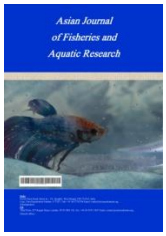

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Water Quality of a Tectonic Lake: Hazar Lake

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

In this study, water quality parameters of Hazar Lake have been investigated and evaluated according to water quality regulations. Some water quality parameters, such as dissolved oxygen, water temperature pH, electrical conductivity salinity, transparency, (Sechii disc depth), Chlorophyll a, total alkalinity, BOD, chloride, calcium, magnesium, total phosphorus, sulfate, ammonium nitrogen, nitrite nitrogene, nitrate nitrogene, total nitrogen were examined between September 2019-August 2020. The results were evaluated according to the quality criteria of the In-Continental Water Resources Classes of The Water Pollution and Control Regulation. According to the regulation, the water quality of Hazar Lake is classified as the 1st class in terms of dissolved oxygen, water temperature, ammonium nitrogen, total phosphorus, nitrate-nitrogen, nitrate nitrogen, biological oxygen demand; as the 3rd class in terms of chloride ion; as 4th class in terms of pH. The average chlorophyll a value of 1.09 µg/L in Lake Hazar indicates that the lake shows oligotrophic lake category feature. Secchi disc depth was 3.8 m), which shows that Hazar Lake is at the oligotrophic level in terms of light transmittance. It is noticed that for total phosphorus less than 10 µg/L, the lake is oligotrophic, for 10-20 µg/L is called mesotrophic, and for more than 20 µg/L is so-called eutrophic. This value was measured 0.02 µg/L in the lake; therefore, it can be concluded that the lake is oligotrophic. In addition, the change in alkalinity values of the lake between 402-450 mg $CaCO_3$/L indicates that the lake has very hard water characteristics. Precautions should be taken to protect ecological balances and prevent water pollution in Hazar Lake.

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Keywords: Hazar Lake; water quality; water pollution; control regulation.

1. INTRODUCTION

Ensuring the sustainable use of a water resource can only meet the anticipated expectations. It may be possible by collecting the monitoring result information. Original monitoring studies provide water resource management and water source of the activity can deliver some require information for assessing the resource, physical, chemical, and biological conditions of the resource [1].

Animal and plant species living in ecologically important water resources are also adversely affected by pollution before humans. Therefore, with the pollution of any aquatic ecosystem, living things at all stages of the food chain are affected. In addition, eutrophication, which occurs as a result of domestic, industrial and agricultural pollution in aquatic ecosystems, and the proliferation of nutrients such as nitrogen and phosphorus in the environment cause excessive reproduction of certain algae species. This excessive reproduction disrupts the oxygen balance in the lake and adversely affects the life of living things [2].

Lakes, which are important water resources for humans, are in constant interaction with the drainage waters filtered from the lands around them or with the pollution factors carried by the streams feeding the lake. It is important to evaluate lakes in terms of pollution factors.

Hazar lake is located in the southeast of Elazig (in Turkey) and was formed on the East Anatolian fault zone. The lake is one of Turkey's most important tectonic lakes and it is ranked as the 2nd wetland class according to the International Ramsar Agreement, also it is recorded as 1st, 2nd, and 3rd natural protected areas. In 1994, a class B wetland of international importance was declared by the Ministry of Environment. Besides, the lake and its surroundings have been declared as a tourism center by the Council of Ministers. Turkey has a strategic geographical location due to the presence of wealthy water resources compared to other countries [3,4]. There were not many studies concerning Hazar lake for investigating this parameter as we worked on them.

The water samples were taken from Hazar Lake for in every months of a year for determination of some physical and chemical properties of lake water. These parameters were taken into account to determine the water resources in the continent and to classify the quality of the water using standard criteria.

2. MATERIALS AND METHODS

2.1 Research Area

The Hazar Lake has been formed on the Eastern Anatolian Fault Zone which is one of the most important tectonic lakes, in the East Southeast-West Northwest direction. Its longest axis and width are approximately 20 and 4 km, approximately. The widest part (5.4 km) is in the east and the narrowest (3.8 km) is in the west. The deepest part of the lake (about 213 m) is located at the northeast end. The estimated thickness of sediments in the lake is 680 m. The lake area is 80 km^2 according to the measurements made at the level of 1238 m, its basin is 273 km^2. The water level in the lake varies around 1240 m and the current water volume of the lake is 1248 m^3. It has been reported as 7.5 $\times$ 109 m^3 in terms of elevation [3]. The East Anatolian Fault Zone passes under the lake [4].

