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RESEARCH ARTICLE

Anthropogenically-induced ecological risks in Lake Erikli, NW Turkey

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Abstract

This study examined the vertical distribution of heavy metals in the core sediments of Lake Erikli, Turkey and their potential ecological risks. Two core samples 48 and 34 cm in length were taken with a Kajak gravity core sampler. The samples were divided into 2 cm sub-samples in the laboratory and analyzed using ICP-MS. The enrichment factors (EF), potential ecological risk factor (PERI) and pollution load index (PLI) were calculated to evaluate the environmental quality of the sediment. According to the results, Cu, Pb, Zn, Ni, and Cr come from natural sources in both cores and there is no anthropogenic contribution to the distribution of these elements, while some anthropogenic effects were detected for As, Cd and Hg. According to the calculated risk index (CRI) for each metal, the potential risk of Cu, Pb, Zn, Ni, As and Cr is low. Two metals posing a threat to the ecosystem were identified; Cd and Hg. PLI values significantly increased from the bottom of the slice to the surface in accordance with the EF and PERI values. Continuation of the pumping of domestic waste into Lake Erikli will accelerate the process of deterioration.

Keywords: Lake Erikli, Core sediment, Metal concentration, Ecological risk, Enrichment factor

Introduction

Lakes are considered important ecosystems due to their use as a freshwater source as well as to feed underground waters, provide a positive contribution to the climate, and regulate environmental conditions (Hou et al., 2013). On the other hand, increasing urbanization and industrialization pose great risks for these important ecosystems. An important group of pollutants discharged into aquatic ecosystems is metals. Some metals used in industry, several of which have important roles in the metabolism of organisms, are natural components in the earth's crust (Uwah et al., 2013). Despite our need for these metals - both natural and anthropogenic - they are a risk to human health and the ecosystem when they reach a certain concentration (Duman et al., 2007; Tao et al., 2012). For example, Cu and Zn exhibit toxic effects at high concentrations despite being valuable micronutrients in aquatic life (Bai et al., 2011). Significant sources of metals entering aquatic ecosystems are: atmospheric depression, waste discharges, agricultural fertilizers, industrial outflows, and metals that reach the water that have accumulated via the food chains in organisms (Ikem & Adisa, 2011; Li et al., 2013; Wang et al., 2014).

Sediment quality is an important indicator of water quality (Zahra et al., 2014). Although metals in sediments are considered as inert pollutants, they can cause ecological damage in certain conditions (Yi et al., 2011). Variable oxidation-reduction conditions, pH, organic / inorganic carbon, and dissolved oxygen concentrations can result in metals being released into the water from the sediment (Çevik et al., 2009; Wang et al., 2012). How to assess the metal accumulation in sediment and to separate anthropogenic effects from natural metal concentrations is a serious issue (Bing et

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al., 2013). Numerous indices are used to predict the human-induced accumulation of metals and possible damage to the environment. The pollution load index (PLI), potential ecological risk index (PERI) and mean probable effect concentration quotient (mPEC-Q) are often used to identify potential ecological risks, while indices such as the enrichment factor (EF), contamination factor (CF), and geo-accumulation index are used to distinguish between natural and human sources (Bing et al., 2013; Hou et al., 2013; Kaya et al., 2017; Kükrer et al., 2015; Kükrer et al., 2018; Long et al., 2006; Yang et al., 2014; Zahra et al., 2014).
In this study, the vertical distribution of heavy metals within two core samples taken from Lake Erikli was examined along with potential ecological effects.

Materials and Methods

Study area

Lake Erikli is a lagoon located in Demirköy district of Kırklareli province in the Marmara Region, NW Turkey (Fig. 1). The lake is fed by the Efendi stream, flowing into the northwestern part of the lake, and the intermittent streams that merge with the lake from the plateau to the north. Because of the geological diversity of Lake Erikli basin, different types of rocks exist. The youngest geologic elements in the basin are alluvial deposits and beach sands. The lake basin is mostly comprised of Tertiary units, including the Trakya formation (unconsolidated sand, gravel and mudstone) and Mert formation (thick-bedded sandstone) (Çağlayan & Yurtsever, 1998; Gazioğlu et al., 1997; Turoğlu, 1997). Mesozoic units extend to the north-east of the lake basin and to the Istranca mountains to the north. The oldest rock group in the area is Paleozoic gneiss, quartzite and schist (Çağlayan & Yurtsever, 1998; Turoğlu, 1997; Burak et al., 2004, Simav et al., 2015; Erginal, 2017; Kuru & Terzi, 2018).

