

# ASSESSMENT OF HEAVY METAL CONTAMINATION AND ACCUMULATION PATTERNS IN THE COASTAL AND DEEP SEDIMENTS OF LAKE SALDA, TURKEY

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## ABSTRACT

In this study, contamination levels were found for 8 different metals (Cu, Pb, Zn, Ni, Mn, Fe, Cd, Cr) and metalloids (As) in sediment samples, coming from 9 different stations, through statistical analysis and sediment assessment at Lake Salda (Turkey). The correlation, cluster, factor and Mann Whitney-U analysis were used for evaluation of the results, and the values of all metals were compared with the limit values of PEL (probable effect level), ERM (effect range median), TEL (threshold effect level), and ERL (effect range low). According to the correlation, PCA and cluster analysis, highest correlation was determined as being between Cu-Mn, Cu-Zn, Fe-Ni, Cr-Ni and Fe-Cr. The weakest relationships with other metals were identified as Pb and As. Additionally, deep and shallow stations were compared and station-based anthropogenic effects were demonstrated. The status of the sediments was considered separately for the studied elements. According to the results, contamination factor, enrichment factor, geoaccumulation index, potential ecological risk factor and quotient toxic unit showed up the highest values for Ni. However, Pb results seemed quite serious at several stations according to the results of the research. The pollution load index was used to find out the baseline and ideal levels throughout the lake.

## KEYWORDS:

Heavy metals, metalloid, pollution, sediment assessment methods, Lake Salda

## INTRODUCTION

Several of the metals (like Cu, Fe, and Zn) are needed for the continuation of life, although a number of the metals (such as Pb, Cd and Hb) exhibit toxic effects, even in low concentrations. Whether they are essential or nonessential, all metals have a toxic effect on every living thing over a certain threshold. Accumulation of heavy metals in aquatic environments has constituted one of the most serious

environmental problems for a long period of time due to intensive industrialization. Large quantities of toxic heavy metals like Cd, Pb, Cr, and Hg are released into ecosystems as contaminants after anthropogenic activities [1]. Whether the source is lithogenic or anthropogenic metals are persistent environmental contaminants [2]. The accumulation of metals has become a serious cause for concern which needs urgent consideration [3]. Heavy metal contamination has been studied by numerous researchers [4-11].

Determination of the metal content in sediment is important for aquatic ecosystems, because sediment can provide extremely important information about the environmental and geochemical pollution status [12, 13]. The data obtained from the sediment quantiles provided strong evidence of the spatio-temporal anthropogenic effect [14]. As a result, research of heavy metal accumulation in sediment has been studied at both sea and fresh water sites [15, 16]. In addition, the sediment should be thought of not only as an environment where the accumulation of metals by deposition, but also a secondary pollutant source from where the metals enter the water or food chain again. This leads changes in environmental conditions [17, 18]. This situation is a key factor in the increased impact of heavy metal accumulation in the sediment. Besides, the existence of very different creatures living in the sediment at the bottom of the food chain, must not be forgotten. A large number of these living beings store intense heavy metal in their bodies once exposed to them. Consumption of these living beings, by creatures higher up the food chain, enables these intense metals to be easily passed up the food chain until they are eventually consumed by humans.

Lake Salda is known to be one of the deepest lakes in Turkey, with a maximum depth of 184 m. Due to its location, it was determined as an area for natural protection in 1989, and a tourism centre in 2004 by the Culture and Tourism Ministries of Turkey. The lake water is rich in magnesium and is one of two important high alkaline lakes, along with Lake Van, also in Turkey. The magnesite deposits located on the west side of the lake, were related to

“White Rock” which has been discovered on Mars [19].

The aim of this study is to determine the current metal situation, anthropogenic sourced metal amount, toxic effect, and rate of potential risk posed to the ecosystem of the current location. This will be done using different statistical and sediment research methods in Lake Salda, which an extremely important lake, not just in Turkey, but in the world. This study will hopefully be the starting point for continued research in the field.

## MATERIALS AND METHODS

**Study Area.** Lake Salda is located in the Burdur sub-basin, in Yesilova district (Figure 1). It is known to be one of the deepest lakes in Turkey, with a maximum depth of 184 m. The lake water is highly alkaline with pH values ranging between 8.90 to 9.05. The lake water is also rich in magnesium, and is one of two important high alkaline lakes, as mentioned, along with Lake Van. The lake is 1139 meters above sea level and covers an area of almost 45 km<sup>2</sup>. The surrounding mountains, bedded ultramafic and carbonate rocks, of Lake Salda, form a drainage basin approximately 148 km<sup>2</sup>. The lake is fed by four main streams, Zehra from the north, Karakova from the west, Köpek from the south-west, and Kuruçay stream from the southern side of the lake. Also, there are many agricultural activities on the northeast of the catchment area.

The geology of the area is mostly dominated by ultramafic rocks and alluvial deposits. Quaternary

Alluvial Unit and Cretaceous Marmaris Peridotite are dominant around the area of the lake. (Figure 2). Marmaris Peridotite occurs as serpentinised ultramafic rocks in some parts but, harzburgite sections are more widespread than any other rock type [20]. Besides, Late Triassic/Lias aged Dutdere Limestone has appeared due to tectonic impact, this is another important lithological unit of the study area. It is located in the south-eastern part of the lake. Dutdere Limestone occurred as medium-thick bedded, locally massif, consisting of recrystallized limestone algae in several areas, and was deposited in a shallow carbonate shelf environment [21].

**Sediment assessment methods.** Background content, or pre-industrial reference values, which are necessary for most of the sediment assessment methods, have been obtained from the literature. The data chosen for this study was by Turekian and Wedepol [22]. These are some of the most preferred for pre-industrial reference values [17, 23, 24].