The units forming the lake basin have generally a magmatic origin and have a structure that can increase the natural radioactivity of the lake. The lake basin is quite hilly. Çelemlik Mountain (1747 m) and Mastar Mountain (1724 m) are located in the north of the basin, which is a depression area in the Eastern Anatolian Fault Zone, and Hazar Baba Mountain (2347 m) in the south. Additionally, the most important stream that feeds the lake arethe Kürk Stream and Behramaz Stream, which joins the lake from the west and east; Zıkkım Creek, Sevsak Creek, and Mogal Creek are other important rivers feeding the lake [5] (Fig. 1). Various researchers have given figures varying between 150-300 m about the depth of Hazar Lake. With a study conducted by DSI in 1995, it was determined that the deepest part of the lake is in the eastern part and is 219 m [6].

It has reported that there are 5 fish species, namely *Alburnus heckeli, Capoeta umbla, Orthrias angorae eregliensis, Cyprinus carpio,* and *Kosswigichthys asquamatus* in Hazar Lake. *Kosswigichthys asquamatus* has been mentioned in the world literature as an endemic species of Hazar Lake [7].

Fig. 1. Map of Hazar

2.2 Sampling, Preparation, and Analysis of Water Samples

Water samples were taken into 500 ml polyethylene bottles by hand-dipping method from the surface and brought to the laboratory by the cold chain. The standards method was used for water samples analyses [8]. The analysis parameters and methods are listed in Table 1. The results have been evaluated according to Water Pollution Control Regulation [9] and a total of 18 water quality parameters, including, dissolved oxygen, water temperature pH, electrical conductivity salinity, transparency, (Sechii disc depth), Chlorophyll a, total alkalinity, BOD, chloride, calcium, magnesium, total phosphorus, sulfate, ammonium nitrogen, nitrite nitrogene, nitrate nitrogene, total nitrogen were examined between September 2019 - August 2020 monthly. The results were evaluated according to the quality criteria of the in-continental water resources classes of the water pollution and control regulation (WPCR).

Table 1. Water quality parameters and methods

Parameters	Methods
Dissolved oxygen (mg O_2/L)	Portable multi-parameter
Water temperature C°	Portable multi-parameter
pH	Portable multi-parameter
Electrical conductivity (µS/cm)	Portable multi-parameter
Salinity %	Portable multi-parameter
Turbidity m	Secchi-Disc depth
Chlorophyll a (µg/L)	Ethanol method
Total Alkalinity (mg $CaCO_3$/L)	EDTA titrimetric method
Biologic Oxygen Demand	ET 612-Lovibond brand BOD device
Chloride (mg Cl^-/L)	Dionex ICS-1000 model Ion Chromatography device using an anion column
Calcium mg Ca^{+2}/L	Atomic absorption spectrometer
Magnesium (mg Mg^{+2}/L)	Atomic absorption spectrometer
Total phosphorus (mg P/L)	Acid separation process + ascorbic acid method
Sulfate (mgSO_4/L)	Dionex ICS-1000 model Ion Chromatography device using an anion column
Ammonium Nitrogen (mg NH^{3-} N/L)	Spectrophotometric method
Nitrite Nitrogen (mg NO^{2-}N/L)	Diazotization spectrophotometric method
Nitrate Nitrogen (mg NO^{3-} N/L)	2.6-dimethylphenol method
Total nitrogen (mgN/L)	Persulfate separation process + 2.6-dimethylphenol method

3. RESULTS AND DISCUSSION

The physical and chemical parameters of the water samples were analyzed and compared with the quality criteria according to the classes of inland water resources in the Water Pollution Control Regulation (WPCR) and the eutrophication control limit values of the lakes. Many values have varied greatly according to months and seasons.

During the sampling period, water temperature values were changed between 4.9-24.6°C. The lowest and highest water temperature value are 4.9 and 24.6°C recorded in January and August, respectively. Alp [10] recorded water temperature between 6.4 - 25.3ºC; Sönmez [11] between 6.2-31.5ºC; Ünlü et al. [12] between 5- 25.6°C, Koçer [13] 4.7- 29.4°C in previous studies in Lake Hazar. Hazar Lake is in I class water is in the quality group in terms of water quality.

