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RESEARCH PAPER

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Heavy Metal Accumulation in Aquatic Macrophytes and Plankton, Water-Sediment in Lake Iznik

Cafer Bulut[1]

[1]Fisheries Research Institute – Egirdir, Isparta (32500), Türkiye

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Corresponding Author
Tel.: +905324472591
E-mail: caferbulut@gmail.com

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Abstract

This study aims to investigate heavy metal accumulation in water-sediment, plankton, and macrophyte samples of Lake Iznik, one of the important lakes of Turkey. In 2016, water-sediment and plankton samples were taken from 19 and 10 stations respectively. In addition, heavy metal analyzes were performed on samples taken from *Potamogeton pectinatus*, *Najas marina*, *Myriophyllum spicatum*, *Typha latifolia*, *Schoenoplectus litoralis*, *Phragmites australis*, which are the most abundant macrophytes in the lake. The data of water and sediment samples were spatially analyzed in GIS and mapped with ArcGIS. In the water samples of Lake Iznik, arsenic (As), mercury (Hg) and in sediment samples, arsenic (As), chromium (Cr), copper (Cu) and nickel (Ni) were detected at remarkable levels. The results revealed that Iznik Lake was under pressure in terms of heavy metals and their effects should be reduced.

Introduction

Water, which is one of the essential elements of living life, plays an active role in the realisation of all kinds of biochemical reactions with the minerals and compounds it contains, as well as being a nutrient (Akın & Akın, 2007; Paul, 2017; Vukašinović-Pešić & Nada Blagojević, 2017). However, increasing human pressure on water resources has revealed the problem of pollution in fresh waters. This situation, which is a contemporary problem, makes it necessary to conduct studies to determine and evaluate the quality of water resources (Arslan, 2008).

Aquatic ecosystems contain the biodiversity necessary for a sustainable environment worldwide. However, pollutants disrupt the natural balance of these water resources and limit their sustainable use (Rajasekar et al., 2022; Mishra et al., 2023).

Heavy metals are generally found in low concentrations in aquatic ecosystems. However, anthropogenic pollutants such as industrial discharges, domestic wastes, and agricultural activities increase the heavy metal concentration and cause severe environmental pollution in coastal areas, lakes, and rivers (Kamala-Kannan et al., 2008). Heavy metals, components of the earth's crust, are taken into the living creatures in various ways. Metals are released naturally, however, mixed with ground and surface waters by the effects of industrial wastes. Exposure to heavy metals can occur through contaminated waters and the atmosphere and food chain around polluting sources (Kumar et al., 2019). Some heavy metals, which are necessary in low concentrations for maintaining metabolic activities in the living body, cause poisoning, various diseases, and disorders at high concentrations. Heavy metals tend to bioaccumulate. It can be found in

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higher amounts in living tissues compared to its surrounding environment (Eroğlu et al., 2008).

Heavy metals (Cu, Mn, Zn, Fe, Pb, Cd, Co, Cr, Hg, etc.) that are transferred to the aquatic environment with pollutants or other means are taken from the environment and necessary body fluids, enzymes, hormones, vitamins, etc. for the vital activities of the organism. These elements are important as an indispensable element due to their catalyst functions for use in the formation of structures and biochemical events. However, if these are found below or above certain limits in the organism's environment, they have negative effects on their physiological activities (Portman, 1972; Uysal & İnan, 1991; Korkmaz et al., 2019).

Since an aquatic area has an ecosystem feature, the water quality of the location is the most critical factor affecting the composition, productivity, abundance and physiological conditions of aquatic species. As a result of the discharge of wastewater from settlements, industries and agricultural activities into rivers, the capacity of the water to absorb these wastes is exceeded and the pollution situation can reach undesirable dimensions (Gümrükçüoğlu & Baştürk, 2008). Geographical Information Systems (GIS) technology and statistical methods are used effectively in water quality management. In many studies on the spatial evaluation of water quality, GIS is used as an important tool with its advantages in integrating and processing the information obtained from different sources and producing new maps that will be very useful in understanding the spatial relationship (Özşahin, 2013).

As a result of global climate change and unconscious use, many lakes in Turkey are in danger of drying up. Due to the decrease in the amount of lake waters, the pollution loads of the lakes are increasing and their utilization levels are decreasing day by day. Lake Iznik is also a lake under the influence of global climate change and pollution load.

The water and sediment samples taken from many points of Lake Iznik were first analyzed and simultaneous and detailed evaluations were made. The results obtained are important for sustainable lake and water resources and will help in sustainable ecosystem management. Within this scope, heavy metal status in water and sediment samples of Lake Iznik was tried to be revealed by creating spatial maps using GIS system.

Furthermore, heavy metal accumulation levels were investigated in plankton samples obtained from the lake and aquatic macrophyte samples found intensively in the lake and the levels of impact at the aquatic ecosystem level were examined. As a result of the study, the heavy metal pollution pressure experienced by Lake Iznik was emphasized and suggestions were made about the measures to be taken in the lake.

Materials & Methods

Study Area and Pollution Load

Lake Iznik is the largest lake in the Marmara Region and the fifth largest lake in Turkey (Figure 1). To the north of Lake Iznik, the Gulf of Izmit; To the west is the Gulf of Gemlik, where the water empties. (Gaygusuz, 2006). It is separated from the Gulf of Gemlik in the west by the 200 m high Karsak Strait. (Öztürk et al., 2005). The length of the lake in the east-west direction is approximately 32 km, and its width in the north-south direction is 12 km, and it resembles an ellipse in shape (Numann, 1958; Özeren, 2004). Its area is the lowest 298-the highest 313 km^2, the catchment area is 1,246 km^2, the height from the sea is 80 m and the deepest

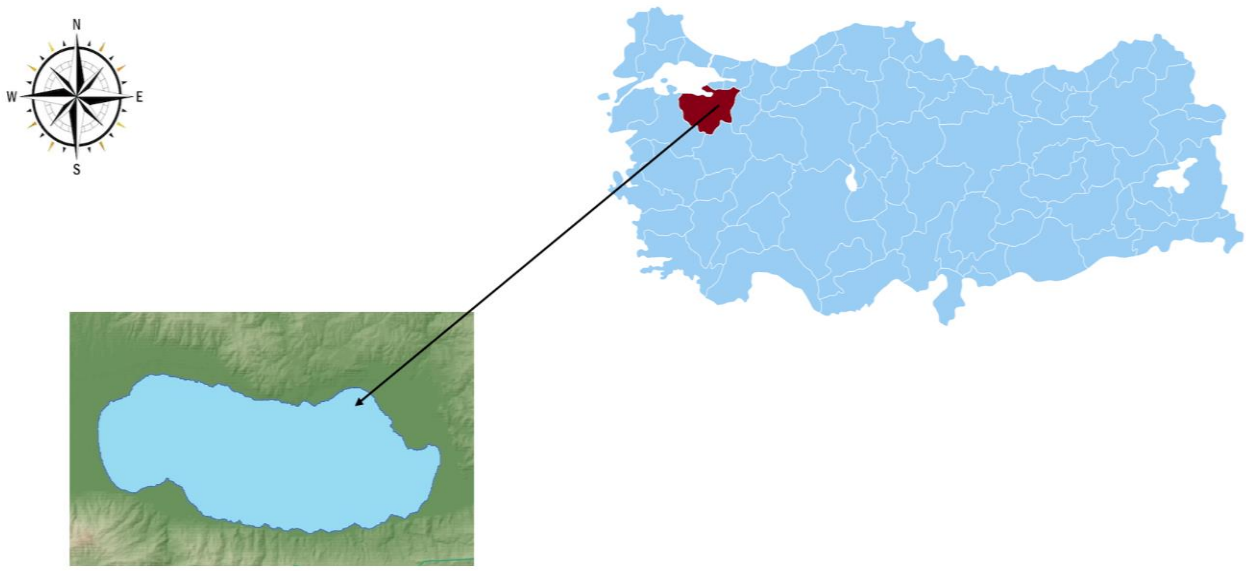


Figure 1. Lake Iznik map.

point is 80 m. (Özeren, 2004). In most of the lake, the depth exceeds 30 m. (Gaygusuz, 2006).

There are over 60 settlement units in the Lake Iznik feeding basin. Of these, Iznik on the eastern shores of the lake and Orhangazi to the west of the lake are large settlements at the district level; Yeniköy, Elbeyli and Sölöz settlements are towns. In contrast, the others are large and small villages. These settlements, especially the settlements on the shores of the lake are based on irrigated agriculture, vegetable and fruit production and olive farming. Accordingly, the use of fertilizers and pesticides is very common in the region. Approximately 9000 hectares of irrigated agricultural land is irrigated with the water of the lake. It is envisaged that this area will be increased by another 7000 hectares with the irrigation facilities under construction. All field and garden owners close to the lake irrigate the agricultural lands by drawing water from Lake Iznik with motor pumps without exception and interruption. The biggest threats to Lake Iznik are industrial wastes; the wastes of olive oil mills and the effects of agricultural activities (Figure 2).

Fertilizer and drug residues reach the lake through surface washing and runoff caused by rainfall. In addition, the tools and equipment used in the spraying of olive groves and other agricultural lands are washed with lake waters and the washing water is discharged into the lake. The sewage and wastewater of all settlements close to the lake is also given to the lake and increasing pollution occurs in the lake waters. Recently, this pollution has now begun to be visibly felt. Pollution in the lake has reached a very high level and has become evident on the coasts of Iznik and Orhangazi and the Sölöz delta. It is seen that olive processing plants in Iznik and Orhangazi, industrial facilities in Orhangazi and slaughterhouse wastes play an important role in this pollution. Wastes and sewage from industrial facilities in Iznik and Orhangazi, surrounding settlements and small olive oil factories also enter the lake. The occasional excessive algae growth and mass fish deaths caused by this attract attention and exhibit a risky situation.

