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Seasonal Monitoring of Metals in Water, Sediment and Mussel (*Unio mancus*) from Atatürk Dam Lake (Euphrates River)

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SUMMARY In this study, water, sediment and *Unio mancus* (Lamarck, 1819) samples were collected from Atatürk Dam Lake (Turkey) seasonally between 2015-2016 years and samples were analysed for certain heavy metal contents (Fe, Cu, Pb, As, Hg, Cr, Mn, Cd, Co, Zn, and Ni). Factors affecting heavy metals uptake and distribution have also been discussed separately. The amounts of heavy metals were quantified by an inductively coupled plasma mass spectrometer (ICPMS). The results showed that the metal concentrations in water were significantly higher than the value of standart drinking water recommended by the WHO and USEPA but metal concentrations in mussels were generally lower than the levels for mussels recommended by World Health Organization (WHO). Only levels of arsenic and lead were higher than permissible limits in all sampling points and seasons. Metal residue levels were higher in the sediments than in the water and mussel. Fe was the predominant residue in water and mussel samples as to Mn was dominant in sediment samples. Results suggest that Atatürk Dam Lake was polluted by different heavy metals, industrial activities and urban wastes for years.

Key Words: *Atatürk Dam Lake, Metal, ICPMS, Sediment, Mussel, Unio mancus*

ÖZET

Atatürk Baraj Gölü (Fırat Nehri) Su, Sediment ve Midyelerinde (*Unio mancus*) Metallerin Mevsimsel İzlenmesi.

Bu çalışmada, Atatürk Baraj Gölü'nden (Türkiye) su, sediment ve *Unio mancus* (Lamarck, 1819) örnekleri 2015-2016 yılları arasında farklı mevsimlerde toplanmış ve örnekler belirli ağır metal içerikleri (Fe, Cu, Pb, As, Hg, Cr, Mn, Cd, Co, Zn ve Ni) için analiz edilmiştir. Ağır metal alımını ve dağılımını etkileyen faktörler de ayrı ayrı tartışılmıştır. Ağır metallerin miktarı bir indüktif olarak eşleşmiş plazma kütle spektrometresi (ICPMS) kullanılarak belirlenmiştir. Sonuçlar, sudaki metal konsantrasyonunun WHO ve USEPA tarafından önerilen standart içme suyu değerinden önemli derecede yüksek olduğunu fakat midyelerdeki metal konsantrasyonunun Dünya Sağlık Örgütü (WHO)'nün midyeler için önerdiği değerden genel olarak daha düşük olduğunu göstermiştir. Yalnız arsenik ve kurşun düzeyleri bütün örnekleme noktaları ve mevsimlerde hoş görülebilir sınırdan yüksektir. Sedimentteki metal kalıntı düzeyleri su ve midyelerdekinden daha yüksektir. Su ve midye örneklerinde Demir, sediment örneklerinde ise Mangan baskındır. Sonuçlar, Atatürk Baraj Gölü'nün farklı ağır metaller, endüstriyel aktiviteler ve kentsel atıklar tarafından yıllardır kirletildiğini göstermektedir.

Anahtar Kelimeler: *Atatürk Baraj Gölü, Metal, ICPMS, Sediment, Midye, Unio mancus*

INTRODUCTION

Metals are permanent and they can bioaccumulate, so they pose a high risk to ecosystems (Townsend et al. 2013). Mining, industrial wastes, use of pesticides and the other antropogenic activities are sources of heavy metals (Chakravarty and Patgiri, 2009). Despite differences in toxic effects of the metals, environmental conditions, exposure time and concentration are important indicators of ecosystem health (Singh et al., 2005). Lake sediments are significant reservoirs of metals in the aquatic environment (Guevara et al. 2005). The metal residues may accumulate in rivers, sediments, aquatic flora, fauna, and microorganisms, due to they may enter into the food chain, they can be a threat to the human health (Varol 2011). Sediments can act as a storage for heavy metal in aquatic environment, but metals cannot fix in sediment forever. With the periodic change of physico-chemical conditions of the water, a portion of these metals is involved in the water column again and become available

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to living organisms (Theofanis, 2001). It is important to learn about the types of trace metals in sediments and determine their main sources in order to avoid river pollution (Sakan et al. 2009). The accumulator property of the bivalve molluscs have made them an indicator of the quality of water ecosystems (Conti and Cecchetti 2003). Bivalves sessile, cosmopolitan, long-lived benthic invertebrates are in contact with the water column and sediment, so they can accumulate the contaminants (Graney et al. 1983). The aquatic chemistry of metals has been widely studied however little is known about the effects of long-term sublethal exposures to metals on freshwater mussels (Mackie 1991). *U. mancus*, the most common bivalve in Atatürk Dam Lake was selected as indicator species in this study because of it is exposed to the pollutants in the reservoir inescapably. *U. mancus* (Lamarck 1819) is synonym of *U. elongatulus* (Pfeiffer 1825) (IUCN 2014). Atatürk Dam Lake is the largest dam lake situated on Euphrates River Basin and it has significant ecological, social, economic, and recreational value and has been contaminated by industrial, agricultural and urban wastes coming from Adiyaman province. Therefore we aimed to assess the current status of metal contamination in the sediments, waters and bivalves at different sample points of Lake. This evaluation can help to develop effective coastal management guidelines and strategies for better management of coastal activities of Atatürk Dam Lake.

