) and Manav and Yerli (2008) indicated eutrophic conditions with a value of 60.16. TSI (TP) of 58.78 was calculated from the 2006 dataset presented by Demir et al. (2014), identifying eutrophic conditions, while assessment of the 2013 data published by Sanal and Demir (2018) showed an even higher eutrophic value of 61.11.

Average Chl *a* values in Mogan Lake in 2023 showed a mesotrophic trophic status of 7.24 mg/m^3 according to OECD (1982). In this study mesotrophic conditions were indicated for 1989 (Bakan, 1990), 1994 (Pulatsü, 1995) from the

respective datasets, whereas analyses of the 2006 (Demir et al., 2014) and 2013 (Sanal & Demir, 2018) data sets yielded eutrophic classifications. Additionally, the 2003 values calculated by Manav (2003) and Manav and Yerli (2008) were found to indicate mesotrophic conditions.

In 2023, Lake Mogan was classified as eutrophic with a TP concentration of 42.28 mg/m³, according to OECD (1982). The lake was reported as mesotrophic in 1994 (Pulatsü, 1995), while it was eutrophic in 2003 (Manav, 2003; Manav & Yerli, 2008), 2006 (Demir et al., 2014) and 2013 (Sanal & Demir, 2018). The decrease in TP concentration in the long term indicates oligotrophication, which is the opposite process of eutrophication (Anderson et al., 2005). Stopping anthropogenic eutrophication and the formation of oligotrophication, which is the opposite process, is only possible by taking rehabilitation measures. A long-term analysis revealed a slight decrease in TSI (CHL), TSI (SD), and TSI (AVG) values in 2023, while the trophic status of lake, according to TSI (AVG), was comparable to that observed in 1989. Although this situation does not exactly indicate oligotrophication, it can be said that it has an effect of the rehabilitation works carried out in the lake. In order to make this assessment, monitoring studies in the lake must continue.

Mean SD value in the lake was determined as 2.1 m. According to this value, the lake was determined eutrophic according to OECD (1982). The lake was hypertrophic in 1989 (Bakan, 1990), eutrophic in 1994 (Pulatsü, 1995), hypertrophic in 2003 (Manav, 2003, Manav & Yerli, 2008), 2006 (Demir et al., 2014) and 2013 (Sanal & Demir, 2018) according to OECD (1982). Lake Mogan is a shallow lake and SD is low because of its bottom is mixed by wind and being exposed to waves.

For the evaluation possible changes in the trophic status of Lake Mogan, each parameter such as Chl *a*, SD, TP used in examining the trophic status give separate results, causing confusion in determining the final trophic status. For this reason, it has been determined that using a single average index value (TSI AVG) instead of different parameters gives practical and clear results. In addition, the use of other TSI(CHL), TSI(TP), TSI(SD) values provides the opportunity to evaluate the nutrients, transparency and chlorophyll relationships in lakes. It was reported that the relationships between TSI indices pointed out dominancy of algae, light attenuation, nutrient limitation or zooplankton grazing (Carlson & Havens, 2005). According to the results obtained, it was determined that the TSI(AVG) value of the lake still indicates eutrophic conditions, although there have been some changes over a 34-year period. However, when looked at on a yearly basis, it is observed that there has been an improvement in the trophic status of the lake in recent years. It is thought that the reason for this is the rehabilitation works carried out in the lake in different years (Topçu, 2006; Gölbaşı Municipality, 2021), various seasonal changes and other factors. Since 1995, some management activities such as macrophyte harvesting, sediment extraction have been carried out in Lake Mogan. Among these, dredging is the most expensive; approximately 2.7 million m^3 of sediment was dredged between 2016 and 2018, and a further 6 million m^3 between 2020 and 2022. Apart from this, as stated by Fakioğlu and Pulatsü (2005), it is recommended to carry out studies to reduce the phosphorus load in the lake, to continue ecological restoration practices in the lake, and to prevent pollution in the lake. Lake deepening studies were carried out by sediment extraction in Hancock Lake in Florida, USA (Tomasko et al., 2009), Kaw Lake in Oklahoma (Alemayehu & Hackett, 2016), Hwoiya Lake in South Korea (Suh et al., 2014), and the trophic status of these lakes was evaluated and improvement was observed in trophic status. TSI provides a measure of changes in water quality and categorical grouping of lakes (Meyer et al., 2025). As a result of a study conducted on 160 lakes in Poland, the importance of integrating the use of TSI into lake monitoring programs was emphasized and it was stated that this approach would increase the effectiveness of management strategies (Karpowicz et al., 2025). For evaluating the improvement of water quality in Lake Mogan, it is necessary to monitor water quality changes with tools such as TSI. TSI may use as a global water quality monitoring tool and it gives an easy and comparable information about the characteristics of waters to decision-makers.

5. CONCLUSION

Each parameter of the trophic status (CHL, SD, and TP) can indicate a different trophic status, thus creating complexity in lake

management. Therefore, using the TSI is a useful tool to indicate long-term changes, anthropogenic impacts, eutrophication, and the results of restoration efforts in lakes. It is clear that the result of the rehabilitation works carried out in Lake Mogan should be evaluated in the long term. The sediment removal studies carried out in two stages in Lake Mogan may have a positive impact on the trophic state of the lake. But the results of the measures taken will be seen over the years. We would like to emphasize that in order to improve the trophic status of a lake, external pressures and effects must first be reduced.

It is also recommended to regularly monitor the water quality to observe positive or negative changes in Mogan and other lakes in long term basis.

We believe that this study will shed light on future research on determining the trophic status of lakes and evaluating the changes that occur over the years.

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CONFLICT OF INTEREST

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

AUTHOR CONTRIBUTIONS

Investigation, Methodology, Analysis, Field Study, Writing - original draft, Visualization, Validation, Data Curation: JE; Conceptualization, Methodology, Writing - review and editing, Visualization, Validation, Investigation, Supervision: ND. All authors approved the final draft.

ETHICAL STATEMENTS

Local Ethics Committee Approval was not obtained because experimental animals were not used in this study.

DATA AVAILABILITY STATEMENT

Data will be made available from the corresponding author on request.

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