In the study, 76 water and 76 sediment samples were collected seasonally in November 2015, February 2016, May 2016 and August 2016 from 19 different locations determined in Lake Iznik. 100 mL sealed polypropylene bottles were used for heavy metal analysis of water samples. A few drops of 0.5 % nitric acid (HNO_3) were added to the bottled water samples for metal analysis and reduced acidity (Hem, 1970). The pH of the water samples was lowered below 2 and stored at +4°C in the refrigerator until the analyzed period.

All sediment samples were taken from the lake with the help of an Ekman scoop and transferred into sample containers. Each sediment sample was first air-dried naturally and pulverized in a mortar and pestle. Each sediment sample was individually sieved and stored separately in clean polyethylene bottles. Approximately 0.5 g of each sediment sample was taken and digested with 2.5 mL nitric acid and 1.5 mL perchloric acid in a Milestone Microwave (Digestion System Smart D model, Sample Pre-digester), (Mokgohloa et al., 2022). Then, organic degradation was carried out and cooled. After the cooled samples were

Figure 2. Settlements and agricultural locations around Lake Iznik.

centrifuged, digested samples were filtered, and their volume was completed to 50 mL with ultrapure water. Heavy metal (As, Cr, Cu, Ni, Zn, Pb, Cd, Hg, Fe, Al and Mn) analyzes of water and sediment samples were performed with Graphite Furnace Atomic Absorption Spectrophotometer (GFAAS; Thermo Scientific, Neslab Thermo Flex 900) in Egirdir Fisheries Research Institute Chemistry Laboratory. The sediment samples were diluted by the GFAAS until they reached the automatic measurement level and analysis were performed. The spatial distributions of the sampled stations are given in Figure 3 and their coordinates are given in Table 1.

Plankton samplings were carried out seasonally. Plankton samples were collected with a plankton net with a mesh size of 55 M and 25 cm diameter, vertically and horizontally from the seven stations representing the Lake. (Figure 4). Phytoplankton and zooplankton samples taken with a plankton scoop for 10 minutes, were passed through filter paper and their wet weights were determined and dried in an oven. After the dry weights were determined and the combustion process was completed, they were acidified with HCl, filtered through blue band filter paper and made up to 50 mL with distilled water.

Macrophyte samples were obtained according to the TS EN 15460 method (Water quality – Guidance standard for the surveying of aquatic macrophytes in lakes). Macrophyte samples were taken along a line of

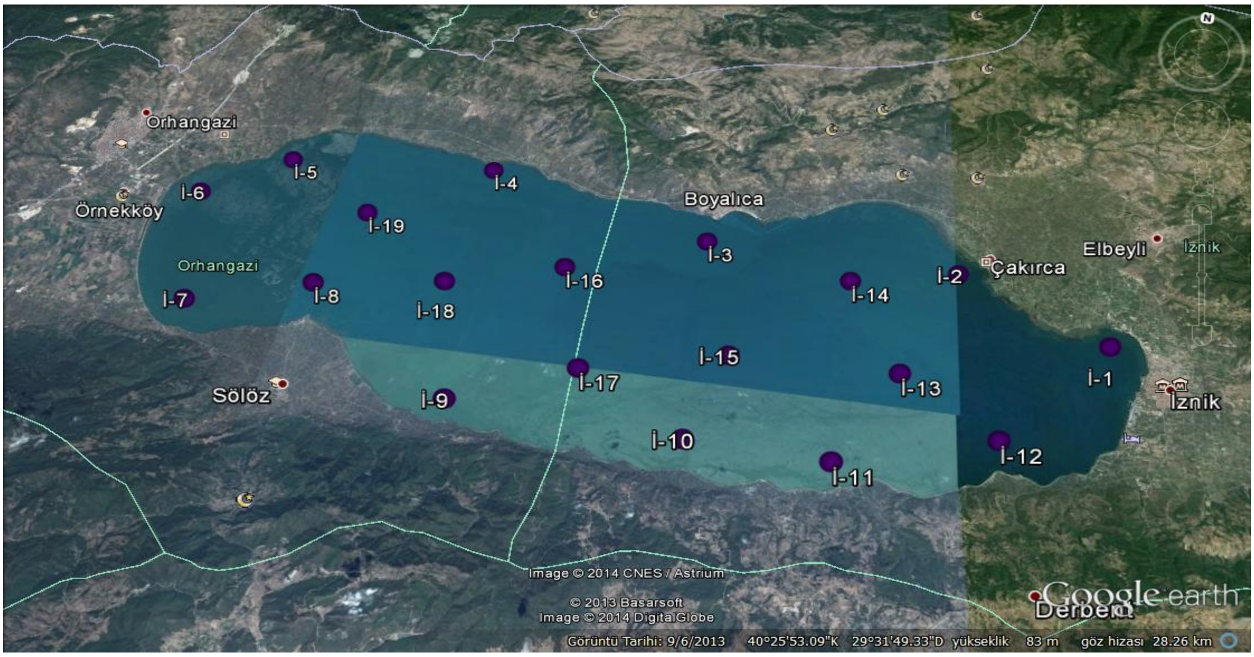


Figure 3. Sampling stations for water and sediment.

Table 1. Coordinates of Lake Iznik water and sediment sampling stations

No	Station Name	Coordinate-1	Coordinate-2
1	Iznik Centre	40°26'22.68"N	29°42'13.78"E
2	Çakırca	40°27'43.11"N	29°39'03.10"E
3	Boyalıca	40°27'55.75"N	29°33'19.78"E
4	Keramet	40°29'15.68"N	29°27'55.89"E
5	Orhangazi	40°29'02.68"N	29°22'57.83"E
6	Örnekköy	40°27'57.76"N	29°21'06.80"E
7	Gölyaka	40°25'19.41"N	29°22'00.52"E
8	Sölöz	40°26'00.12"N	29°24'41.51"E
9	Narlıca	40°23'48.49"N	29°28'23.13"E
10	Müşküle	40°23'32.03"N	29°33'24.15"E
11	Göllüce	40°23'24.76"N	29°36'24.36"E
12	Dırazali	40°24'10.34"N	29°39'44.98"E
13	Iznik Middle of the Lake-1	40°25'19.78"N	29°37'45.42"E
14	Iznik Middle of the Lake-2	40°27'18.17"N	29°36'38.79"E
15	Iznik Middle of the Lake-3	40°25'20.29"N	29°34'07.47"E
16	Iznik Middle of the Lake-4	40°26'57.54"N	29°30'12.92"E
17	Iznik Middle of the Lake-5	40°24'43.75"N	29°31'00.18"E
18	Iznik Middle of the Lake-6	40°26'20.64"N	29°27'36.37"E
19	Iznik Middle of the Lake-7	40°27'49.57"N	29°25'17.15"E

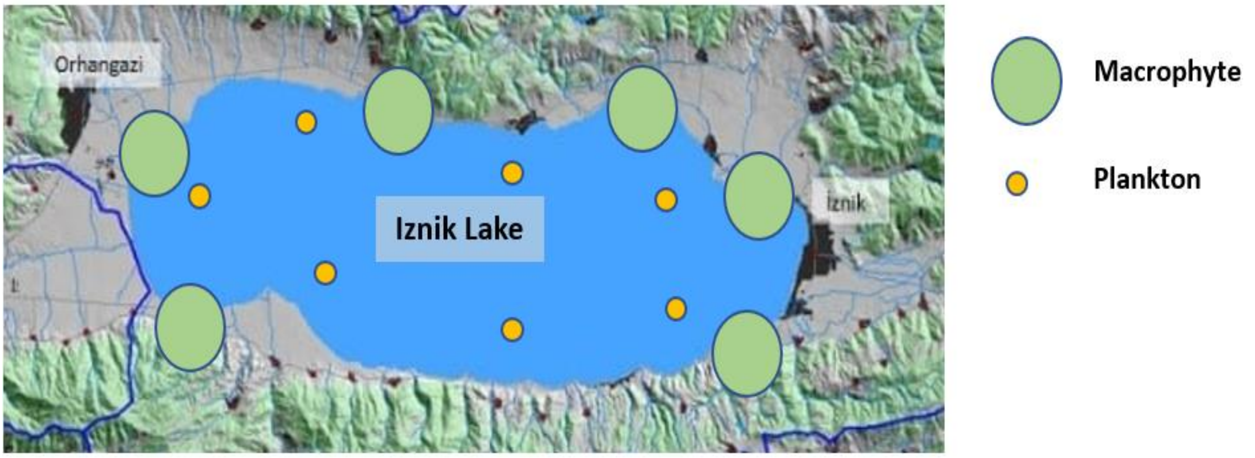


Figure 4. Plankton and macrophyte sampling stations.

3-6 m and 7-8 individuals from each species were selected. The extracted samples were kept in a press and 70% alcohol to be identified. Samples were dried for heavy metal analysis. While sampling the stems and leaves of *Potamogeton pectinatus* (syn. *Stuckenia pectinata*), *Najas marina* and *Myriophyllum spicatum* species; roots, stems and leaves of *Typha latifolia*, *Schoenoplectus litoralis* and *Phragmites australis* were sampled.

Macrophyte samples were dried, weighed 1 g, and 10 mL of 65% suprapur HNO_3 was added and kept at room temperature overnight. The samples taken on the heating plate were first heated at 120°C for 4 hours, and then the temperature was increased to 140°C, and the dissolving process was continued until 1 mL of HNO_3 remained. After it was allowed to cool, the remaining part was filtered into a 25 mL flask with blue band filter paper. Balloons and filter papers were washed with 1% HNO_3. The volume was purified twice and made up to 25 mL with distilled water. Analysis of Pb, As, Ni, Cd, Cu, Cr, Mn and Zn as heavy metals in water and sediment samples was carried out with Thermo Graphite Furnace Atomic Absorption Spectrophotometer (AAS) in Egirdir Fisheries Research Institute Chemistry Laboratory.

