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Full Length Research Paper

Assessment of heavy metals in Lake Uluabat, Turkey

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The accumulation of heavy metals (Cu, Ni, Zn, Cd, Pb, Cr, B, As) was measured in water, plankton and sediment samples taken from different areas of Lake Uluabat during January 2003 to February 2004. The sequential extraction used in this study is useful to assess the potential mobility of heavy metals in the sediment indirectly. In this study, Cu, Pb, Cr, Cd, Ni and Zn concentrations were detected at higher levels at Lake Uluabat for selected stations, especially in plankton samples. The magnitude of heavy metal concentrations in water and plankton samples was determined as B>Zn>As>Cd>Pb>Ni>Cr and Zn>Ni>Cu>Cr>Cd>Pb, respectively. The mobile heavy metals in sediment samples were sequenced as Pb>Cu>Cr>Ni>Cd>Zn, whereas the magnitude of easily mobilizable metal concentration was determined as Pb>Ni>Cr>Cu>Cd>Zn. Concentration of Cu and Cr in mobile fraction is detected higher than in easily mobilizable fraction. Concentration of Pb, Cd, Zn and Ni in mobile fraction is detected in lower levels than in easily mobilizable fraction.

Key words: Fraction of heavy metals, Lake Uluabat, plankton, sediment, water.

INTRODUCTION

Fresh water lakes support many life forms, providing recreation and game fishing to the communities, as well as being a good source of water for drinking and water production by municipal water works. The contamination of soils, sediments, water resources and biota by heavy metals is of major concern especially in many industrialized countries because of their toxicity, persistence and bioaccumulative nature (Ikem et al., 2003). Toxic metals can alter many physiological processes and biochemical parameters, either in blood or in tissues including structural deformations in aquatic animals (Cengiz and Ünlü, 2002; Barlas et al., 2005). Being non-biodegradable, they can be concentrated along the food chain, producing their toxic effects at points often far away from the source of pollution (Fernandez et al., 2000).

The build-up of metals in sediments has significant environmental implications for local communities, as well as for lake quality (Demirak et al., 2006). Sediment contitutes the most important sink of metals and other pollutants; it can act as a non-point source and has the potential to release the sediment-bound metals and other pollutants to overlying waters, and in turn adversely affects aquatic organisms (Wang et al., 2004).

Many important wetlands in Turkey have been polluted by different type of heavy metals and other contaminants like Lake Uluabat. Lake Uluabat, which is located in Marmara region, Bursa (TURKEY) (40º10' N, 28º35' E) is one of the most productive lakes with respect to aquatic ecosystems. It has a mean surface area of 133.1 km^2 in 1984, 120.5 km^2 in 1993 and 116.8 km^2 in 1998. Lake Uluabat is one of the most important wetlands not only in Turkey but also in the Middle East and Europe. It is one of the most nationally and internationally important area. The Lake is staging site for globally threatened and legally protected species such as Pygmy cormorant, Phalacrocorax pygmeus, the Dalmatian Pelecanus crispus and the Otter Lutra lutra. During the first full survey of breeding birds at Lake Uluabat in 1998 by the Royal Society for the Protection of Birds (RSBP), Lake Uluabat was found to be the most important site in Turkey for Pygmy cormorant and Whiskered Tern Chlidonia hybriddus. Lake Uluabat is also the second most important site for the globally threatened Ferrugionus Duck Aythya nyroca. Accordingly, Lake Uluabat is an incredibly important site. Besides, Lake Ulubat has the largest white