MATERIALS and METHODS

Sampling points

Water, sediment and bivalve samples were collected at four stations: Sitilce, Samsat, Karakoç, Taşpınar (Figure 1). The sampling points were chosen based on pollution in the main industrial sector and wastewater discharge point of Adiyaman basins of the Atatürk Dam Lake. Sitilce (St-1) known as polluted, is mostly contributed through the wastewater discharges from Adiyaman Province (especially untreated municipal and industrial effluents) while Samsat (St-2) is clean area of the lake. Karakoç (St-3) is polluted area by untreated wastewaters and Taşpınar (St-4) is one of the dirtiest regions due to discharge of industrial wastes from the Eğriçay Creek.

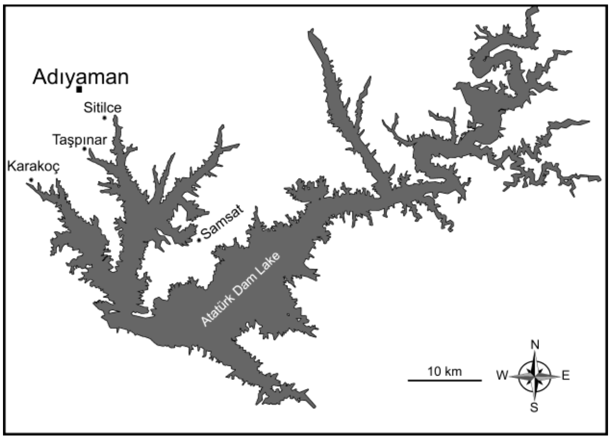

Figure 1. The map of the study area

Sample collection

Water, sediment and mussel were taken between 2015 and 2016. The water samples were collected using a Ruttner water sampler (Hydro-Bios 2 L, 0.5 m long) and placed in glass bottles of 1 L capacity. Some physico-chemical parameters of water were measured at each sampling point. The water samples were carried to laboratory in dark-colored bottles with cold chains for chemical analyses. The sampling of sediments were performed with a Eckman grab sampler which has surface area of 0.185 m^2 (Hydro-Bios, Kiel, Germany). The bivalves were collected by fishermen in the study areas and they were transported to the laboratory within the ice boxes. Ten specimens of *U. mancus* were collected from each sampling point. The length and growth of each bivalve shell was measured and the digestive system removed from the shell. Digestive glands of mussels were kept at -80 °C until analysis.

Water quality analyses

Water temperature, dissolved oxygen concentrations, conductivity and pH were recorded in the field using portable meters. COD, ammonium, nitrate, nitrite, phosphate and total hardness values were determined by the spectrophotometer DR/2010 model Hachlange.

Microwave digestion of sediments and mussels

The sediment samples were digested with an acid mixture using a Berghof microwave digestion system according to EPA 3051. The weighted sediment samples (0.5 g to 1,0 g) were feed into the digestion vessel and operated by the following steps to extract appropriate species gradually. Step 1, Adding 3 mL of nitric acid (HNO_3 65 %), 9 ml of hydrochloric acid (HCl 37 %) and shaking the mixture carefully or stir with a clean teflon or a glass bar. Step 2, Waiting at least 2 min before the vessel is closed. Step 3, Heating in the microwave oven with the following program.

Step	1	2	3
T (°C)	160	190	175
P (bar)	40	40	40
Power (%)	80	90	80
Ta (min.)	5	1	1
Time (min)	5	15	10

Digestive systems of mussels are digested in an acid solution using a Berghof microwave digestion system. 250 mg of the sample is weighed into the digestion vessel and 5 ml of nitric acid is added and the mixture is shaked carefully or stired with a clean teflon or a glass bar. It is waited at least 20 minutes before the vessel is closed and heated in the microwave oven with the following program.

Quantification of metal residues in the samples

The certain trace elements (As, Cd, Cr, Fe, Cu, Hg, Mn, Pb, Co, Ni, and Zn) were analyzed in the water, sediment and mussel samples. The research was carried out using an inductively coupled plasma mass spectrometer NexION 350X with a universal cell technology (UCT) (PerkinElmer, USA) and model solutions. The main ICP-MS instrumental operating conditions are shown in Table 1. The model solutions were prepared using standard solutions (PerkinElmer, USA) and deionized water. The analytical signal of elements was measured in standard/KED and collision modes. The choice of the effective correction conditions of the polyatomic interferences was made by the determination of the optimal helium flow rate in the range from 0.5 to 3.5 ml/min.