The main geomorphological features of the Lake Erikli basin consist of highlands and lowlands and the slopes connecting them. The highlands, covered mostly with oak and fagus communities, are dissected by streams such as the Efendi, Üvezli, and Geyik, which drain into Lake Erikli. Lake Erikli and its surroundings are dominated by a Black Sea climate. According to data obtained from Iğneada Meteorological Station (IMS), annual rainfall is 800 mm. However, Demirköy Meteorological Station, which represents the higher parts of the area, reveals that the annual average rainfall exceeds 1000 mm. Most rain falls in autumn and winter (Gazioğlu, et al., 2016; Uludağ, 2018).

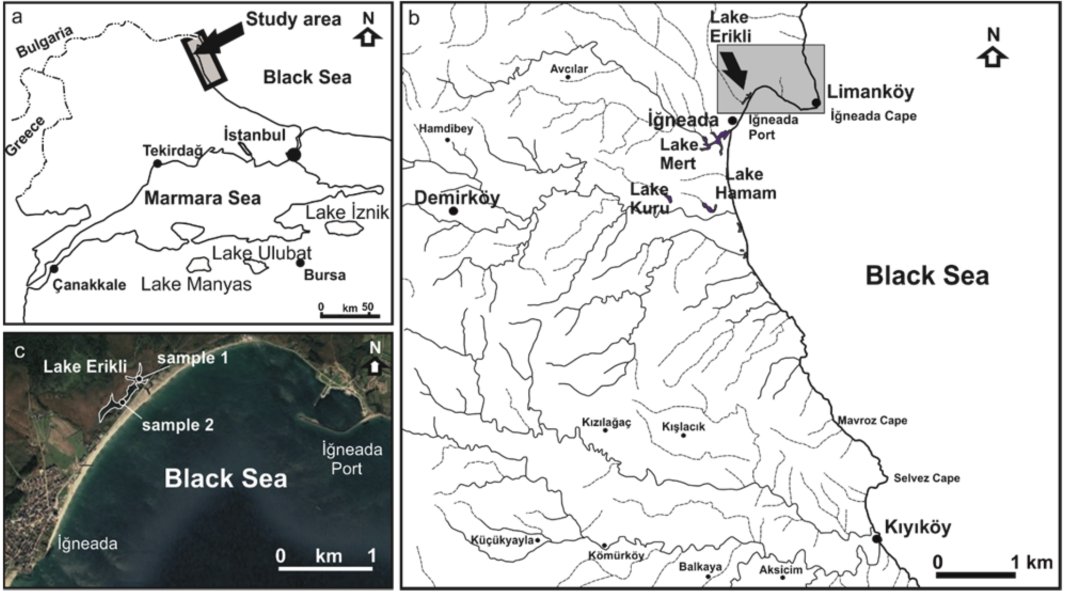

Fig1. Study area and location of sampling stations.

As a result of this precipitation, the lake is connected with the sea from the autumn months onwards. In the summer, the connection is interrupted during periods when precipitation is relatively low. According to IMS, the coldest month is January (3.7oC) while the warmest monthly average is 21.5oC in July (Uludağ, 2018).

Erikli shore is shrinking from year to year due to the sediment transported by rivers and eutrophication from the lake. The area of the lake was 87,715 m2 as calculated from 1960 topography maps. From 1972 aerial photographs and 2006 satellite images, the size has gradually narrowed to 74,751 m2 and 36,369 m2, respectively (Uludağ, 2018).

Analytical procedure

Two core samples 48 and 34 cm in length were taken from Erikli Lake with a Kajak gravity core sampler. The samples were divided into 2 cm sub-samples in the laboratory and these were sent to the Bureau Veritas Mineral Laboratory (Canada) for elemental analysis of the material using ICP-MS.