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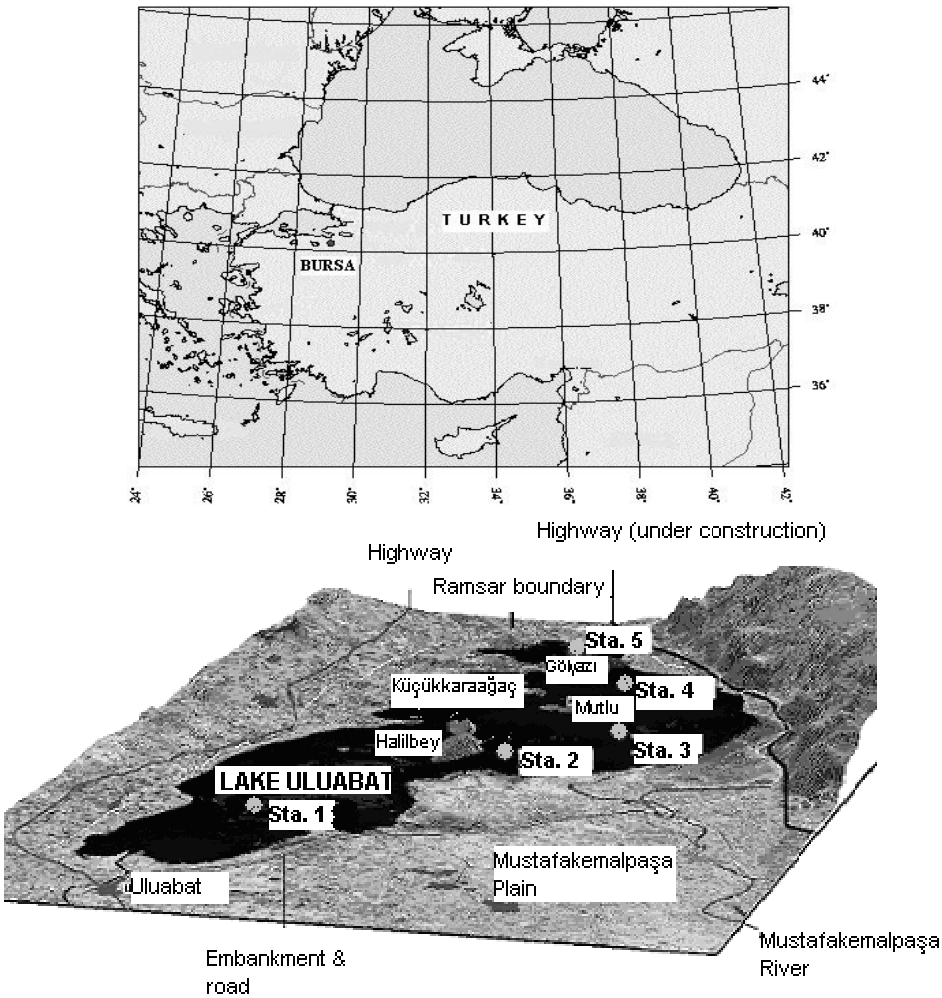

Figure 1. A map of Lake Uluabat (Aksoy and Özsoy, 2002).

water lily beds in Turkey (Anonymous, 2000). Due to its importance, Lake Uluabat was designated by the Ministry of Environment as a RAMSAR site in 1998 and consequently it was chosen as a partner of International Living Lakes Network in the 4th International Conference at EXPO 2000 (Aksoy and Özsoy, 2002).

The objective of this study was to examine the concentration of selected heavy metals in water, sediment and plankton samples at different stations in Lake Uluabat, during February 2003 – January 2004. In addition it was aimed to evaluate the distribution of mobile and easily mobilizable metal fractions in sediments of Lake Uluabat.

MATERIALS AND METHODS

A map of Lake Uluabat showing sampling locations is presented in Figure 1. Sampling of the Lake's water for analytical purposes was performed monthly from February 2003 to January 2004 from 5 different stations. The first station was near the outflow of Lake Uluabat. The second station was in the southern of the Island Halilbey. The animal wastes runs to the Lake at the shores in the biggest island of the Lake, Halilbey. Furthermore, the entrance of the Mustafakemalpaşa stream is close to the second station. The third station was in the southwestern of Island Mutlu, which is located nearby the village of Eskikaraağaç. Domestic wastewater drains to the lake from this place. The fourth station was between Island Mutlu and village of Eskikaraağaç. The new highway passes close to the villages. And finally the fifth station was near the village of Akçalar. Domestic and industrial wastewaters especially, that arise from a tinning factory are discharged to the lake from Akçalar.

Water and plankton samples were collected from the water surface in 1 liter pre-cleaned polyethylene bottles. Water samples were filtered through Whatman membrane filters (cellulose nitrate). 150 ml of water samples were acidified with HNO_3 and kept for analyses. Plankton samples were taken with the aid of plankton sampler (Hydrobios Kiel plankton net). Filtered plankton samples (Whatman glass microfiber filter (GF/C) were acidified with HCl and kept for analyses. Sediment samples were collected using pre-cleaned stainless steel sediment sampler and immediately placed in plastic bags. Samples were transported to the laboratory as soon as possible and air-dried in the laboratory at room temperature (21˚C ± 2). Air-dried sediment samples were homogenized and sieved (0.2 mm). Sediment samples were stored in acid washed polyethylene bottles. Sequential extractions have been applied using extractants with progressively increasing extraction capacity. In order to extract mobile fraction (F1) and easily mobilizable fraction (F2) of heavy metals ammonium nitrate and acetate ammonium buffer solutions were used (Zeien and Brümmer, 1989). All glassware used for the analyses were carefully cleaned with nitric acid followed by rinsing with distilled water before use. All reagents used were of analytical reagent grade (Merck, Germany). Deionized water was used throughout the study. All analyses were done in duplicate.

