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Investigation of heavy metal accumulation in Sapanca Lake sediment by using pollution indices

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ABSTRACT

70 samples of surface sediments (from 0 to 5 cm depth) were seasonally taken between 2015 and 2017 from Sapanca Lake, the major drinking water source of Sakarya Province, Turkey. The scope of the study was to examine and assess the ecological risk of toxic metals such as Al, As, Ba, Cd, Co, Cr, Cu, Fe, Ni, Pb, Zn which are observed in the sediments collected from 10 different sample points of Sapanca Lake. Accumulation levels of toxic metals concentrations in the sediment samples were dissolved by using the microwave method and then measured with inductively coupled plasma atomic emission spectroscopy. The levels of toxic metal concentrations were identified as Fe > Al > Zn > Ba > Ni > Cr > As > Pb > Cu > Co > Cd, from highest to lowest, respectively. The quality of sediment is determined as "uncontaminated" according to The Sediment Quality Guidelines. Furthermore, sediment pollution is found not to be at toxic level. In addition, the sediments were evaluated by using following pollution indices: contamination factor, enrichment factor (EF) and geo-accumulation index. According to EF pollution index, higher rates for As and Cd indicate the presence of anthropogenic activities such as the consumption of fuel-oil in the industry and traffic.

Keywords: Heavy metals; Sediment quality; Enrichment factor; Geo-accumulation; Eco-toxicological risk; Sapanca Lake

1. Introduction

Lakes are the most sensitive water sources to pollution among the surface waters. Furthermore, lakes play important roles in the occurrence of many events in the ecosystem such as regulating climate, cycling water and serving as biotope for organisms [1–4]. Due to the persistence of environmental conditions, heavy metals and pesticides progressively accumulate in the sediment of lakes. The sediments of water environments, such as lakes and rivers, are the receivers of the pollutants [5]. Sediments have crucial importance for the lake ecosystems. Furthermore, sediments explicitly determine the quality of water. Persistent inorganic and organic pollutants may accumulate in the sediment for many years. This may lead the pollutants to create toxic effects for both aquatic organisms and human health. Some of the heavy metals such as Co, Cu and Zn perform vital roles for ontogeny. Furthermore, the presence of high concentrations of the other metals such as As, Ba, Cd, Cr, Cu and Pb are extremely toxic for both human and aquatic life [6]. A specific amount of Cr is essential for vital activities; on the other hand, high concentrations of this element may cause liver and kidney disorders. It may also lead to carcinogenicity [7–9]. Other heavy metals may cause Alzheimer's disease, congenital anomalies, kidney damage, chronic toxicity, cancer, brain damage and chronic illnesses [10].

Low concentration of heavy metals in the sediments do not create hazard for aquatic ecosystems [4]. However, heavy metals enter into the lakes via various means such as atmospheric deposition, soil erosion, human activity

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and geological weathering [11]. Human activities (industry, traffic, fertilizer and unplanned urbanization) particularly cause heavy metal pollution in the aquatic ecosystems and they increase the heavy metal content in the sediment [12]. The pollution arising from the human activities may create hazard for flora, fauna and microorganism and may negatively affect the water quality. Heavy metals are easily deposited on the surface of sediments and they are immobilized by the chemical events [13]. Heavy metals in the sediments are transferred to the water interface depending on the environmental conditions (pH, dissolved oxygen, oxidation-reduction potential (ORP), temperature) [14]. However, some natural factors (organic matter, grain sizes and sediment facies) can affect this transfer between the sediment and water interface [4]. Heavy metals pose a high risk for the environment due to their accumulative, persistent and toxic effects [15]. Thus, various studies have determined the heavy metals concentration both in the water and sediment environment [6,16–21].

Depending on the heavy metal content, toxicity and bioavailability, many different pollutant indices can be used to assess the environmental risks, especially in the surface of sediments [22]. Several pollution indices such as contamination factor (CF), sediment quality guidelines, ecological risk factor, enrichment factor (EF) and geo-accumulation index (I_{geo}) can be employed to assess the environmental risk of heavy metals in the sediments. For the estimation of the effects of anthropogenic activities on the sediment quality, pollution indices such as EF and I_{geo} have been widely used [23–25]. The CF gives information about the level of heavy metals in the sediments [18]. The sediment quality guidelines are employed to determine the high impact levels of aquatic organisms and the state of the chemicals in the sediments [26].

Sapanca Basin is located in 40° 41″N to 40° 44″N and 30° 09″E to 30° 20″E in Sakarya Province, Marmara Region, Turkey. It forms a part of deep lake ecosystem which is located between İzmit Bay and Adapazarı Plain. Surface area of the lake is 45 km^2, the mean depth of the lake is 28.5 m and the maximum depth is 60 m. [27]. Sapanca Lake is an important drinking water source for the Marmara region. The Lake is surrounded with the D-100 motorway to the north, E-80 (TEM Anatolian Highway) to the south and a railway line. Although there are several establishments in Sapanca Basin, the highway located near the lake is the most important pollutant source. Due to its importance as a major drinking water source in the region, many studies have been conducted in order to determine the pollution level in the lake. As a result of these studies, heavy metal pollution has been determined in the Sapanca Lake and in its sediment. When the facilities in the lake basin are examined in terms of the wastewater discharged, it has been found that some of these facilities discharge the wastewater in the treatment plant and into the sewage. Some of the domestic wastewater is deposited in the septic tank, and some of the qualified wastewater is collected in the septic tank at regular intervals. The results of these studies determined that industrial establishments in this region do not discharge the wastewater to the lake [28]. Underground waters are also known to feed the activity of the lake.

