

Article

Evaluation of Water and Sediment Quality in Lake Mogan, Türkiye

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Abstract: The wetlands, with their delicate ecosystems, play a crucial role in regulating water regimes and supporting diverse plant and animal communities, particularly those associated with water habitats. Mogan Lake, located within the Gölbaşı Special Environmental Protection Area, stands out as a unique habitat, hosting over 200 bird species. This study aimed to assess the current water quality of Mogan Lake by analysing various water quality variables. Three sampling sites, representing the northern, middle, and southern parts of the lake, were selected to examine both surface water and bottom sludge characteristics through the analysis of 29 pollutant variables. Water samples were collected from 30 cm beneath the water surface and 50 cm above the bottom of the lake. Sediment samples were collected from the sludge at the lake basin. Additionally, to understand their impact on the lake's water quality, 26 pollutants were also measured in water samples taken from the five main streams that feed the lake. The results reveal a significant level of organic pollution in the lake, along with elevated nitrogen levels indicating hypertrophic conditions. Although organic pollutants were detected in the lake bottom sediment through analysis, they are considered non-hazardous in terms of heavy metals and other inorganic variables.

Keywords: Mogan Lake; water quality; surface sediments; organic pollution



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1. Introduction

Due to the increasing world population and industrialisation, studies on the protection of the quantity and quality of water have gained great importance. Worldwide, water has been transferred from one place to another and used for various purposes, such as water supply, flood control, and electricity generation [1]. While water is transported from one place to another, it also carries pollutants, depending on various conditions. The transport of pollutants depends on the climatic, meteorological, geographical, and geological conditions and reaches the receiving environments through transformation reactions and complex transport [2]. Although lakes constitute 87% of surface fresh water and cover < 1% of the land area, they stand out, especially for their water supply and recreation opportunities [3,4].

Lake ecosystems are increasingly affected by anthropogenic effects as a result of agricultural, industrial, and domestic pollution. The massive increases in nitrogen and phosphorus loads in relatively still waters such as lakes and reservoirs are a serious environmental problem on a global scale [5]. The causes of eutrophication are different in water bodies, and the effective factors include environmental effects such as nutrient enrichment, temperature, salinity, hydrodynamics, carbon dioxide, element balance, and biological diversity [6]. The negative effects of high nutrient levels in lakes on aquatic biodiversity pose a problem for the lake's intended use and users [7]. With the increase in anthropogenic resources and global warming, it is expected that lakes, which allow the reproduction of harmful algae species, will increase by more than 20 percent by the year

2050 [8]. Lakes have an important role in the United Nations' Sustainable Development Goals (SDGs), and efforts to control eutrophication and reveal the current water quality are of great importance in order to achieve these goals [9]. For these reasons, the control of nutrient substances in lake environments is essential within the scope of sustainable water management.

In addition to nutrients, heavy metal concentrations in lake environments are increasing with human activities. Heavy metal pollution arrives in the receiving environment mainly through geological weathering, coal burning, atmospheric deposition, or discharge of industrial wastes [10]. In freshwater resources, Pb, Cd, Hg, and Cr come to the fore [11]. Heavy metals are one of the most important undesirable pollutants in aquatic ecosystems, with their negative effects and persistent properties in aquatic microorganisms [12]. Some heavy metals, such as Mn, Zn, Cu, and Fe, are required for the metabolic activities of organisms at certain concentrations, but when these metals exceed a certain level in organisms, they can cause acute or chronic toxicity [13]. In addition, heavy metals have toxic effects on aquatic plants and plankton at very low concentrations.

There are many studies that have evaluated surface water quality in the literature [14–19]. In a study conducted in 2018, physicochemical variables, metal concentrations, and current water quality were examined by sampling twice in July and August 2017 at 16 sampling stations in Lake Kenyir [20]. A study conducted in 2003 evaluated the water quality caused by human activities in the Mogan and Eymir lakes [21]. Six monitoring stations were selected from the streams feeding the lakes and compared with the quality variables (QVs) in the ASKI (Ankara Water and Sewerage Administration General Directorate) report published in 1995 [21]. It was concluded that the lakes had improved WQVs, according to the report from 1995. Another study, conducted in 1997, investigated the changes in chlorophyll-a, nitrogen, and phosphorus concentrations in samples taken from Mogan Lake in the ice-free seasons of 1992, 1993, and 1994 [22]. The findings showed that the total phosphorus (TP) and chlorophyll-a concentrations in the lake were meso-eutrophic [22]. In addition, within the scope of the study, the TP budget of Lake Mogan was measured for a period of 22 months. In addition to these studies, there are many articles that have tried to reveal the water quality of lakes with various statistical methods [23,24]. In a study conducted in 2019, monitoring was carried out for 1 year in order to determine the water quality of Saraydüzü Dam Lake in Sinop. In this context, 28 basic variables were measured monthly at six stations. During the study, it was concluded that the phosphate and nitrogen loads that would put the ecosystem at risk did not reach the lake environment. At the same time, it was concluded that there was no excessive oxygen consumption due to the oxidation of organic matter [25].

This study aimed to reveal the current water quality class of Mogan Lake by examining the water quality variables (WQVs). Lake Mogan has wetlands that host many microorganisms and more than 200 different bird species. Long-term, sustainable management of lakes is essential due to the increasing number of point and non-point pollutants. The main objective of this study was to take stock of the current water quality of the lake and establish the extent to which pollutants are threatening the environment, which can undoubtedly also have serious repercussions on human health.

2. Materials and Methods

2.1. Study Area

Mogan Lake is a freshwater lake located within the borders of Gölbaşı District, 20 km south of Ankara. The lake, which has a surface area of 561.20 ha., is located at an elevation of 972 m (Figure 1). Lakes formed by natural dams formed by alluvial deposits in the Mid-Holocene and the region where the lake is located form the upstream of the Ankara River Subbasin [26]. Lake Mogan is fed by more than five large and small streams and underground water sources [27]. These are the Yavrucak, Başpınar, Gölçük, Su kesen, Virancık, and Çölova Streams. These streams pass through agricultural lands and reach Mogan Lake and then Eymir Lake, which is located downstream of Mogan Lake. The lake

forms the main part of the wetland complex in the basin, which is mainly fed by some streams and underground water sources from various directions [3,26]. Mogan Lake was declared a “Special Environmental Protection Area” by the Ministry of Environment in 1990 [28].