Cu, Pb, Cr, Cd, Ni, Zn concentrations in all samples were analysed by atomic adsorption spectrophotometer with air-acetylene flame method (UNICAM 929 AA Spectrometer). In addition boron and arsenic analyses were performed by using kits (Merck) in water samples. Some physical parameters such as pH and temperature (Metrohm type pH meter), $EC_{(25°C)}$ (Jenway 4310 type conductometer) and dissolved oxygen (DO) (Winkler method) were also measured during the study period. Measurements and analyses were per-formed according to standard methods (APHA, 1998).

RESULTS

Heavy metals appeared in all of the samples analyzed. The evaluated data in water, sediment and plankton samples are shown in Tables 1 – 4. Higher copper concentrations were detected in water and plankton samples, in March and April. In June, the Cu residue level was found low in water samples. In plankton samples lowest Cu level was found in August. In sediment samples, highest Cu level in F1 was found in September and lowest level in November. In F2, highest Cu level was found in January and lowest level in September.

Mean boron concentrations were detected in water samples at higher levels in February (1.6278 mg l^{-1}) and lowest level was found in June (0.0842 mg l^{-1}). Mostly boron concentrations were observed over critical level.

Arsenic concentrations were detected at low levels, mostly non detectable in water samples.

Lead concentrations in water samples were detected at similar levels for each month. In plankton samples, lead concentrations were detected at a higher degree in April (mean concentrations 4.302 mg g^{-1}). In sediment samples, highest Pb level in both F1 and F2 was found in October. Lowest level in F1 was found in September and in F2 in August.

In general, chrome was below detection limit (0.01 mg l^{-1}) in water samples. In plankton samples, chrome concentrations were detected at a higher degree in October (mean 6.557mg g^{-1}) and lowest Cr level was found in July (0.476 mg g^{-1}). In sediment samples, highest Cr level in F1 was found in April and lowest level in March. In F2 highest Cr level was found in August and lowest level in May.

Mean cadmium concentrations in water samples, which were collected in April, were found to be highest level (mean 0.0614 mg l^{-1}). In December, Cd level was found low in water samples. In plankton samples, mean cadmium concentrations were high in April (5.68 mg g^{-1}) and low in August (0.222 mg g^{-1}). In sediment samples, highest cadmium level in F1 was found in May and lowest level in October. In F2 highest cadmium level was found in July and lowest level in April.

Mean Ni concentrations in water samples were high in July and August (0.0343 mg l^{-1}, 0.0331 mg l^{-1}, respectively), in addition to this, low in October (0.0119 mg l^{-1}). Also, in plankton samples mean Ni concentrations were significantly higher in April (30.794 mg g^{-1}). However, Ni concentrations were low in August (1.380 mg g^{-1}) in plankton samples. In sediment samples highest nickel level in F1 was found in September and lowest level in December. In F2 highest nickel level was found in October and lowest level in June.

Mean Zn concentrations in water samples were high in March (0.2102 mg l^{-1}) and low in November (0.0564 mg l^{-1}). Also, in plankton samples, mean Zn concentrations were significantly higher in April (84.284 mg g^{-1}). However, Ni concentrations were low in August (2.513 mg g^{-1}) in plankton samples. In sediment samples highest zinc level in F1 was found in September and lowest level in February. In F2, highest zinc level was found in May and lowest level in August (Tables 1 – 6).

Seasonal variation of physical properties of water samples for the average of 5 stations are given in Table 5. The temperature of water ranged between 9.28 - 25.68°C and the pH ranged between 8.63 - 8.78. Conductivity values ranged between 501 – 721 µS cm^{-1}. Also dissolved oxygen values changed from 8.01 to 11.28 mg l^{-1} (Table 5).

DISCUSSION

Both Mustafakemalpaşa and Karacabey Districts are the main residential areas around the Lake Uluabat. The main human activity at the Lake is fishing. Also, agricultural lands and industry surround the Lake. The River Mustafakemalpaşa is the Lake's major inflow, but there is also input from underground springs. It drains a large part of the regions of Southern Marmara and Northern Aegeis, bringing large quantities of urban and industrial waste into the Lake basin each year (Altınsaçlı and Griffiths, 2001). Furthermore, drainage water from the surrounding fields seeps back into the lake.

The pollution which occurs from Mustafakemalpaşa Stream, and its tributaries Orhaneli stream and Emet stream, is directly transported to the Lake. Boron which leaks from boron mines is carried by Mustafa-kemalpaşa stream. Sixteen population centers are located around the Lake Uluabat and 67 population centers located around the Mustafakemalpaşa, Orhaneli and Emet streams (Demir et al., 1998).