The aims of this study are (1) to determine the heavy metals concentration (Al, As, Ba, Cd, Co, Cr, Cu, Fe, Ni, Pb, Zn) in the Sapanca Lake sediment between 2015 and 2017 as well as to determine its characteristics; (2) to assess the pollution levels and (3) to determine the environmental ecological risks of heavy metals by employing various pollution indices.

2. Materials and methods

2.1. Sampling

70 surface sediments samples (from 0 to 5 cm depth) were seasonally collected from Sapanca Lake by means of Van Veen grab samplers, between 2015 autumn and 2017 spring (Fig. 1). GPS was employed to locate all sampling sites. Sediment samples were taken from Sapanca Lake in accordance with TS EN ISO Standard "Water Quality – Sampling – Sampling Guide from Bottom Sediment" numbered 5667 and dated December 12, 1995 [29]. After sampling, the sediment samples were sealed in clean PE bags and they were preserved in the laboratory for further analysis. In the laboratory, the samples were dried at 105°C, and passed through a 100 mesh sieve for the removal of stones and plants, and then processed by means of another 200 mesh nylon sieve [30]. Sieved samples were then transferred to airtight PE bags [31].

2.2. Metal analysis

Sediment samples were digested in accordance with EPA 3052 in order to analyze them in Milestone Ethos D microwave closed system [32]. After adding 1 g of sediment sample to 100 mL capacity Teflon vessel, sediment sample was digested with acid mixture (6 mL HNO_3 and 2 mL H_2O_2) for 25 min by means of microwave system. After this step, the aqueous solution was filtered with blue band filter paper and the residue was diluted to 25 mL with distilled water [33,34]. All laboratory materials were soaked in 10% HNO_3 (v/v) overnight and rinsed with distilled water before using. All the acids were of suprapure quality and reagents used in the experiment were of analytical grade.

Reagent blanks, sample replicates, calibration with standard solutions and standard reference materials (NCS DC73312 Stream Sediment) were employed to ensure the quality of all analyses. The recovery ratios were determined to be over 95% for each of the heavy metals (As 96.8%, Ba 95.6%, Cd 97.7%, Co 95.3%, Cr 97.4%, Cu 120.5%, Ni 98.3%, Pb 104%, Zn 98.8%). The amount of organic matter in the sediment was also calculated. Before starting the burning process, the crucibles were kept at 440°C for 2 h and then they were kept for 1 h for fixed weighing. 5 g of the dried and sieved sediment sample were weighed. The sediment was burned in the porcelain crucible at 440°C for 4 h. The lost amount was calculated as the total amount of organic matter [35]. 20 g of sediment samples were taken and put into a 50 mL beaker. Then, the deionized water (1:2.5) was added to the sample. pH, salinity, ORP and conductivity values were measured 10 min after shaking the beaker thoroughly. The values were measured by using the YSI Professional Plus Multiparameter instrument [36,37].

3. Results and discussion

3.1. Sediment characteristics

Some parameters of sediment quality affecting the heavy metal accumulation and its distribution in the sediment