Dissolved oxygen values have been measured in the range of 6.1-11.9 mg/L. Fig. 2 reveals that the dissolved oxygen records lowest value (6.1 mg/L) in September and highest (11.9 mg/L) in December. The average dissolved oxygen value is 8.73 mg/L. Accordingly, the lake achieves the first-class water quality in terms of DO. Alp [10] measured the lowest dissolved oxygen amount as 7.6 mg/L and the highest 13.1 mg/L. Sönmez [11] recorded the dissolved oxygen amount between 7.1-13.6 mg/L. The highest dissolved oxygen amounts in the two studies were observed to be slightly higher than in our study.

On the other hand, the average dissolved oxygen value is 14.19°C (Fig. 2). It can be seen that the lowest and highest oxygen saturation value was recorded in October (with 82%) and July (with 119%), respectively. Also, the average dissolved oxygen value was 97%.

The pH range found in natural waters is between >2-12 extremes and most open lakes have pH values between 6-9. Very high pH values are often found in closed basins where the water contains a very high concentration of soda. Hard water calcareous lakes are usually buffered at pH>8 [14].

Fig. 2 shows that the lowest pH value was recorded in January with 8.6, and the highest value was 10.1 in July. The average annual pH value of Hazar Lake was recorded as 9.2. Accordingly, the lake is basic and can be classified in the quality group. Alp [10] recorded a pH value between 9.1-9.3. Sönmez [11] measured the pH value between 7.5 and 11.9. Ünlü et al. [12] calculated the average pH value in Lake Hazar as 8.90. Koçer [13] measured the lowest pH value as 8.5 and the highest as 9.4 Compared to previous studies, no significant change in pH was observed over time.The pH value of Lake Hazar was recorded as 9.1-9.5 in the surface water by Akbay and Anul [15] who conducted a study between January and April (1994). Compared to previous studies, pH values of the lake always determined over 7.5. The fact that mostly pH values <9.0 were observed between december, january and february during our research suggests that especially in the winter periods when the water temperature is low, the decrease in bicarbonate and carbonate causes the pH value to decrease in the lake.

The lowest electrical conductivity value was recorded in February with 1708 µS/cm, the highest value was 2298 µS/cm in august. The average electrical conductivity value was 2000.08 µS/cm (Fig. 2). Akbay and Anul [15] recorded the electrical conductivity in surface water as 2162 -2522 µS/cm in the study they conducted in the open region of Lake Hazar between January and April. Salinity values were changed between 0.3-0.4 ‰. The average value was recorded as 0.34‰.

For determining the turbidity Secchi disc depth was used. Turbidity (Secchi disk depth) values varied between 2.75-5 m throughout the measuring time. But it never fell below 2 m. Thus, Hazar Lake is mesotrophic in terms of light transmittance. Taylor et al. [16] reported the Secchi disc depth as > 3.7 m in oligotrophic lakes, 2.0-6.1 m in mesotrophic lakes, and <2 m in eutrophic lakes. According to data (3.8 m Secchi disc depth), Hazar Lake is at the oligotrophic level in terms of light transmittance. Koçer [13] found the average Secchi disk depth as 2.9 m. The researcher stated that Hazar Lake was in the mesotrophic class in terms of its trophic state with its mean disk depth.

Akbay and Anul [15] determined the Secchi disc depth to be between 1.97-3.94 m. Yıldırım [17] on the other hand, measured the depth of the between 1.5-3.6 m in the western and northern parts of the lake. The range of Secchi disc depths measured in both studies largely matched the amounts we determined in our study. According to most of the indices in the literature, Lake Hazar is classified as mesotrophic in terms of its trophic status with its average Secchi disc depth [16,18].