Contamination factor ( $C_f^i$ ) is one of the most important sediment assessment methods. It is extremely simple and effective. It is also the starting point for many further evaluations including the contamination for every metal to be done separately. It was first used by [25]. The formula is as follows.

$$C_f^i = C^i / C_n^i \quad (1)$$

$C^i$  = Metal concentration in the sample

$C_n^i$  = Pre-civilization reference value

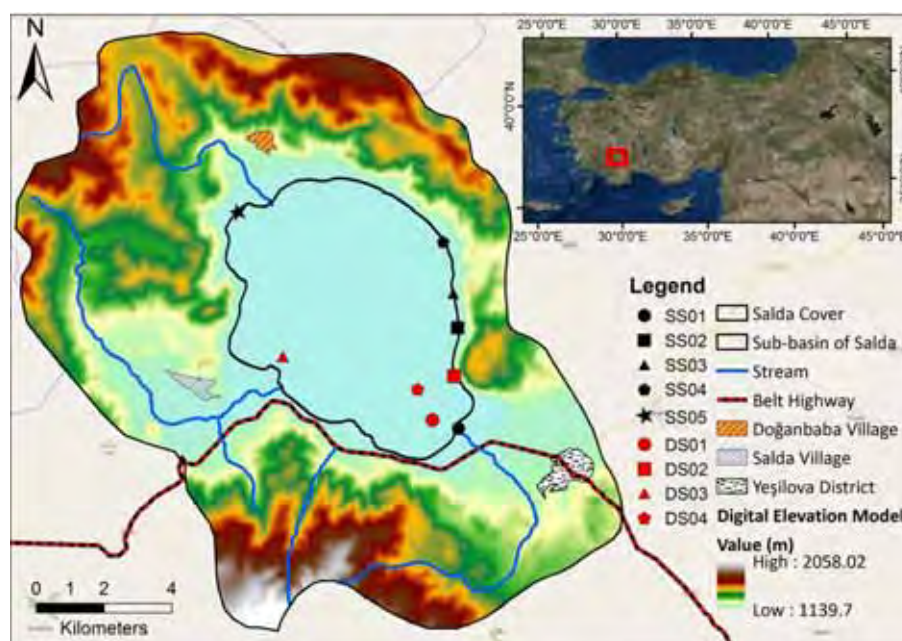
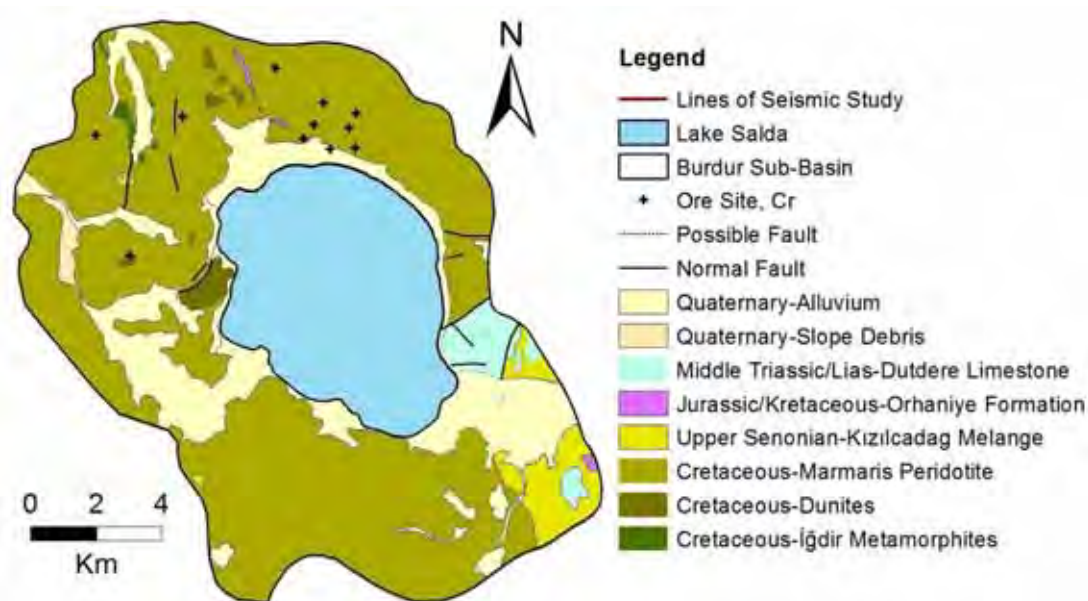


FIGURE 1  
Location Map with Sample Locations



**FIGURE 2**  
Geology Map of the Study Area

Degree of contamination ( $C_d$ ) method determines the total of the contamination factors for metals [25]. The formula is as follows.

$$C_d = \sum_{i=1}^n C_f^i \quad (2)$$

$C_f^i$  = Contamination factor

However, the degree of contamination is a difficult method to study, because it is not possible for all metals to be studied in every situation. This issue has been eliminated with the development of a formula by Abraham and Parker [26]. The difference between mCd from Cd is mCd, used to give an average value. The formula of modified degree of contamination ( $mC_d$ ) is as follows;

$$mC_d = \frac{\sum_{i=1}^n C_f^i}{n} \quad (3)$$

$C_f^i$  = Contamination factor

n = Total number of metals

The Pollution load index (PLI) method provides easy comparison of different locations in the same or different studies, and was developed by Tomlinson et al. [27]. The formula is as follows.

$$PLI = (C_{f1} \times C_{f2} \times C_{f3} \dots \times C_{fn})^{1/n} \quad (4)$$

$C_{f1}$  = Contamination Factor

n = Total number of metals

Enrichment factor (EF) is another extremely important method which helps in determining the anthropogenic sourced metal pollution [28]. The formula is as follow;

$$EF = \frac{C_n/C_{ref}}{B_n/B_{ref}} \quad (5)$$

$C_n$  = Metal concentration in sample

$C_{ref}$  = Metal concentration in reference environment (Earth's crust)

$B_n$  = Reference element (Fe) concentration in sample

$B_{ref}$  = Reference element concentration in reference environment

One element of high concentration on earth's crust is used as a reference element. The high concentrated elements are effected less from anthropogenic additive relatively for this reason, Fe was chosen as the reference element in this study. There are many studies in which Fe has been used as the reference element [29, 30].