A part of the concentrator wastewaters of the active chrome mine of Harmancık at Emet stream is discharged through the Kınık stream, having been attained in "resting pool" and precipitated most of its suspension materials. Also it reaches to the Emet stream through the Kınık Stream after discharging (Anonymous, 1999).

There are lots of pollution sources in the Lake's own

Table 1. Heavy metal concentrations in water samples (mg l^{-1}) (Values indicates the average of 5 stations.).

Month / Metals	February 03 Mean Min-Max	March 03 Mean Min-Max	April 03 Mean Min-Max	May 03 Mean Min-Max	June 03 Mean Min-Max	July 03 Mean Min-Max	August 03 Mean Min-Max	September 03 Mean Min-Max	October 03 Mean Min-Max	November 03 Mean Min-Max	December 03 Mean Min-Max	January 04 Mean Min-Max	Aver.±SD
Cu	0.1382	0.1962	0.2518	0.1616	0.0842	0.0920	0.1064	0.1372	0.1710	0.0860	0.1648	0.1038	0.141±0.05
	0.0175-0.177	0.127-0.245	0.122-0.0359	0.03-0.326	0.005-0.192	0.03-0.15	0.004-0.23	0.009-0.285	0.004-0.259	0.045-0.122	0.118-0.261	0.059-0.144	
B	1.6278	0.6886	0.5532	0.5702	0.5026	0.702	1.472	0.9958	1.244	1.228	1.268	0.6586	0.9592±0.03
	0-2.57	0.594-0.891	0.488-0.653	0.497-0.604	0.425-0.549	0.65-0.753	1.42-1.48	0.913-1.08	1.19-1.35	0.93-1.43	1.11-1.63	1.606-0.757	
As	0.04	0	0	0	0.02	0.1	0.26	0.1	0.02	0	0	0	0.045±0.01
	0-0.1	0	0	0	0.01	0.1-0.1	0.1-0.5	0-0.5	0-0.1	0	0	0	
Pb	0.0230	0.0255	0.0285	0.0243	0.0268	0.0310	0.0280	0.0245	0.0263	0.0220	0.0263	0.0200	0.025±0.003
	0.021-0.025	0.023-0.028	0.027-0.03	0.022-0.027	0.024-0.03	0.024-0.037	0.022-0.034	0.021-0.028	0.024-0.003	<0.02-0.022	<0.02-0.032	<0.02-0.02	
Cr	0.0540	0.0100	0.0100	0.0184	0.0100	0.0880	0.0088	0.0100	0.0100	0.0100	0.0100	0.0128	0.021±0.024
	0.025-0.119	<0.01-0.01	<0.01-0.01	0.025-0.037	<0.01-0.01	<0.01-0.033	<0.01-0.004	<0.01-0.01	<0.01-0.01	<0.01-0.01	<0.01-0.01	0.009-0.025	
Cd	0.0580	0.0480	0.0614	0.0254	0.0510	0.0500	0.0502	0.0534	0.0242	0.0270	0.0132	0.0292	0.04±0.02
	0.043-0.077	0.031-0.066	0.044-0.072	0.018-0.035	0.041-0.062	0.032-0.069	0.028-0.061	0.041-0.065	0.018-0.038	0.017-0.037	0.008-0.021	0.022-0.037	
Ni	0.0160	0.0176	0.0197	0.0245	0.0290	0.0343	0.0331	0.0227	0.0119	0.0185	0.0268	0.0161	0.022±0.007
	0.0127-0.0201	0.0157-0.0201	0.0176-0.0218	0.0195-0.029	0.0277-0.0301	0.0274-0.0403	0.0234-0.0399	0.0196-0.0287	0.0105-0.0135	0.017-0.0196	0.0171-0.0397	0.011-0.0224	
Zn	0.1436	0.2102	0.1888	0.1756	0.1494	0.1190	0.0618	0.1196	0.1084	0.0564	0.0796	0.1594	0.13±0.05
	0.046-0.287	0.135-0.448	0.026-0.554	0.104-0.212	0.126-0.183	0.087-0.136	0.039-0.077	0.089-0.15	0.081-0.13	0.002-0.103	0.063-0,092	0.087-0.205	

Table 2. Heavy metal concentrations in plankton samples (mg g^{-1}-dry weight) (values indicates the average of 5 stations).