GIS Applications and Multivariate Statistical Analysis

The presented study used Geographical Information Systems (GIS) techniques in all maps and spatial analyses. First of all, the hard-copy topographic map was digitized and a 3-D model was prepared. This 3-D model was used as a base for all maps produced. The coordinates of the boreholes from which water samples were taken during the field studies were recorded with GPS and transferred to the GIS environment. All the analysis results obtained were matched with these coordinates and the hydrogeochemical database of the study was created in ArcGIS 10.8 software. These databases were transformed into spatial distribution maps in grid format with 10 m spatial resolution by using the IDW interpolation method in ArcGIS software. Finally, Pearson's correlation analysis was done for statistical relationships between all physicochemical parameters and calculated index values evaluated in the study.

All the data obtained as a result of the research were evaluated with the help of the SPSS 25.0 package program and Microsoft Excel 2021. Comparison of groups in parametric data showing normal distribution. A one-way ANOVA test was used to analyze variance. The significance level was accepted as $\alpha=0.05$ in all statistical tests. Statistical similarities and differences between all variables were observed by a two-way analysis of variance (ANOVA). According to the results obtained, Surface Water Quality Regulation (Anonymous, 2021). The values detected in the sediment were evaluated according to the consensus-based Sediment Quality Directive (SQG) developed by MacDonald et al., (2000). The results were expressed as mean all experiments were performed triplicately.

Results

Heavy Metal Concentrations in Lake Water

The results of the heavy metal analyses in the lake water were statistically given in Table 2, Table 3 and Figure 5. National and international regulations were taken into consideration to assess lake water pollution in the study area (Quality Criteria of Continental Surface Water Resources by Class in terms of General Chemical and Physicochemical Parameters, Specific Pollutants and Environmental Quality Standards for Surface Water Resources, Priority Substances and Environmental Quality Standards for Surface Water Resources (Anonymous, 2021) and Sediment Quality Criteria (MacDonald et al., 2000).

Cd element concentration was determined below the detection measurement limits in the lake water. Al (average 13.664 µg/L) was the most concentrated element in the Lake water, followed by Fe (average 11.374 µg/L). As, Hg, Pb and Zn values were determined

Table 2. Statistical summary of the heavy metal concentrations (µg/L) in water samples of Lake Iznik

Parameters	N	Minimum	Maximum	Mean	Std. Deviation
Hg		0.08	0.22	0.111	0.034
Pb		0.20	1.50	0.611	0.307
As		2.30	12.96	5.922	2.943
Ni		0.03	2.39	0.269	0.340
Cu		0.04	2.15	0.398	0.395
Cr	19	0.02	1.02	0.320	0.240
Cd		<0.05	<0.05	<0.05	0.000
Mn		1.31	3.85	2.532	0.589
Zn		0.09	6.35	2.430	1.341
Al		7.56	20.71	13.664	3.263
Fe		5.48	20.14	11.374	3.299

Table 3. Pearson correlation results for heavy metal water samples from Lake Iznik

	Hg	Pb	As	Ni	Cu	Cr	Mn	Zn	Al	Fe
Hg										
Pb	.672** .000									
As	-.162 .163	.011 .927								
Ni	-.228* .047	-.105 .368	-.082 .480							
Cu	.150 .197	.351** .002	-.027 .816	-.032 .783						
Cr	.278* .015	.186 .107	-.262* .022	-.131 .259	.076 .513					
Mn	.231* .045	.230* .046	-.191 .098	-.101 .385	.148 .203	.492** .000				
Zn	.473** .000	.419** .000	-.081 .487	-.055 .639	.106 .362	.474** .000	.399** .000			
Al	.578** .000	.600** .000	-.215 .062	-.030 .797	.421** .000	.484** .000	.387** .001	.445** .000		
Fe	.448** .000	.618** .000	-.057 .625	-.083 .476	.409** .000	.185 .109	.375** .001	.306** .007	.702** .000	

**. Correlation significance level 0.01 (2-tailed).
*. Correlation significance level 0.05 (2-tailed).

as between 2.30-12.96 µg/L, 0.08-0.22 µg/L, 0.20-1.50 µg/L and 0.09-6.35 µg/L, respectively (Table 2). OneWay ANOVA results showed that Hg (F: 2.231, $p<0.05$, df:18), Pb (F: 8.558, $p<0.001$, df.18) and Fe (F: 6.823, $p<0.001$, df.18) were found to be significantly different according to sampling stations.

When the heavy metal variability graphs of the stations are examined, the variability values of the data are remarkable, especially in Hg, Pb, Ni, Cu and Fe values. In particular, heavy metals such as Hg, Pb, Ni show the level of interaction from industrial areas, while Cu and Fe show the extent of interaction from agricultural areas. This situation was revealed by detailing with spatial maps in GIS maps (Figure 5).

When the maps obtained as a result of the GIS system were examined, elemental concentrations were higher at stations I2, I4, I5 and I6 for Al and Fe; I1, I5, I6 and I8 for Hg; I5, I6 and I7 for Pb; I4 for Cu; I7, I10, I11 for As; and I6 and I12 for Zn (Figure 6 and Figure 7). This situation shows that there is an interaction from industrial areas, especially on the Orhangazi side.

Heavy Metal Concentrations in Lake Sediment

The analysis results of the heavy metals in the lake sediments were statistically shown in Table 4, Table 5 and Figure 8. National and international regulations were taken into consideration to assess lake water pollution in the study area.

When the sediment data are analysed, it is seen that the most intense Al and Fe elements are found. These two elements, which are already the most abundant in nature, were also the most abundant in the sediment. Al was found at an average of 22277 mg/kg and Fe at 20982 mg/kg. These were followed by Mn (average 1103 mg/kg). Zn values varied between 51-

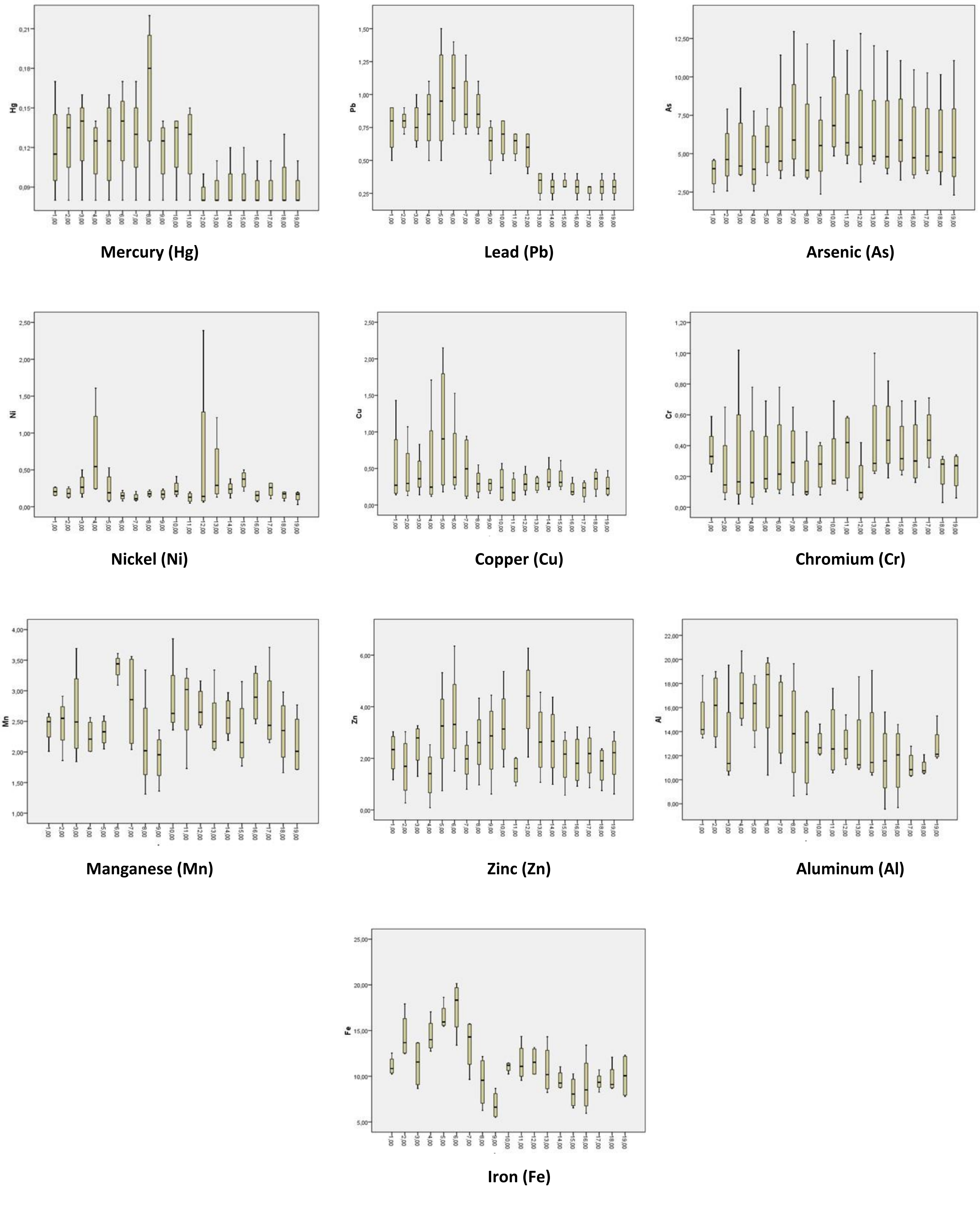
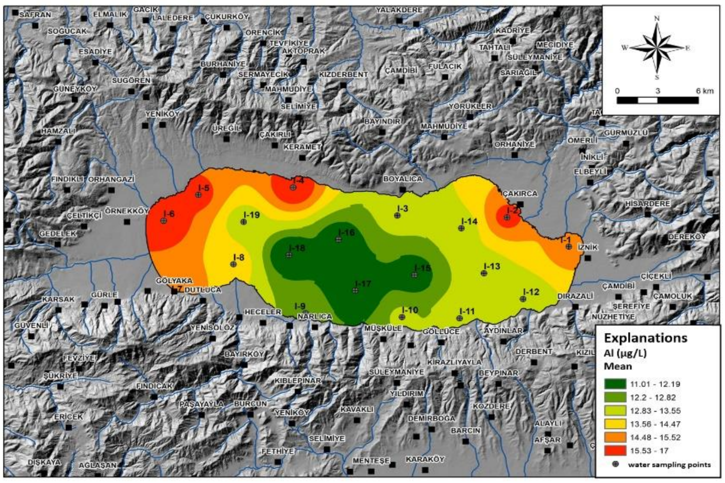
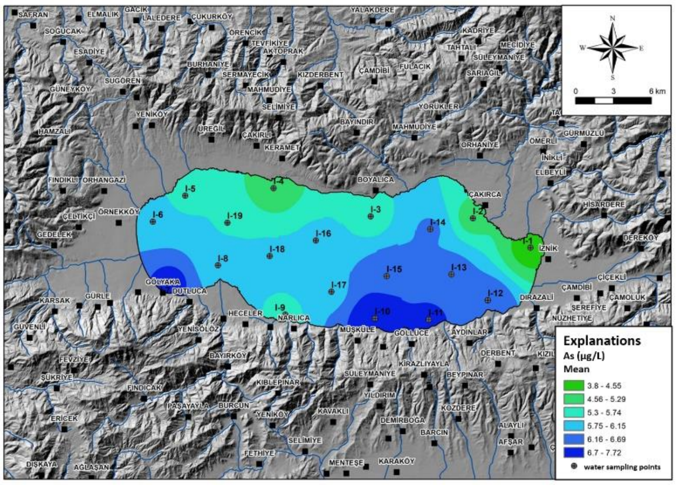