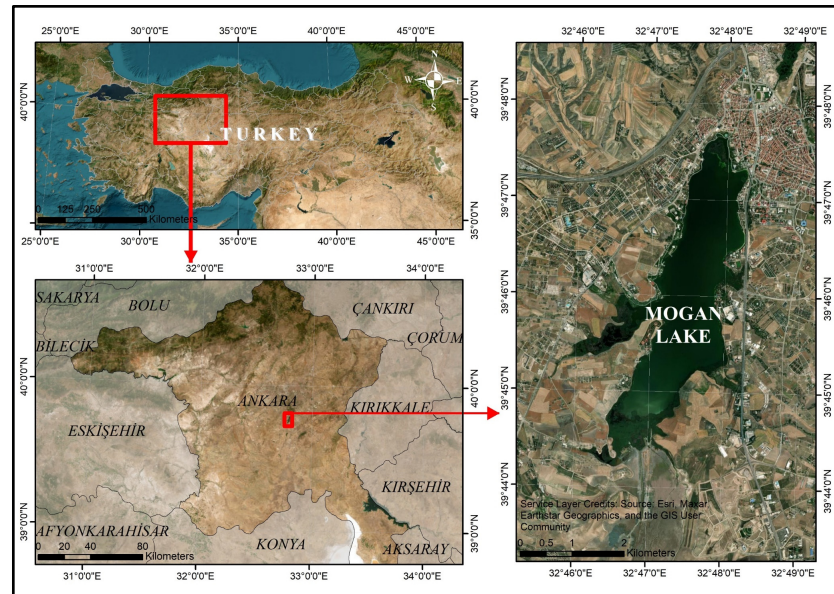


Figure 1. Study area (Mogan Lake).

Approximately 70% of the surface water that enters Mogan Lake (flow and precipitation) occurs between March and May. At the beginning of June, the lake water level reaches its maximum, and 90% of the annual water intake of the lake is provided in this month. The average elevation of the lake surface is around 973.30 m in early June. June is the most intense period of biological activity. Towards the end of June, with the evaporation due to the increase in temperature, the water intake in the lake decreases, and the elevation of the water drops to 972 m, which is at the lowest level between September and November. The critical level, which is ecologically important for Lake Mogan, is 972.50 m. Below this level, water quality, and thus biological, problems may occur due to the decrease in the lake water volume [29]. Some characteristics of Mogan Lake are summarised in Table 1 [3].

Table 1. Some characteristics of Mogan Lake [3].

Specification	Value
Catchment area (km ²)	925
Lake width (km)	1.1
Lake length (km)	6
Lake circumference (km)	14
Water reserve (million m ³)	11.63
Depth (m)	3–5
Lake surface (km ²)	6.35
Water level fluctuations (m)	0.5–0.8

Despite the rapid decrease in agricultural areas in Gölbaşı, livestock farming is still widely practised. The district is home to 8042 cattle and 3096 beef cattle. In Oğulbey District, located south of the lake, there is a breeding farm. Meat products in breeding farms are typically placed in brine tanks [30]. In these tanks filled with saline solution, the meat is immersed in the brine for salting. This process allows the salt to penetrate the meat, enhancing its flavour. Additionally, substantial amounts of salt are used in drying processes to facilitate carcass cleaning and improve meat durability.

2.2. Water and Sediment Sampling

The study area is geographically situated in a structure that extends narrowly in the north–south direction. There are urban areas at the north end of the lake and agricultural areas at the south end. Therefore, at three different points (North [LN], Middle [LM], and South [LS]), parts of the lake were sampled on the north–south line in order to determine the characteristics of the surface water and bottom sludge. The samples were taken in April, when the lake ecosystem was most active. After the water samples were taken, they were transported to the laboratory by means of chemical protection and cold chain procedures in accordance with the Turkish Water Pollution Control Regulation Sampling and Analysis Methods [31]. Water samples were taken from 30 cm below the lake surface and 50 cm above the bottom of the lake, while sediment samples were taken from the bottom sludge. The satellite image and coordinates of the three sampling points are given in Figure 2.

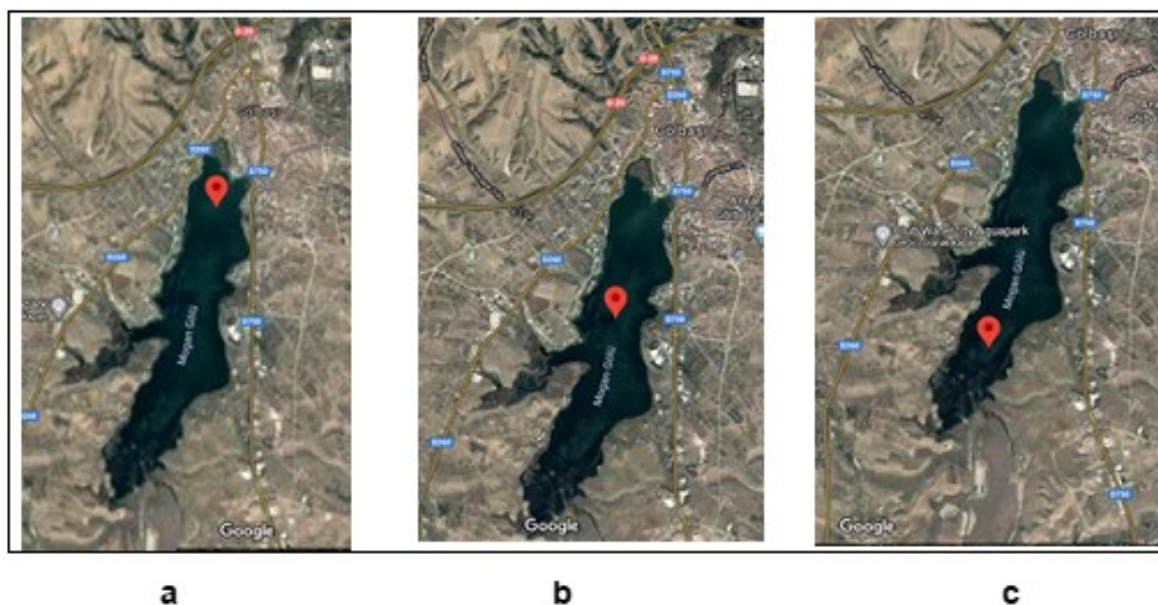


Figure 2. Mogan Lake sampling points, satellite images, and coordinates. (a) Lake North Point (LN): 39.78297 N–32.79711 E; (b) Lake Midpoint (LM): 39.76920 N–32.79268 E; (c) Lake South Point (LS): 39.74988 N–32.78554 E.