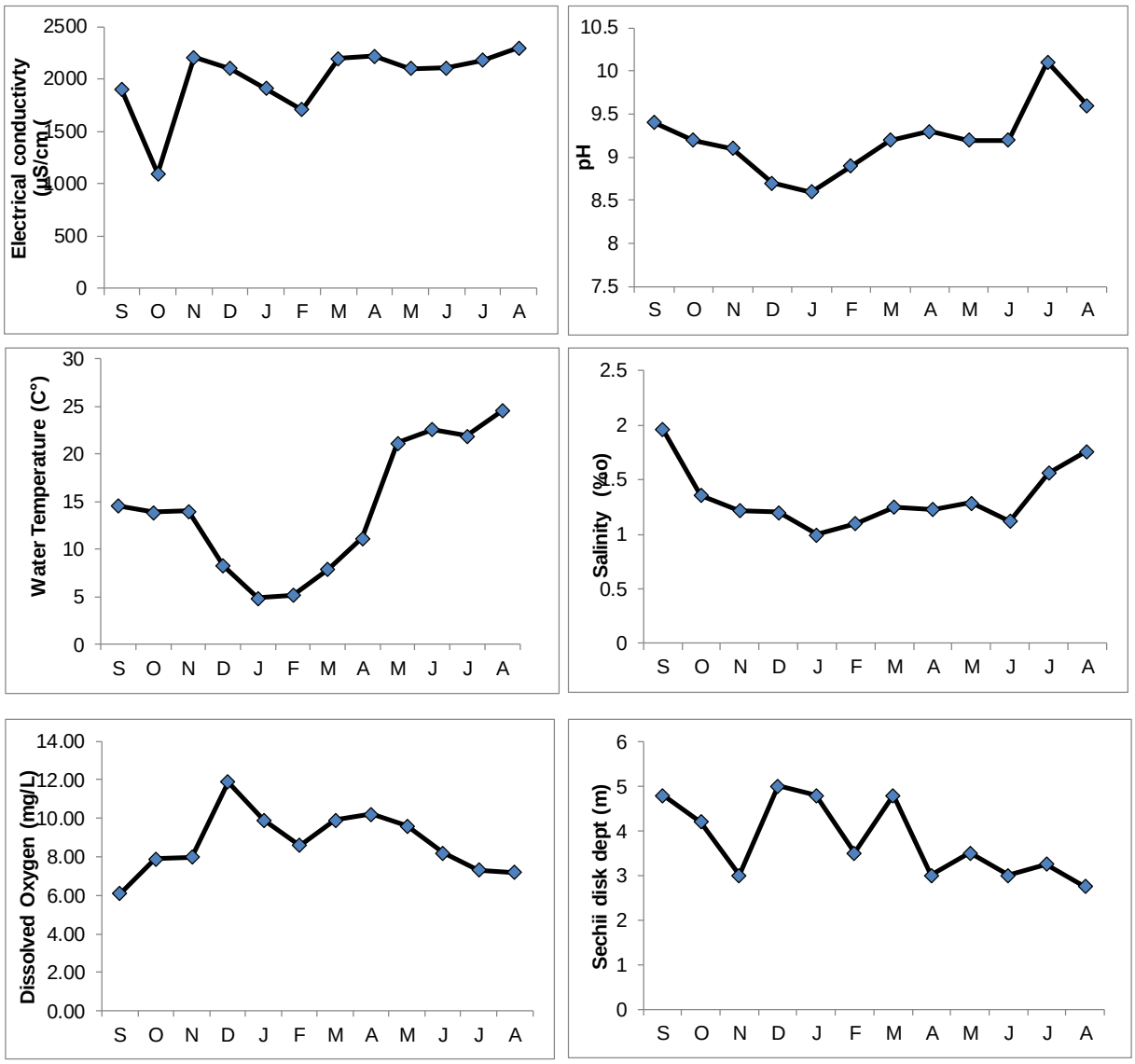

Fig. 2. Variations of electrical conductivity, water temperature, dissolved oxygen, pH, salinity and Sechii disk depth values in Hazar Lake

The lowest Chlorophyll a value was recorded in December with 0.3 µg/L, the highest value was 1.9 µg/L in May. The average Chlorophyll a value was 1.09 µg/L (Fig. 3). According to Alp [10] chlorophyll amounts were changed between 0.3 and 12.4 µg/L. Sönmez [11] recorded the amount of chlorophyll between 0.4 and 9.3 µg/L. Koçer [13] found these values in the lake between 0.2 and 2.6 µg/L. According to Thoman and Mueller [19] while chlorophyll-a is <4 µg/L in a lake, the lake is oligotrophic, 4-10 µg/L mesotrophic, and > 10 µg/L eutrophic. The average chlorophyll a value of 1.09 µg/ L in Lake Hazar indicates that it is in the oligotrophic lake category.