Month / Metals	February 03 Mean Min-Max	March 03 Mean Min-Max	April 03 Mean Min-Max	May 03 Mean Min-Max	June 03 Mean Min-Max	July 03 Mean Min-Max	August 03 Mean Min-Max	September 03 Mean Min-Max	October 03 Mean Min-Max	November 03 Mean Min-Max	December 03 Mean Min-Max	January 04 Mean Min-Max	Aver.±SD
Cu	2.299 1.361-4.156	16.990 9.778-23.968	23.882 4.539-60.667	6.291 3.229-10.6	4.740 3.17-6.547	2.240 0-4.069	0.670 0.331-1.08	8.340 2.468-24.546	6.760 4.539-9.235	1.110 0.0105-2.171	4.620 0.77-16.667	3.900 1.421-7.556	6.82±6.91
Pb	0.537 0.29-0.71	0.604 0.31-0.78	4.302 1.76-11.33	0.672 0.41-1.2	0.442 0.33-0.6	0.200 0-0.46	0.109 <0.057-0.18	0.410 <0.16-0.41	0.913 <0.52-1.35	0.650 <0.11-0.96	0.307 <0.155-1.66	1.060 0..32-3	0.85±1.12
Cr	3.031 0.807-6.818	0.238 <0.139-0.323	1.270 <0.588-3.333	1.140 0.162-2.483	1.260 <0.1-3.108	0.476 0-2.121	0.175 0.055-0.406	2.585 0.927-6.909	6.557 1.447-22.235	0.189 0.956-0.3571	0.660 0.341-0.828	2.590 <0.278-8.889	1.68±1.83
Cd	1.392 0.76-2.29	0.722 0.41-0.96	5.680 2.05-11.6	1.268 0.94-1.8	0.490 0.35-0.79	0.630 0.43-1.22	0.222 0.123-0.49	1.600 0.53-4.63	1.660 0.81-3.41	1.200 0.38-2.28	1.604 0.52-5.08	0.988 0.33-3.11	1.45±1.41
Ni	2.412 0.29-4.68	4.594 2.81-6.28	30.794 15.3-64	4.545 4.22-4.98	2.676 0.81-4.94	1.972 0-3.31	1.380 0.91-2.81	6.918 1.24-20.72	6.058 3.65-11.94	4.054 1.11-7.11	5.148 1.23-16.6	11.082 3.33-19.88	6.8±7.99
Zn	13.339 8.347-17.625	24.521 12.667-31	84.284 34.529-193.33	15.717 6.960-26.16	10.534 6.66-14.189	6.784 0-14.776	2.513 1.707-4.797	18.392 4.621-52.727	24.102 16.128-45.529	10.383 2.883-18.393	12.479 3.612-39.083	20.432 8.42-61.6	20.29±21.22

Table 3. Mobile heavy metal concentrations in sediment samples (mg g^{-1}) (values indicates the average of 5 stations).

Month / Metals	February 03 Mean Min-Max	March 03 Mean Min-Max	April 03 Mean Min-Max	May 03 Mean Min-Max	June 03 Mean Min-Max	July 03 Mean Min-Max	August 03 Mean Min-Max	September 03 Mean Min-Max	October 03 Mean Min-Max	November 03 Mean Min-Max	December 03 Mean Min-Max	January 04 Mean Min-Max	Aver.±SD
Cu	0.0221 0.0207-0.0246	0.0061 0.0021-0.0113	0.0045 0.0024-0.0101	0.0061 0.0031-0.0091	0.0069 0.0017-0.0141	0.0036 0.0019-0.006	0.0090 0.0005-0.0207	0.0527 0.0149-0.186	0.0218 0.0199-0.0244	0.0020 0.0005-0.0037	0.0075 0.0019-0.0227	0.0035 0.0001-0.0129	0.012±0.014
Pb	0.0146 0.005-0.236	0.0154 0.0035-0.0253	0.0105 0.0063-0.0151	0.0160 0.006-0.0223	0.0148 0.0011-0.0239	0.0129 0.0054-0.0244	0.0132 0.0089-0.0236	0.0100 0.004-0.0195	0.0190 0.0048-0.058	0.0122 0.0006-0.0193	0.0102 0.0029-0.0201	0.0132 0.0084-0.0172	0.013±0.002
Cr	0.0062 0.0026-0.0134	0.0048 0.0008-0.0152	0.0117 0.0072-0.018	0.0101 0.0036-0.0143	0.0108 0.0068-0.0197	0,0090 0.004-0.0148	0.0109 0.001-0.0154	0.0075 0.032-0.017	0.0113 0.0075-0.0167	0.0099 0.0084-0.0128	0.0094 0.0048-0.0175	0.0080 0.0046-0.0138	0.009±0.002
Cd	0.0025 0.0018-0.0032	0.0019 0.001-0.0032	0.0019 0.0013-0.0026	0.0062 0.0012-0.0229	0.0034 0.0028-0.005	0.0018 0.0011-0.0031	0.0025 0.0011-0.004	0.0045 0.0017-0.0068	0.0016 0.0005-0.0031	0.0017 0.0006-0.0033	0.0020 0.0012-0.0036	0.0020 0.0012-0.0031	0.002±0.001

Table 3. Contd.