One of the methods that is used for determining levels of anthropogenic contamination, is the Geoaccumulation index ( $I_{geo}$ ). The calculation is done as follows [31].

$$I_{geo} = \log_2 \frac{C_n}{1.5 \times B_n} \quad (6)$$

$C_n$  = Metal concentration in the sediment

$B_n$  = Background content of the metal

1.5 = Constant for natural fluctuation

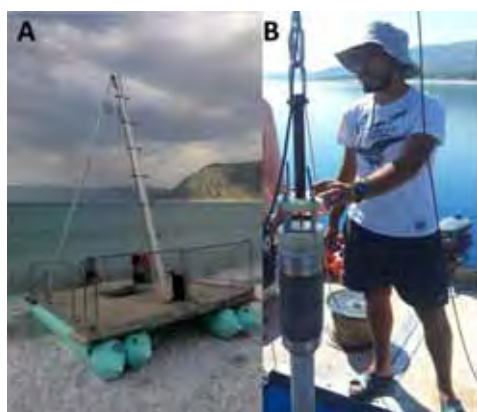
Potential Ecological Risk Factor ( $E_r^i$ ) is another method used to look at levels of contamination caused by metals and the risk for the aquatic environment. It was first introduced by Hakanson [25]. The formula is as follow;

$$E_r^i = T_r^i \times \frac{C_i}{C_o} \quad (7)$$

$T_r^i$  = Toxic response factor

$C_i$  = Metal concentration in sample

$C_o$  = Pre-civilization reference value



**FIGURE 3**  
**Floating Platform (A) and Core Sampler on Field (B)**

The sum of the toxic units ( $\Sigma TU$ s) is the sum of the values obtained by proportioning metal amounts determined using samples, and the PEL (Probable Effect Level) value belongs to those metals [32, 33]. Quotient toxic unit is the percentage type of the ratio the toxic unit value of every metal to  $\Sigma TU$  value. They are frequently used [34, 35].

**Statistical methods.** The Mann Whitney-U test has been used in order to keep sample numbers to the number to a minimum, regardless of normality

of distribution. The test has a 95% level of significance. For the same reason, the Spearman Correlation Analysis was preferred in correlation analysis. The correlation tests have a 95% and 99% level of significance respectively. The extraction method for Principle Component Analysis was carried out according to the Varimax, with Kaiser Normalization. Cluster analysis was done using the Ward's method, on Euclidean distance intervals and the Z-score correction [36]. All statistics were collated using SPSS v21.

**Sampling and Element Analysis.** Using a floating platform (Figure 3a), sediment samples were collected at shallow and deep points of the lake. This was done using the gravity method (Figure 3b), which is used for core logging on lakes. Samples were taken at the deepest points. The deepest measurement was DS02 with a depth of 96 meters, and was chosen for the possible extension of the main fault that was located on the south-western side of the lake.

The gravity corer is a general-purpose tool that relies on its weight for penetration into the seabed. In this study, a 20 kg weight was used for the core sampler. The sediment that was in the first cm of the core, was used for analysis. Surface sampling was also done on the coastal sides of the lake, which was almost 50 cm in depth, by hand from the aquatic environment (Table 1).

**TABLE 1**  
**Basic Information for Sample Locations**

Locations	X	Y	Depth (m)
SS01	740164	4155772	<0.5
SS02	740144	4158764	<0.5
SS03	740009	4159788	<0.5
SS04	739714	4161318	<0.5
SS05	733647	4162215	<0.5
DS01	739392	4156021	36
DS02	740038	4157335	96
DS03	734975	4157915	22
DS04	738961	4156947	48

**TABLE 2**  
**Reference Material for Sediment Samples**

Name	mg/kg	Calculate ppb	Measure ppb	mg/kg	Recovery
Cu	30	240	214.63	26.8	89.4
Pb	37.7	301.6	300.8	37.6	99.7
As	27.6	220.8	300.2	37.5	136.0
Ni	44.9	359.2	400.8	50.1	111.6
Cr	104	832	772.2	96.5	92.8
Cd	0.26	2.08	2.668	0.3	128.3
Mn	34600	276800	177100	22137.5	64.0
Fe	67400	539200	512400	64050.0	95.0
V	170	1360	1037	129.6	76.3
Co	19.8	158.4	201.4	25.2	127.1
Zn	223	1784	2800	350.0	157.0

**TABLE 3**  
**Heavy Metal Concentrations of Sediment Samples and Limit Values**

Locations	Cu (ppm)	Pb (ppm)	Zn (ppm)	Ni (ppm)	Mn (ppm)	Fe (ppm)	As (ppm)	Cd (ppm)	Cr (ppm)
SS01	<b>8.73</b>	6.57	19.78	<b>1691.54</b>	<b>550.25</b>	<b>44682.84</b>	1.02	0.09	<b>160.07</b>
SS02	1.42	6.07	3.12	221.32	73.32	5692.02	1.48	0.05	36.16
SS03	1.64	2.17	5.72	454.22	173.58	12690.75	0.70	0.05	77.72
SS04	<b>0.88</b>	<b>1.72</b>	<b>2.37</b>	<b>47.00</b>	<b>9.00</b>	<b>2579.96</b>	1.24	<b>0.03</b>	<b>10.48</b>
SS05	3.21	5.36	18.11	548.33	304.70	19761.49	<b>0.65</b>	0.05	107.02
DS01	3.95	13.14	20.50	477.25	321.50	17568.75	1.61	0.10	84.53
DS02	2.81	<b>383.11</b>	11.48	234.91	202.59	11445.86	0.87	0.07	55.76
DS03	3.03	19.29	16.06	361.68	205.18	12618.28	<b>2.30</b>	0.12	58.95
DS04	5.81	196.92	<b>31.06</b>	442.61	413.67	19167.91	1.38	<b>0.18</b>	85.18
<b>Max.</b>	8.73	383.11	31.06	1691.54	550.25	44682.84	2.30	0.18	160.07
<b>Min.</b>	0.88	1.72	2.37	47.00	9.00	2579.96	0.65	0.03	10.48
<b>Median</b>	3.03	6.57	16.06	442.61	205.18	12690.75	1.24	0.07	77.72
<b>PEL</b>	197	91.3	315	36			17	3.53	90
<b>ERM</b>	390	110	270	50			85	9	145
<b>TEL</b>	35.7	35	123	18			5.90	0.6	37.3
<b>ERL</b>	70	35	120	30			33	5	80
<b>Reference</b>	45	20	95	68	850	47200	13	0.3	90
<b>Tox.</b>	5	5	1	5	1		10	30	2

SS: Shallow Sediment

DS: Deep Sediment

Bolt Character: Refers Maximum Value

Italic Character: Refer Minimum Value

PEL: Probable effect level [37]

ERM: Effect range median [38]

TEL: Threshold effect level [37]

ERL: Effect range low [38]

Reference: Distribution of the elements in the earth's crust (shales) [22]

Tox: Toxic response factor [25, 39].