The lowest total alkalinity value was recorded in October with 389 mg $CaCO_3$/L, the highest value was 450 mg $CaCO_3$/L in September. The average total alkalinity value was 422.25 mg $CaCO_3$/L (Fig. 3). Since its Alkalinity values of lake range were between 402-450 mg $CaCO_3$/L, so it has a very hard water feature. Ünlü et al. [12] recorded total alkalinity values in the lake between 570-852 mg $CaCO_3$/L. They classified Hazar Lake as an alkali lake in terms of total alkalinity values. Hazar Lake has got very hard water feature waters (> 30 Fr°) [20]. This high alkalinity is directly proportional to the high pH. In this case, high temperature, organic matter, and other with the presence of toxic substances, the lake may become toxic.

The lowest Biological Oxygen Demand (BOD) value was recorded in December with 1.82, the

highest value was 6.02 in April (Fig. 3). The average total BOD value was 3.52. In a study for Lake Hazar, BOD analyzes were made only at a depth of 0.5 m. The mean BOD value obtained in this study was 8.9 mg/L. The highest value was measured in September with 14 mg/L and the lowest value was measured in march with 4 mg/L [21]. According to the classification criteria of inland water resources in the Water Pollution Control Regulation, the researcher stated that Hazar Lake is in the II. and III class water quality group. In our research, it was determined that the lake has I class water quality in terms of BOD as Quality Criteria According to the Classes of Internal Water Resources.

The lowest chloride value was recorded in may with 373 mg Cl^-/L the highest value was 420 mg Cl^-/L in October. The average total chloride value was 397.3 mg Cl^-/L. According to Quality Criteria by Classes of Surface Water Resources chloride values over 400 mg Cl^-/L indicate IV class water. An average of 6 g of chloride is excreted per person per day from human urine. At normal concentrations, chlorine does not pose any health hazards. However, salt taste occurs at concentrations higher than 250 mg/L [20].

The lowest calcium value was recorded in february with 65.8 mg Ca^{+2}/L the highest value 87.9 mg Ca^{+2}/L in july. The average calcium value was 76.6 mg Ca^{+2}/L. Calcium is essential for fish and plant growth. In trout farming, it is desirable that the calcium value of the water be between 4-160 mg/L [22] (Fig. 3).