Table 1. ICP-MS instrumental operating conditions

Component / Parameter	Type / Value / Mode
Nebulizer	Mainhard (concentric)
Spray Chamber	Glass Cyclonic
Triple Cone Interface Material	Nickel
Plasma Gas Flow	18.0 L/min
Auxiliary Gas Flow	1.2 L/min
Nebulizer Gas Flow	0.84 L/min
Sample Uptake Rate	1 mL/min
RF Power	1150 W
Integration Time	600 ms
Replicates per Sample	3
Mode of Operation	STD/KED Mode Collision (using He gas)

Statistical analyses

The data were analyzed using XLSTAT 2016 programme. A Pearson correlation analysis was used to determine the relationship among the heavy metals based on sampling points.

RESULTS and DISCUSSION

Data on water quality parameters of Atatürk Dam Lake are shown in Table 2. The values of water quality parameters were lower in Taşpınar (St-4) and Sitilce (St-1) than Samsat (St-2) and Karakoç (St-3) (Table 2). Table 3 shows data on average concentrations of metals in the water samples. The metal concentrations in the water samples were followed this decreasing order Fe>Zn>Cu>Mn>Ni>Pb>Co>As>Cr> Cd>Hg. The mean concentrations of Fe, Zn, Cu, Mn, Ni, Pb, Co, As, Cr, Cd and Hg are 24.66, 4.38, 4.26, 2.95, 1.60, 1.078, 0.745, 0.51, 0.311, 0.16, 0.015 mg L^{-1}, respectively. According to areas, the mean concentrations of metals were in this order: Karakoç>Samsat>Taşpınar> Sitilce. The heavy metal contents of the water in Karakoç (St-3) were the highest, which were obviously higher than the other three stations. The highest and lowest concentrations were found in October and April respectively according to the sampling seasons. Drop in water level of the Dam Lake may cause an increase in the concentration of pollutants in the water at the beginning of the autumn.

The results of sediment samples were shown in Table 4. Generally, the concentrations of metals in the sediments followed this decreasing order Mn>Ni>Fe>Cr>Zn>Cu>Co> Hg>As>Pb>Cd. According to sampling points, the mean concentrations of metals were Karakoç>Taşpınar>Sitilce> Samsat. The concentrations of metals in Karakoç (St-3) and Taşpınar (St-4) were relatively higher than Sitilce (St-1) and Samsat (St-2). The metal levels in Taşpınar (St-4) and Sitilce (St-1) located in the close area were almost same. Taşpınar and Sitilce are known to have pollution mostly contributed through the untreated municipal and industrial effluents of Adiyaman Province. The lowest metal concentrations were in Samsat (St-2) where was detected as the control point. The highest metal concentrations in sediment samples were determined in Karakoç (Cr: 77.71, Co: 18.07, Cu: 18.73, Fe: 101.45, Mn: 204.5, Ni: 134.72, Pb: 2.79, Zn: 17.54, Hg: 3.53, Cd: 0.54, As: 3.62 mg kg^{-1}) and the lowest concentrations were in Samsat (Cr: 18.62, Co: 3, Cu: 3.23, Fe: 19.1, Mn: 70.81, Ni: 21.8, Pb: 1.4, Zn: 8.52, Hg: 5.8, Cd: 0.5, As: 3.08 mg kg^{-1}). The highest mean concentration of metals were in July. Sudden increase of temperature in July may have caused an increase in toxic substances in water and sediment. The values of metal residues in mussel samples are shown in Table 5. The order of heavy metal levels in the mussel samples were Fe>Mn>Zn>Cu>As>Ni> Pb>Cr>Cd>Co>Hg and the mean contents were 101.44, 48.75, 9.85, 2.33, 2.12, 0.94, 0.53, 0.29, 0.2, 0.14, 0.05 mg kg^{-1}, respectively.

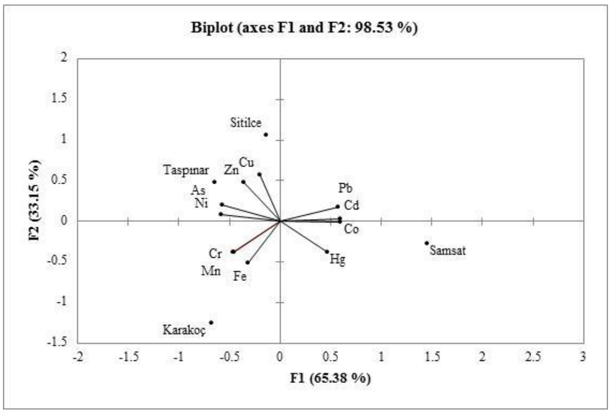

Figure 2. Bi plots for principal component analysis of metals in water of sampling points