Table 2 lists the pollutant variables and analysis methods used for the water samples and the sludge samples taken from the lake's bottom. The analysed variables included total nitrogen (TN), total phosphorus (TP), biological oxygen demand (BOD_5), chemical oxygen demand (COD), total Kjeldahl nitrogen (TKN), detergent, sulphur (H_2S), ortho-phosphate, and heavy metals (Hg, Pb, Cu, Zn, Ni, Cr, and Cd). A professional diver used a stainless-steel scoop to collect bottom sludge samples from the same coordinates as the water samples. Sediments were collected by the diver using the standard surface grab collection with scoops and grabs technique, which allows sediment samples to be contained in a closed chamber, eliminating the dispersion of finer particles into the water. The samples were tightly sealed and transported to the laboratory for analysis. Heavy metal analyses were conducted using the ICP-OES device, while other variables were analysed according to standard methods [32].

Table 2. Methods and units used in the analysis of the samples taken: (a) pollutant variables and analysis methods for water samples taken from a depth of 30 cm from the surface; (b) pollutant variables and analysis methods for the lake bottom surface sediment.

WQV	Pollutant Variables and Analysis Methods for Water Samples Taken from a Depth of 30 cm from the Surface (a)		Pollutant Variables and Analysis Methods for the Lake Bottom Surface Sediment (b)	
	Method	Unit	Method	Unit
pH	SM 4500 H+ B [33] Electrometric method	-	TS ISO 10390 [34] Electrometric method	-
Cond.	SM 2510 B [33] Electrometric method	ms/cm	-	-
T	SM 2550 B [33] Electrometric method	-	SM 2550 B [33] Electrometric method	-
Colour	SM 2120 C [33] Spectrophotometric method	Pt-Co	-	-
Turb.	SM 2130 B [33] Nephelometric method	NTU	-	-
BOD ₅	SM 5210 B [33] Standard method	mg/L	-	-
TOC	-	-	EN 13137 [35] Gravimetric method	mg/kg
COD	SM 5220 B [33] Open reflux titrimetric method	mg/L	-	-
DO	SM 4500 O G [33] Membrane electrode method	mg/L	-	-
SSs	SM 2540 D [33] Gravimetric method	mg/L	-	-
TSs	SM 2540 B [33] Gravimetric method	mg/L	SM 2540 G [33] Gravimetric method	%
VSs	SM 2540 E [33] Gravimetric method	mg/L	SM 2540 E [33] Gravimetric method	%
TDSs	SM 2540 C [33] Gravimetric method	mg/L	-	-
O&G	SM 5520 B [33] Gravimetric method	mg/L	-	-
MBASs	SM 5540 C [33] Spectrophotometric method	mg/L	-	-
CSs	-	-	SM 2540 F [33]	mL/L
DOC	-	-	TS 8195 EN 1484 [36] SM 4500 P D [33]	mg/L
P-PO ₄	SM 4500 P D [33] Spectrophotometric method	mg/L	Spectrophotometric method	mg/L
TN	Calculation	mg/L	-	-
TKN	SM 4500 Norg B [33]	mg/L	-	-
S-H ₂ S	SM 4500 S-2 D [33] Spectrophotometric method	mg/L	SM 4500 S-2 D [33] Spectrophotometric method	mg/L
TP	SM 4500 P D [33] Macro-Kjeldahl Method	mg/L	EPA 200.7 [32] ICP-OES method	mg/kg
Chl-a	ISO 10260 [37]	µg/L	-	-
SD	EPA 841-B-97-003 [38]	m	-	-
TC	SM 9222 B [33] Membrane filtration technique	EMS/100 mL	-	EMS/100 mL
Dens.	-	-	-	g/mL
Hg	EPA 200.7 [32] ICP-OES method	mg/L	EPA 200.7 [32] ICP-OES method	mg/kg
Zn	EPA 200.7 [32] ICP-OES method	mg/L	EPA 200.7 [32] ICP-OES method	mg/kg
Pb	EPA 200.7 [32] ICP-OES method	mg/L	EPA 200.7 [32] ICP-OES method	mg/kg

Table 2. Cont.

WQV	Pollutant Variables and Analysis Methods for Water Samples Taken from a Depth of 30 cm from the Surface (a)		Pollutant Variables and Analysis Methods for the Lake Bottom Surface Sediment (b)	
	Method	Unit	Method	Unit
Ni	EPA 200.7 [32]	mg/L	EPA 200.7 [32]	mg/kg
	ICP-OES method		ICP-OES method	
Cu	EPA 200.7 [32]	mg/L	EPA 200.7 [32]	mg/kg
	ICP-OES method		ICP-OES method	
Cd	EPA 200.7 [32]	mg/L	EPA 200.7 [32]	mg/kg
	ICP-OES method		ICP-OES method	
Cr	EPA 200.7 [32]	mg/L	EPA 200.7 [32]	mg/kg
	ICP-OES method		ICP-OES method	

Notes: WQV, water quality variable; Cond., conductivity; T, temperature; Turb., turbidity; BOD₅, biological oxygen demand; TOC, total organic carbon; COD, chemical oxygen demand; DO, dissolved oxygen; SSs, suspended solids; TSs, total solids; VSs, volatile solids; TDSs, total dissolved solids; O&G, oil and grease; MBASs, methylene blue active substances; CSSs, collapsible solids; DOC, dissolved organic carbon; P-PO₄, ortho-phosphate; TN, total nitrogen; TKN, total Kjeldahl nitrogen; S-H₂S, sulphur; TP, total phosphorus; Chl-a, chlorophyll-a; SD, Secchi disc depth; TC, total coliform; Dens., density; JT, jar test.

A hydrometric test was applied to measure the interaction of the bottom sludge samples taken from the study area with water and to determine the water absorption capacity, permeability, water holding capacity, and similar properties of the soil. A hydrometer analysis was used to assess the distribution of the soil particle size. The hydrometer test was conducted according to ISO 17892-4 standards [39]. The samples were treated with sodium hexametaphosphate to form complex Ca⁺⁺, Al³⁺, Fe³⁺, and other cations that bind clay and silt particles into aggregates. Organic matter was suspended in this solution. The density of the soil suspension was determined with a hydrometer calibrated to read in grammes of solids per litre after the sand settled and, again, after the silt settled. Corrections were made to the density and temperature of the dispersing solution.