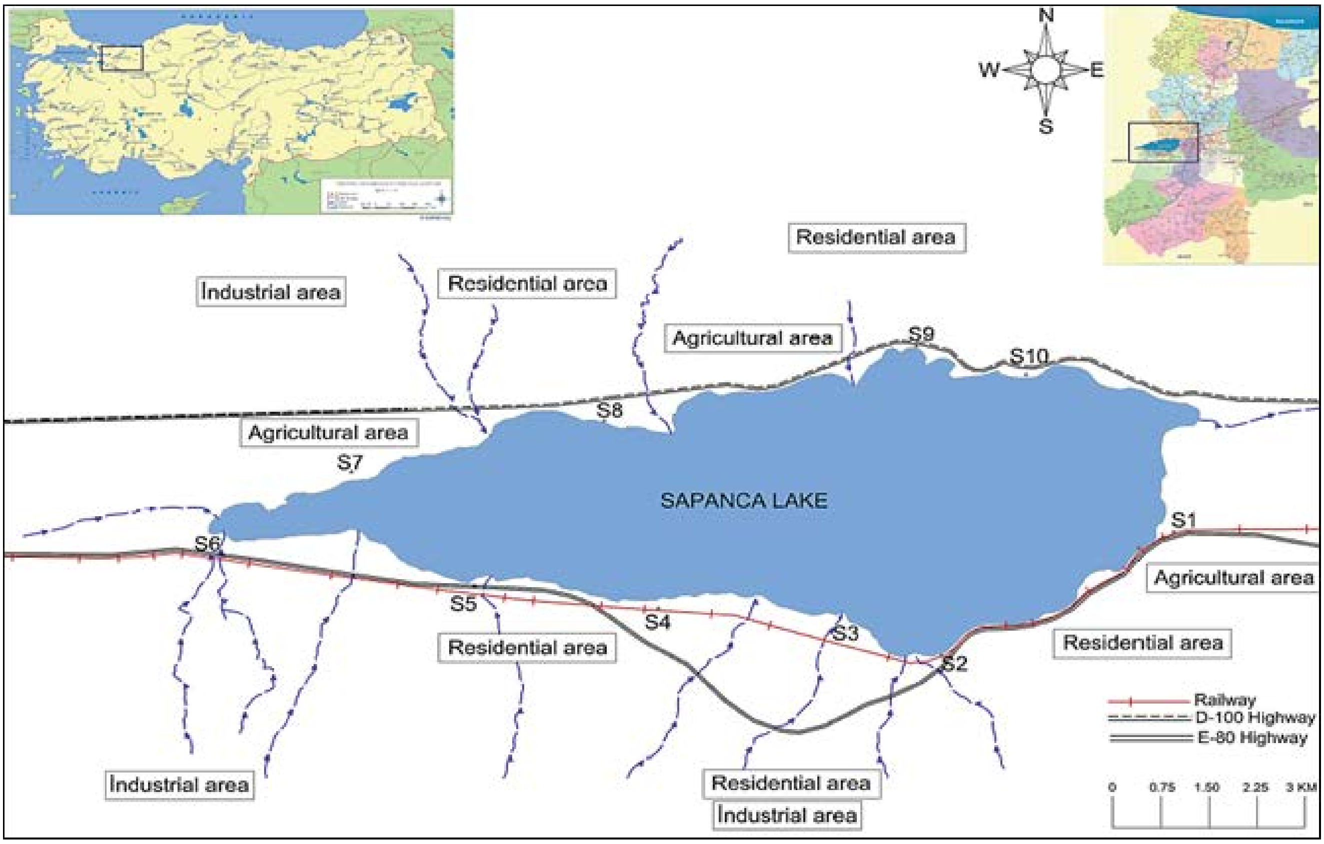

Fig. 1. Map of sediment samples in Sapanca Lake, Sakarya, Turkey.

were measured (Table 1). The transition of heavy metal to water is affected by the sediment influencing factors. Table 1 presents the statistical data of average values of seasonal sediment data from autumn 2015 to spring 2017.

pH is the most important parameter for controlling the heavy metal mobility in the sediment. If pH value decreases in sediment, the adsorption abilities and bioavailability of the metals decrease and the mobility of heavy metal increases [38]. pH values are between 8.62 and 6.98 and conductivity values are between 160.1 and 1,294 μS cm^{-1}. Mean salinity value is 306.19 ppt and the maximum value is 640 ppt. The main reason for the higher salinity value is the fertilizer consumption in some regions for landscaping and fruit growing.

Table 1
Sediment quality parameters in the lake

	pH	*C* (μS cm^{-1})	SAL (ppt)	ORP (mV)	OM%	OC%
N	70	70	70	70	70	70
Minimum	6.98	160.1	80	9.1	1.63	0.95
Maximum	8.62	1,294	640	324.9	22.83	13.24
STD	0.45	247.76	134.06	98.41	3.38	1.96
Median	7.85	562	309	245.8	7.34	4.25
Mean	7.82	565.32	306.19	186.15	7.14	4.14

C: conductivity; Sal: salinity; ORP: oxidation–reduction potential; OM: organic matter; OC: organic carbon.

ORP in the sediment is one of the key factors for the heavy metal mobility. ORP value is between 9.1 and 324.90 mV in the Lake. As ORP value increases, the heavy metals bounded with organic matter or heavy metal in the form of sulfides desorb and the heavy metals in the sediment mix into the water. On the other hand, ORP is an important parameter to determine the quality of water. Organic compounds in the sediment play a key role in the transformation of heavy metal. The heavy metals are mostly found in the organic matter in the sediment. The level of organic matter content of the lake sediment is found to be quite low. Maximum organic matter is 22.83% and maximum organic carbon is 13.14% in the sediment of Sapanca Lake.

Sediments accumulating in delta and water resources are generally fine-grained [39]. Sediments deriving from major erosions and small basins usually include higher amounts of clay and silt [40]. Classification of sediment type was based on TS 1900-1 method and the particle size of sediment is found to be between 0.0625 and 2 mm. The facies of the sediment is presented in Fig. 2. The sediment of Sapanca Lake consists mostly of silt. Particle size of silt is between 0.0039 and 0.0625 mm and particle size of clay is smaller than 0.0039 mm. Particle size of sand is between 0.062 and 2 mm. Fine water materials begin to accumulate in the water sources where the flow rate is low. As expected, sediments were fine-grained [41]. The sediments consist primarily of silt and the

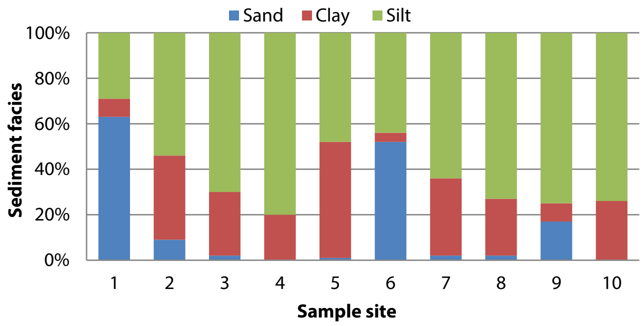

Fig. 2. Sediment facies distribution in Sapanca Lake.

highest silt (80%) content is found in 4th sampling site. The highest sand content is found to be 63% in 1st sampling site and 52% in 6th sampling site, respectively. Pollutants caused by human activities are associated with the clay and silt fractions in the soil and sediment [24].