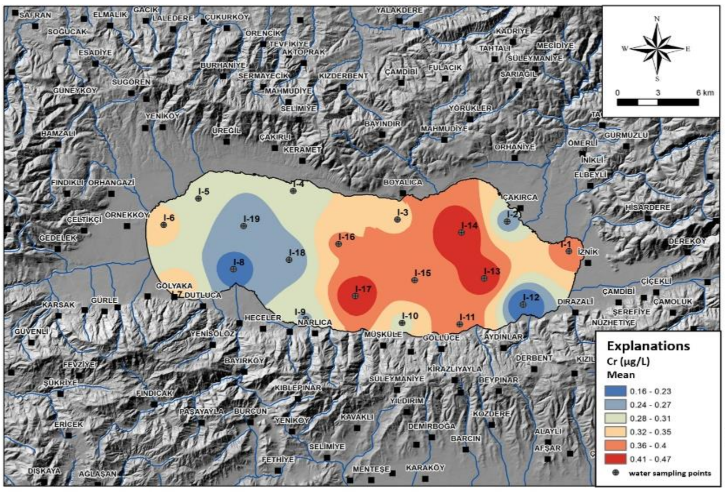
Figure 5. Average heavy metal concentrations in the water of Lake İznik according to the stations.



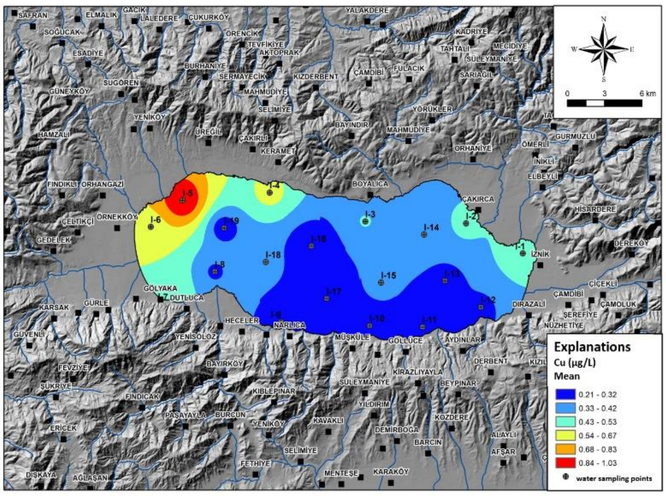
Aluminum (Al)



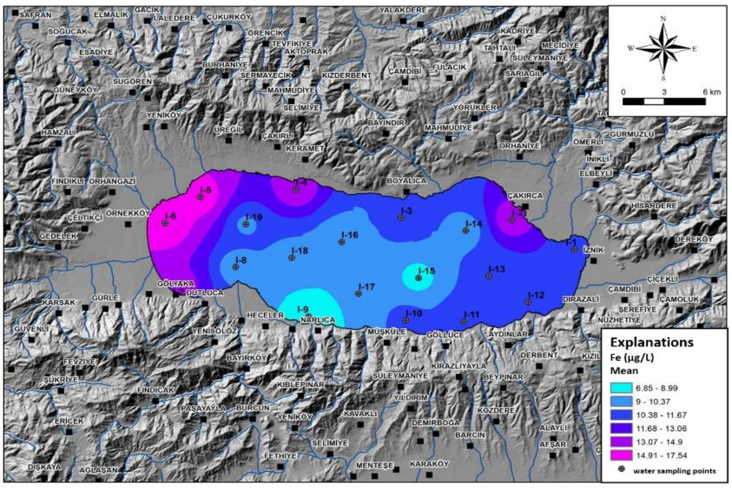
Arsenic (As)



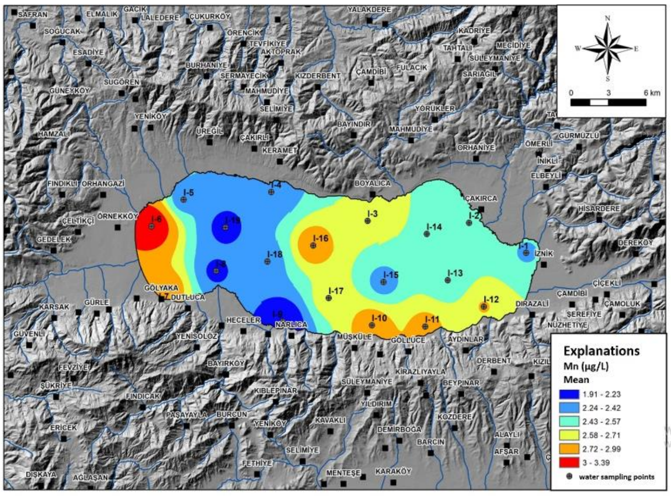
Chromium (Cr)



Copper (Cu)

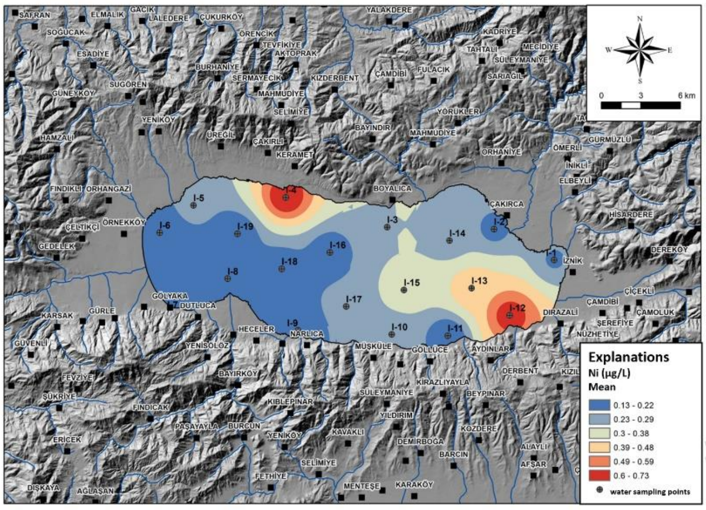


Iron (Fe)

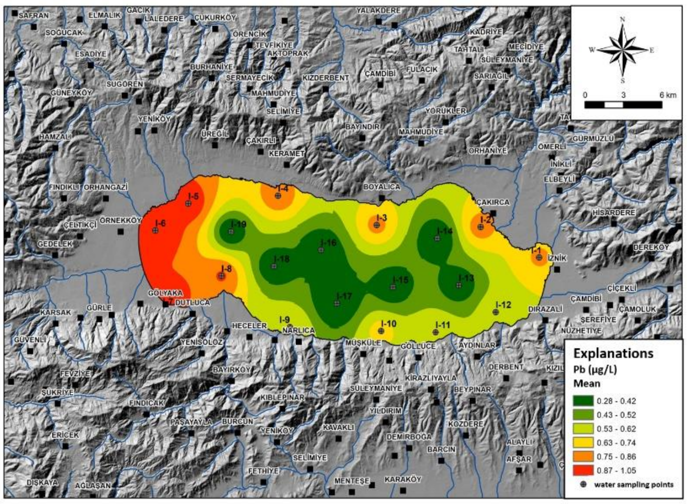


Manganese (Mn)

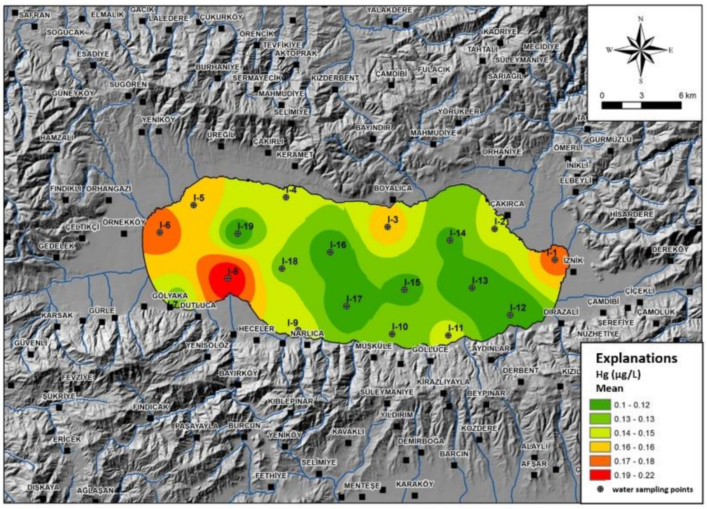
Figure 6. Al, As, Cr, Cu, Fe and Mn distribution maps of average surface water in Lake Iznik