The samples were analysed at the Research and Application Centre for Environmental and Earth Sciences, Istanbul University. The 3051a microwave extraction method (microwave assisted acid digestion of sediments, sludge, soils, and oils) was used for microwave heating. Porcelain crucibles were weighed, both empty and with sediment samples, on precision scales with a sensitivity of 4 digits. Then, the sediments in the porcelain crucibles were heated with digit heat model drying and a sterilization oven for 1.5 hours. After heating, they were weighed again, and the dry unit weight was calculated. Dry sediments were grinded using an agate mortar, 0.2 g was weighed for each sample. The samples were put into microwave tubes and mixed with 1.5 ml (1 unit) nitric acid (HNO<sub>3</sub>) and 4.5 ml (3 unit) hydrochloric acid (HCl). They were put into the Marsxpress model microwave. The samples were dissolved with acid in 3 different sets in the microwave system. The sets were 300, 600, and 1200 watts, and 120, 150, and 180 C with 100% performance and 15 minutes for each, respectively. After 45 minutes, the samples were taken out and put into the refrigerator to reduce temperature. The tubes were opened carefully in the fume cupboard in order to let the gas resulting from the reaction out. Lastly, the samples were integrated with water, up to 25 ml in sterilized tubes, to prepare

for samples analysis. Two devices were chosen to complete analysis based on the reference material (Table 2). The Perkin Elmer Atomic Absorption Spectroscopy (Perkin Elmer F-AAS 400) was used for the level 1ppm (mg/l) and the elements Iron (Fe), Manganese (Mn) and Zink (Zn). The Perkin Elmer Graphite Atomic Absorption Spectroscopy (Perkin Elmer GF-AAS 600) was used for the level 1ppb (µg/l) and the elements Copper (Cu), Lead (Pb), Nickel (Ni), Cadmium (Cd), Chromium (Cr), Arsenic (As) and Vanadium (V). Repeatability standard deviation value has been presented below as 5%. The decomposition process of sediments has been done using the same procedure, as standard sediment. Background corrections, which were sourced by decomposition acid, have also been done.

## RESULTS AND DISCUSSIONS

**Amounts for each element.** All the results obtained for the studied elements have been given in Table 3 as totals for Lake Salda. Table 3 also provides various limit values for the studied metal and metalloid. Although Pb and Cr values have high concentrations at some stations, Ni amounts have been

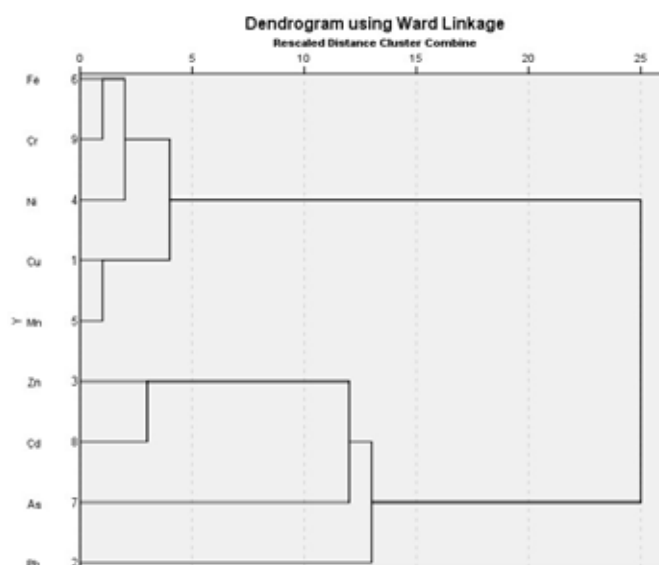
determined as over the limit values for all of the stations. Ni is the most common element, while evaluating the elements according to the limit values, Fe is the most common and Cd is the least common element by amount. The other elements are under the limit values except Pb, Cr and Ni.

PEL: "Represents the concentration above which adverse effects are expected to occur frequently", TEL: "Represents the concentration below which adverse effects are expected to occur only rarely" [37], ERM: "Represents the chemical concentration above which adverse effects would frequently occur", ERL: "Represents the chemical concentration below where adverse effects would be rarely observed" [38] are meaningful for the limit values [40]. When Cr value was analysed on the basis of station, the highest value was observed in SS01 station. 160.07 mg/kg value is above all limit values for this station (Table 3). However, the lowest amount determined for Cr, which is 36.16 mg / kg (SS02), remained below all of the values in Table 3.