The enrichment factor was calculated to determine whether the source of the metal concentrations found in the sediment was natural processes or due to anthropogenic effects. This factor was obtained by dividing the measured metal / reference element value by the background metal / reference element value (Çevik et al., 2009; Vrhovnik et al., 2013; Yilgor et al., 2012). Al was used as the reference element. The obtained values were evaluated according to Sutherland (2000): EF <2 no enrichment / minimal enrichment, EF = 2-5 moderate enrichment, EF = 5-20 substantial enrichment, EF = 20-40 very high enrichment, and EF = 40> points to high enrichment at an extreme level. Pollution Load Index was used to measure the quality of the Lake Erikli sediment (Suresh et al., 2011), using the following equation (Eq.1.)

$$PLI = (CF_1 \times CF_2 \times ...CF_n)^{1/n} \qquad \text{Eq. 1.}$$

where CF is the current metal concentration divided by the background metal concentration, and N is the number of metals. A 1-degree decline in PLI value indicates an increase in deterioration in sediment quality.

Potential Ecological Risk Index (PERI) was used to estimate possible ecological effects of sediment-dispersed metals (Hakanson, 1980). Through this index, the potential ecological risks of metals individually and integrated are calculated. The calculation was based on the formula (Eq.2.).

$$Er^i = C^i_f \times Tr^i \qquad \text{Eq. 2}$$

where Cif refers to the contamination factor and Tri expresses the toxic responsibility coefficient. The toxic responsibility coefficients of the metals were found to be: Hg = 40, Cd = 30, As = 10, Cu = Pb = Ni = 5, Cr = 2, Zn = 1 (Guo et al., 2010). The integrated PERI value was calculated using the following formula (eq.3.)

$$PERI = \sum Er^i \qquad \text{Eq. 3.}$$

The following scale was used in assessing the potential ecological risk index: Eri <40 low potential ecological risk, 40 ≤ Eri <80 medium potential ecological risk, 80 ≤ Eri <160 significant potential ecological risk, 160 ≤ Eri <320 high potential ecological risk, Eri ≥ 320 very high potential ecological risk, PERI <150 low ecological risk, 150 ≤ PERI <300 medium ecological risk, 300 ≤ PERI <600 significant ecological risk, and PERI ≥ 600 very high ecological risk. Factor analysis was applied to identify possible sources of elements.

Results and discussion

Vertical distribution of metals

Minimum and maximum mean and standard error values are given in Table 1, based on the results of metal analysis in the core samples taken from Lake Erikli. Although there are some small differences according to these results, it is observed that the values of the two core sections are generally close to each other. Vertical variations of the metal concentrations in the samples are given in 3 2. The Cu concentration was found to be relatively lower in core E2. The Cu values of the two core samples showed an opposite trend between core depths 8 and 26 cm. Although the Pb concentration is not reversed between 14 and 32 cm depth, it proceeds together at depths between 0-14 cm and increases towards the surface.

Figure 2 shows that Pb values tend to increase. Zn concentrations in E1 and E2 cores tend to increase together at a depth of 6 cm, with an inverse relationship from 6 to 26 cm core depth. Values below 26 cm appear to be constant. Concentrations of Ni and Mn do not fluctuate much in either core, but were distributed in opposite directions. The distribution of Fe in the two sections shows a tendency to increase towards the surface in the first 10 cm. In the lower parts of the sections there is an inverse correlation.