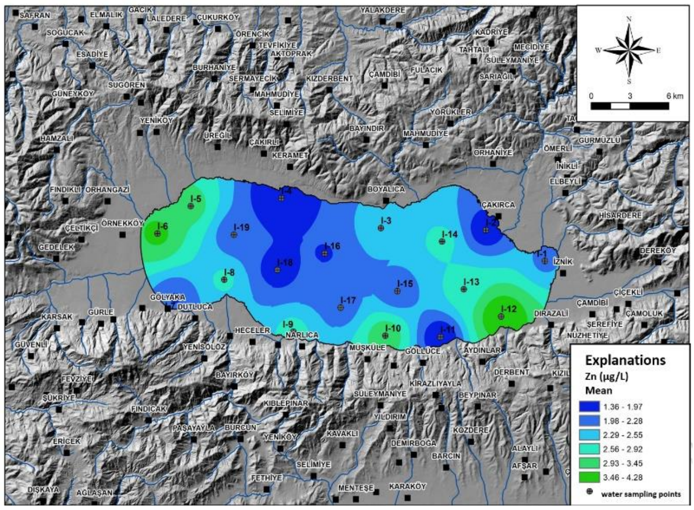
Nickel (Ni)



Lead (Pb)



Mercury (Hg)



Zinc (Zn)

Figure 7. Ni, Pb, Hg and Zn distributions in Lake Iznik water

Table 4. The heavy metal concentrations (mg/kg) in sediment samples of Lake Iznik (N=19)

Parameters	Minimum	Maximum	Mean	Std. Deviation
Hg	0.03	0.07	0.05	0.01
Pb	16.5	28.4	22.58	2.49
As	15.4	48.6	26.33	6.87
Ni	30.2	62.1	45.19	7.23
Cu	38.1	65.1	51.84	7.00
Cr	38.1	71.5	52.62	8.26
Cd	0.14	0.28	0.20	0.03
Mn	809	1564	1103.11	152.05
Zn	51	103.2	75.51	12.20
Al	16100	30400	22277.63	3378.35
Fe	15500	26500	20982.89	2476.74

Table 5. Pearson correlation results for heavy metal sediment samples from Lake Iznik

	Hg	Pb	As	Ni	Cd	Cu	Cr	Mn	Zn	Al	Fe
Hg											
Pb	.103										
	.375										
As	.168	.316**									
	.147	.005									
Ni	.102	.373**	.295**								
	.380	.001	.010								
Cd	.111	.650**	.314**	.270*							
	.339	.000	.006	.019							
Cu	.102	.126	.250*	.026	.341**						
	.379	.277	.029	.825	.003						
Cr	-.248*	-.173	.176	.266*	-.292*	-.120					
	.031	.136	.127	.020	.010	.301					
Mn	-.232*	.524**	.465**	.265*	.538**	.127	.019				
	.044	.000	.000	.021	.000	.273	.871				
Zn	.219	.571**	.385**	.082	.546**	.345**	-.329**	.273*			
	.057	.000	.001	.480	.000	.002	.004	.017			
Al	-.063	.639**	.278*	.176	.626**	.183	-.268*	.667**	.401**		
	.586	.000	.015	.129	.000	.114	.019	.000	.000		
Fe	.121	.528**	.223	.072	.645**	.222	-.408**	.392**	.319**	.630**	
	.300	.000	.053	.536	.000	.054	.000	.000	.005	.000	

**. Correlation significance level 0.01 (2-tailed).
*. Correlation significance level 0.05 (2-tailed).

103.2 mg/kg; Cr values 38.1-71.5 mg/kg; Cu values 38.1-65.1 mg/kg; Ni values 30.2-62.1 mg/kg; As values 15.4-48.6 mg/kg and Pb values 16.5-28.4. Cd and Hg values varied between 0.14-0.28 mg/kg and 0.03-0.07 mg/kg, respectively. The results show that there is a large amount of metal accumulation in the sediment of Lake Iznik (Table 4).

When the results of Pearson Correlation analysis are analysed, it is seen that there is a close relationship between Cd-Pb, Pb-Al, Cd-Al, Cd-Hg, Cd-Fe, Mn-Al and Fe-Al (Table 5). OneWay ANOVA results showed that Hg (F: 14.499, p<0.001, df:18), Pb (F: 4.434, p<0.001, df.18), Cd F: 4.531, p<0.001, df.18), Cu (F: 8.166, p<0.001, df.18), Cu (F: 3.195, p<0.001, df.18), Zn (F: 9.995, p<0.001, df.18) and Fe (F: 4.867, p<0.001, df.18) were found to be significantly different according to sampling stations (Figure 8).

When the maps obtained as a result of the GIS system were analysed, it was seen that sediment levels were higher at stations I6 for Al; I2 for As; I2, I5, I6 for Cd; I1, I2, I10, I11 for Cu; I1, I4, I5 and I6 and I7 for Fe; I3 for Hg; I5, I6 and I7 for Ni; I1, I5, I6, I7 and I8 for Pb (Figure 9 and Figure 10). When the results are analysed, it is seen that Lake Iznik is particularly affected by residential, industrial and agricultural areas in terms of sediment metal accumulation.

Plankton

Heavy metal results and graphs in plankton samples obtained from Lake Iznik are given in Table 6 and Figure 11. When the data are analysed, it is seen that Cu is the most abundant and Cd is the least abundant. The order of presence in plankton samples is Cu>Zn>Mn>Ni>Cr>Pb>As>Cd. On average, Cu values were 4.042 mg/kg; Zn values 3.071 mg/kg; Mn values 2.074 mg/kg; Ni values 1.634 mg/kg; Cr values 1.438 mg/kg; Pb values 0,4285 gm/kg; As values 0.165 mg/kg and Cd values 0.0042 mg/kg.

Macrophyte

Heavy metal results and graphs of macrophyte samples obtained from Lake Iznik are given in Table 7, Figure 12, Figure 13 and Figure 14. When the data are analysed, it is seen that Mn and Zn elements are found the most. However, it is seen that these plants, which feed on sediment, act as bioremediation by taking heavy metals from the environment. The highest accumulation was found in the root zone of *T.latifolia* and *P.australis* species, while significant accumulation was also found in the root zone of *S.litoralis* and leaf zone of *P.pectinatus*. The most negligible accumulation was detected in the steam zone of *N.marina*.

Discussion

Regulations, criteria and previous studies were taken as references in the evaluation of the data obtained from the samples in Lake Iznik. When the results of the water samples are evaluated according to the Regulation on Surface Water Quality, it is seen that

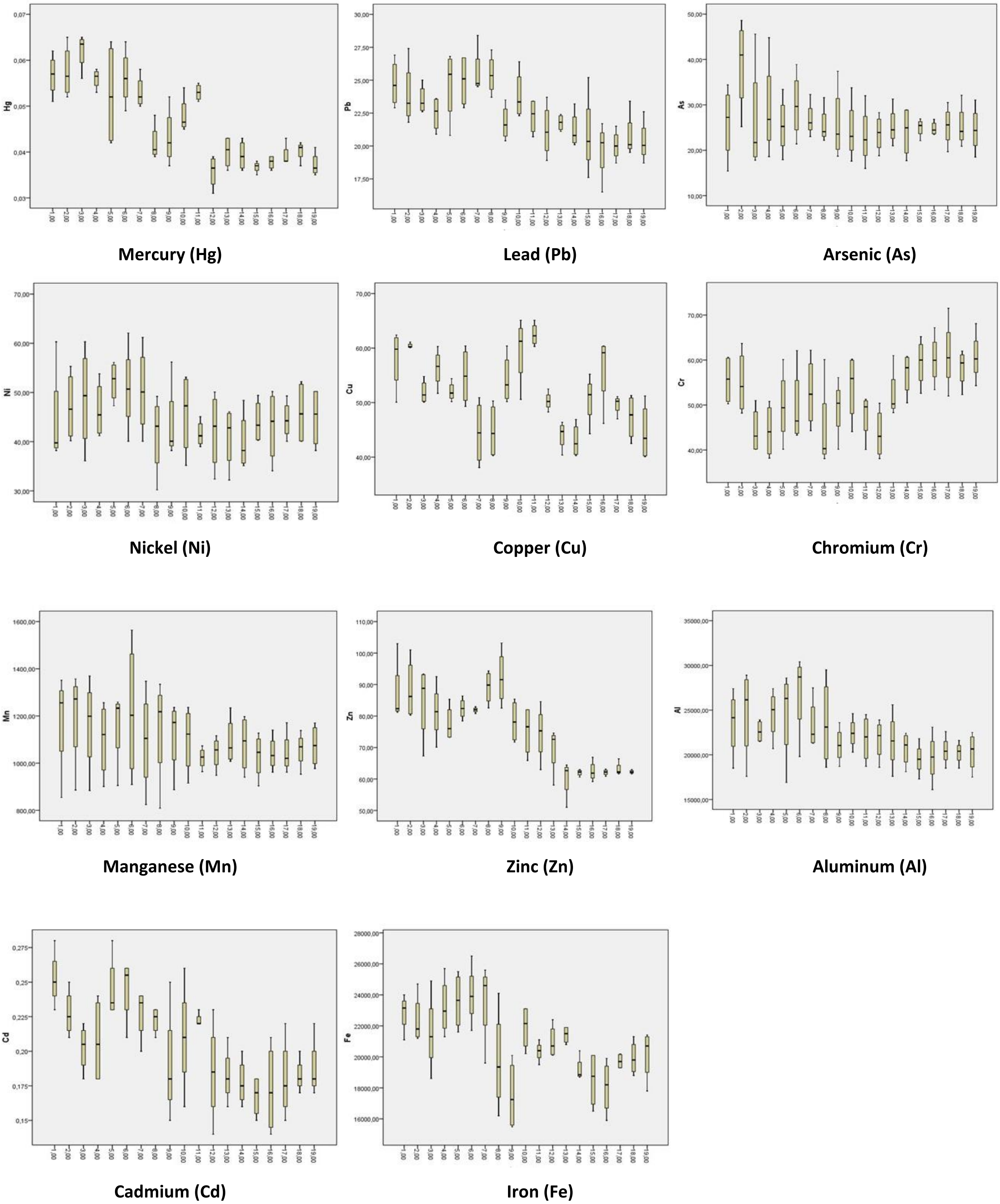


Figure 8. Average heavy metal concentrations in sediment of Lake İznik according to the stations.