3.2. Heavy metal concentrations in the sediment

Sediment samples were collected as shown in Fig. 1 in seven different seasons (between 2015 autumn and 2017 spring). The mean values of samples collected seasonally from each sampling sites were calculated and specified in Table 2. When the heavy metal concentrations are examined, high proportions of Al and Fe are found in the sediment. Therefore, it has been found that these elements abound in the soil of Sapanca Lake basin. Compared with other elements, larger concentrations of these elements are also found in the sediment of Lake. These elements are originated from crust.

Heavy metals concentrations in the sediment are found as Fe > Al > Ba > As > Zn > Ni > Cr > Cu > Co > Cd, respectively. Ba concentration is found to be between 16.42 and 50.11 mg kg^{-1}. The possible reasons for higher concentration of these heavy metals can be E-5 highway, railway and TEM (E-80) highway. As, Zn concentration is between 19.76, 34.21, 22.94 and 50.68 mg kg^{-1}, respectively. Ni concentration is found to be between 12.17 and 59.13 mg kg^{-1}. The most important sources of pollution affecting Sapanca Lake are industrial facilities and traffic. Other important sources of pollution are fertilizers and agricultural facilities such as fruit and flower cultivation.

When the heavy metals are examined on the basis of the stations, the highest values for Al, Ba and Pb are observed at 4th station; the highest values for As and Cd are observed at 3rd station; the highest values for Co, Cr, Cu, Ni and Zn are observed at 2nd station; and last, the highest value for Fe is observed at 10th station. Considering the pollutant sources around Lake Sapanca (as shown in Fig. 1), As and Cd originate from traffic while Co, Cr, Cu, Ni and Zn originate both from traffic and agricultural area. Al, Ba and Pb indicate the presence of pollutant accumulation in the Lake sediment due to the location of the station, where the highest values for these elements are observed.

The sediment quality affects the heavy metal accumulation and its distribution in the sediments, so the relationship between the heavy metals and sediment characteristics are identified by using the Pearson correlation in Table 3. The positive significant correlations indicate that these heavy metals may have originated from the same pollutant source and thus may have some similar properties. There is no significant correlation between Fe and other metals, which indicates that Fe may have originated from various pollutant sources.

3.3. Pollution level of heavy metals in sediment

The environmental influence of heavy metals and pollution level can be identified by employing pollution indices CF, EF and I_{geo}. EF is a widespread method for evaluating the sediment quality and comparing contaminations in different environments [40,42]. For the estimation of the anthropogenic effects on sediments or soils, these pollution indices are calculated for metal level above the uncontaminated background levels [43,44]. A CF (C_f^i) is employed to describe the contamination of a toxic substance in a lake basin [45] and is given as follows:

$$C_f^i = \frac{C_{0-1}^i}{C_n^i} \quad (1)$$

where C_{0-1}^i is the mean content of the substance i from at least 5 sample sites, and C_n^i is the pre-industrial reference level for

Table 2
Mean heavy metal concentrations in Sapanca Lake, mg kg^{-1}

Sample sites	Al	As	Ba	Cd	Co	Cr	Cu	Fe	Ni	Pb	Zn
1	8,230.96	25.69	38.63	0.60	4.92	19.11	7.69	13,028.46	20.11	10.50	22.94
2	19,142.15	28.15	43.74	1.25	9.90	51.56	25.01	31,043.53	59.13	23.48	50.68
3	19,066.57	34.21	49.93	1.32	5.41	17.69	17.73	22,785.38	18.69	18.41	37.42
4	19,342.44	32.37	50.11	1.24	9.46	40.19	25.61	32,027.43	45.54	24.08	48.90
5	9,524.73	24.20	16.83	0.52	6.47	16.43	17.03	23,526.80	23.45	17.76	43.46
6	9,524.73	24.20	16.83	0.52	6.47	16.43	17.03	23,526.80	23.45	17.76	43.46
7	15,478.82	19.76	40.15	0.79	5.77	16.92	16.01	21,223.36	20.23	16.90	34.35
8	12,947.79	32.12	40.64	0.85	4.89	13.07	14.79	20,307.50	15.74	18.04	35.00
9	9,705.30	19.51	16.42	0.49	4.78	8.54	10.79	18,889.04	12.17	13.79	30.42
10	17,559.37	34.21	50.14	1.05	7.73	22.74	22.20	76,704.85	28.79	22.09	48.15

Number of sampling: 70

Table 3
Pearson correlations between heavy metals and physicochemical characteristics