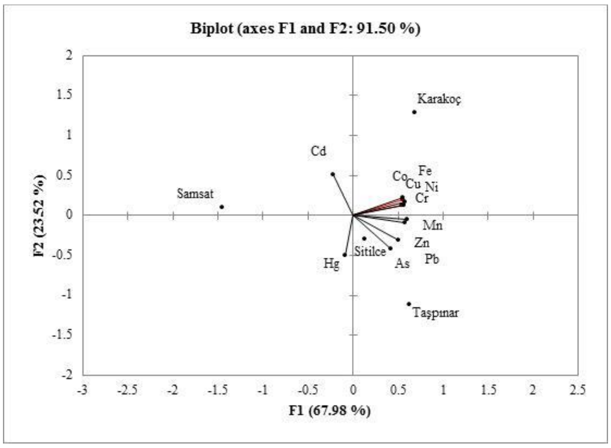

Figure 3. Bi plots for principal component analysis of metals in sediment of sampling points

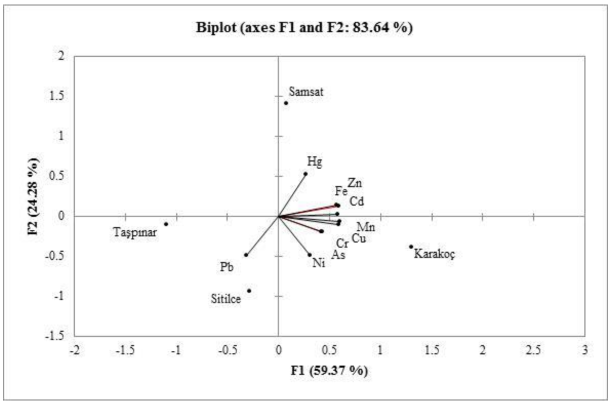

Figure 4. Bi plots for principal component analysis of metals in sediment of sampling points

According to the sampling points, the metal contents in the mussel samples collected from Karakoç (St-3) were slightly higher than the other three areas. It was positively correlated with the metal contents from the sediment and water samples. In Sitilce (St-1) and Karakoç (St-3), the Fe contents reached to 255.77 and 233.41 mg kg^{-1}, respectively, which indicate that the bivalves could have the high accumulative ability of Fe. The second most dominant metal was Mn with contents, ranged from 0.06 to 223.09 mg kg^{-1}. The Co and Hg concentrations were relatively lower, ranged from 0.028 to 0.290 and 0.0078 to 0.202 mg kg^{-1}, respectively. We found out that the concentration levels of Mn and Fe were major parts of the total metal mass. On the other hand, the metal contents in July were slightly higher than the others. This relative increase, especially in the summer months, may be related to the pollutants associated with the agricultural activities. Similar studies on metal concentrations for fish in Atatürk Dam Lake were carried out (Karadede and Unlu 2000; Oymak et al. 2009; Mol et al. 2010). Concentration of Mn was 1.5 and 23 times higher than values reported for some of the fish species (Karadede and Unlu, 2000) and for *Tor grypus* (Oymak et al., 2009) from Atatürk Dam Lake, respectively. Concentrations of Pb and As were 2 and 10 times higher than several fish species reported by Mol et al. (2010) from Atatürk Dam Lake, respectively. The reasons for these increases in metals may be increases in industrial, agricultural and anthropogenic activities over time. Another reason for these increases may be more accumulation of metals in mussels than in fish because they are sessile organisms.

A plot of factor coordinates for all significant observations was established using the factors obtained from factor loading analysis to evaluate which sampling variables were closely related (Figure 2,3,4). The results of correlation analyses (bivariate correlations with Pearson correlations coefficients) among metal concentrations in water, sediment and mussels based on sampling points, showed that there were strong positive correlations among all the metals in Sitilce and Taşpınar (Figure 2,3,4). In water samples, the metal and sampling points were reduced to 2 main factors (factors 1 and 2). The first and second factor corresponding to the largest eigenvalue accounts for approximately 65.38% and 33.15% of the total variance respectively.

The nearest concentrations value of As, Ni, Zn and Cu with each other were in Sitilce and Taşpınar and the total factor account was 91.50% (Figure 2). The level of almost all metals in sediment samples of Sitilce, Taşpınar and Karakoç closed to each other (Figure 3). The mussel samples in Karakoç, Sitilce and Samsat had similar metal species and content (Figure 4). The account of total factor was 83.64%. Data in Table 6, 7 and 8 provide the correlation matrices of the metals obtained from the PCA in water, sediment and mussel samples respectively. According to these tables, the metals have showed strong corelation with each other generally, and the most of the correlation coefficients were higher than 0.7 (absolute value) except As.