ISO 17892-4 is applicable to the laboratory determination of the particle size distribution of a soil test specimen by sieving, sedimentation, or a combination of both within the scope of geotechnical investigations [39]. The particle size distribution is one of the most important physical characteristics of soil. The classification of soils is mainly based on their particle size distributions. Many geotechnical and geohydrological properties of soil are related to the particle size distribution. The particle size distribution provides a description of soil based on a subdivision into discrete classes of particle sizes. The size of each class can be determined by sieving and/or sedimentation. Coarse soils are usually tested by sieving, but fine and mixed soils are usually tested by a combination of sieving and sedimentation, depending on the composition of the soil [39].

2.3. Collection of Water Samples from the Streams Feeding the Lake

In order to examine the pollution impact of the sources feeding Mogan Lake on the lake water quality, five sampling stations were selected from the streams feeding the lake. The locations of the samples taken from the streams feeding Mogan Lake on the map are given in Figure 3. The sampling point in Çölova Stream (SP2) was 5.73 km away from Mogan Lake. The sampling point in Yavrucak Stream (SP1) was 500 m behind the point where it connected to Çölova Stream. The sampling point of Kesikköprü Stream, marked as SP3, was 5.31 km away from Mogan Lake. The Su Kesen Stream (SP4) sampling point was approximately 400 m away from the lake in the north–east direction of the lake. Başpınar Stream is shown as SP5. The sampling was conducted with at least a two-day interval from the last rainfall, and attention was paid to ensuring that the weather was free of precipitation.

According to the analysis results obtained in the study, the results of the pollution variables obtained from the lake and the streams were evaluated according to the Water

Pollution Control Regulation [40]. The Ministry of Agriculture and Forestry's classification system consists of four classes:

- I. High-quality water (Class I water quality indicates “very good” water status (blue colour).
- II. Slightly polluted water (Class II water quality indicates “good” water status (green colour).
- III. Contaminated water (Class III water quality indicates “medium” water status (yellow colour).
- IV. Highly polluted water (Class IV water quality indicates “weak” water status (red colour).

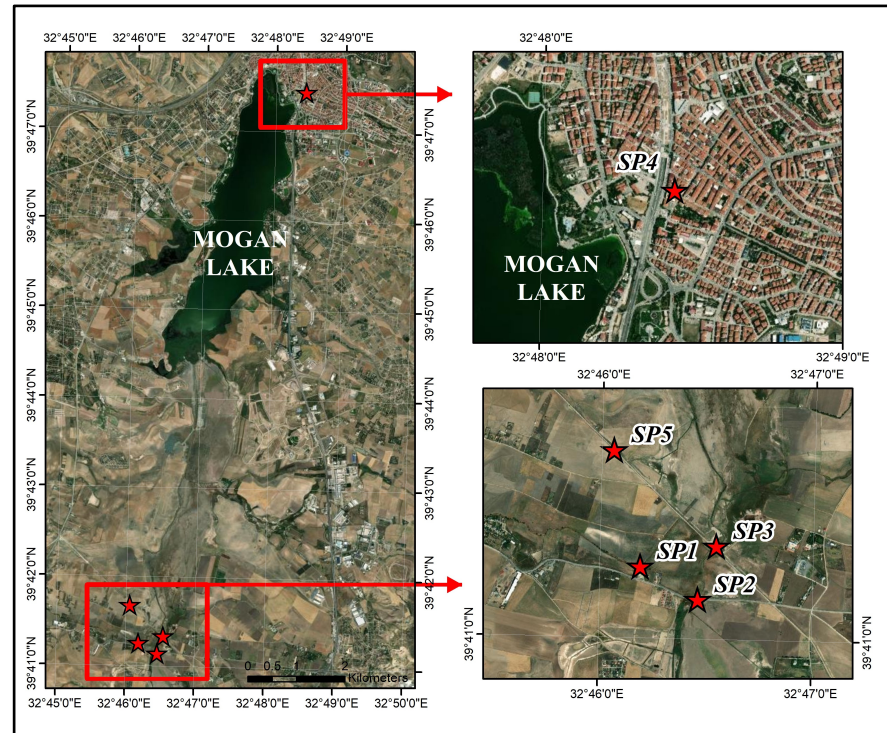


Figure 3. Satellite images of the streams feeding Mogan Lake.

3. Results

3.1. Water Quality

In Table 3, the results of the LN, LM, and LS water samples and related water quality classes are reported. When Table 3 is examined, it is seen that some organic origin pollution variables are at very high levels. The assessment of pollution variables involves the classification of inland surface water resources based on general chemical and physicochemical variables. Water samples collected from the LN region were found to be Class II (good water class) as per variables including BOD₅, COD, and TKN.

Table 3. Lake surface water quality variable results.

WQV	Unit	SP			WQVCL			
		LN	LM	LS	I	II	III	IV
T	°C	16.8	16.8	20.3	25	25	30	>30
Colour	Pt-Co	10	11	11	5	50	300	>300
Turb.	NTU	5	7	6				
SD	m	3.5	3.5	3.5	>4	4–2	1.9–1.0	<1.0
Chl-a	mg/L	<0.05	<0.05	<0.05	<0.0035	0.035–0.009	0.0091–0.025	>0.025
SSs	mg/L	<11	<11	14				
TSs	mg/L	15	12	21				

Table 3. Cont.

WQV	Unit	SP			WQVCL			
		LN	LM	LS	I	II	III	IV
VSs	mg/L	<55	<55	<55				
TDSs	mg/L	<60	<60	<60	500	1500	5000	>5000
DO	mg/L	8.37	7.91	6	8	6	3	<3
Cond.	µs/cm	2620	2560	2610	<400	1000	3000	>3000
pH		9.47	9.4	9.16	6.5–8.5	6.5–8.5	6.0–9.0	6.0–9.0 except
COD	mg/L	66	85	86	<25	50	70	>70
BOD ₅	mg/L	15	21	20.7	<4	8	20	>20
P-PO ₄	mg/L	<0.003	0.011	0.023	<0.05	0.16	0.65	>0.65
TKN	mg/L	1.3	1.9	1.8	0.5	1.5	5	>5
TN	mg/L	2.1	2.2	2.3	<3.5	11.5	25	>25
TP	mg/L	0.03	0.035	0.048	0.02	0.16	0.65	>0.65
O&G	mg/L	<10	<10	<10	0.02	0.3	0.5	>0.5
MBASs	mg/L	<0.025	<0.025	<0.025	0.05	0.2	1	>1.5
S-H ₂ S	mg/L	<0.1	<0.1	<0.1	2	2	10	>10
TC	EMS/100 mL	0	0	0	100	20,000	100,000	>100,000
Hg	mg/L	<0.0001	<0.0001	<0.0001	0.0001	0.0005	0.002	>0.002
Pb	mg/L	<0.01	<0.01	<0.01	0.01	0.02	0.05	>0.05
Cu	mg/L	<0.01	<0.01	<0.01	0.02	0.05	0.2	>0.2
Zn	mg/L	<0.01	0.01	0.014	0.2	0.5	2	>2
Ni	mg/L	<0.01	<0.01	<0.01	0.02	0.05	0.2	>0.2
Cr	mg/L	<0.01	<0.01	<0.01	0.02	0.05	0.2	>0.2
Cd	mg/L	<0.001	<0.001	<0.001	0.003	0.005	0.01	>0.01