	C	SAL	pH	ORP	OM%	OC%	Al	As	Ba	Cd	Co	Cr	Cu	Fe	Ni	Pb	Zn
C	1	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
SAL	0.933**	1	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
pH	–0.137	–0.076	1	–	–	–	–	–	–	–	–	–	–	–	–	–	–
ORP	–0.008	–0.122	–0.852**	1	–	–	–	–	–	–	–	–	–	–	–	–	–
OM%	0.362**	0.297*	–0.156	0.014	1	–	–	–	–	–	–	–	–	–	–	–	–
OC%	0.362**	0.296*	–0.156	0.014	1.000**	1	–	–	–	–	–	–	–	–	–	–	–
Al	0.231	0.124	–0.582**	0.483**	0.395**	0.395**	1	–	–	–	–	–	–	–	–	–	–
As	0.103	–0.032	–0.666**	0.643**	0.323**	0.323**	0.788**	1	–	–	–	–	–	–	–	–	–
Ba	0.323**	0.293*	–0.425**	0.263*	0.363**	0.363**	0.753**	0.608**	1	–	–	–	–	–	–	–	–
Cd	0.130	0.027	–0.681**	0.607**	0.329**	0.329**	0.931**	0.893**	0.729**	1	–	–	–	–	–	–	–
Co	0.095	–0.013	–0.669**	0.640**	0.291*	0.291*	0.834**	0.784**	0.577**	0.865**	1	–	–	–	–	–	–
Cr	0.199	0.130	–0.576**	0.505**	0.292*	0.292*	0.781**	0.610**	0.636**	0.786**	0.910**	1	–	–	–	–	–
Cu	0.141	0.040	–0.657**	0.580**	0.355**	0.355**	0.900**	0.850**	0.603**	0.917**	0.950**	0.832**	1	–	–	–	–
Fe	0.154	0.076	–0.152	0.179	0.171	0.171	0.327**	0.270*	0.170	0.249*	0.290*	0.200	0.326**	1	–	–	–
Ni	0.195	0.110	–0.576**	0.532**	0.286*	0.286*	0.757**	0.615**	0.574**	0.758**	0.933**	0.986**	0.850**	0.234	1	–	–
Pb	0.115	0.013	–0.665**	0.591**	0.379**	0.379**	0.913**	0.875**	0.615**	0.920**	0.912**	0.788**	0.973**	0.306*	0.795**	1	–
Zn	0.089	0.008	–0.606**	0.516**	0.325**	0.324**	0.849**	0.783**	0.542**	0.834**	0.882**	0.764**	0.930**	0.286*	0.781**	0.943**	1

*Correlation is significant at the 0.05 level.
**Correlation is significant at the 0.01 level.
C: conductivity; SAL: salinity; ORP: oxidation–reduction potential; OM: organic matter; OC: organic carbon.

the substance. The CF is interpreted as follows: $C_f^i < 1$, low CF; $1 \le C_f^i\, 3$, moderate CFs; $3 \le C_f^i\, 6$, considerable CFs; and $C_f^i \ge 6$, very high CF.

Degree of contamination (Cd) is defined as the sum of all CFs of the basin. Cd is defined as the sum of the Cf for the eight pollutant types according to Hakanson [45]. Cd is offered as a measure of the degree of overall contamination in a sampling site.

$$C_d = \sum_{i=1}^{7} C_f^i = \sum_{i=1}^{7} \frac{C_{0-1}^{-i}}{C_n^i} \quad (2)$$

The contamination degree is interpreted as follows: $C_d < 7$ low degree of contamination; $7 < C_d < 14$ moderate degree of contamination; $14 < C_d < 28$ considerable degree of contamination; $C_d < 28$ very high degree of contamination.

The CF C_f values are presented in Table 4. The sediment contamination is found to be low for Al, Ba, Co, Cr, Cu, Fe, Ni as well as Zn; and moderate for As. The sediment contamination is generally moderate for C_d. However, considerable contamination has been found in the 2nd, 3rd, 4th and 10th sampling sites in Sapanca Lake, according to the Hakanson classification [45]. The sediment contamination is low for Fe, but only moderate contamination is found in 10th sampling site. The sediment contamination is low for Pb, but only moderate contamination is found in the 2nd, 4th and 10th sampling sites.

The contamination degree values are presented in Table 4. C_d values indicate general moderate degree of contamination in the sediment of Sapanca Lake.

The EF is calculated in Eq. (3) [46]:

$$\mathrm{EF} = \frac{\left(\dfrac{M_{\text{sample}}}{N_{\text{sample}}}\right)}{\left(\dfrac{M_{\text{background}}}{N_{\text{background}}}\right)} \quad (3)$$

M_{sample} is the value of the examined metal in the sediment. N_{sample} is the value of the normalization element in the sediment. $M_{\text{background}}$ is the background value of the studied metal. $N_{\text{background}}$ is the background value of the normalization metal. The studied metal value should be normalized by using conservative elements such as Fe, Al, Li, Sc and TOC. Normalization elements can be determined by Pearson correlation [47,48]. The Pearson correlation coefficients among the heavy metals are presented in Table 3. Background values for EF calculations were selected from Turekian and Wedepohl as well as from Hakanson [45,49]. The EF value of heavy metal is often employed to indicate whether this metal has originated due to the natural weather conditions from soil or due to the anthropogenic sources, meaning environmental contamination.