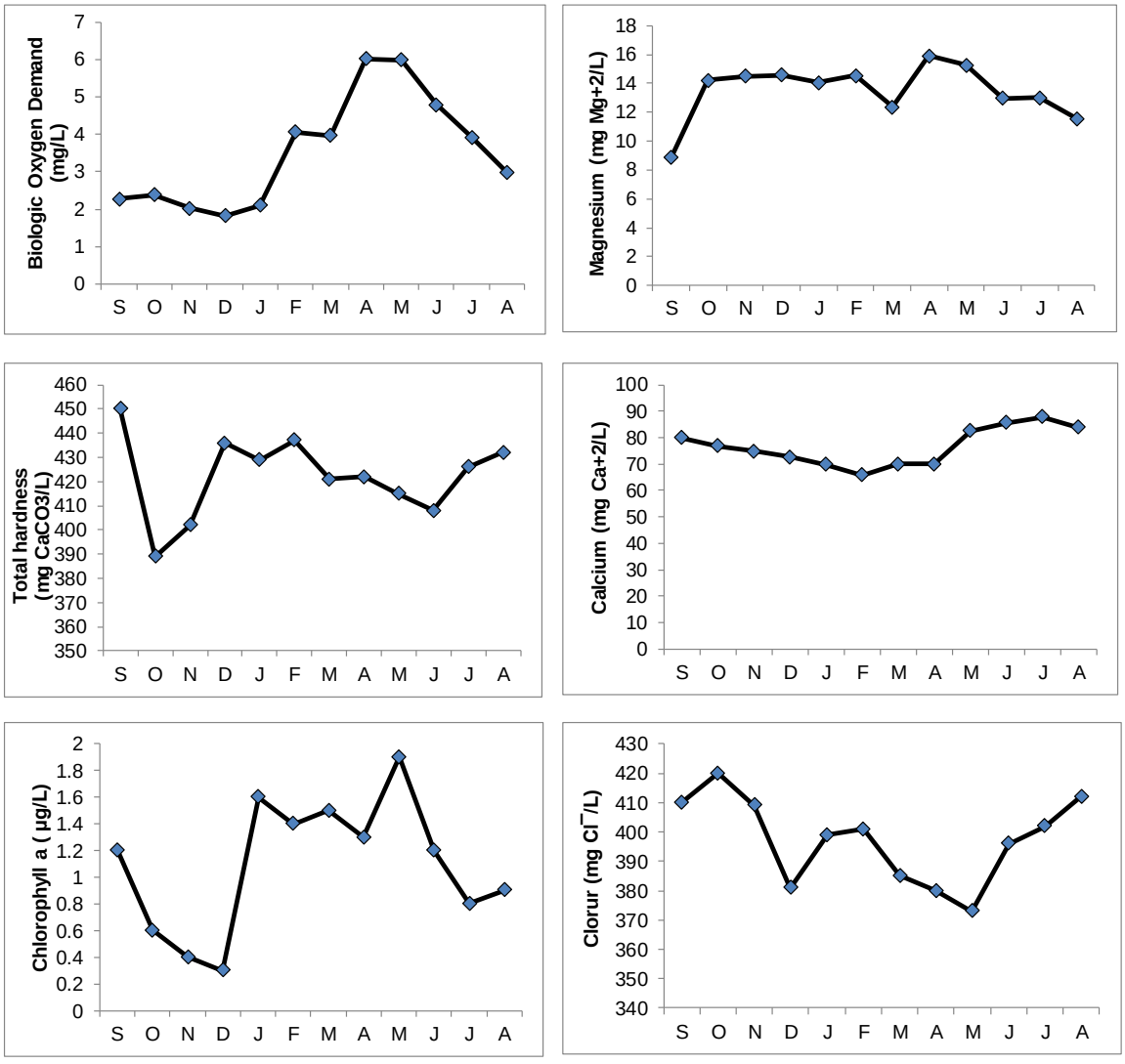

Fig. 3. Variations of BOD, total hardness, chrophyll a, magnesium, calcium and clorur values in Hazar Lake