Notes: Class I (blue), high-quality water; Class II (green), slightly polluted water; Class III (yellow), contaminated water; Class IV (red), highly polluted water; WQV, water quality variable; SP, sample point; WQVCL, water quality variable classification limit; T, temperature; Turb., turbidity; SD, Secchi disc depth; Chl-a, chlorophyll-a; SSs, suspended solids; TSs, total solids; VSs, volatile solids; TDSs, total dissolved solids; DO, dissolved oxygen; Cond., conductivity; COD, chemical oxygen demand; BOD₅, biological oxygen demand; P-PO₄, ortho-phosphate; TKN, total Kjeldahl nitrogen; TN, total nitrogen; TP, total phosphorus; O&G, oil and grease surfactant; MBASs, methylene blue active substances; S-H₂S, sulphur; TC, total coliform.

The results of the pollutant parameter analysis performed on the water samples taken from the water column 50 cm above the bottom of Mogan Lake are given in Table 4.

Table 4. Mogan Lake North [bottom +50 cm water column water] analysis results.

WQV	Unit	SP			WQVCL			
		LN	LM	LS	I	II	III	IV
COD	mg/L	153	85	76	<25	50	70	>70
BOD ₅	mg/L	42	21	17	<4	8	20	>20
P-PO ₄		0.011	0.019	0.021	<0.05	0.16	0.65	>0.65
TKN	mg/L	1.7	1.6	1.9	<0.5	1.5	5	>5
TN	mg/L	1.9	2.1	2.0	<3.5	11.5	25	>25
TP	mg/L	0.03	0.032	0.048	0.02	0.16	0.65	>0.65
MBASs	mg/L	<0.025	<0.025	<0.025	0.05	0.2	1	>1.5
S-H ₂ S	mg/L	<0.1	<0.1	<0.1	2	2	10	>10

Table 4. Cont.

WQV	Unit	SP			WQVCL			
		LN	LM	LS	I	II	III	IV
Hg	mg/L	<0.0001	<0.0001	<0.0001	0.0001	0.0005	0.002	>0.002
Pb	mg/L	<0.01	<0.01	<0.01	0.01	0.02	0.05	>0.05
Cu	mg/L	<0.01	<0.01	<0.01	0.02	0.05	0.2	>0.2
Zn	mg/L	<0.01	<0.01	<0.01	0.2	0.5	2	>2
Ni	mg/L	<0.01	<0.01	<0.01	0.02	0.05	0.2	>0.2
Cr	mg/L	<0.01	<0.01	<0.01	0.02	0.05	0.2	>0.2
Cd	mg/L	<0.001	<0.001	<0.001	0.003	0.005	0.01	>0.01

Notes: Class I (blue), high-quality water; Class II (green), slightly polluted water; Class III (yellow), contaminated water; Class IV (red), highly polluted water; WQV, water quality variable; SP, sample point; WQVCL, water quality variable classification limit; COD, chemical oxygen demand; BOD₅, biological oxygen demand; P-PO₄, ortho-phosphate; TKN, total Kjeldahl nitrogen; TN, total nitrogen; TP, total phosphorus; MBASs, methylene blue active substances; S-H₂S, sulphur.

When the Mogan Lake water quality values were evaluated in terms of the trophic levels in the lake, the TN was measured as varying between 1.9 and 2.3 mg/L, and the TP was measured as varying between 0.03 and 0.048 mg/L.

3.2. Surface Sediments Quality

The analysis results for the bottom sludge sediments are given in Table 5. The pH values of the sediment were found to be neutral at each point.

Table 5. Mogan Lake Bottom Sediment Analysis Results.

Variable	Unit	LN	LM	LS
T	°C	17.2	17.5	16.7
SSs	%	20	19	31
Dens.	g/mL	0.98	1.05	1.1
pH		7.45	7.12	7.59
S-H ₂ S	mg/L	0.88	1.01	0.77
TP	mg/kg	2056.3	1545.2	2402
TN	mg/kg	945.45	1021.33	1121.57
P-PO ₄	mg/L	112.3	79.7	149
VSs	%	10	17	22.5
CSs	g/L	1000	960	960
DOC	g/L	13.1	16.1	14.2
TOC	mg/kg	17,550	23,869	19,202
Hg	mg/kg	<0.025	<0.025	<0.025
Pb	mg/kg	28.3	23.6	38.5
Cu	mg/kg	<2.5	<2.5	<2.5
Zn	mg/kg	29.4	29.77	21.6
Ni	mg/kg	19.5	24.2	31.9
Cr	mg/kg	4.9	4.8	9.1
Cd	mg/kg	0.5	0.42	0.69

Notes: T, temperature; SSs, suspended solids; Dens., density; S-H₂S, sulphur; TP, total phosphorus; TN, total nitrogen; P-PO₄, ortho-phosphate; VSs, volatile solids; CSs, collapsible solids; DOC, dissolved organic carbon; TOC, total organic carbon.

In the hydrometer test studies carried out on the sediment samples, the inorganic composition of the sludge was determined. The particle size distribution of soil or sludge, which contains a significant number of fine particles (silt and clay), cannot be performed by sieve analysis. Therefore, a hydrometer analysis was used to assess the distribution of the soil particle size [41]. The proportions of the sand, clay, and silt contents in the samples are given in Figure 4. The sand contents in the sediments in the northern and middle parts

of the lake were found to be high, while the clay content in the southern part was high. It was observed that the silt content in all three regions was lower than the dominant sand or clay content.