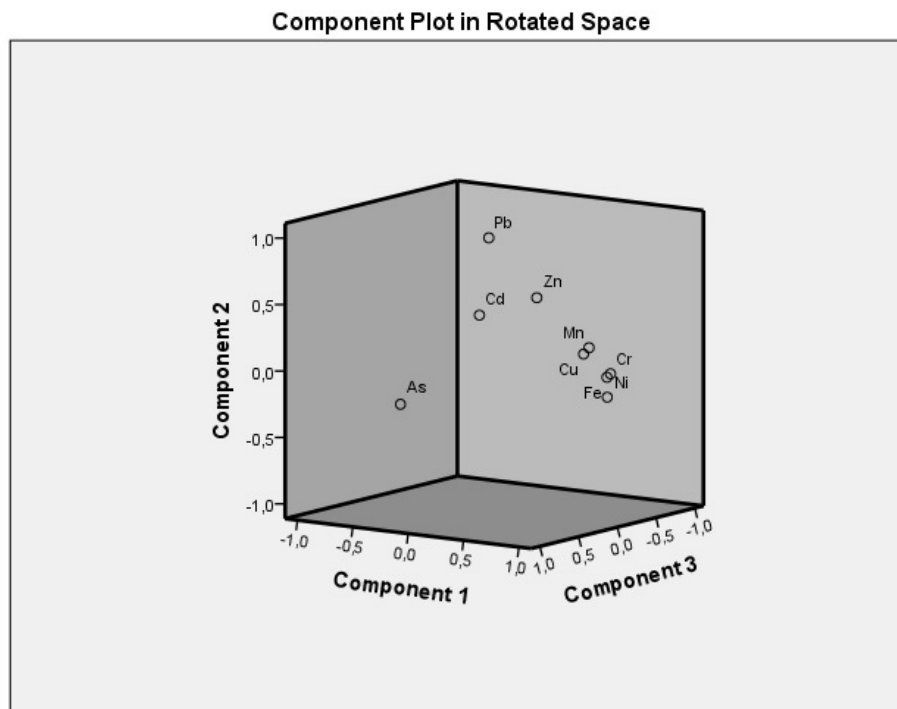
The highest values of Pb were observed in DS02 and DS04 stations which are located in the inner part of the lake. Also, the amount of Pb found in the other interior stations of the lake, was more than in the shore sections. Mann Whitney-U analysis also supports this data, in which a comparison was made between inner and coastal areas. According to the results, the Pb amount in the inner part of the lake is more than in the coastal part ( $p < 0.05$ ). So, this supports the hypothesis about Pb entering the lake via anthropogenic sources and also being deposited into the lake. The other result that supports this case is Cluster Analysis. According to the distance matrix of the analysis (Proximity Matrix), Pb is the farthest element in all studied elements, which also means having a lesser relationship with the other elements

(Table 4). This situation can be clearly seen in the analysis of the dendrogram (Figure 4). It can also be seen in the Principle Component Analysis (Figure 5). Pb can be observed as the farthest element from the others, together with the Component and Rotated Component Matrix results (Table 5). Including correlation analysis results Pb (Table 6), Cd can be seen as the most related element to Pb for all analysis. Also, as is related with Pb in factor analysis results, the amount of As is far below the limit. However, Pb-Cd relation is also an important result. Because, like Pb, Cd is also one of the elements accumulated as a result of anthropogenic activities, Cd amount is more in the inner parts, like Pb, than the coastal parts of the lake ( $p < 0.05$ ). In addition to these results, there was not observed to be any element which has a significant difference between inner parts and coastal parts of the lake among the studied elements, except for Cd and Pb ( $p > 0.05$ ).

Nickel forms several minerals and is strongly enriched in ultramafic and mafic lithologies. Cr is also enriched in ultramafic rocks up to as much as 1000–3000 mg/kg, along with elements such as Ni. A large proportion of the Ni in stream sediment is held in detrital silicate and oxide minerals that are resistant to weathering. The range of Ni values in soil vary from 0.2 to 450 mg/kg according to rock type [41]. On the other hand, anthropogenic sources of nickel could come from fertilisers, steel works, metal plating and coinage, fuel combustion and detergents [42]. In the presence of some organic complexing agents, Ni is capable of forming neutral or negatively charged complexes, making the metal highly mobile in relation to other trace elements. Consequently, Ni concentrations may be high in stream water contaminated by sewage and leachate from waste tips [43].



**FIGURE 4**  
**Dendrogram of Cluster Analysis**



**FIGURE 5**  
**Component Plot of Factor Analysis**

**TABLE 4**  
**Cluster Analysis**

	Cu	Pb	Zn	Ni	Mn	Fe	As	Cd	Cr
Cu	.000	4.178	2.119	1.503	1.064	1.139	4.365	2.675	1.580
Pb	4.178	.000	3.877	4.804	4.207	4.580	4.728	3.620	4.590
Zn	2.119	3.877	.000	3.227	1.603	2.599	4.011	1.652	2.498
Ni	1.503	4.804	3.227	.000	1.844	.853	4.755	3.785	1.293
Mn	1.064	4.207	1.603	1.844	.000	1.111	4.562	2.644	1.126
Fe	1.139	4.580	2.599	.853	1.111	.000	4.761	3.421	.848
As	4.365	4.728	4.011	4.755	4.562	4.761	.000	3.142	4.910
Cd	2.675	3.620	1.652	3.785	2.644	3.421	3.142	.000	3.436
Cr	1.580	4.590	2.498	1.293	1.126	.848	4.910	3.436	.000

**TABLE 5**  
**Component and Rotated Component Matrix Results**

	Component (Component Matrix <sup>a</sup> )			Component (Rotated Component Matrix <sup>b</sup> )		
	1	2	3	1	2	3
Cu	.976			.939	.202	.190
Pb		.544		-.135	.923	-.121
Zn	.724	.475		.585	.604	.288
Ni	.891	-.378		.959	-.161	
Mn	.985			.947	.242	.130
Fe	.961	-.244		.992		
As	-.124	.598	.752	-.195	-.184	.932
Cd	.556	.786	.150	.380	.517	.734
Cr	.937	-.284		.973		-.109

a: 3 components extracted.

b: Rotation converged in 5 iterations.

**TABLE 6**  
**Correlation Analysis**

	Cu	Pb	Zn	Ni	Mn	Fe	As	Cd	Cr
Cu	1.000								
Pb	.606*	1.000							
Zn	.970**	.655*	1.000						
Ni	.834**	.255	.764**	1.000					
Mn	.989**	.600	.945**	.827**	1.000				
Fe	.897**	.355	.827**	.936**	.927**	1.000			
As	.178	.336	.245	-.173	.118	-.145	1.000		
Cd	.811**	.855**	.851**	.469	.782**	.552	.533	1.000	
Cr	.916**	.364	.864**	.945**	.909**	.945**	-.109	.593	1.000

\*. Correlation is significant at the 0.05 level (2-tailed).

\*\* . Correlation is significant at the 0.01 level (2-tailed).