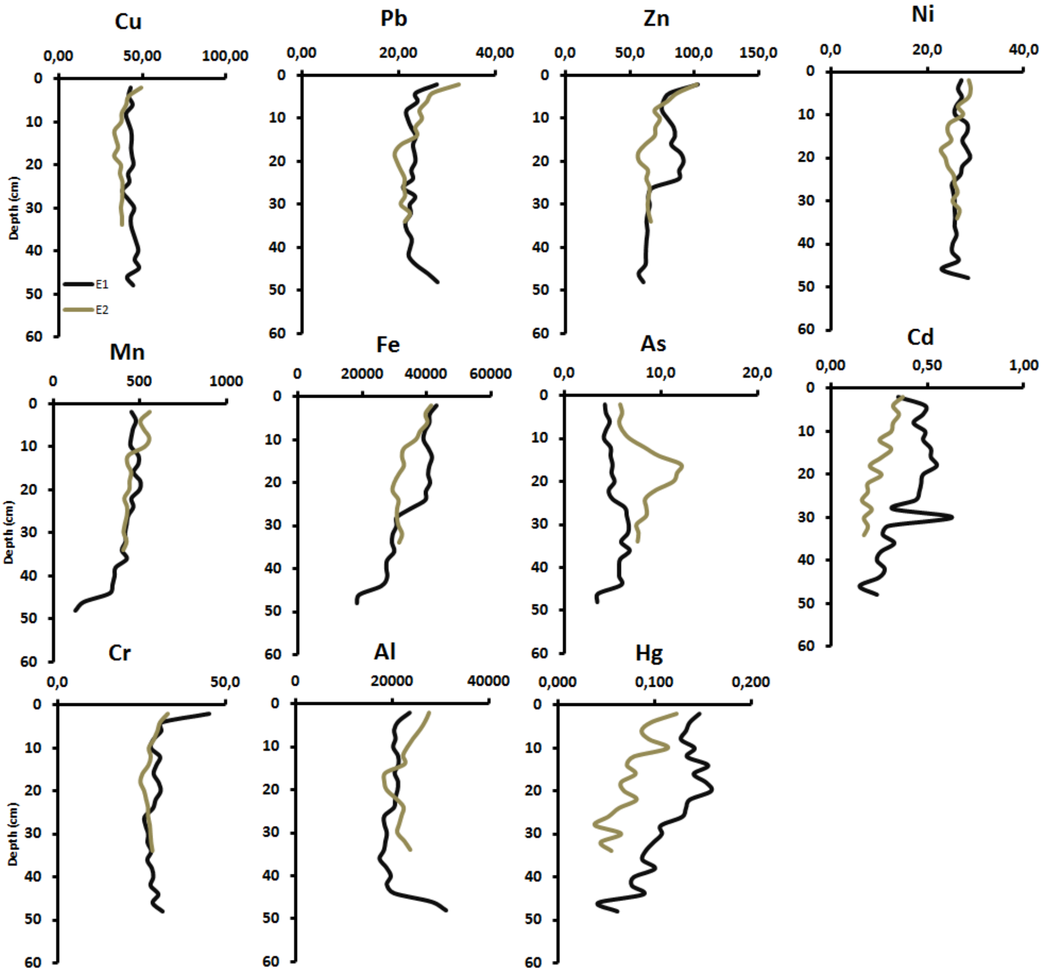

Fig. 2. Vertical distribution of metal concentrations expressed in *parts per million* (*ppm).*

The As distribution in the cores is quite different from each other. An obvious peak was detected in the E2 core in the range of 14-16 cm, while no change was observed except for small fluctuations in core E1. The concentration of Cd in core E2 shows an increase from bottom to top with little fluctuation. In E1 core, however, it tends to decrease towards the surface in the range of 0-18 cm. Although the Cr distribution in cores implies an inverse relationship in the range of 8-22 cm, it increases near the surface and this increasing tendency seems to be continuing. Al and Hg concentrations similarly increased consistently

Table. 1. Descriptive statistics of variables (expressed in ppm).

Sample		Cu	Pb	Zn	Ni	Mn	Fe	As	Cd	Cr	Al	Hg
E1	Av.	43.31	23.24	74.26	26.49	409.25	34020,8	5.20	0.39	29.46	20812.5	0.115
	Min.	37.64	20.92	57.0	23.0	125.0	18400	3.4	0.15	26.0	17400	0.041
	Max.	48.06	28.03	103.0	28.9	502.0	42900	6.8	0.63	45.3	31100	0.158
	SE	0.49	0.36	2.59	0.28	19.23	1502.6	0.20	0.03	0.76	625.1	0.007
E2	Av.	37.65	22.77	69.31	25.91	456.88	33723.5	8.30	0.25	27.75	22535.3	0.07
	Min.	32.87	19.05	56.6	22.9	402.0	29500	5.7	0.16	24.7	18400	0.038
	Max.	49.49	32.39	102.1	29.0	560.0	41400	12.1	0.37	32.9	27700	0.122
	SE	0.92	0.81	2.72	0.42	13.35	933.1	0.49	0.02	0.48	645.8	0.006
	BG	44.53	21.4	60.7	23.0	125	18400	3.4	0.15	31.4	20400	0.041

Table 2. Comparison of metal concentrations (expressed in ppm) in Lake Erikli with other lakes in Turkey.