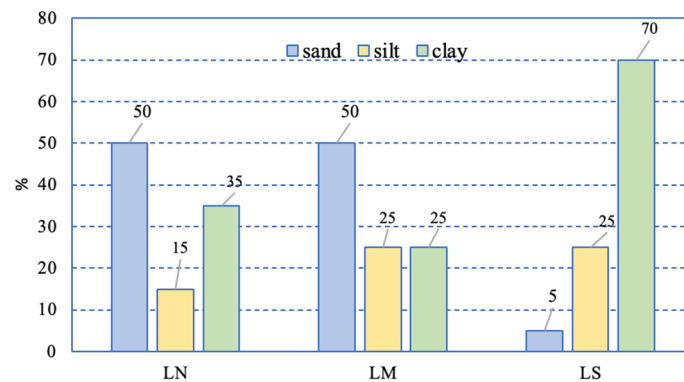


Figure 4. Granulometric compositions of the sediment samples.

3.3. Quality Variables of the Streams Feeding Mogan Lake

The results of the QVs of the streams feeding Lake Mogan are given in Table 6.

Table 6. Water analysis results of streams feeding Lake Mogan.

WQV	Unit	SP1	SP2	SP3	SP4	SP5	WQVCL			
							I	II	III	IV
T	°C	12.2	17.3	17.4	20.1	18.8	25	25	30	>30
Colour	Pt-Co	10	35	29	12	20	5	50	300	>300
Turb.	NTU	7	22	19	7	11				
Chl-a	µg/L	<50	<50	<50	<50	<50	<3.5	3.5–9.0	9.1–25	>25
SSs	mg/L	37	73	49	21	51				
TSs	mg/L	45	87	59	39	68				
VSs	mg/L	<55	<55	<55	<55	<55				
TDSs	mg/L	<60	<60	<60	<60	<60	500	1500	5000	>5000
DO	mg/L	9.55	6.78	7.33	13.24	6.21	8	6	3	<3
Cond.	µs/cm	4150	3040	17,550	5320	11,010	<400	1000	3000	>3000
pH		7.67	9.31	9.03	9.41	8.48	6.5–8.5	6.5–8.5	6.0–9.0	6.0–9.0 except
COD	mg/L	118	166	163	92	124	25	50	70	>70
BOD ₅	mg/L	18	51	47	29	37	4	8	20	>20
TKN	mg/L	1.7	1.5	1.3	1.9	1.7	0.5	1.5	5	>5
TN	mg/L	2.3	1.9	1.8	2.4	2.1	<3.5	11.5	25	>25
TP	mg/L	0.018	0.23	0.1	0.2	0.3	0.02	0.16	0.65	>0.65
O&G	mg/L	<10	<10	<10	<10	<10	0.02	0.3	0.5	>0.5
S-H ₂ S	mg/L	<0.1	<0.1	<0.1	<0.1	<0.1	2	2	10	>10
TC	EMS/100 mL	0	0	0	0	0	100	20,000	100,000	>100,000
Hg	mg/L	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	0.0001	0.0005	0.002	>0.002
Pb	mg/L	<0.01	<0.01	<0.01	<0.01	<0.01	0.01	0.02	0.05	>0.05
Cu	mg/L	<0.01	<0.01	<0.01	<0.01	<0.01	0.02	0.05	0.2	>0.2
Zn	mg/L	0.0241	<0.01	0.0357	0.02844	0.1073	0.2	0.5	2	>2
Ni	mg/L	<0.01	<0.01	<0.01	<0.01	<0.01	0.02	0.05	0.2	>0.2
Cr	mg/L	<0.01	<0.01	<0.01	<0.01	<0.01	0.02	0.05	0.2	>0.2
Cd	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	0.003	0.005	0.01	>0.01

Notes: WQV, water quality variable; WQVCL, water quality variable classification limit; T, temperature; Turb., turbidity; Chl-a, chlorophyll-a; SSs, suspended solids; TSs, total solids; VSs, volatile solids; TDSs, total dissolved solids; DO, dissolved oxygen; Cond., conductivity; COD, chemical oxygen demand; BOD₅, biological oxygen demand; TKN, total Kjeldahl nitrogen; TN, total nitrogen; TP, total phosphorus; O&G, oil and grease; S-H₂S, sulphur; TC, total coliform.

4. Discussion

4.1. Evaluation of Water Quality

The LM and LS regions of the lake were classified as Class IV, the highly polluted water class, in terms of the COD and BOD₅ levels. The total coliform parameter was measured at zero in the water samples. This value was an indicator that showed that there was no fresh domestic wastewater mixture in the lake environment. The values of Hg, Pb, Cu, Zn, Ni, Cr, and Cd, which are inorganic components, were also below the levels in the highest quality criteria. Low levels of metal and heavy metal concentrations are an indication that the pollution in the aquatic environment is of organic origin.

In the analyses carried out on the water samples taken from the water column 50 cm above the bottom of the lake (Table 4), it was seen that the COD and BOD₅ values in the North (LN) region were well above the upper limits of 70 mg/L and 20 mg/L, which are the upper limits that determine poor water quality (Class IV). In all water analyses, the highest COD value was found to be 153 mg/L, which was measured in the northern region (LN) (Table 4). The TKN values of the water samples taken from the bottom of the lake indicated a Class III water quality. This shows that the increasing organic pollution in the northern region was due to urbanisation in this region. It is thought that the COD and BOD₅ values, which increased as the water layer approached the ground, were an indication of the mixing of pollutants from the sediment. As in the surface water, total coliform was not found in the bottom water column. As in the water samples taken from the surface of the same spot, the values of inorganic components such as Hg, Pb, Cu, Zn, Ni, Cr, and Cd were also below the highest quality (Class I) limits (Table 4).

Table 7 shows that the electrical conductivity was found to be high compared with previous studies conducted at Mogan Lake and some other lakes. The high conductivity value in the lake is believed to originate from these sources. High concentrations of salt can pose challenges for freshwater organisms and freshwater ecosystems [42]. In the lake environment, the osmotic pressure can lead to water and nutrient deficiencies in plants, causing growth problems. Moreover, organisms that are not tolerant to saline water are greatly affected by high salt concentrations. This situation can lead to a decrease in biological diversity in lake ecosystems and even the extinction of certain species. Furthermore, high salinity values are among the variables that affect the intended use of freshwater resources. Saline waters are unsuitable for drinking, agricultural irrigation, and industrial use. This difficulty in managing freshwater resources complicates sustainable water management and increases treatment costs.