Ni	0.0101 0.0069-0.0161	0.0079 0.0025-0.0123	0.0074 0.0013-0.0138	0.0051 0.0012-0.0113	0.0078 0.0038-0.0132	0.0110 0.0072-0.0149	0.0062 0.0045-0.0089	0.0123 0.007-0.0178	0.0099 0.0029-0.0167	0.0070 0.0041-0.0106	0.0046 0.0016-0.0071	0.0096 0.0047-0.0225	0.008±0.002
Zn	0.0007 0.002-0.013	0.0014 0.0005-0.0024	0.0025 0.0009-0.0044	0.0020 0.0013-0.0033	0.0010 0.0005-0.0015	0.0013 0.0003-0.0038	0.0009 0.0005-0.0014	0.0021 0.0004-0.0035	0.0015 0.0001-0.0035	0.0012 0.0003-0.0026	0.0018 0.0002-0.0064	0.0014 0.003-0.0036	0.001±0.0005

Table 4. Easily mobilizable heavy metal concentrations in sediment samples (mg g^{-1}) (Values indicates the average of 5 stations).

Month / Metals	February 03 Mean Min-Max	March 03 Mean Min-Max	April 03 Mean Min-Max	May 03 Mean Min-Max	June 03 Mean Min-Max	July 03 Mean Min-Max	August 03 Mean Min-Max	September 03 Mean Min-Max	October 03 Mean Min-Max	November 03 Mean Min-Max	December 03 Mean Min-Max	January 04 Mean Min-Max	Aver.±SD
Cu	0.0079 0.0041-0.0106	0.056 0.0015-0.0096	0.0023 0.0005-0.0036	0.0019 0.0001-0.0034	0.0091 0.0006-0.0178	0.0044 0.0025-0.0068	0.0104 0.0014-0.0186	0.0012 0.0005-0.0026	0.0014 0.0006-0.0023	0.0093 0.0006-0.0209	0.0074 0.0036-0.0112	0.0207 0.0174-0.0222	0.006±0.005
Pb	0.0095 0.0061-0.0135	0.0130 0.0052-0.023	0.0161 0.0084-0.026	0.0191 0.0085-0.0242	0.0095 0.0043-0.0199	0.0148 0.0056-0.0218	0.0076 0.0033-0.0167	0.0183 0.0083-0.0308	0.0360 0.0112-0.114	0.0129 0.005-0.0291	0.0098 0.0004-0.0194	0.0106 0.0078-0.0146	0.014±0.007
Cr	0.0067 0.0039-0.0112	0.0072 0.0008-0.0149	0.0108 0.0093-0.0118	0.0032 0.0013-0.0054	0.0070 0.0037-0.0081	0.0087 0.0034-0.0161	0.0113 0.0074-0.0145	0.0091 0.0006-0.0143	0.0074 0.0015-0.0129	0.0072 0.003-0.0147	0.0068 0.0015-0.0122	0.0081 0.0037-0.0114	0.007±0.002
Cd	0.0026 0.0012-0.0048	0.0024 0.0014-0.0033	0.0020 0.0007-0.0039	0.0031 0.0017-0.006	0.0024 0.0005-0.0038	0.0057 0.0008-0.0229	0.0033 0.0029-0.0039	0.0032 0.0016-0.0045	0.0022 0.001-0.0035	0.0024 0.0011-0.0042	0.0030 0.0013-0.0044	0.0033 0.0026-0.0038	0.002±0.0009
Ni	0.0114 0.0013-0.0171	0.0114 0.0055-0.0171	0.0130 0.0103-0.0184	0.0102 0.0059-0.0189	0.0079 0.001-0.0115	0.0119 0.0056-0.0244	0.0079 0.0037-0.0141	0.0096 0.0037-0.053	0.0135 0.0093-0.0166	0.0090 0.0032-0.0175	0.0118 0.0049-0.0183	0.0106 0.0063-0.0157	0.01±0.001
Zn	0.0026 0.0001-0.0054	0.0020 0.0011-0.0045	0.0030 0.0013-0.0056	0.0037 0.0011-0.0053	0.0012 0.0004-0.0038	0.0025 0.0018-0.0045	0.0006 0.0001-0.0013	0.0025 0.0006-0.0059	0.0022 0.0001-0.0077	0.0018 0.0003-0.0039	0.0017 0.0006-0.0048	0.0027 0.0002-0.0049	0.002±0.0008

Table 5. Seasonal variations of physical parameters in Lake Uluabat (values indicate the average of 5 stations).