Lake	Cu	Pb	Zn	Ni	Mn	Fe	As	Cd	Cr	Al	Hg	References
Uluabat	119.2	110.7	171	209.4				0.699	57.9			Arslan et al. (2010)
Beyşehir	-	32.65	-	-	-	-	-	13.05	10.63	-	0.24	Altındağ and Yiğit (2005)
Sapanca	26.68	15.20	62	26.72	337.81	-	-	0.29	19.09		-	Duman et al. (2007)
Mogan	15.13	0.822	13.786	-	125.668	3577	-	-	28.55	-	-	Benzer et al. (2013)
Aktaş	27.58	16.86	56.86	47.34	900.89	20522.2	6.52	0.25	34.46	20566.7	0.05	Kükrer (2017)
Seyhan Dam	19.80		39.09		803.63	39350		2.15	118.95			Çevik et al. (2009)
Erikli	**40.96**	**23.04**	**72.20**	**26.25**	**429**	**33897.6**	**6.49**	**0.33**	**28.75**	**21526.8**	**0.10**	**This study**

on the surface, although they show inverse relations at the lower levels of the cores. There is a dramatic increase in the surface concentration of Hg.

Enrichment factor

According to the results of the enrichment factor (EF) index applied to determine the sources of the metal content in E1 and E2 cores, it is seen that Cu, Pb, Zn, Ni, and Cr arise from natural sources in both cores and there is no anthropogenic contribution to the distribution of these elements. If the EF values are less than 0.5, it is stated that the values of 0.5-1, caused by the mobilization of metals, point to natural sources, and values greater than 1.5 can be evaluated as anthropogenic (Zhang and Liu, 2002; Zhang, 1995).