Table 7. Water quality studies about lakes in the literature.

Lake	Mean DO (mg/L)	Mean pH	Mean T (°C)	Mean Cond. (µS/cm)	Mean SSs (mg/L)	Mean COD (mg/L)	Mean TN (mg/L)	Mean TP (mg/L)	Mean BOD ₅ (mg/L)	References
In this study	7.43	9.34	17.97	2596.67	<11	79	2.2	0.038	18.9	
Mogan Lake (Spring months in 2013, Türkiye)	6.75		21		27.5	58	0.055	0.06	-	[29]
Saraydüzü Dam Lake (Türkiye)	12.87	8.45	12	229.88	1.78	1.69	-	-	0.93	[25]
Nanhu Lake (China)	4.95	8.32	29.55	-	-	33.13	6.34	0.34	-	[43]
Loktak Lake (India)	7.03	7.26	24.29	160.74	51.46	19.48	0.36	0.54	4.98	[44]
Gala Lake (Türkiye)	8.04	8.2	21.5	-	-	37	-	-	10.2	[45]
Aktaş Lake (Türkiye)	6.86	9.28	20.3	893	30	115	1.09	0.35	28.5	
Çıldır Lake (Türkiye)	8.86	7.94	16.9	134	19.9	19.6	0.4	0.14	4.7	[46]
Aygır Lake (Türkiye)	7.97	8.58	16.7	180	2	25.2	0.47	0.13	7.1	
Deniz Lake (Türkiye)	7.42	8.47	20.2	243	5.7	20.7	0.35	0.16	4.6	
Balık Lake (Türkiye)	7.33	8.67	18	141	4.7	34.9	0.57	0.19	8	

Notes: DO, dissolved oxygen; T, temperature; Cond., conductivity; SSs, suspended solids; COD, chemical oxygen demand; TN, total nitrogen; TP, total phosphorus; BOD₅, biological oxygen demand.

Mogan Lake also contains high concentrations of TN compared with other studies in the literature [44,46–48]. During the slaughtering process in breeding farms, water is contaminated with high concentrations of blood, urine, and faeces. Animal urine and faeces contain organic nitrogen compounds such as ammonia (NH_3) and urea ($\text{CO}(\text{NH}_2)_2$) at high concentrations [49]. The high nitrogen concentration in Nanhu Lake is believed to be largely attributed to sewage treatment plant tailwater and domestic sewage discharge, accounting for approximately 80% of the total sources (Table 7) [43]. Additionally, in these farms, nitrogen compounds released from the fragmentation of amino acids and proteins in animal blood mix with the wastewater. Furthermore, NH_3 and $\text{CO}(\text{NH}_2)_2$ can react with water to form ammonium hydroxide (NH_4OH), which is a weak base and can contribute to an increase in pH by generating OH^- ions. Moreover, it is believed that cleaning agents and disinfectants used in the breeding farm and surrounding facilities may slightly increase the pH of the lake. Additionally, compared with other lakes, Mogan Lake exhibits high concentrations of organic matter (COD and BOD_5) (Table 7). The lake is under pressure from domestic pollutant discharges in the north, as well as pollutants seeping from agricultural lands and the breeding farm in the south. Organic matter, pesticides, fertilisers, soil erosion, urban and industrial waste, and various pollutants can contribute to high COD concentrations in aquatic environments [50].

4.2. Evaluation of Surface Sediments

High levels of TN and TP are an indication of the long-term accumulation of organic pollutants in the lake ecosystem. In this study, the highest TP and TN values were measured at the LS point. It can be said that this situation is related to the bottom structure and hydrodynamic structure of the lake. In addition, the TN and TP values measured in the sediment show that there is long-term organic pollution in the lake environment. The relationship between lake sediment TP and TN and water phosphorus and nitrogen is complex and depends on various factors, such as sediment composition, nutrient inputs, lake morphology, and hydrological conditions. Lake sediments can act as sinks or sources for phosphorus and nitrogen. They can adsorb and release these nutrients depending on conditions such as the redox potential, pH, and organic matter content. The composition and characteristics of lake sediments, such as the grain size, organic content, and mineral composition, influence their nutrient retention capacity and release dynamics [51].

When the compositions of the sediment samples given in Figure 4 were examined, it was seen that the clay ratio at the LS point was at least twice as high as that in other regions. The high clay content in the sediment composition causes the TN and TP absorbed in the sediment to be released into the water, indirectly increasing their concentrations in the water. Understanding the intricate relationship between lake sediment nutrients and water nutrients is essential for effective lake management and conservation efforts, especially in mitigating eutrophication and maintaining water quality.

When the literature and regulations were examined, it was observed that the heavy metal contents in the bottom sediments were below the permissible limits. TOC is a parameter that indicates the presence of organic (carbon-based) impurities in a water system. The TOC values in the sediment samples indicated the presence of carbon-based organic pollutants in the lake.

4.3. Evaluation of the Quality Variables of the Streams Feeding Mogan Lake

Evaluating the findings obtained from the analysis of the water samples according to the pollution variables of SP1, it was seen that the BOD_5 value was 18 mg/L and indicated Class III—medium water quality, and the COD value of 118 mg/L indicated Class IV—poor water quality. In terms of the TKN parameter, it was found to be in Class III—medium water quality. The high TKN may be associated with the presence of agricultural lands and the use of fertilisers upstream of the stream. The conductivity value of 4150 $\mu\text{S}/\text{cm}$ indicates Class IV—poor water quality. A high conductivity value indicates a high level of dissolved anions and cations in the water. The total coliform parameter was measured

as zero in the water samples. The values of Hg, Pb, Cu, Zn, Ni, Cr, and Cd, which are inorganic components, were also below the highest quality limits. The high concentrations of organic pollutants may have been associated with various agricultural activities as well as domestic and industrial discharges to the lake environment in previous years. In SP2, the water quality seemed to be Class IV—poor water quality, with values of 51 mg/L for BOD₅ and 166 mg/L for COD (Table 6). These two indicator variable levels were two times higher than the limits of the poorest water quality criteria in the regulations. In terms of the TKN parameter, it was in Class III. The conductivity value of 3040 $\mu\text{S}/\text{cm}$ also indicated Class IV—poor water quality. The pH values of the measured samples were all above the limit range of 6 to 9, with a value of 9.31 (Table 6). In natural waters, pH is an important factor as it directly affects many biological and chemical activities. Weak acids and bases can dissolve with pH fluctuations. Many compounds (cyanide, ammonia, heavy metals, hydrogen sulphide, and hydrogen) are affected by this dissolution [52]. If a lake hosts various fish species, the optimum pH range should be between 6.5 and 8 [53].