Table 2. Some water quality parameters of Atatürk Dam Lake during the study period

Stations	**Seasons**	Diss O_2 (ppm)	Temp (°C)	Conduct (IS/cm)	pH	NH_4 (ppm)	NO_2 (ppm)	NO_3 (ppm)	PO_4^{-3} (ppm)	COD
St-1	Apr	9.30	20.80	373	8.11	0.27	0.08	4.34	0.01	765
St-2	Apr	11.50	16.90	427	7.76	0.03	1.17	33.2	11.80	62.50
St-3	Apr	9.60	18.30	396	7.91	0.04	0.05	4.95	0.06	196
St-4	Apr	9.20	19.10	434	7.81	0.33	0.15	3.49	0.04	87.60
St-1	Jul	6.7	28.90	355	7.98	0.19	0.02	0.69	0.04	653
St-2	Jul	7.80	27.50	375	7.40	0.02	0.02	1.24	0.04	56.30
St-3	Jul	5.60	30.80	379	7.71	0.14	0.03	2.02	0.04	188
St-4	Jul	6.20	29.20	368	8	0.02	0.02	0.88	0.05	92.30
St-1	Oct	10.90	17.50	347	8.28	0.32	0.04	1.52	0.04	156
St-2	Oct	7.40	17.70	343	8.31	0.06	0.03	1.01	0.05	54.40
St-3	Oct	6.70	19.70	328	8.14	0	0.03	1.47	0.05	91
St-4	Oct	6.60	18.10	363	8.20	0.28	0.04	1.25	0.11	57.10
St-1	Jan	11.60	15.10	426	10.05	0.01	0.08	2.25	0.03	129
St-2	Jan	12.60	14.30	440	9.92	0.08	0.07	3.13	0.06	76.70
St-3	Jan	10.60	14.50	435	9.64	0.11	0.03	2.91	0.04	185
St-4	Jan	11.20	15.40	468	9.31	0.23	0.05	2.06	0.05	130

Table 3. Seasonal concentration of metals (mg L^{-1}; mean±SD) in water of sampling points

Stations	Seasons	Cr	Co	Cu	Fe	Mn	Ni	Pb	Zn	Hg	Cd	As
St-1	Apr	0.22±0.03	0.72±0.05	ND	7.46±0.5	1.92±0.4	1.22±0.2	ND	1.81±0.5	ND	ND	ND
St-2	Apr	0.11±0.005	0.49±0.03	1.45±0.3	5.35±0.3	0.14±0.05	0.2±0.04	ND	0.93±0.07	ND	ND	ND
St-3	Apr	0.33±0.03	0.67±0.05	1.68±0.4	18.28±2.36	1.90±0.2	1.45±0.3	ND	1.32±0.3	ND	ND	ND
St-4	Apr	0.49±0.02	0.63±0.04	ND	8.25±0.6	2.43±0.7	1.41±0.2	ND	1.13±0.2	ND	ND	ND
St-1	Jul	0.14±0.05	0.17±0.003	4.23±0.6	8.22±0.5	1.49±0.3	1.72±0.3	0.72±0.05	4.45±0.8	0.012±0.003	0.11±0.06	0.003±0.0003
St-2	Jul	0.12±0.02	0.13±0.002	2.90±0.3	4.19±0.4	0.36±0.02	1.21±0.2	0.08±0.012	2.87±0.6	0.008±0.0005	0.018±0.002	0.003±0.0004
St-3	Jul	0.27±0.04	0.17±0.01	2.05±0.2	22.91±3.55	2.78±0.6	1.69±0.4	0.13±0.02	1.87±0.4	0.017±0.002	0.015±0.003	0.003±0.0002
St-4	Jul	0.16±0.006	0.20±0.01	2.66±0.3	9.69±0.8	0.97±0.05	2.30±0.5	0.21±0.04	1.12±0.2	0.010±0.006	0.019±0.003	0.003±0.0005
St-1	Oct	0.33±0.02	1.53±0.6	9.10±0.8	11.69±2.12	4.54±0.6	2.23±0.5	2.39±0.5	8.42±0.9	0.017±0.003	0.42±0.05	0.002±0.0001
St-2	Oct	0.35±0.03	1.48±0.5	6.01±0.4	23.55±3.22	3.43±0.5	1.38±0.2	2.18±0.3	4.59±0.5	0.048±0.004	0.39±0.04	0.002±0.0006
St-3	Oct	0.56±0.05	1.57±0.5	8.97±0.6	81.37±5.75	9.41±0.8	2.35±0.6	2.35±0.4	7.39±0.3	0.014±0.005	0.43±0.06	0.002±0.0002
St-4	Oct	0.36±0.02	1.56±0.4	9.54±0.7	26.10±4.45	4.31±0.3	2.38±0.4	2.69±0.6	9.67±0.8	0.026±0.003	0.43±0.05	0.002±0.0002
St-1	Jan	0.28±0.04	0.71±0.03	2.83±0.3	18.98±1.98	1.59±0.06	1.18±0.2	0.56±0.02	4.76±0.6	0.007±0.0009	0.11±0.03	1.56±0.7
St-2	Jan	0.64±0.05	0.63±0.04	3.39±0.2	65.17±4.32	4.04±0.5	1.61±0.3	0.65±0.03	9.53±0.9	0.007±0.0006	0.11±0.04	1.62±0.8
St-3	Jan	0.35±0.02	0.59±0.03	1.55±0.2	49.74±3.86	3.53±0.2	1.42±0.2	0.49±0.01	4.15±0.3	0.004±0.0003	0.094±0.005	1.33±0.3
St-4	Jan	0.27±0.02	0.65±0.02	3.21±0.3	33.59±2.21	4.35±0.2	1.91±0.3	0.49±0.02	6.11±0.4	0.008±0.0004	0.097±0.007	1.64±0.5