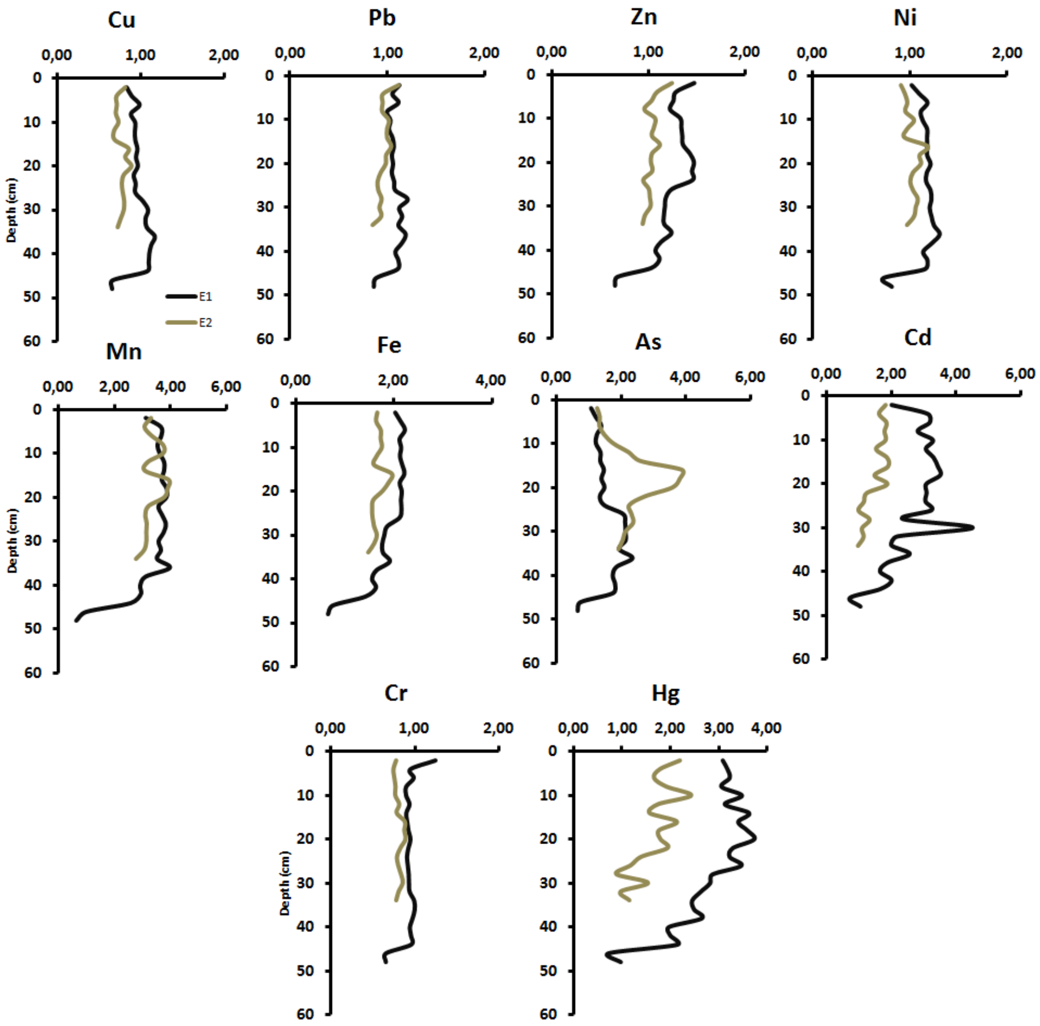

Fig. 3. Vertical distribution of EF values.

Based on this view, the Zn and Cr values approach the critical boundary in the surface sediment of the area where the E1 core was taken. The Mn concentration indicates a moderate enrichment in all of E2, while a large portion of E1 indicates the presence of a similar enrichment. The Fe concentration is slightly above the value of 2 in the first 26 cm of the E1 section, while all values in the E2 section indicate minimal enrichment. The As concentration is explained by transportation from natural sources in the first 24 cm of the E1 section, but slightly below the limit value of 2 in the lower part. On the other hand, in the enrichment of As, the E2 section gives different data. The accumulation of As at a depth from 10 to 34 cm is noteworthy. The values towards the surface return to normal level. Another element in which the accumulation sources differ between the two cores is Cd. While the Cd values along the E2 section show minimal enrichment, the enrichment of anthropogenic origin over 34 cm in E1 section is striking. In the EF distribution calculated for Hg, the two cores show obvious differences. Although the EF values in the E2 section sometimes exceed 2, no large deviations from the boundary value were observed. In the E1 section, values above 40 cm indicate moderate enrichment. The different EF values observed for As, Cd and Hg between the two sections suggest that there may be sediment input from independent sources into the two sampling sites.

Potential Ecological Risk Index (PERI) and Pollution Load Index (PLI)

The PERI and PLI values were obtained, respectively, for ecological potential risks that metals could separately and integrally create and to demonstrate the environmental quality of the sediment (Fig. 4). According to the calculated risk index for each metal, the potential for Cu, Pb, Zn, Ni, As and Cr is low. Two metals posing a threat to the ecosystem were identified; Cd and Hg. The first 0-20 cm in E2 core section contains moderate risk. In the E1 section, the core depth between 46 and 48 cm carries no risk, while the 4-26 cm range represents a significant risk. However, the rest of the core section indicates only a moderate risk. When the integrated potential risks of the metals were examined, a moderate risk was found between 0-22 cm in the E2 section, and a moderate risk was found in the whole of E1 core except for the last 2 cm. Suresh et al. (2011) reported that the ideal value for PLI is 0, 1 is the threshold value, and beyond these values represents environmental degradation. PLI values significantly increased from the bottom to the surface in accordance with the enrichment factor and PERI values. This shows that over time, sediment metal concentrations are increasing due to anthropogenic effects and that the actual sediment quality is deteriorating, leading to danger for the ecosystem.

Table 3. Weight of components according to principal component analysis.