Parameter	Spring	Summer	Fall Spring	Winter	Aver±SD (Min-Max)
Temprature (˚C)	9.28	25.68	20.38	10.06	16.35±8.01 (6.6 - 28)
DO (mg l^{-1})	10.87	8.01	8.36	11.28	9.63±1.68 (5.4 - 13.2)
EC (µS cm^{-1})	501	606	721	569	599±92 (434 - 751)
pH	8.7	8.65	8.78	8.63	8.69±006 (8.4 - 9.11)

Table 6. Heavy metal concentrations in Lake Ulubat water samples and guidelines.

Parameter	Cd	Cu	Pb	Zn	Cr	B	As	Ni
This study (mg l^{-1})	0.04±0.02	0.141±0.05	0.025±0.003	0.13±0.05	0.021±0.024	0.9592±0.03	0.045±0.01	0.022±0.007
Water Quality Criteria[a]								
CMC (µg l^{-1})	2.0	13	65	120	16	-	340	470
CCC (µg l^{-1})	0.25	9	2.5	120	11	-	150	52
Turkish Environmental Guidelines[b]								
Class I (µg l^{-1})	3	20	10	200	20	1000	20	20
Class II (µg l^{-1})	5	50	20	500	50	1000	50	50
Class III (µg l^{-1})	10	200	50	2000	200	1000	100	200
Class IV(µg l^{-1})	>10	>200	>50	>2000	>200	>1000	>100	>200

[a]US EPA; [b]Turkish Environmental Guidelines.

river basin. The most important one of the polluters discharged to the lake from Akçalar, is the polluters that Musa stream brings. The domestic and the industrial waste waters that stem from a tinning factory with 1200 m^3 wastewater discharge daily, is being transmitted to the Lake Uluabat through the Musa stream having been treated in the actual treatment facility.

Animal wastes run to the Lake at the shores in the biggest island of the Lake, Halilbey. When all these effects are taken into consideration, it is seen that, all these polluters combine together in the Lake and result in the pollution of the Lake.

In this study, Cu, Pb, Cr, Cd, Ni and Zn concentrations were detected at higher levels at Lake Uluabat for selected stations, especially in plankton samples. Significant heavy metal concentrations in plankton samples indicate heavy metal entrance through food chain. The accumulation of the heavy metal in plank-ton depends on the factors like absorption properties of the species and the seasonal changes. It is known that the quantity of the heavy metal depends on the concentrations in the water and on partially sediment. The opinion which supports the results of Lake Uluabat shows that organisms accumulate all elements between 100 to 1000 times when compared with their surroundings.

Generally, increased metal concentrations in water resulted in increased metal concentration in biota (Klavins et al., 1998). In water samples of Lake Uluabat, Zn and Cu concentrations were significantly higher. Compared with previous studies, the Zn results (mean 0.13 mg l^{-1}) are higher than these of Lake Quarun (0.02 ppm), Rayan 1 (0.02 ppm) and Rayan 2 (0.01 ppm) (Mansour and Sidky, 2003). Zn concentration of Lake Lapland (1.84 µg l^{-1}) (Mannio et al., 1995) is higher than that of Lake Uluabat. Cu concentrations of Lake Dominic was found to be 3.93 mg l^{-1} (Szymanowska et al., 1999). Zhou et al. (1998) studied Zn, Pb, Cd, Cr and Cu and reported that only Cu was found in the water-soluble fraction in inland waters of Hong Kong. Boron concentrations were detected partially higher in outflow of the Lake (1st sta.) and Island Halilbey (2nd sta.). That's because of the inflow of Mustafakemalpaşa stream, drains boron to the Lake, pass close to these places.

Generally, in water samples of Lake Uluabat, some heavy metal (B, Zn, Cu) concentrations were observed higher during the winter and spring. It is thought that this may be caused by pollution load drained via streams. The high concentration of some heavy metals (As, Ni, Cr and Pb) may be related to reduction of the Lake water level. Concentration differences were not observed among the stations.