Table 4. Seasonal concentration of metals in sediment (mg kg^{-1}; mean±SD) of sampling points

Stations	Seasons	Cr	Co	Cu	Fe	Mn	Ni	Pb	Zn	Hg	Cd	As
St-1	Apr	15.76±0.65	6.70±0.23	15.10±0.33	12.40±0.32	10.17±0.25	88.90±3.76	1.42±0.45	1.24±0.64	0.69±0.04	ND	1.14±0.2
St-2	Apr	9.33±0.32	1.80±0.08	0.04±0.002	5.70±0.15	4.52±0.22	4.91±0.21	0.17±0.06	3.69±0.09	ND	1.43±0.4	1.19±0.3
St-3	Apr	18.33±0.55	12.01±0.26	0.33±0.05	18.00±0.34	1.03±0.03	110.60±4.7	0.42±0.03	0.67±0.02	ND	1.26±0.3	1.12±0.1
St-4	Apr	17.95±0.54	8.50±0.15	0.16±0.03	19.40±0.35	7.71±0.26	8.29±0.66	0.46±0.03	1.44±0.56	ND	0.16±0.2	1.69±0.2
St-1	Jul	48.57±0.83	10.43±0.43	15.68±0.34	257.03±12.68	492.47±36.73	61.45±2.12	3.78±0.67	31.25±0.33	0.01±0.001	0.03±0.001	3.31±0.4
St-2	Jul	23.51±0.42	2.81±0.15	5.65±0.25	61.81±1.56	144.25±12.34	28.95±0.97	0.87±0.05	12.91±0.21	0.05±0.002	0.08±0.003	1.19±0.1
St-3	Jul	89.84±2.56	16.87±0.54	24.09±0.56	327.37±25.55	449.12±27.86	147.48±5.7	1.80±0.78	32.14±0.85	0.04±0.002	0.04±0.002	1.88±0.1
St-4	Jul	71.09±2.50	12.28±0.32	14.46±0.35	230.16±8.76	445.75±18.92	120.25±4.9	3.58±0.20	29.70±0.76	ND	0.01±0.001	3.72±0.4
St-1	Oct	48.98±0.92	8.68±0.17	11.29±0.28	15.75±0.35	0.34±0.03	68.43±2.45	5.98±0.22	0.03±0.002	1.75±0.34	0.36±0.02	2.10±0.3
St-2	Oct	24.98±0.87	3.80±0.05	3.34±0.12	4.43±0.13	0.14±0.02	29.16±0.43	3.60±0.18	0.01±0.001	1.47±0.21	0.37±0.02	0.92±0.03
St-3	Oct	141.08±4.45	22.44±0.65	32.61±0.67	38.87±0.56	0.39±0.05	181.00±5.2	5.37±0.34	0.05±0.002	1.79±0.35	0.38±0.03	2.17±0.2
St-4	Oct	101.89±3.22	15.61±0.44	21.78±0.36	25.85±0.42	0.38±0.05	160.56±3.4	8.63±0.42	0.05±0.002	1.78±0.28	0.37±0.02	5.56±0.25
St-1	Jan	27.48±0.56	10.69±0.37	10.91±0.29	16.44±0.23	368.60±21.79	47.75±1.13	3.39±0.19	33.12±0.54	14.63±0.24	0.26±0.02	8.88±0.37
St-2	Jan	16.64±0.34	3.62±0.23	3.89±0.17	4.46±0.18	134.33±7.65	24.20±0.87	0.97±0.06	17.46±0.13	15.89±0.25	0.11±0.01	9.01±0.12
St-3	Jan	61.60±1.23	20.97±0.54	17.89±0.38	21.55±0.33	367.44±20.84	99.78±9.32	3.57±0.32	37.28±0.57	8.77±0.12	0.47±0.03	9.30±0.16
St-4	Jan	78.29±2.21	17.08±0.46	12.31±0.31	21.49±0.24	407.32±39.13	166.48±11.	3.81±0.36	40.40±0.65	13.01±0.15	0.33±0.02	9.11±0.14

Table 5. Seasonal concentration of metals (mg kg^{-1} wet wt; mean±SD) in mussel of sampling points