	Component 1	*Component*	*Component*
E1.Cu	-0.124599	-0.0015244	**0.808468**
E1.Pb	-0.0809559	**0.506332**	0.101298
E1.Zn	**0.403219**	0.196379	0.0222008
E1.Ni	0.281179	0.208532	**0.387232**
E1.Mn	**0.404609**	-0.207716	0.0436716
E1.Fe	**0.439981**	-0.00285436	-0.0668995
E1.As	-0.0583576	**-0.454415**	0.314695
E1.Cd	**0.378969**	-0.0844579	-0.0705404
E1.Cr	0.142955	**0.403109**	0.222434
E1.Al	-0.12889	**0.492237**	-0.160325
E1.Hg	**0.441486**	-0.000932584	-0.0101895

	Component 1	*Component* 2
E2.Cu	**0.282908**	-0.233136
E2.Pb	**0.332215**	0.0392021
E2.Zn	**0.328143**	-0.0381694
E2.Ni	**0.302062**	-0.268324
E2.Mn	0.290998	**0.368416**
E2.Fe	**0.326264**	0.168952
E2.As	-0.279903	**0.349913**
E2.Cd	0.271186	**0.457408**
E2.Cr	**0.317998**	-0.27266
E2.Al	**0.317966**	-0.251089
E2.Hg	0.255805	**0.487166**