When the EF value of the metal is below 0.5 (EF < 0.5), the value suggests that the heavy metal originated from Earth's crust. If the EF value is between 0.5 and 1.5 (0.5 < EF < 1.5), the heavy metal can be from crustal materials or natural weathering processes. However, a value higher than 1.5 (EF > 1.5) suggests that the heavy metal originated from non-crustal materials or, mostly due to the non-natural weathering processes [50]. In addition, according to different sediment pollution indices, sediment quality can be interpreted as follows: natural sediments (0–2), low polluted sediments (2–5), moderately polluted sediments (5–10), highly polluted sediments (10–20) and dangerous sediments (>20) [15,51]. The EFs for heavy metals in the sediments are presented in Table 5.

In Sapanca Lake, the EF ranges of these metals are determined as follows: 7.85–19.21 (mean 12.84) for As, 0.23–0.65 (mean 0.36) for Ba, 13.47–19.40 (mean 16.18) for Cd, 1.19–2.86 (2.08) for Co, 0.78–2.39 (mean 1.40) for Cr, 1.65–3.18 (mean 2.24) for Cu, 1.15–3.63 (mean 2.26) for Ni, 3.86–7.46 (mean 5.44) for Pb and 1.65–3.84 (mean 2.51) for Zn.

EF values for As, Cd, Co, Cu, Ni, Pb and Zn are higher than 1.5, indicating the fact that a significant portion of the trace metals originate from non-crustal materials or due to

Table 4
Contamination factors and degree of contamination of sediments in Sapanca Lake

Sample sites	C_f											C_d
	Al	As	Ba	Cd	Co	Cr	Cu	Fe	Ni	Pb	Zn	
1	0.10	1.98	0.07	2.00	0.26	0.21	0.17	0.28	0.30	0.52	0.24	6.12
2	0.24	2.17	0.08	4.17	0.52	0.57	0.56	0.66	0.87	1.17	0.53	11.54
3	0.24	2.63	0.09	4.41	0.28	0.20	0.39	0.48	0.27	0.92	0.39	10.31
4	0.24	2.49	0.09	4.14	0.50	0.45	0.57	0.68	0.67	1.20	0.51	11.54
5	0.12	1.86	0.03	1.72	0.34	0.18	0.38	0.50	0.34	0.89	0.46	6.82
6	0.12	1.86	0.03	1.72	0.34	0.18	0.38	0.50	0.34	0.89	0.46	6.82
7	0.19	1.52	0.07	2.63	0.30	0.19	0.36	0.45	0.30	0.84	0.36	7.22
8	0.16	2.47	0.07	2.82	0.26	0.15	0.33	0.43	0.23	0.90	0.37	8.19
9	0.12	1.50	0.03	1.63	0.25	0.09	0.24	0.40	0.18	0.69	0.32	5.46
10	0.22	2.63	0.09	3.50	0.41	0.25	0.49	1.63	0.42	1.10	0.51	11.25
Minimum	0.10	1.50	0.03	1.63	0.25	0.09	0.17	0.28	0.18	0.52	0.24	5.46
Maximum	0.24	2.63	0.09	4.41	0.52	0.57	0.57	1.63	0.87	1.20	0.53	11.54
STD	0.06	0.43	0.02	1.11	0.10	0.15	0.13	0.38	0.21	0.21	0.09	2.39
Mean	0.18	2.11	0.06	2.87	0.35	0.25	0.39	0.60	0.39	0.91	0.42	8.53

Table 5
Enrichment factors for heavy metals

EF	As	Ba	Cd	Co	Cr	Cu	Ni	Pb	Zn
1	19.21	0.65	19.40	2.52	2.06	1.66	2.87	5.10	2.35
2	9.05	0.32	17.43	2.18	2.39	2.32	3.63	4.91	2.23
3	11.04	0.36	18.50	1.19	0.82	1.65	1.15	3.86	1.65
4	10.30	0.36	17.12	2.06	1.85	2.35	2.77	4.98	2.13
5	15.64	0.24	14.46	2.86	1.53	3.18	2.90	7.46	3.84
6	15.64	0.24	14.46	2.86	1.53	3.18	2.90	7.46	3.84
7	7.55	0.36	13.60	1.57	0.97	1.84	1.54	4.37	1.87
8	15.27	0.43	17.45	1.59	0.90	2.03	1.43	5.57	2.28
9	12.37	0.23	13.47	2.08	0.78	1.98	1.48	5.68	2.64
10	11.99	0.39	15.96	1.85	1.15	2.25	1.93	5.03	2.31
Minimum	7.85	0.23	13.47	1.19	0.78	1.65	1.15	3.86	1.65
Maximum	19.21	0.65	19.40	2.86	2.39	3.18	3.63	7.46	3.84
STD	3.53	0.12	2.10	0.55	0.57	0.55	0.85	1.19	0.75
Mean	12.84	0.36	16.18	2.08	1.40	2.24	2.26	5.44	2.51

non-natural weathering processes. The EF values for these metals indicate that the source of pollution may be the anthropogenic activities. Especially, the EF values for As and Cd are much higher than 1.5. These high values indicate the presence of anthropogenic activities such as the consumption of fuel-oil in the industry and traffic. When the EF values are examined and compared with other sediment pollution indices, the sediment quality is determined as highly polluted, due to the high EF values of As and Cd. The sediment is found to be moderately polluted in terms of Pb value. In addition, it is found to be low polluted in terms of Ni, Cu, Co, Zn values. EF values for Cr are lower than 1.5, indicating the crustal components or natural weathering processes. However, EF values for Ba are lower than 0.5, indicating origination from the crust of Earth; that is, it is a part of natural sediment.