Table 6 shows heavy metal concentrations in Lake Uluabat water samples and guidelines. Water quality regulations in Turkey divide inland waters into four classes (Turkish Environmental Guidelines, 1988). Class I refer to clean water that can be used for domestic purposes after simple disinfection, for recreation and irrigation. Class II refers to fairly clean water that can be used as domestic water after treatment, for recreational purposes or for fishing, farming, etc. Class III includes polluted water, which can only be used as industrial water after treatment. Class IV refers to heavily polluted water that should not be used at all (Demirak et al., 2006). Accordingly, Lake Uluabat has been identified as Class I regarding to B, Zn, Ni and Cr; as Class II regarding to As; and as Class III regarding to Cu, Pb; and as Class IV regarding to Cd. The mean concentrations of Pb, As, Ni are lower and Cd, Cu, Zn, Cr are higher than criteria maximum concentrations (CMC). Moreover, according to US EPA (2006), the mean concentrations of As, Ni are lower and Cd, Cu, Zn, Pb, Cr are higher than criteria continuous concentration (CCC) value of the US EPA water quality (Table 6).

According to literature, numerous factors play a role in determining the level of accumulated cadmium, including source, exposure level, distance from contamination source and the presence of other ions. Heavy metal toxicity is affected by temperature, dissolved oxygen concentrations and pH. In addition, differences in species and water hardness might affect the toxicity (Barlas, 1999).

Metal distribution among specific forms varies widely based on the chemical properties of metals and soil characteristics. Thus, it is important to evaluate the availibility and mobility of heavy metals to establish environmental guidelines for potential toxic hazards and to understand chemical behaviour and fate of heavy metal contaminants in soils (Ma and Rao, 1997). The sequential extraction used in this study is useful to assess the potential mobility of heavy metals in the sediment indirectly.

Pb concentration levels in sediments were consistently higher than Cd concentration levels. These results could be explained by the fact that Cd in sediments is mainly associated with the carbonate fraction and it is a readily solubilized metal, whereas Pb is mainly associated with the Fe-Mn oxide fraction and has higher retention in sediments (Fernandez et al., 2000). Domestic and industrial effluents, municipal runoffs and atmospheric deposition may be the major sources of the observed high level of Pb. The contribution of Pb from the use of leaded petrol in outboard boat engines and automobiles and car batteries is possibly significant (Kishe and Machiwa, 2003). Similarly, pollutants that are present surrounding Lake Uluabat explain Pb pollution observed in Lake.

Concentration of Cu and Cr in mobile fraction is detected higher than in easily mobilizable fraction. According to these result Cu and Cr are more available to aquatic life. Concentration of Pb, Cd, Zn and Ni in mobile fraction is detected in lower levels than in easily mobilizable fraction, which means they are less available to aquatic fauna and less changes of entering into the human food chain. Sekhar et al. (2003) who studied Kolleru Lake reported that Zn, Cd, Cu and Pb are mostly associated with mobilizable fraction. Wang et al. (2004) reported that the portion of heavy metals, based on three-step sequential extraction procedure, indicates relatively high mobility of Zn, Cu, Pb and Ni in the sediments.

In sediment, mobile fraction levels are higher than easily mobilizable fraction levels, which mean high percenttage of salinity is found and availability of adsorbtion in sediment is insufficient. The magnitude of heavy metal concentrations in water samples was B>Cu>Zn>As>Cd>Pb>Ni>Cr; in plankton samples Zn>Ni>Cu>Cr>Cd>Pb; in sediment samples in mobile fraction Pb>Cu>Cr>Ni>Cd>Zn and in easily mobilizable fraction Pb>Ni>Cr>Cu>Cd>Zn. The series of biological consumption of microelements by phytoplankton (Zn>Ni>Cu>Cr>Cd>Pb) suggest an explanation of the rapid accumulation of Cd, Zn and Pb in the bottom deposits of eutrophic lakes.

Hellawell (1988) reported that heavy metal toxicity is affected by temperature, dissolved oxygen concentrations and pH. Cd is very toxic to fish and other aquatic organisms, however, temperature, pH and water hardness are factors that influence its toxicity and uptake by fish (Barlas et al., 2005). In Lake Uluabat, all physical parameters varied within the normal range.

Conclusion

Lake Uluabat is one of the most important wetlands not only in Turkey but also in the Middle East and Europe. The results of the present study clearly demonstrate that Lake Uluabat is contaminated with Cd, Pb, Cu, Cr, Ni and Zn. In sediment, mobile fraction levels, is higher than easily mobilizable fraction levels, which means salinity found is excessive and availability of adsorbtion in sediment is insufficient. There should be effort to protect Lake Uluabat from pollution to reduce environmental risks and this study may provide valuable data for future research on Lake Uluabat. The main topics that may be needed to be investigated are control of industrial and domestic discharges, regular observation of pollutants, evaluation of effect of pollutants on Lake's ecosystem over the long term, coordinating the pollution source and preventing inflow of pollutants to the Lake.

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