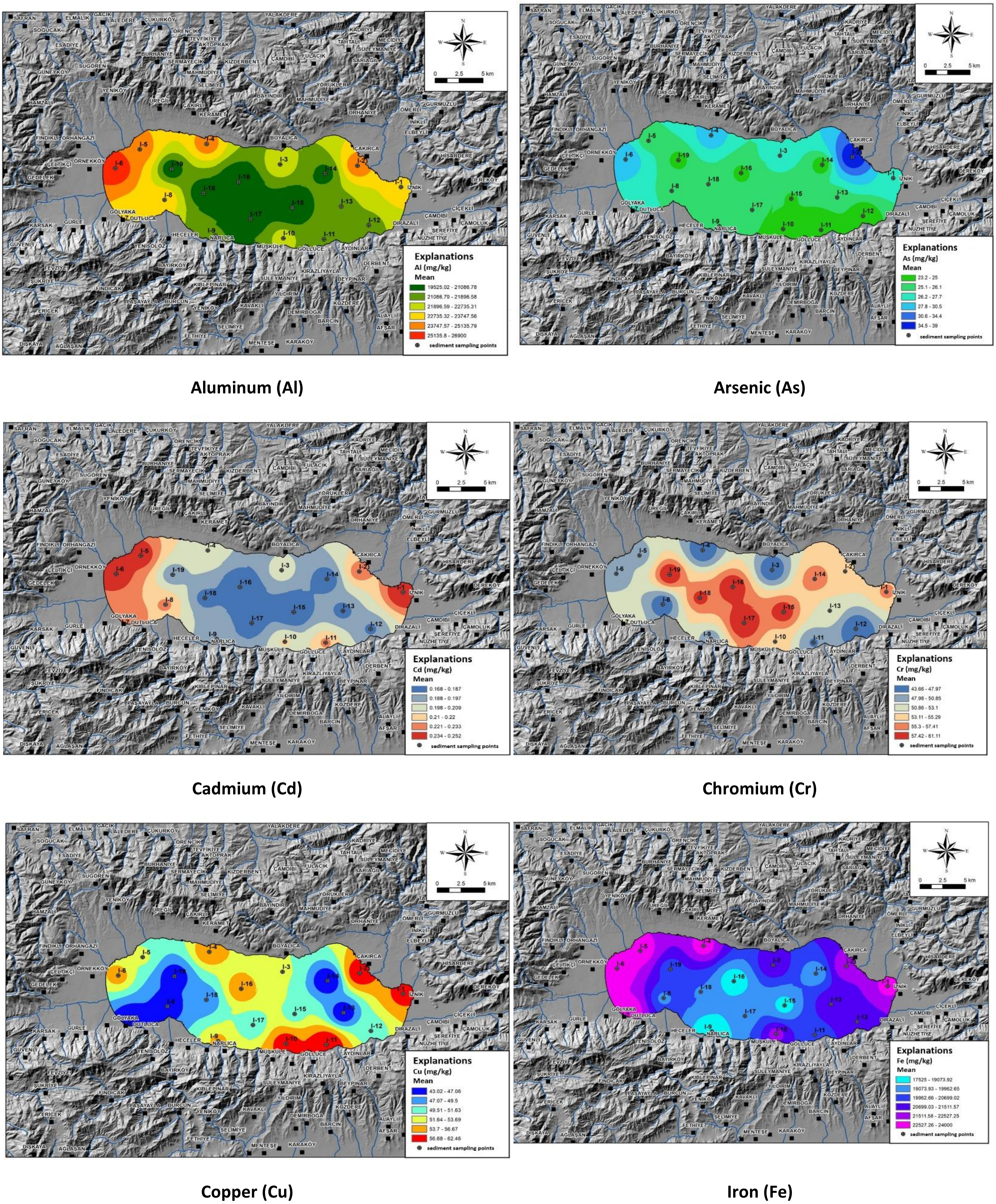
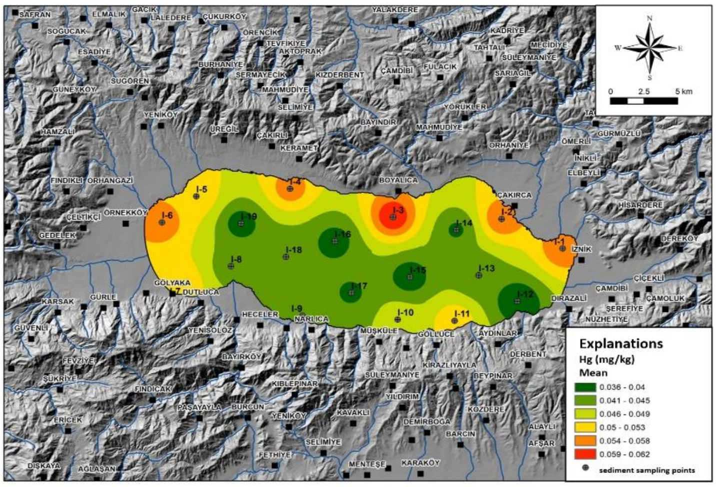
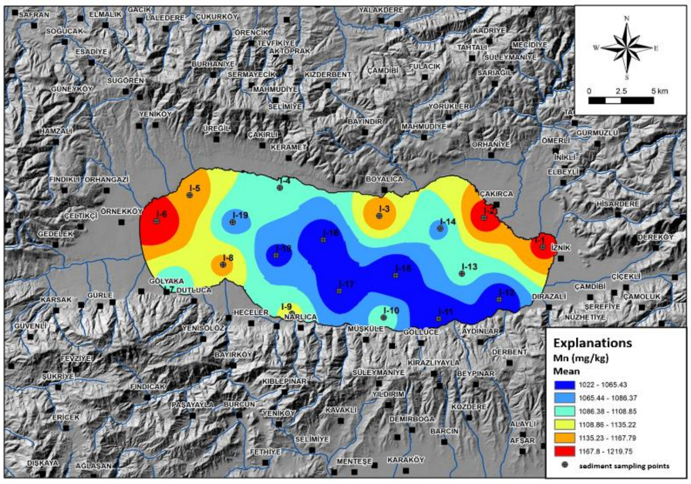


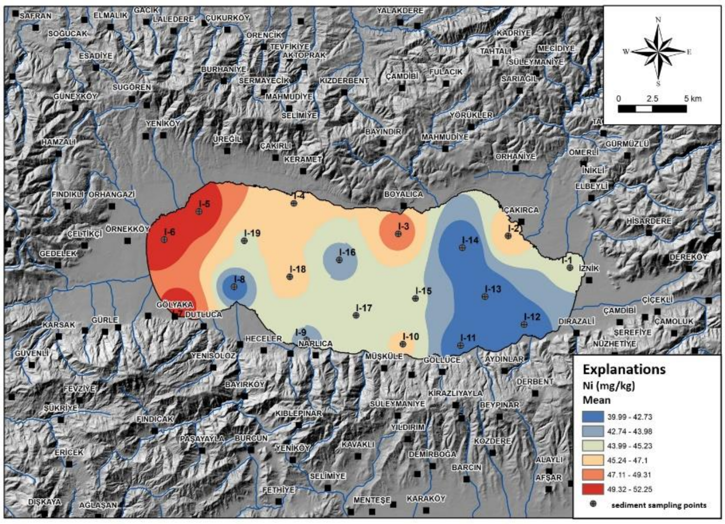
Figure 9. Al, As, Cd, Cr, Cu and Fe distribution maps of average sediment water in Lake Iznik.



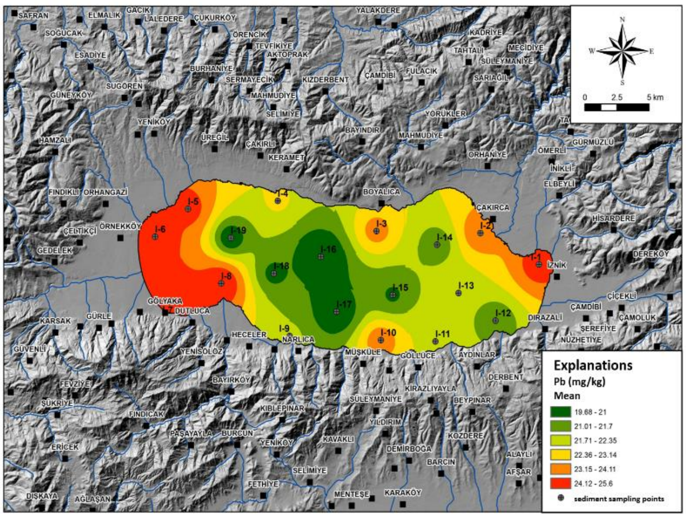
Mercury (Hg)



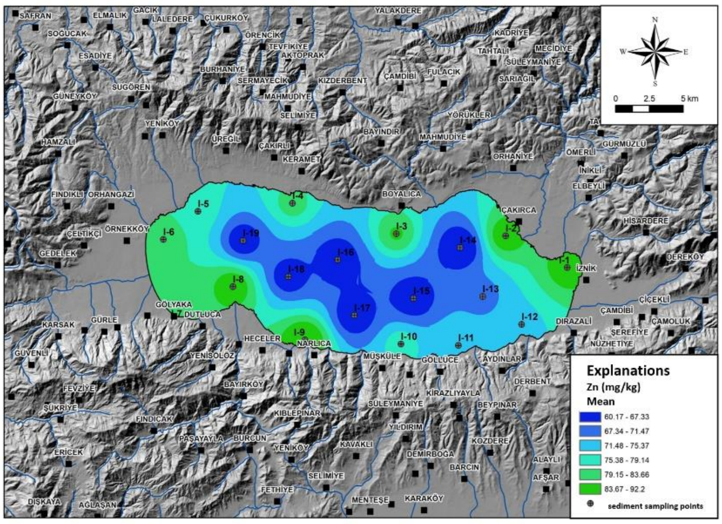
Manganese (Mn)