The geo-accumulation index is employed in order to assess and determine the metal pollution in the sediment. This method evaluates the level of metal pollution with regard to seven enrichment classes of the index. Geo-accumulation index has been widely employed to assess the quality of soils or sediments. It determines the contamination with regard to current metal levels and pre-industrial levels [52]. The calculation for this index is presented in Eq. (4):

$$I_{\text{geo}} = \log 2\left(\frac{C_n}{1.5 \times B_n}\right) \quad (4)$$

C_n is the metal concentration in the sediment, the B_n is the background concentration of element and 1.5 is the background matrix correction factor due to lithogenic effects [53,54]. Pollution level calculated with the geo-accumulation index equation is presented in Table 6. Background values are taken from Turekian and Wedepohl [49]. "I_{geo}" provides a method to establish the "pollution load" in sediments for the heavy metals in the current study, in the sediments above the background values, but it does not clarify the mobilization and bioavailability of the heavy metals [18].

The mean geo-accumulation indices of Al (−3.17), Ba (−4.71), Co (−2.16), Cr (−2.79), Cu (−2.04), Fe (−1.49), Ni (−2.09), Pb (−0.75) and Zn (−1.89) are lower than zero (I_{geo}<0), indicating that these metals generally do not pollute the Lake (Table 7). This class is called as uncontaminated. On the other hand, the mean geo-accumulation indices of As and Cd are 0.46 and 0.84, respectively. These values range from 0 to 1 and these values in I_{geo} class 1, defined as uncontaminated to moderately contaminated for As and Cd in the sediment. As and Cd contaminations are caused by anthropogenic activities. The sediment is uncontaminated for Fe, but sediment only from the 10th sampling site is found to be between uncontaminated to moderately contaminated levels.

Table 6
Classes for geo-accumulation

I_{geo} value	I_{geo} class	Designation of sediment quality
>5	6	Extremely contaminated
4–5	5	Strongly to extremely contaminated
3–4	4	Strongly contaminated
2–3	3	Moderately to strongly contaminated
1–2	2	Moderately contaminated
0–1	1	Uncontaminated to moderately contaminated
0	0	Uncontaminated

3.4. Ecotoxicological approach for heavy metals

Sediment quality guidelines are employed to determine the sediment pollutant levels, the cleaning of contaminated sites with domestic and industrial wastes, the pollutant inputs and the distribution of pollutants in the aquatic system. In addition, these guidelines are used to determine ecological or human risks, the contamination in the living tissue, the degree of polluted areas and the advantageous use of sediments. Sediment quality guidelines are designed to help determine the sediment quality. Numerical sediment quality guidelines (SQGs) have been employed to identify the relevant contaminants in the aquatic ecosystems [55–57].

Table 7
Geo-accumulation index for sediments in Sapanca Lake

I_{geo}	Al	As	Ba	Cd	Co	Cr	Cu	Fe	Ni	Pb	Zn
1	−3.87	0.40	−4.49	0.41	−2.53	−2.82	−3.13	−2.44	−2.34	−1.51	−2.64
2	−2.65	0.53	−4.31	1.48	−1.52	−1.39	−1.43	−1.19	−0.79	−0.35	−1.49
3	−2.65	0.81	−4.12	1.56	−2.40	−2.93	−1.93	−1.64	−2.45	−0.70	−1.93
4	−2.63	0.73	−4.12	1.46	−1.59	−1.75	−1.40	−1.14	−1.16	−0.32	−1.54
5	−3.66	0.31	−5.69	0.20	−2.14	−3.04	−1.99	−1.59	−2.12	−0.76	−1.71
6	−3.66	0.31	−5.69	0.20	−2.14	−3.04	−1.99	−1.59	−2.12	−0.76	−1.71
7	−2.95	0.02	−4.44	0.81	−2.30	−3.00	−2.08	−1.74	−2.33	−0.83	−2.05
8	−3.21	0.72	−4.42	0.91	−2.54	−3.37	−2.19	−1.80	−2.70	−0.73	−2.03
9	−3.63	0.00	−5.73	0.12	−2.57	−3.98	−2.64	−1.91	−3.07	−1.12	−2.23
10	−2.77	0.81	−4.12	1.22	−1.88	−2.57	−1.60	0.12	−1.82	−0.44	−1.57
Minimum	−3.87	0.00	−5.73	0.12	−2.57	−3.98	−3.13	−2.44	−3.07	−1.51	−2.64
Maximum	−2.63	0.81	−4.12	1.56	−1.52	−1.39	−1.40	0.12	−0.79	−0.32	−1.49
STD	0.49	0.31	0.70	0.58	0.39	0.75	0.54	0.67	0.68	0.36	0.36
Mean	−3.17	0.46	−4.71	0.84	−2.16	−2.79	−2.04	−1.49	−2.09	−0.75	−1.89

Sediment quality guidelines are derived from theoretical and empirical approaches depending on the potential effects of organisms settled in the sediments in clean waters. These guidelines have different approaches listed as follows: approach of equilibrium differentiation (EqPa) [56,58,59], approach of choice of concentration levels [60], approach of rate effects [61], approach of level effects [62] and approach of possible visible effects [63]. Effect based on the sediment quality guidelines was grouped, depending on the common opinion after the selected sediment quality criteria have been established [55]. In particular, SQGs are generated to protect sediment-settled organisms in the clean water ecosystems; they are grouped into two categories as threshold effect levels (TELs) and probable effect levels (PELs). TEL covers the concentrations below the level of pollution. It has been determined not to have harmful effects on sediment-settled organisms.