**Relationships between the elements.** Cu and Mn elements show the highest correlation (Cu-Mn:  $r=0.989$ ) on the correlation analysis and component matrix (Tables 5 and 6). There are other studies where strong correlations between these elements have been noted, but there are situations where the correlation cannot be observed due to changes tin location [44]. The correlation between Cu and Zn follows this correlation (Cu-Zn:  $r=0.970$ ). The same case is also valid for the correlation between Cu and Zn. While strong correlations are apparent between these two elements [45], there are some cases where the correlation couldn't be observed [28]. Both Cu and Zn can correlate with all studied elements, except As. These elements also have the strongest correlations, Mn with other elements, according to the strongest relationship distance matrix. The elements having the closest distances are Fe-Ni (0.853 euclidean distance) and Fe-Cr (0.848 euclidean distance) (Table 4, Figures 4 and 5) and also, they have parallel results on the cluster analysis. The Elements As and Pb have the weakest relationships with other elements for two analysis. As did not correlate with any element in the correlation analysis. There is not another element which correlated with any other element except As. Pb has its strongest correlation with Cd which is not essential for maintaining life (Pb-Cd:  $r=0.855$ ). The other elements correlated with Pb are Zn and Cu. However, the correlation between these two elements is relatively weak (Pb-Zn:  $r=0.655$ , Pb-Cu:  $r=0.606$ ). Fe-Ni and Fe-Cr relationships are extremely strong as shown by the cluster analysis (Fe-Ni:  $r=0.936$ , Fe-Cr:  $r=0.945$ ). There are some cases where such correlations have been observed, or different impacts on sediment from these elements [46, 47, 48].

**Evaluation of the sediment.** On the basis of the sediment assessment methods, the central point is to determine the amount of metal as injected to the porous medium by anthropogenic effects. This basis can be by comparing the metal amount of the existing sediment with the average of the pre-industrial era, or earth's crust that belong to that era. In the next step, the risk posed by ecologic and toxic effects are

tried to be determined by the elements injected to the porous medium artificially. Many ways are used in the evaluation of sediment. Some methods reveal the current status for each element, and some are aimed at understanding the total effect of all studied elements.

**Contamination Factor ( $C_f^i$ ), Degree of contamination ( $C_d$ ) and Modified degree of contamination ( $mC_d$ ) and Pollution Load Index (PLI).**

Both  $C_f^i$ , and  $C_d$ , as well as  $mC_d$  are frequently used methods used for showing the status of existing ecosystems [13, 28, 49]. These methods, which are simple and very effective, can provide us with detailed information about the status of available sediment.

$C_f^i$  values are, in general, under 1 for the study carried out (Table 7). This result means relatively low contamination, according to the 4-way scale created by Hakanson [28]. However, especially Ni, reveals the profile as being highly contaminated for many sites, unlike the general situation. The lowest  $C_f^i$  value was obtained for Ni, at station SS04. Ni is on the lowest level of the scale at this station. Pb has reached the highest level on the scale, as Ni, at the DS02 and DS04 stations. This is not a risky case, except for these 2 stations. Cr shows moderate contamination according to the scale at stations SS01 and SS06. Other stations are clean in terms of Cr.

$C_d$  is actually the total of  $C_f^i$  values of all the studied elements. This doesn't reveal the current situation one by one, unlike the contamination factor. Instead, it reveals the total current status of all the elements for only one value. The values obtained by Hakanson are evaluated on the 4-way scale [28]. Accordingly, if Lake Salda is evaluated on the basis of station, the highest values are obtained for SS01 and DS02. Considerable contamination was recorded at these stations, which is the third step of the 4-way scale. SS04 is the station where the lowest Cd value has been recorded and low contamination found, measuring only at the bottom step of the scale (Table 8).



**TABLE 7**  
Contamination Factors of the Sediment Samples

	Contamination Factor								
	Cu	Pb	Zn	Ni	Mn	Fe	As	Cd	Cr
SS01	0.19	0.33	0.21	24.88	0.65	0.95	0.08	0.30	1.78
SS02	0.03	0.30	0.03	3.25	0.09	0.12	0.11	0.16	0.40
SS03	0.04	0.11	0.06	6.68	0.20	0.27	0.05	0.17	0.86
SS04	0.02	0.09	0.02	0.69	0.01	0.05	0.10	0.09	0.12
SS05	0.07	0.27	0.19	8.06	0.36	0.42	0.05	0.16	1.19
DS01	0.09	0.66	0.22	7.02	0.38	0.37	0.12	0.34	0.94
DS02	0.06	19.16	0.12	3.45	0.24	0.24	0.07	0.24	0.62
DS03	0.07	0.96	0.17	5.32	0.24	0.27	0.18	0.41	0.66
DS04	0.13	9.85	0.33	6.51	0.49	0.41	0.11	0.61	0.95
$C_f^i < 1$ respectively to low	$1 \leq C_f^i < 3$ moderate		$3 \leq C_f^i < 6$ considerable			$C_f^i \geq 6$ very high			

**TABLE 8**  
Sediment Methods, Reveal the Current Status through Total Metal Amount

SS01	SS02	SS03	SS04	SS05	DS01	DS02	DS03	DS04
<b>Degree of contamination (<math>C_d</math>)</b>								
23.36	4.5	8.44	1.19	10.77	10.13	24.2	8.27	19.37
$C_d \leq 8$ low	$8 \leq C_d \leq 16$ moderate		$16 \leq C_d \leq 32$ considerable			$C_d \geq 32$ very high		
<b>Modified degree of contamination (<math>mC_d</math>)</b>								
3.26	0.50	0.94	0.13	1.20	1.12	2.69	0.92	2.15
$mC_d < 1.5$ nil to very low	$1.5 \leq mC_d < 2$ low	$2 \leq mC_d < 4$ moderate	$4 \leq mC_d < 8$ high	$8 \leq mC_d < 16$ very high	$16 \leq mC_d < 32$ extremely high	$mC_d \geq 32$ ultra-high		
<b>Pollution Load Index (PLI)</b>								
0.59	0.16	0.21	0.06	0.33	0.43	0.40	0.38	0.68
0 perfection	1 baseline		>1 deterioration					

$mC_d$  gives only one value for total current status of all elements as  $C_d$ . However, it relates the current situation to the number of elements, unlike  $C_d$ . This method was developed by Abraham and Parker, designed as a 7-way scale [26]. Accordingly, 9 stations were studied at Lake Salda switches between two scales, the bottom, nil, to very low contamination and the 3rd step is moderate contamination (Table 8).