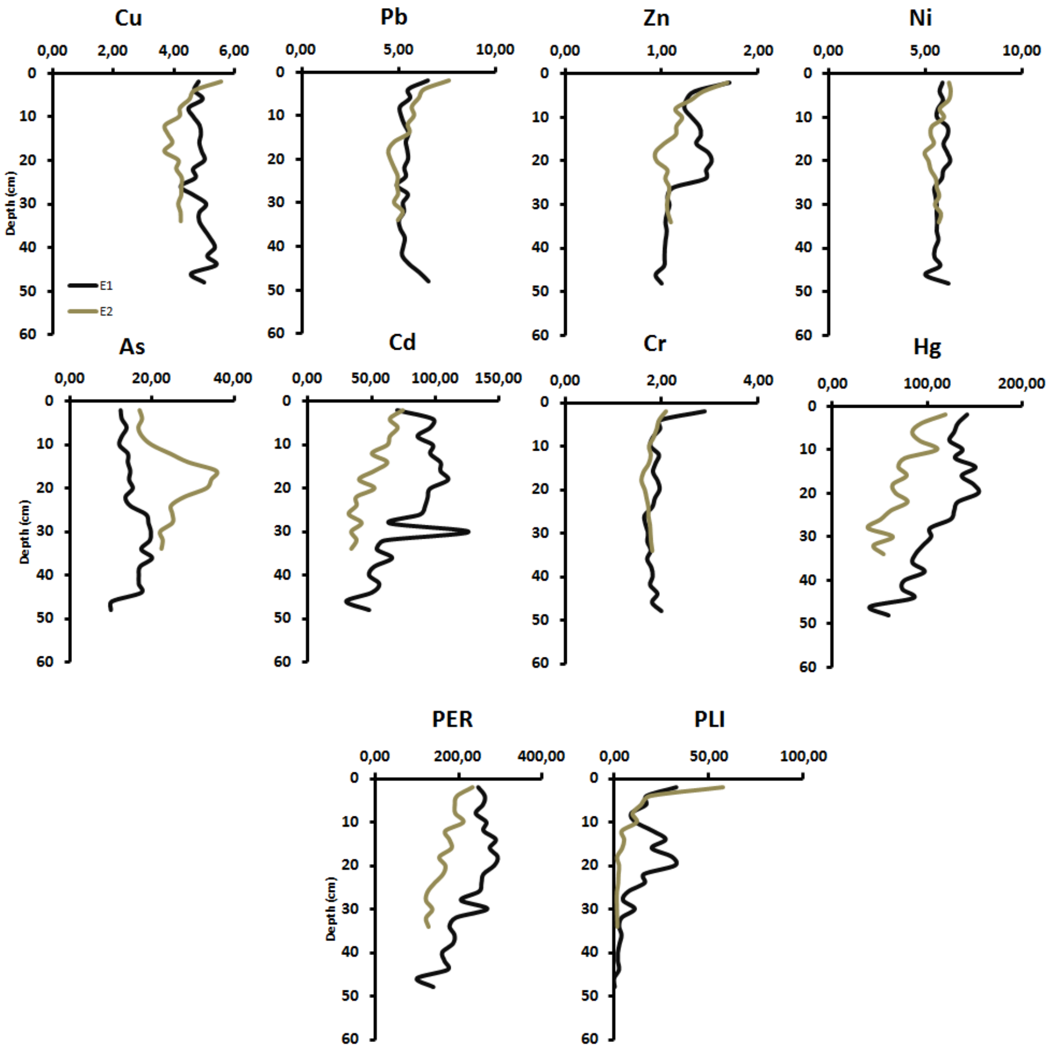

Fig. 4. Vertical distribution of metals and PLI values.

Comparative assessment

The metal concentrations derived from core samples at Lake Erikli were compared with other lakes located in different parts of Turkey (Table 2). Accordingly, the Cu concentration in Lake Erikli is higher than Sapanca, Mogan, Aktaş and Seyhan lakes but lower than in Lake Uluabat. Likewise, Pb concentration is higher than Sapanca, Mogan and Aktaş lakes but lower than Uluabat and Beyşehir. It was determined that the Zn content in the Erikli sediment is lower than Lake Uluabat but higher than the other lakes in comparison. Ni concentration seems to be at lower levels than lakes Uluabat, Sapanca and Aktaş. While the Mn values of Sapanca and Mogan are lower than Lake Erikli, the values of lakes Aktaş and Seyhan are quite high. As regards the concentration of As, close values were observed in Lake Aktaş. The Cd values measured in Lake Erikli were found lower than Uluabat, Beyşehir and Seyhan, but higher than Aktaş and Sapanca. It is seen that the Cr content of Beyşehiri, Sapanca and Mogan are lower than Erikli and the other lakes have higher Cr content. Hg content was higher than Lake Aktaş and lower than Lake Beyşehir.

Principal component analysis

Multivariate statistical analyses provide a way to determine the sources and transport routes of metals and have been used in many studies (Bai et al., 2011; Gao et al., 2013). Principal Component Analysis (PCA) was applied separately to the data from both cores at Lake Erikli to estimate possible sources of metals and the migration processes. Three components were identified in the E1 core section with Eigenvalue > 1, along with two components in the E2 section. The three components in the E1 core account for 87.20% of the total variance. The first component describes 45.19% of the variance in the dataset, including Zn, Mn, Fe, Cd and Hg. Since this component contains elements with a high enrichment factor except for Zn, it reflects the common source of these elements. Zn also seems to share a common transport process with these elements. 30.33% of the second component changes are explained and consist predominantly of Cr, Al, Pb and As. The third and last component describes 11.68% of the total variance and contains Ni and Cu. This indicates that these two elements share common source and transport processes. The two components in the E2 core account for 88.96% of the total variance. Pb, Zn, Ni, Fe, Cr and Al explain 76.94% of the first component variance. This component is a terrestrial / lithogenic effect. The second component constitues 12.03% of the variance and is composed of Mn, As, Cd, and Hg. Considering that these elements have high enrichment factors in E2, this component is an anthropogenic effect. These four elements share common sources and migration processes.

Conclusions

It was determined that the sediment quality of Lake Erikli, which is fed by rivers and where household waste brought down by these rivers is gradually being discharged, is in the process of deterioration. The enrichment of Mn, Cd, and Hg is especially noteworthy. The increasing tendency in Zn and Cr also indicates the risk of anthropogenic pollution by these two metals in the near future. The sediment quality decreased according to PERI and PLI values. In particular, Hg and Cd pose a risk to the ecosystem. The increase of corruption along the cores from the bottom to the surface clearly shows human-induced pressure on the lake. Continued pumping of domestic wastes will accelerate the process of deterioration. Thus, pollution studies should be carried out on a wider scale and measures should be taken to save the lake from these hazards and reveal the dimensions of the danger to Lake Erikli's unique ecosystem.

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