Threshold effect levels (TELs) [59,62] contain effect range-low value [61], lowest effect levels [60], minimum possible effect [64], recommended sediment quality [65]. PEL covers concentrations above the level of pollution. It has been determined to have harmful effects on sediment-settled organisms [55]. PEL [59,62,65,66] contain effect range median value [61,65,66], high effect levels [60] and threshold toxic effects [64].

Table 8 presents the concentrations of heavy metal pollution in the 10th station, polluted with heavy metal. For the determination of eco-toxicological content, TELs and PELs were assigned to sediment quality guidelines. As concentration does not exceed PEL concentration (except for 3rd and 10th stations). Although the level of environmental pollution is high, there is no pollution at the toxic level. Cd (except for 2nd, 3rd, 4th and 10th sampling sites) and Ni (except for 2nd sampling site) did not exceed the PEL concentration and there is no contamination at toxic level. Cr, Cu, Pb and Zn are below the TEL values; that is, they are not at the toxic level. Thus they are below the pollution levels.

Table 8
Mean heavy metal concentrations in Sapanca Lake sediments and TEL, PEL guideline values for heavy metals mg kg^{-1}

Sample sites	Al	As	Ba	Cd	Co	Cr	Cu	Fe	Ni	Pb	Zn
1	8,230.96	25.69	38.63	0.60	4.92	19.11	7.69	13,028.46	20.11	10.50	22.94
2	19,142.15	28.15	43.74	1.25	9.90	51.56	25.01	31,043.53	59.13	23.48	50.68
3	19,066.57	34.21	49.93	1.32	5.41	17.69	17.73	22,785.38	18.69	18.41	37.42
4	19,342.44	32.37	50.11	1.24	9.46	40.19	25.61	32,027.43	45.54	24.08	48.90
5	9,524.73	24.20	16.83	0.52	6.47	16.43	17.03	23,526.80	23.45	17.76	43.46
6	9,524.73	24.20	16.83	0.52	6.47	16.43	17.03	23,526.80	23.45	17.76	43.46
7	15,478.82	19.76	40.15	0.79	5.77	16.92	16.01	21,223.36	20.23	16.90	34.35
8	12,947.79	32.12	40.64	0.85	4.89	13.07	14.79	20,307.50	15.74	18.04	35.00
9	9,705.30	19.51	16.42	0.49	4.78	8.54	10.79	18,889.04	12.17	13.79	30.42
10	17,559.37	34.21	50.14	1.05	7.73	22.74	22.20	76,704.85	28.79	22.09	48.15
Mean	14,052.29	27.44	36.34	0.86	6.58	22.27	17.39	28,306.32	26.73	18.28	39.48
TEL	–	9.79	–	0.99	–	43.4	31.6	–	22.7	35.8	121
PEL	–	33	–	4.98	–	111	149	–	48.6	128	459

4. Conclusion

11 heavy metals in the sediment of the Sapanca Lake were examined to investigate the accumulation and contamination levels. The impact of anthropogenic heavy metal pollution (As, Ba, Cd, Co, Cu, Cr, Ni, Pb and Zn) was examined by employing pollution indices CF, EF and I_{geo}. Heavy metal concentrations in the sediment samples were examined and the highest values were determined for Zn, Ba, Ni and Pb except for Al, Fe in the sediment. It indicates that Sapanca Lake is exposed to anthropogenic pollution such as traffic and industry. Considering the EFs of heavy metals, the EFs of As and Cd in the sediment are extremely higher than the EFs of other metals. Also, EF values for these metals (except for Ba and Cr) are higher than 1.5. This situation indicates that the heavy metal concentration in the Sapanca Lake was largely affected by the anthropogenic activities. There are many industrial establishments and important highways in the Sapanca Lake basin. The accumulation of these metals in the lake sediment is due to pollutants coming from soil and water. According to contamination degree, the Lake sediment quality has moderate degree of contamination; for As and Cd, the sediment has moderate contamination degree. Geo-accumulation index is not readily comparable to the other pollution indices due to the nature of calculation. So, the sediment quality is determined as "uncontaminated" to "moderately contaminated" only for Ba and Cd. According to examined pollutant indices, Cd is the most noticeable one among the heavy metals. The traffic and industry are thought to be the source of heavy metal in some areas while phosphate fertilizer used is thought to be the source in the other areas in the basin of Sapanca Lake. According to the sediment quality guidelines (PEC and TEC), the average total metal concentrations in Lake Sapanca samples are compared with the clean reference sediment sample and reference values in the crust. Potential ecological effects and environmental risks of heavy metals in polluted sediments have been assessed. Finally, SQGs values for metals are found not to exceed PEL (probable effect level) and Cr, Cu, Pb and Zn values are found not to exceed TEL. This means that heavy metal pollution is not at the toxic level for the sediment of Sapanca Lake.

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