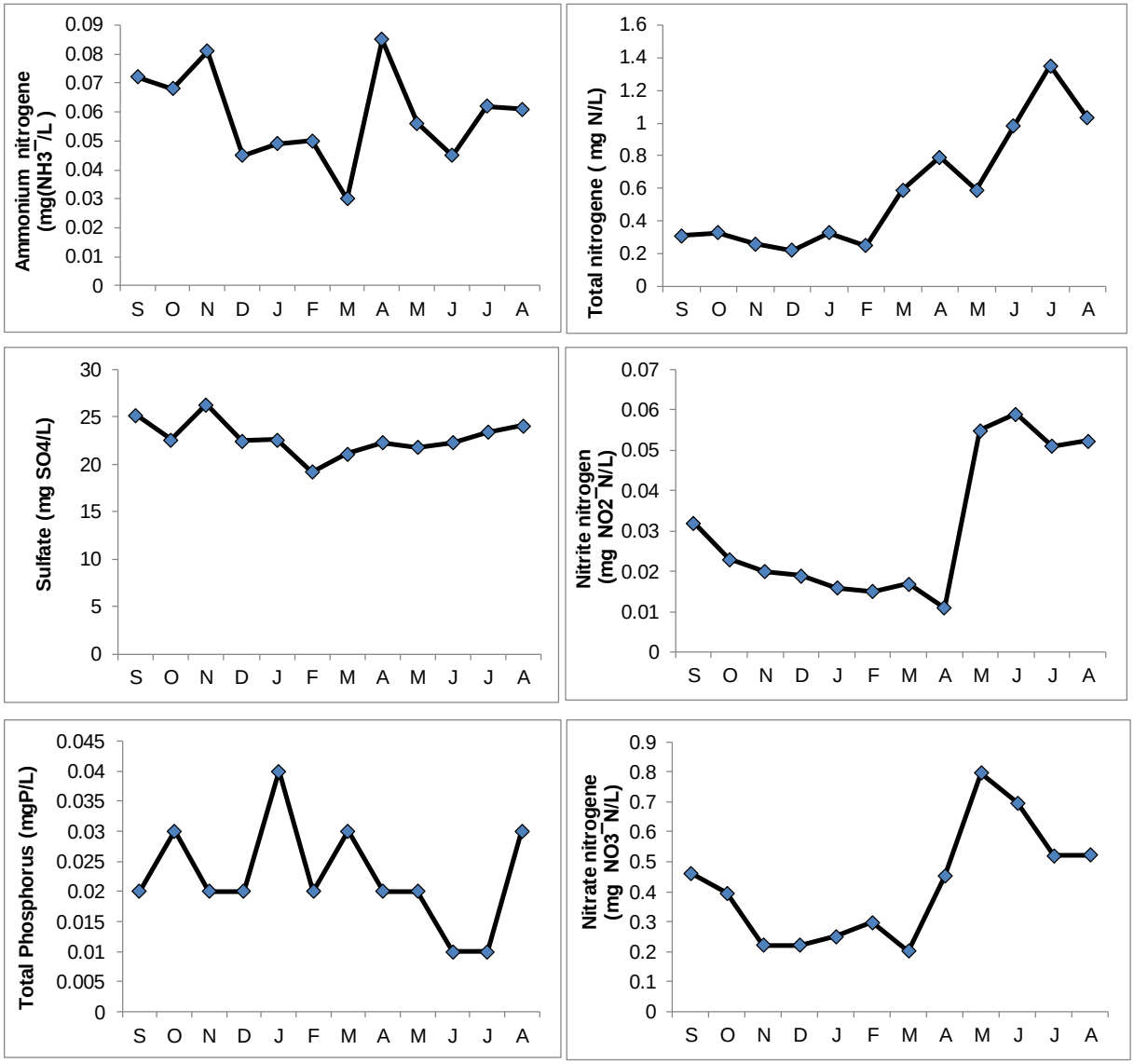

Fig. 4. Variations of ammonium nitrogene, sulfate, total phosphorus, total nitrogene, nitrite nitrogene and nitrate nitrogene values in Hazar Lake.

The lowest magnesium value was recorded in december with 5.9 mg Mg^{+2}/L the highest value was 6.9 mg Mg^{+2}/L in November. The average magnesium value was 6.34 mg Mg^{+2}/L (Fig. 3). Koçer [13] determined the magnesium value in Hazar Lake as, 101 – 103 mg Mg^{+2}/L, Anul and Akbay [15] 102-114 mg Mg^{+2}/L, Yıldırım [17] 33-113 mg Mg^{+2}/L. The magnesium amounts determined in all three studies showed higher values than the amounts determined during our research. Wetzel [23] stated that the solubility of magnesium compounds is much higher than that of calcium supplements, and that under normal natural conditions, magnesium as carbonate and hydroxide compounds is only significant in rare conditions such as very high pH values (>10) claimed to have precipitated. As a result of these properties, he stated that magnesium concentrations are relatively conservative and show little change. In this study, monthly magnesium values are found to be close to each other.

Fig. 4 displays total phosphorus values were in the range 0.01-0.04 mg P/L. These values were under eutrophication control limit values of WPCR. In some publications, it is stated that these values have increased over the years [16]. If the total phosphorus is <10 µg/L, the lake is oligotrophic, 10-20 µg/L mesotrophic, and > 20 µg/L is eutrophic. This value was measured 0.02 µg/L in the lake and determined as oligotrophic.

Wetzel [23] stated that the total phosphorus content is <1-5 µg P/L in ultraoligotrophic lakes, 5-10 µg P/L in oligo-mesotrophic lakes, and 10-30 µg P/L in meso-eutrophic lakes. This value was measured 0.025 µg/L in the lake and determined as oligotrophic.

The lowest sulfate value was recorded in February with 19.2 mg SO_4/L the highest value was 26.3 mg SO_4/L in November. The average value was 22.7 mg SO_4/L. The lowest ammonium nitrogen value was recorded in March with 0.030 mg NH_3^-N/L the highest value was 0.085 mg NH_3^-N/L in April. The average value was 0.058 NH_3^-N/L (Fig. 4).

The lowest nitrate-nitrogen value was recorded in April with 0.011 mg NO_2^-N/L the highest value was 0.059 mg NO_2^-N/L in June. The average value was 0.030 mg NO_2^-N/L (Fig. 4). The lowest nitrate-nitrogen value was recorded in March with 0.201 mg NO_3^-N/L the highest value was 0.796 mg NO_3^-N/L in May. The average value was 0.775 mg NO_3^-N/L (Fig. 4).

The lowest total nitrogen value was recorded in December with 0.22 mg N/L the highest value was 1.35 mg N/L in July. Fig. 4 showed that the average total nitrogen value is 0.585 mg N/L. In this study, the lowest total nitrogen value was recorded in December with 0.22 mg N/L the highest value was 1.35 mg N/L in July. The average total nitrogen value was 0.585 mg N/L Koçer [13] calculated the average total nitrogen amount of Hazar Lake as 0.49 ± 0.29 mg N/L.