Nickel (Ni)



Lead (Pb)



Zinc (Zn)

Figure 10. Hg, Mn, Ni, Pb and Zn distributions of sediment water in Lake Iznik

Table 6. Seasonal variations of average heavy metal concentrations of plankton in Lake Iznik (mg/kg)

	Cu	As	Cr	Ni	Cd	Pb	Mn	Zn
Winter	4.012	0.154	1.334	1.885	0.0038	0.341	2.210	3.183
Spring	4.812	0.206	2.865	2.036	0.0054	0.062	0.618	0.890
Summer	4.842	0.153	1.176	1.366	0.0051	1.196	3.060	4.407
Autumn	2.501	0.148	0.378	1.249	0.0024	0.115	2.406	3.645

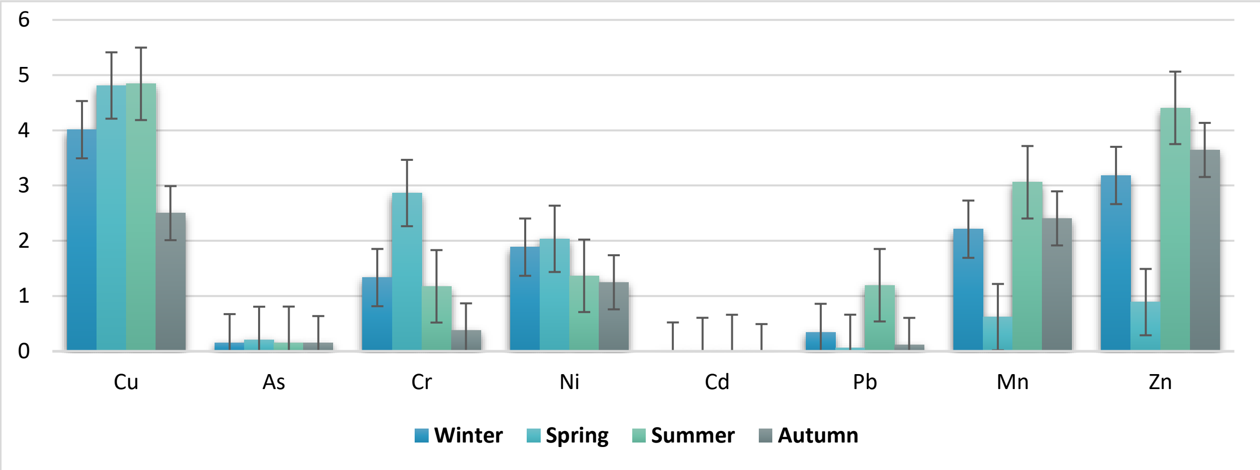


Figure 11. Variation graph of heavy metals in Lake Iznik plankton samples

Table 7. Average heavy metal concentrations of macrophytes of Lake Iznik (mg/kg)

		Cd	Pb	Ni	Cr	Mn	Cu	Zn	As
M.spicatum	Stem	0.14±0.06	6.4±1.7	1.83±0.40	1.18±0.22	66.2±16.5	5.6±1.1	43.6±7.4	1.98±0.34
	Leaf	0.26±0.09	17.0±2.7	4.10±0.78	2.65±0.37	199.4±18.3	10.8±2.4	75.2±8.8	4.12±0.44
P.pectinatus	Stem	0.24±0.05	11.0±2.1	2.17±0.65	1.93±0.16	81.4±15.9	9.2±1.3	80.0±8.1	3.00±0.33
	Leaf	0.47±0.08	25.2±2.4	3.50±0.64	3.95±0.51	251.8±24.3	17.2±1.3	131.8±28.6	6.02±0.51
N.marina	Stem	0.18±0.04	5.0±2.5	1.96±0.24	2.58±0.90	41.4±9.2	5.0±1.6	42.8±14.4	1.37±0.27
	Leaf	0.41±0.05	5.8±2.4	2.94±0.58	4.98±1.02	133.0±17.8	10.8±1.1	69.8±24.1	27.0±0.28
S.litoralis	Root	0.91±0.05	19.0±5.1	4.36±0.17	10.6±2.1	131.4±16.1	33.6±6.1	224.8±24.8	3.26±0.23
	Stem	0.66±0.06	110.4±2.7	3.20±0.73	6.4±1.5	55.0±13.1	11.6±5.0	120.2±10.8	2.54±0.15
	Leaf	0.48±0.05	5.2±0.8	1.64±0.43	3.8±1.6	44.8±8.3	7.4±1.5	75.0±9.1	1.72±0.16
T.latifolia	Root	2.75±0.56	14.0±3.3	14.62±2.25	18.2±1.9	259.6±37.2	9.6±1.1	400.6±37.5	6.01±1.22
	Stem	0.33±0.06	1.6±0.4	3.82±0.50	4.4±1.1	158.2±10.6	4.6±0.5	64.8±8.4	1.11±0.20
	Leaf	0.05±0.03	1.9±0.8	0.74±0.23	2.6±0.5	169.4±15.1	3.2±0.4	77.4±9.3	1.14±0.32
P.australis	Root	1.60±0.48	17.4±3.8	17.54±2.70	26.2±4.8	380.4±44.6	37.2±5.8	480.7±44.9	6.28±1.38
	Stem	0.38±0.05	1.8±0.5	4.58±0.60	10.0±1.6	155.4±34.2	17.0±2.6	77.8±10.1	1.42±0.19
	Leaf	0.11±0.05	2.4±0.7	0.89±0.28	5.0±1.0	172.4±26.3	6.6±1.8	92.9±11.1	1.22±0.18

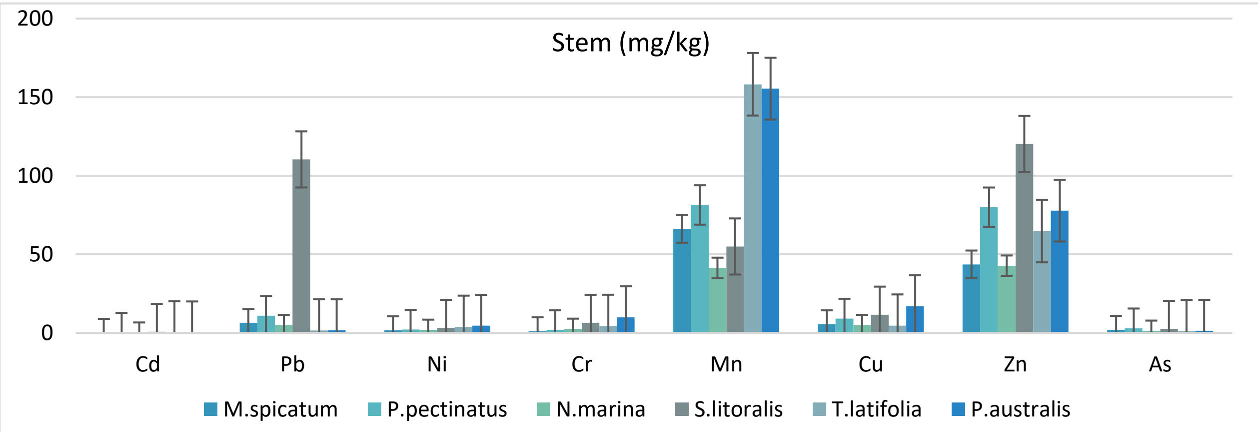


Figure 12. Graph of heavy metal changes in the stem of Lake Iznik macrophyte samples

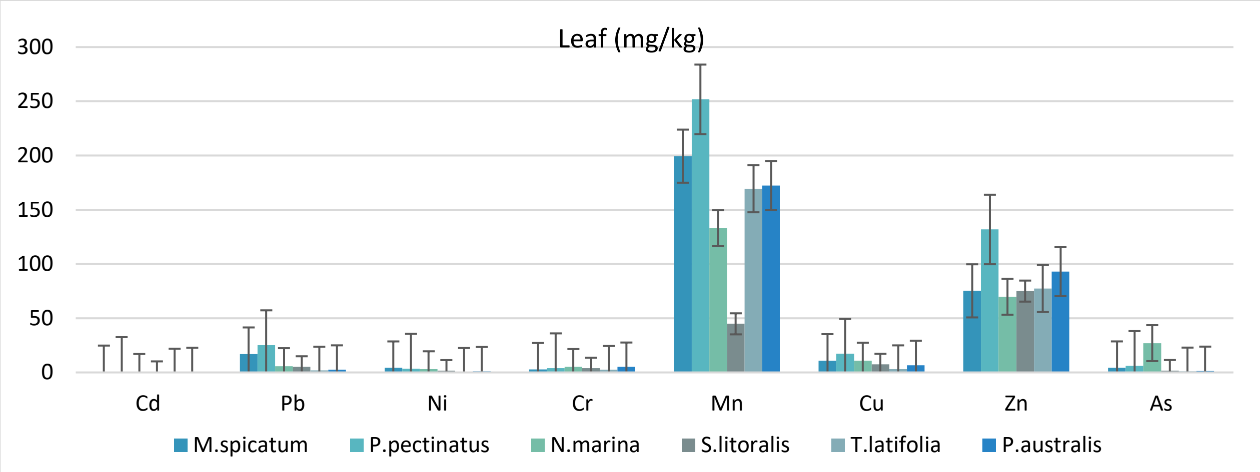


Figure 13. Heavy metal variations in the leaf of macrophyte samples in Lake Iznik.