Stations	Seasons	Cr	Co	Cu	Fe	Mn	Ni	Pb	Zn	Hg	Cd	As
St-1	Apr	0.49±0.04	0.14±0.03	0.85±0.05	13.64±0.86	0.18±0.05	0.13±0.03	0.25±0.02	0.25±0.03	0.009±0.0002	0.09±0.003	1.87±0.56
St-2	Apr	0.29±0.01	0.04±0.005	0.79±0.03	27.42±0.95	0.42±0.06	0.15±0.03	0.24±0.02	0.18±0.02	0.009±0.0001	0.14±0.05	0.71±0.04
St-3	Apr	0.32±0.02	0.08±0.005	0.92±0.08	40.53±1.12	0.18±0.01	0.19±0.02	0.44±0.03	0.24±0.02	0.014±0.005	0.38±0.02	1.77±0.43
St-4	Apr	0.36±0.01	0.03±0.002	0.85±0.04	14.86±0.45	0.25±0.02	0.14±0.02	0.41±0.03	0.22±0.02	0.011±0.004	0.09±0.004	2.14±0.82
St-1	Jul	0.43±0.03	0.12±0.02	1.93±0.35	255.77±8.55	135.69±6.75	0.36±0.05	0.05±0.004	12.11±1.45	0.007±0.0002	0.06±0.003	1.23±0.64
St-2	Jul	0.24±0.01	0.03±0.004	2.09±0.56	187.58±9.24	60.98±2.36	0.57±0.06	0.08±0.005	20.13±1.68	0.019±0.004	0.13±0.05	1.64±0.72
St-3	Jul	0.41±0.02	0.07±0.005	3.07±0.67	233.41±7.43	223.09±9.85	0.42±0.03	0.05±0.006	13.00±1.22	0.014±0.005	0.50±0.06	2.43±0.93
St-4	Jul	0.16±0.01	0.03±0.003	1.36±0.23	159.19±5.45	40.65±2.23	0.24±0.02	0.02±0.001	6.63±1.15	0.007±0.0008	0.09±0.007	0.88±0.05
St-1	Oct	0.29±0.01	0.29±0.02	3.41±0.65	0.40±0.02	0.87±0.05	0.81±0.07	1.70±0.5	14.19±1.67	0.105±0.06	0.22±0.04	2.53±0.55
St-2	Oct	0.36±0.02	0.24±0.02	3.66±0.88	0.27±0.01	0.06±0.003	0.37±0.03	1.48±0.3	10.26±1.43	0.202±0.07	0.39±0.05	2.84±0.63
St-3	Oct	0.32±0.04	0.24±0.02	4.86±0.25	0.51±0.03	0.15±0.04	0.88±0.06	1.45±0.3	16.38±1.36	0.172±0.05	0.45±0.03	3.89±0.94
St-4	Oct	0.19±0.005	0.20±0.01	3.44±0.55	0.43±0.02	0.12±0.03	0.63±0.02	1.61±0.5	13.88±1.13	0.135±0.04	0.17±0.01	3.72±0.67
St-1	Jan	0.15±0.01	0.21±0.05	2.71±0.24	88.94±3.78	10.69±1.65	2.89±0.85	0.17±0.03	11.59±1.22	0.008±0.0007	0.05±0.008	1.86±0.34
St-2	Jan	0.29±0.02	0.20±0.05	2.65±0.25	236.28±12.35	100.62±7.93	0.39±0.03	0.17±0.02	12.22±1.87	0.017±0.006	0.14±0.07	2.18±0.76
St-3	Jan	0.29±0.02	0.21±0.04	3.08±0.76	257.46±15.56	178.09±8.27	4.37±1.12	0.15±0.05	16.05±2.35	0.011±0.004	0.23±0.02	2.51±0.65
St-4	Jan	0.12±0.01	0.14±0.01	1.63±0.34	106.32±4.79	27.95±1.12	2.44±0.56	0.15±0.02	10.24±1.24	0.008±0.0005	0.05±0.004	1.59±0.42