PLI is a method starting from  $C_f^i$  that reveals the current situation based on all the general elements, and evaluates with a 3-way scale, it was developed by Tomlinson et al. [27]. However, there are more detailed scales available [50]. Both scales, according to the recent literature, have been used in former studies [28, 46]. The results for all stations were determined on the first and second level, which are ideal level and baseline on the study carried out. Level 3 deterioration was not observed at any of the stations (Table 8). SS04 was identified as the cleanest station according to the PLI. Stations SS01 and DS04 were found to have relatively higher levels of contamination compared with other stations.

**Enrichment Factor (EF) and Geoaccumulation Index ( $I_{geo}$ ).** Both EF and  $I_{geo}$  are methods used to identify the level of contamination in the environment separately from the base metal. EF is a method which reveals the geochemical profile of different areas and allows comparison of the profiles in these areas [51]. For this reason, it has been used in many studies that demonstrate the accumulation of sediment profiles [44, 52]. However, when assessing the EF profile it has been seen that scales comprising a different number of digits have been used for various studies according to the literature [51, 52, 53]. The highest value obtained for Pb was in DS02 station during this study (Table 9). Pb almost doubled the highest value, which took it almost to the level of extremely high on the scale. Pb has also been determined as being at a very high level for station DS04. No problem can be seen for Pb, except for at these two stations. Pb levels on the other stations are observed at the bottom of the scale. Another important element is Ni for the EF profile. Ni has been not shown up to be high at all stations, different from Pb. Ni is at level 3 or 4 for all stations according to the

5-way scale. Cr is one other element which attracts attention. Cr has been determined as moderate at all stations (determined very close to the border of moderate but minimal only in station SS01). Other elements have been determined as minimal for all stations except these elements. EF also shows a table similar to the  $I_{geo}$  (Table 10). The stations DS02 and DS04, are located on the 5. and 4. places on the 7-way scale for Pb, respectively, and these values are the highest for Pb. The lowest level on the scales has been determined for Pb at other stations. Unlike the EF,  $I_{geo}$  has determined the situation of Ni at SS01 as being at level 6, which was determined as the highest for all the studied metals. 1, 2 and 4. levels have been identified for the other stations in the scale. Any condition that would cause problems for other metals, wasn't detected by  $I_{geo}$ . Although Ef and  $I_{geo}$  give parallel results in this study, the situation of EF is more concerning according to  $I_{geo}$ .

#### Potential Ecological Risk Factor ( $E^i_r$ ), Sum of the toxic units ( $\Sigma TU$ s) and Quotient Toxic

**Unit.** In this study, Potential Ecological Risk Factor ( $E^i_r$ ) was used to determine the effect on living beings and the ecosystem separately for all metals, not anthropogenic sourced metal accumulation, which was different to the other methods. It is one of the methods used for sediment studies [45, 54]. Hakanson [25] determined a 5-step scale for evaluating the results. The method used for assessing the total toxic effect formed by high risk metals, is the potential ecological risk index. This index shows the total for the metals; Hg, Cd, As, Pb, Cu, Cr, Zn. However, the assessment of potential ecological risk index was not done because Hg content was not to be included in this study. According to the results, Ni and Pb are the what need to be focused on (Table 11). Ni was found to be at step 3., a considerable amount, at station SS01 and step 2., a moderate level, at station SS05. On the other hand, Pb was determined as considerable at station DS02, and as moderate at station DS04. There wasn't observed to be an urgent situation in terms of other metals, and all metals were determined as low for all situations.

**TABLE 9**  
Enrichment Factor Values of Studied Heavy Metals

Enrichment factor (EF)									
	Cu	Pb	Zn	Ni	Mn	Fe	As	Cd	Cr
SS01	0.20	0.35	0.22	26.28	0.68	Reference element	0.08	0.32	1.88
SS02	0.26	2.52	0.27	26.99	0.72		0.95	1.29	3.33
SS03	0.14	0.40	0.22	24.84	0.76		0.20	0.62	3.21
SS04	0.36	1.57	0.46	12.65	0.19		1.75	1.64	2.13
SS05	0.17	0.64	0.46	19.26	0.86		0.12	0.37	2.84
DS01	0.24	1.76	0.58	18.86	1.02		0.33	0.92	2.52
DS02	0.26	78.99	0.50	14.25	0.98		0.28	0.98	2.56
DS03	0.25	3.61	0.63	19.90	0.90		0.66	1.52	2.45
DS04	0.32	24.25	0.81	16.03	1.20		0.26	1.50	2.33
EF<2	2≤EF<5		5≤EF<20		20≤EF<40		EF≥40		
minimal	moderate		significant		very high		extremely high		

**TABLE 10**  
Geoaccumulation Values ( $I_{geo}$ ) of Studied Heavy Metals

Geoaccumulation Index ( $I_{geo}$ )									
	Cu	Pb	Zn	Ni	Mn	Fe	As	Cd	Cr
SS01	-2.95	-2.19	-2.85	4.05	-1.21	-0.66	-4.25	-2.32	0.25
SS02	-5.57	-2.30	-5.51	1.12	-4.12	-3.64	-3.72	-3.27	-1.90
SS03	-5.37	-3.79	-4.64	2.15	-2.88	-2.48	-4.81	-3.16	-0.80
SS04	-6.25	-4.13	-5.91	-1.12	-7.15	-4.78	-3.97	-4.07	-3.69
SS05	-4.39	-2.49	-2.98	2.43	-2.07	-1.84	-4.90	-3.26	-0.34
DS01	-4.10	-1.19	-2.80	2.23	-1.99	-2.01	-3.60	-2.13	-0.68
DS02	-4.59	3.67	-3.63	1.20	-2.65	-2.63	-4.49	-2.66	-1.28
DS03	-4.48	-0.64	-3.15	1.83	-2.64	-2.49	-3.08	-1.88	-1.20
DS04	-3.54	2.71	-2.20	2.12	-1.62	-1.89	-3.82	-1.30	-0.66
$I_{geo} \leq 0$	$0 < I_{geo} < 1$		$1 < I_{geo} < 2$	$2 < I_{geo} < 3$	$3 < I_{geo} < 4$	$4 < I_{geo} < 5$	$I_{geo} \geq 5$		
practically uncontaminated	uncontaminated to moderately		moderately	moderately to strongly	strongly	strong to extremely	extremely		