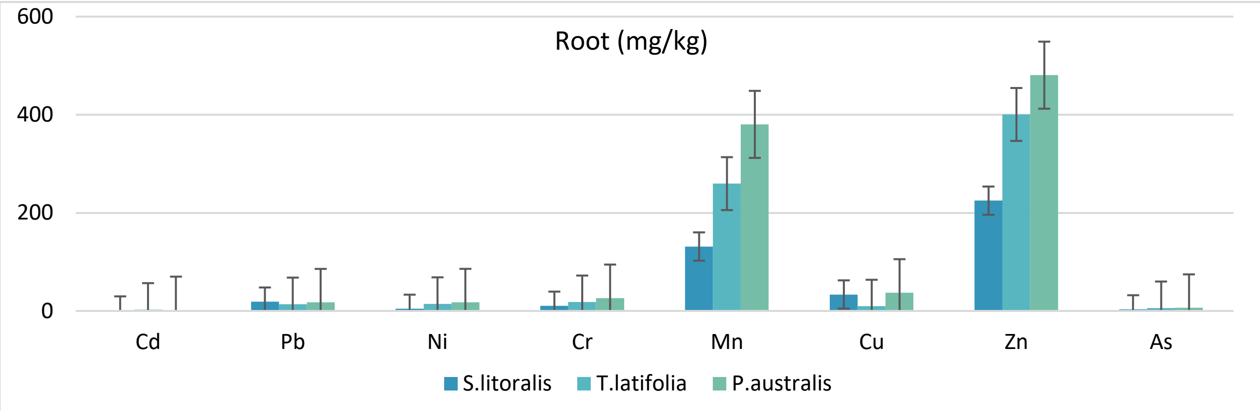


Figure 14. Heavy metal variations in the roots of macrophyte samples in Lake Iznik.

Mn values show Class I characteristics. When evaluated with the annual mean environmental quality standard (YO-ÇKS) in the same regulation, it is seen that the Al value is high. Also, it is seen that all average values are below the limit values (Anonymous, 2021) (Table 8) when evaluated with the maximum permissible environmental quality standard (MAK-ÇKS). The effect of the pH value of the lake is essential in this. The average pH level of Lake Iznik is around 9. The high pH of the water (9,0-9,2) decreases the dissolution percentage of metals. This is because metals bound to suspended particles in sediment and water can only be released if the water is acidic (Karadede, 1997).

Gölge et al., (1986), As a result of their work in Beyşehir Lake, K, Ca, Na, Hg in the north of the lake; In the south, they reported that it was high in terms of Co, Ni, Cr, Cu, B and Mo concentrations, and that the reason for this was the wastes of Beyşehir District, however, the lake was an uncontaminated lake in terms of toxic element concentrations. A similar situation is valid for Lake Iznik and the impact from settlements, industrial areas and agricultural areas was found to be higher than other areas.

Bulut et al. (2012), in their study conducted in 2010, investigated the significant heavy metal accumulations in the water and sediment structure of Uluabat Lake. As a result of the study, they found significant increases in the lake water, especially in winter sampling compared to the summer season and reported that the highest detected heavy metals were Fe, Al, Mn, As, Zn, Pb, Cu, Hg and Cd values were above the specified limits. In the lake sediment, Fe was the most accumulated metal, followed by Al, Mn, Ni, Zn, As, Cu, Pb and Hg and Cd values were above the limits. As a result, they concluded that serious amounts of heavy metal accumulation occurred in the water and especially in the sediment structure of Uluabat Lake and that this accumulation was caused by industrial pollutants and that protective measures should be taken without delay to prevent this pollution. A similar situation is valid for Lake Iznik and it is seen that the settlements and factories in Orhangazi region have negative effects on the lake, especially the sediment structure.

MacDonald et al. (2000) categorised metals into many classes according to their effects on sediment according to their concentrations. The important classifications on water quality, fish, other aquatic products and living organisms in sediment are presented below:

- LEL (Lowest effect level): The impact of sediments is considered to be clean. The majority of organisms living in the sediment have the lowest impact at this concentration level.

- TEL (Threshold effect level): Represents the concentration at which there is a slight chance of adverse effects.

- MET (Minimal effect threshold): The effect given by sediments is considered to be clean. The majority of organisms living in the sediment have the lowest effect at this concentration level.

When Lake Iznik sediment were evaluated according to the sediment quality criteria determined by MacDonald et al. (2000). Hg, Pb, As, Ni, Cu, Cr values were found above the threshold effect values whereas Cd and Zn were found below. This situation shows that Lake Iznik is at risk regarding pollutant and toxic parameters (Table 9).

Burada et al. (2014) analysed Cd, Cr, Ni, Pb, Mn and Zn parameters in zooplankton of the Danube Delta, Romania. They reported that the highest levels of Cr was 24.962 µg/g, Mn was 29.714 µg/g, Cd was 2.874 µg/g, Pb values ranged between 0.118-1.014 µg/g and Zn was 74.644 µg/g. Widiastuti et al. (2023) investigated the accumulation levels of the effects of mining activities on plankton in Way Ratai River. They reported that the highest concentration was Fe in plankton samples (0.725 mg/L in the river and 1.294 mg/L on the shore), Cd, Cu, Fe, Mn and Zn levels exceeded water quality standards, while Ag and Pb metals were not detected.

Table 8. Evaluation of heavy metal parameters of Lake Iznik according to the Surface Water Quality Regulation

Quality Criteria of Continental Surface Water Resources by Class in terms of General Chemical and Physicochemical Parameters				
Water Quality Parameters	Water Quality Classes			Our work
	I (very good)	II (good)	III (intermediate)	
Mn (µg/L)	≤ 100	500	> 500	2.5

Specific Pollutants and Environmental Quality Standards for Surface Water Resources				
Chemical Name	CAS No.	YO-ÇKS Rivers/ Lakes (µg/L)	MAK-ÇKS Rivers/ Lakes (µg/L)	Our work
Al	7429-90-5	2.2	27	13.6
As	7440-38-2	53	53	5.9
Cu	7440-50-8	1.6	3.1	0.4
Zn	7440-66-6	5.9	231	2.4
Fe	7439-89-6	36	101	11.4
Cr	7440-47-3	1.6	142	0.3

Priority Substances and Environmental Quality Standards for Surface Water Resources				
Article Name	CAS No.	YO-CCS Rivers/Lakes (µg/L)	MAK-ÇKS Rivers/Lakes (µg/L)	Our work
Cd and compounds	7440-43-9	< 0.08 (Class 1) 0.08 (Class 2) 0.09 (Class 3) 0.15 (Class 4) 0.25 (Class 5)	< 0.45 (Class 1) 0.45 (Class 2) 0.6 (Class 3) 0.9 (Class 4) 1.5 (Class 5)	<0.05
Pb and compounds	7439-92-1	1.2	14	0.6
Hg and compounds	7439-97-6	-	0.07	0.1
Ni and its compounds	7440-02-0	4	34	0.2

Table 9. Evaluation of sediment heavy metal parameters of Lake Iznik according to sediment quality criteria (MacDonald et al., 2000)

Parameters	Minimum	Mean	TEC (Effect Threshold Concentrations)		
			TEL (Threshold effect level)	LEL (Lowest effect level)	MET (Minimal effect threshold)
Hg	0.03	0.05	0.174	0.2	0.2
Pb	16.5	22.58	35	31	42
As	15.4	26.33	5.9	6	7
Ni	30.2	45.19	18	16	35
Cu	38.1	51.84	35.7	16	28
Cr	38.1	52.62	37.3	26	55
Cd	0.14	0.20	0.596	0.6	0.9
Mn	809	1103.11	-	-	-
Zn	51	75.51	123	120	150
Al	16100	22277.63	-	-	-
Fe	15500	20982.89	-	-	-

When the results obtained are compared with the plankton results of Lake Iznik, it is seen that the results of Lake Iznik are lower. This is mainly due to the fact that the lake basin is large and varies with rainfall and river regime.

Fawzy et al. (2012), reported the most intense accumulation of heavy metal on six macrophyte species in the Nile River, Egypt, such as *C. demersum* > *E. crassipes* > *M. spicatum* > *E. pyramidalis* > *T. domingensis* > *P. australis* and the heavy metal element order was Zn>Cu>Pb>Cd, respectively. Demirezen and Aksoy (2004) investigated the heavy metal accumulation of *Typha angustifolia* (L.) and *Potamogeton pectinatus* (L.) species in Sultansazlığı (Kayseri). As a result of the study, they reported that they found higher accumulation in the organs of *T. angustifolia* compared to *P. pectinatus*, and they found significantly higher Cd content, especially in submerged plants compared to helophytes (*P. pectinatus*), which indicates water pollution. They also reported that a similar situation was observed for other parameters in the water-sediment-macrophyte cycle, which were found in plant organs at an interrelated level, indicating both the effects of macrophytes in the phytoremediation process and the pollution in the area. A similar situation is also present in Lake Iznik and higher accumulation retention rates were found in reed plants (*P.australis* and *T. angustifolia*) than floating plants. This situation also shows that Lake Iznik is under risk in terms of metal accumulation. However, both field studies and studies conducted in laboratory and greenhouse conditions have reported that aquatic macrophytes' metal accumulation levels are different and plant tissues' metal accumulation rates are in the form of root > stem > leaf, respectively (Doğan, 2011).

Conclusion

In this context, in order to protect Lake Iznik and the lake ecosystem, which is located in the southeast of the Marmara region and where productive agricultural areas are located, first of all, construction around the lake is not allowed, preventing domestic and industrial facilities that directly or indirectly affect the lake from discharging their wastewater into the lake or streams pouring into the lake; industrial plants must be prevented from dumping sewage into lakes and streams. In addition, within the scope of intensive agricultural activities around the lake, the use of drugs and fertilizers should be controlled and it is of great importance to show the necessary sensitivity to the use of such chemicals and their mixing with the lake.

Ethical Statement

This study has been conducted in an ethical and responsible manner, and in full compliance with all relevant codes of experimentation and legislations.

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Author Contribution

This study is performed by single author.

Conflict of Interest

The author declare that they have no known competing financial or non-financial, professional, or personal conflicts that could have appeared to influence the work reported in this paper.

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