Hakanson and Jansson [24] the total nitrogen content of oligotrophic lakes as <0.35 mg N/L and the total nitrogen content of mesotrophic lakes as 0.35-0.50 mg N/L; Nürnberg [18] reported the total nitrogen content of oligotrophic lakes as <0.35 mg N/L and the total nitrogen content of mesotrophic lakes as 0.35-0.65 mg N/L. According to these statements, it can be said that Lake Hazar has a mesotrophic character in terms of total nitrogen content. According to the widely accepted OECD values [25] Lake Hazar is oligotrophic in terms of average total nitrogen content.

Ammonium nitrogen values are currently under the limit values. However, due to the high pH value of the lake, the NH_4 ions in the environment could change the NH_3 form and may cause toxic effects for fish. Therefore, in high pH and temperature values, the harmful effects of organic substances that will mix into the lake will be even more. The ammonium nitrogen values were recorded with 0.030 - 0.085mg NH_3^-N/L. Ünlü et al. [12] recorded ammonium nitrogen values between 0.09- 0.13-mg/L. With the research of Cici [26] a decrease in ammonium nitrogen over time in comparison is seen.

Chloride values ranged from 373-420 mg Cl^-/L. The high chloride values are an indication of the high value of EC. According to the electrical conductivity values (average 2002.08 µS/cm), Hazar Lake is IV. class water quality and is not suitable for irrigation. Ünlü et al. [12] recorded chloride values between 354-418 mg/L. Chloride concentration has got direct importance in terms of both industrial water quality and irrigation water quality.

Total phosphorus values were in the range 0.01-0.04 mg P/L. These values were under eutrophication control limit values of WPCR. In some publications, it is stated that these values have increased over the years [14]. If the total phosphorus is <10 µg/L, the lake is oligotrophic, 10-20 µg/L mesotrophic, and > 20 µg/L is eutrophic. Wetzel [14] stated that the total phosphorus content is <1-5 µg P/L in ultraoligotrophic lakes, 5-10 µg P/L in oligo-mesotrophic lakes, and 10-30 µg P/L in meso-eutrophic lakes. Therefore, according to Wetzel's statement Hazar Lake is an ultraoligotrophic lake.

Taylor et al. [16] determined the total phosphorus content of oligotrophic lakes as <10 µg P/L and the total phosphorus content of mesotrophic lakes as 10-30 µg P/L; Hakanson and Jansson ([24] the total phosphorus content of oligotrophic lakes as <10 µg P/L and the total phosphorus content of mesotrophic lakes as 8-25 µg P/L; Nürnberg [18] determined the total phosphorus content of oligotrophic lakes as <10 µg P/L and the total phosphorus content of mesotrophic lakes as 10-30 µg P/L; OECD [25] reported that the total phosphorus content of oligotrophic lakes is 3.0-17.7 µg P/L (average 8.0 µg P/L) and the total phosphorus content of mesotrophic lakes is 10.9-95.6 µg P/L (average). 26.7 µg P/L).

According to these literatures, it can be said that Hazar Lake has an oligotrophic feature according to the result of the total phosphorus value measured as 0.02 µg/5 on average.

Consequently, to the regulation, Hazar Lake is classified as 1st class in terms of dissolved oxygen, oxygen saturation, water temperature,

ammonium nitrogen, total phosphorus, nitrate-nitrogen, nitrate nitrogen, biological oxygen demand; in terms of chloride ion as 3rd class, in terms of pH as 4th class water quality.

4. CONCLUSION

To conclude, the datas were assessed by the quality standards of the in-continental water resources classes of the water contamination and control guidelines. As per the guideline, the water quality of Hazar Lake has classified the first class in terms of dissolved oxygen, oxygen saturation, water temperature, ammonium nitrogen, total phosphorus, nitriate nitrogen, nitrate nitrogen, biological oxygen requested.

In this study, it was determined that the temperature of the lake varied between 4.9 and 24.6°C. In previous years, attempts were made to breed trout in cages in the lake.The water temperature measured in the summer period remains above the growth limit for trout and is very close to the vital limit. It should be taken into account that this situation may affect the sustainable production in the lake. It has been determined that the pH values of the lake vary between 8.6 and 10.1. It should be taken into account that this situation may adversely affect the aquaculture performance.

Irregular and unplanned housing control around Hazar Lake should be taken under the implementation of legal regulations for coastal protection. The water level of the lake should be protected in a way that does not affect the ecological balance. Aquatic habitats should be monitored periodically and continuously, considering their usage patterns. A well-managed monitoring program will provide very useful information for environmental management.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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