**TABLE 11**  
Table of Potential Ecological Risk Factor ( $E_r^i$ ) Values

Samples	Potential Ecological Risk Factor ( $E_{rf}^i$ )								
	Cu	Pb	Zn	Ni	Mn	Fe	As	Cd	Cr
SS01	0.36	1.85	0.19	33.73	0.39	0.77	7.43	1.86	
SS02	0.18	0.54	0.06	33.40	0.20	0.54	5.03	1.73	
SS03	0.10	0.43	0.02	3.46	0.01	0.96	2.69	0.23	
SS04	0.36	1.34	0.19	40.32	0.36	0.50	4.70	2.38	
SS05	0.10	0.51	0.00	5.62	0.02	0.71	2.41	0.51	
DS01	0.31	95.78	0.12	17.27	0.24	0.67	7.14	1.24	
DS02	0.34	4.82	0.17	26.59	0.24	1.77	12.20	1.31	
DS03	0.65	49.23	0.33	32.55	0.49	1.06	18.31	1.89	
DS04	0.97	1.64	0.21	124.38	0.65	0.79	9.04	3.56	
$E_r^i < 40$	$40 \leq E_r^i < 80$		$80 \leq E_r^i < 160$		$160 \leq E_r^i < 320$		$320 \geq E_r^i$		
Low	moderate		considerable		high		very high		

**TABLE 12**  
Proportional Toxic Unit Values of the Elements

	Quotient Toxic Unit									
	Cu	Pb	Zn	Ni	Mn	Fe	As	Cd	Cr	$\Sigma TU$
SS01	0.09%	0.15%	0.13%	95.83%			0.12%	0.05%	3.63%	49.03
SS02	0.11%	0.99%	0.15%	91.30%			1.30%	0.20%	5.97%	6.73
SS03	0.06%	0.17%	0.13%	92.87%			0.30%	0.10%	6.36%	13.59
SS04	0.29%	1.23%	0.49%	85.13%			4.77%	0.50%	7.59%	1.53
SS05	0.10%	0.35%	0.35%	91.73%			0.23%	0.08%	7.16%	16.60
DS01	0.14%	0.99%	0.45%	91.12%			0.65%	0.20%	6.46%	14.55
DS02	0.12%	36.61%	0.32%	56.92%			0.45%	0.18%	5.41%	11.46
DS03	0.14%	1.89%	0.46%	90.11%			1.21%	0.31%	5.88%	11.15
DS04	0.19%	13.77%	0.63%	78.51%			0.52%	0.33%	6.04%	15.66

$\Sigma$  TUs, has been used for evaluating the general reliability of the stations, and toxic effects originating from metals have been shown using this method (Table 12). According to the results, the highest value for total level of toxic effects was found at station SS01. SS05, DS04, DS01 stations follow, respectively. In the study benefited from the Quotient Toksik Unit, determining the ratios of total toxic effects of metals one by one. The results show the highest rate was shown to be Ni. The impact of Ni on toxic effect changes between from 95.8% and 56.92% (Table 12). Cr is another important element in relation to the toxic effect. The ratio of Cr ranges from 10.34% and 3.63%. Pb reaches higher ratios of between 36.61% and 13.77% at stations DS02 and DS04, respectively.

## CONCLUSIONS

The study carried out aimed to determine the anthropogenic sourced metal accumulation in the environment and to understand the toxic effect of the amounts of metal on the aquatic ecosystem by investigating metal quantities in the sediment of Lake Salda. Also, it reveals the relationship between metal

deposition and environmental pollution. The metal accumulation was mostly found to be Pb and Ni elements at stations DS02, DS04 and SS01. DS02 and DS04 seemed to be an extension of a fault, and SS01 is along the main stream that recharges the lake. Ni amounts could come from the ultramafic rocks. However, the high amounts of Pb are likely to be due to the anthropogenic effects, although the lake is an area of natural protection. There is strong evidence to suggest Pb has accumulated in the lake through movement. Ni has been determined as having the highest risk for the lake. Along with the variation of Ni amounts, it measures on the higher parts of the scales used for all the studied stations: the metals were studied using sediment assessment methods. Lake Salda is an area of natural protection, and has been for a long time. However, Ni is a common metal for industrial use. Ni comes probably from the dissolved antigorite minerals which are observed in the study area and its near environ. Pb results are also extremely important, these were taken in the deeper parts of the lake with Ni at two stations. Cr is also an element that should be evaluated based on the risk range for the lake, and Cr is enriched by ultramafic rocks, along with elements such as Ni, but there is an ore site for Cr on the northern side of the lake, Cr is

again another element that occurs in significant quantities in rocks. That is out of question for any risky situation for the other elements. The lake was evaluated as both element and station base. So, the results of 2 stations (SS01 and DS04) were concluded to be more critical than the others. SS01 is one of the main streams that recharges the lake, and is on the Yeşilova site. DS04 is the deepest sediment that was collected (96 m depth) and is on the extension of the main fault.

To conclude, Lake Salda, nowadays, is regularly discussed throughout Turkey, because there are plans to build a dam on the Düden brook, which merges with Karakova stream in the western part and is one of the main recharging surface waters for the lake. So, there are several campaigns being introduced so people can understand the importance of the lake. Although Lake Salda is one of the most important lakes in Turkey, and even the world, there are few studies about it. As the study is new it will be of importance for current works. Finally, it seems that the lake, which is of great importance, could be at risk of anthropogenic pollution from Pb and Ni elements, as shown in all of the results. The reasons could be natural for other elements including Ni, though Ni can be anthropogenic as revealed in the results. However, industrial and agricultural activities in surrounding villages, also the belt highway, which is located on the southern part of the lake, could be reasons for the pollution, especially Pb.

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