In the SP3 stream, the BOD₅ and the COD values in the water samples taken from this area were found to be 47 mg/L and 163 mg/L, respectively, which indicated Class IV—poor water quality (Table 6). These two indicator variables were two times higher than the limits of the poorest water quality level in the regulations. The pH value of the samples was 9.03, which was also above the limit range value of 6–9. The conductivity measurement indicated the water quality to be in Class IV, with a value of 17,550 $\mu\text{S}/\text{cm}$ (Table 6). With the chemical decomposition of rocks, the presence of dissolved ions in water increases, which leads to an increase in both conductivity and pH values. The measured conductivity value was five times more than the upper limit of >3000 set in the national regulations [40]. In the SP4 stream, the BOD₅ and COD values were found to be 29 mg/L and 92 mg/L, respectively, which indicated Class IV—poor water quality. These two indicator variables were well above the limits of the poorest water quality level acknowledged in the regulations. The TKN parameter with a value of 1.9 mg/L indicated Class III—medium water quality. The pH value of the samples was found to be 9.41, again above the highest range limit value of 9. The conductivity measurement indicated Class IV—poor water quality, with a value of 5320 $\mu\text{S}/\text{cm}$ (Table 6). The TP parameter was within Class III, with a value of 0.2 mg/L. TP mixes into the receiving environment by means of fertilisers, detergents, and wastewater containing household surfactants. It is thought that the periodic increases in the TP levels are caused by residential and agricultural areas around the lake [54]. Finally, the BOD₅ value of 37 mg/L and the COD value of 124 mg/L from the analysis of SP5 indicated Class IV—poor water quality. These two indicator variables were well above the limits of the poorest water quality criteria in the regulations. The TKN variables with a value of 1.7 mg/L and a pH of 8.48 indicated Class III—medium water quality. The conductivity measurement indicated Class IV—poor water quality with a value of 11,010 $\mu\text{S}/\text{cm}$ (Table 6). The DO parameter, with a value of 6.21 mg/L, was found to be within Class II. It is understood that the high organic matter content decreased the oxygen levels in the medium.

Table 8 presents the data from the study conducted in 2003 [21]. The WQVs represent the month of July in 1999. The breeding farm, located in the southern part of Mogan Lake, started operating in 2010. The sudden increases in COD and conductivity are believed to be largely caused by the breeding farm. It is observed that the concentrations of TN and TP entering the lake show a decreasing trend compared with the 1990s, likely due to the better control of agricultural activities nowadays [29]. This reduction in nutrient concentrations indicates the effectiveness of the measures implemented to manage and regulate agricultural practices. Continuous efforts in this regard can contribute to the preservation and restoration of Mogan Lake's ecological balance and ensure the sustainability of its water resources.

Table 8. Quality variables of streams feeding Mogan Lake [21].

Feeding Stream	Reference Stations	T (°C)	Cond. (µs/cm)	DO (mg/L)	COD (mg/L)	TKN (mg/L)	TP (mg/L)	SS (mg/L)	TC (EMS/100 mL)
SP1	[21] This Study	22.1	534	7.6	44	4.65	0.21	190	3334
		12.2	4150	9.55	118	1.7	0.018	37	0
SP2	[21] This Study	25.1	1600	8.5	67	12.95	0.21	23	3334
		17.3	3040	6.78	166	1.5	0.23	73	0
SP4	[21] This Study	24	763	10.8	39	2.96	0.35	<10	5556
		20.1	5320	13.24	92	1.9	0.2	21	0
SP5	[21] This Study	19.8	990	4.7	36	2.81	0.22	108	8889
		18.8	11,010	6.21	124	1.7	0.3	51	0

Notes: T, Temperature; Cond., conductivity; DO, dissolved oxygen; COD, chemical oxygen demand; TKN, total Kjeldahl nitrogen; TP, total phosphorus; SSs, suspend solids; TC, total coliform.

5. Conclusions

Mogan Lake and similar wetlands are important ecosystems as they contain various kinds of habitats and allow different species to live there. Therefore, environmental problems such as odour pollution, aesthetic pollution, a decrease in the lake reservoir area, a decrease in biodiversity, and the inability to use the lake water in agriculture have occurred due to anthropogenic lake bottom sludge.

According to the results of the analysis of the water samples taken from the surface of Mogan Lake, it was understood that there was an intense amount of organic pollution. In the water samples, TN values varying between 1.9 and 2.3 mg/L, and TP values varying between 0.03 and 0.048 mg/L were determined. The TN concentration in Mogan Lake was at sufficient levels for eutrophication, but the TP amounts were at hypertrophic levels. Considering the high load of phosphorus content in the bottom sediments, it is understood that there is a possibility that P can be released in pulses once hypoxic or anoxic conditions form at the water/sediment interface. However, due to the high DO levels, it is difficult to predict if eutrophication conditions may occur or not. Furthermore, according to the particle size analysis results of the sediments (Figure 4), as the finer particle content ratio was high, the interaction of the sediment with the lake water is expected. In light of all this information, it is understood that measurements should be made over a wider period and data range in order to obtain precise information about how the ecological situation in the lake will change in the future. Eutrophication control is very important for the effective management of water quality in sensitive areas such as Lake Mogan.

When the sediment samples from Mogan Lake were analysed, it was observed that the heavy metal contents were low. When the previous studies were reviewed, it was seen that no heavy metal contents that may threaten the lives of living things had been found in the bottom sludge samples [29]. It was also seen that the bottom sludge analysis results obtained within the scope of this study were in agreement with those found in previous years.

In order to solve the recent environmental problems around Mogan Lake, primarily the discharge of domestic and industrial wastewater into the lake was taken under control, but this has only prevented the further pollution of the lake. The pollutants, which were carried into the lake for many years, will still exist in the lake ecosystem. Pollution types with very different components and concentrations from the discharges that may originate from the coastal areas of Lake Mogan are remarkable. Therefore, pollution in the Mogan Lake Basin, especially from agricultural and a small number of mining and domestic discharges, causes negative changes in the water quality of the lake through the streams that feed Mogan Lake. Improving the water quality of Mogan Lake is only possible by identifying diffuse and point pollutants in the streams feeding the lake and developing management recommendations.

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