Table 6. Correlation matrix (Pearson (n)) of metals in water samples

Variables	Cr	Co	Cu	Fe	Mn	Ni	Pb	Zn	Hg	Cd	As
Cr	**1**	-0.732	-0.334	0.922	**0.970**	0.674	-0.884	-0.074	-0.184	-0.798	0.484
Co	-0.732	**1**	-0.340	-0.515	-0.771	-0.931	**0.953**	-0.615	0.782	**0.986**	-0.946
Cu	-0.334	-0.340	**1**	-0.630	-0.336	0.470	-0.038	0.935	-0.852	-0.288	0.623
Fe	0.922	-0.515	-0.630	**1**	0.943	0.358	-0.750	-0.352	0.131	-0.559	0.211
Mn	**0.970**	-0.771	-0.336	0.943	**1**	0.628	-0.927	-0.024	-0.206	-0.798	0.524
Ni	0.674	-0.931	0.470	0.358	0.628	**1**	-0.836	0.646	-0.827	**-0.962**	0.922
Pb	-0.884	**0.953**	-0.038	-0.750	-0.927	-0.836	**1**	-0.352	0.556	**0.954**	-0.804
Zn	-0.074	-0.615	0.935	-0.352	-0.024	0.646	-0.352	**1**	**-0.963**	-0.542	0.836
Hg	-0.184	0.782	-0.852	0.131	-0.206	-0.827	0.556	**-0.963**	**1**	0.739	-0.940
Cd	-0.798	**0.986**	-0.288	-0.559	-0.798	**-0.962**	**0.954**	-0.542	0.739	**1**	-0.911
As	0.484	-0.946	0.623	0.211	0.524	0.922	-0.804	0.836	-0.940	-0.911	**1**

Table 7. Correlation matrix (Pearson (n)) of metals in sediment samples

Variables	Cr	Co	Cu	Fe	Mn	Ni	Pb	Zn	Hg	Cd	As
Cr	**1**	**0.975**	0.842	0.860	0.707	**0.992**	0.551	0.830	-0.093	0.018	0.562
Co	**0.975**	**1**	0.938	0.944	0.774	**0.990**	0.557	0.871	-0.292	0.026	0.465
Cu	0.842	0.938	**1**	**0.995**	0.857	0.896	0.592	0.894	-0.521	-0.063	0.346
Fe	0.860	0.944	**0.995**	**1**	0.900	0.914	0.669	0.935	-0.439	-0.150	0.440
Mn	0.707	0.774	0.857	0.900	**1**	0.784	0.916	**0.981**	-0.173	-0.566	0.691
Ni	**0.992**	**0.990**	0.896	0.914	0.784	**1**	0.616	0.886	-0.154	-0.051	0.573
Pb	0.551	0.557	0.592	0.669	0.916	0.616	**1**	0.883	0.205	-0.816	0.888
Zn	0.830	0.871	0.894	0.935	**0.981**	0.886	0.883	**1**	-0.135	-0.457	0.718
Hg	-0.093	-0.292	-0.521	-0.439	-0.173	-0.154	0.205	-0.135	**1**	-0.442	0.588
Cd	0.018	0.026	-0.063	-0.150	-0.566	-0.051	-0.816	-0.457	-0.442	**1**	-0.741
As	0.562	0.465	0.346	0.440	0.691	0.573	0.888	0.718	0.588	-0.741	**1**

Table 8. Correlation matrix (Pearson (n)) of metals in mussel samples

Variables	Cr	Co	Cu	Fe	Mn	Ni	Pb	Zn	Hg	Cd	As
Cr	**1**	0.908	0.718	0.655	0.627	0.408	-0.309	0.757	-0.066	0.471	0.180
Co	0.908	**1**	0.400	0.279	0.311	0.384	0.017	0.416	-0.445	0.097	-0.063
Cu	0.718	0.400	**1**	0.943	**0.988**	0.597	-0.423	0.903	0.366	**0.951**	0.745
Fe	0.655	0.279	0.943	**1**	0.903	0.299	-0.699	**0.979**	0.625	0.926	0.575
Mn	0.627	0.311	**0.988**	0.903	**1**	0.672	-0.329	0.834	0.338	**0.970**	0.838
Ni	0.408	0.384	0.597	0.299	0.672	**1**	0.474	0.214	-0.411	0.530	0.806
Pb	-0.309	0.017	-0.423	-0.699	-0.329	0.474	**1**	-0.746	-0.878	-0.453	0.081
Zn	0.757	0.416	0.903	**0.979**	0.834	0.214	-0.746	**1**	0.578	0.834	0.419
Hg	-0.066	-0.445	0.366	0.625	0.338	-0.411	-0.878	0.578	**1**	0.538	0.165
Cd	0.471	0.097	**0.951**	0.926	**0.970**	0.530	-0.453	0.834	0.538	**1**	0.837
As	0.180	-0.063	0.745	0.575	0.838	0.806	0.081	0.419	0.165	0.837	**1**

The metal concentrations in water were found significantly higher than drinking water standarts according to WHO and USEPA but metal concentrations in mussels were generally below the limit values set by World Health Organization (WHO) for mussels (USEPA 1989; WHO 1993). Only level of arsenic was higher than permissible limit of 1 mg kg^{-1} in all sampling points and seasons. Concentration of Pb was also higher than maximum level of 1.5 mg kg^{-1} in Sitilce and Taşpınar on October.

As a result, it can be concluded that mussels collected from Atatürk Dam Lake did not pose a great threat to human health but metal concentrations of water and sediment were very high. The continuous monitoring studies must be carried out on bioaccumulation and biomagnifications of metals and their effects on aquatic organisms and humans in the dam lake.

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