IJEGEO

*International Journal of Environment and Geoinformatics 10(3):040-047 (2023)*

**Research Article**

# Ecological Risk Analysis of Lake Arin Sediments (Bitlis, Türkiye)

**Sümeyye Faydalgel[1], Ahmet Evren Erginal[2]**

[1] Geography Education, Faculty of Education, Çanakkale Onsekiz Mart University, Çanakkale, TÜRKIYE
[2]Department of Turkish and Social Sciences Education, School of Graduate Studies, Çanakkale Onsekiz Mart University, Çanakkale, TÜRKIYE

* E-mail: aerginal@comu.edu.tr

Received 18.06.2023
Accepted 02.09.2023

**How to cite:** Faydagel and Erginal (2023). Ecological Risk Analysis of Lake Arin Sediments (Bitlis, Türkiye), *International Journal of Environment and Geoinformatics (IJEGEO)*, 10(3): 040-047, doi. 10.30897/ijegeo.1316284

## Abstract

This study aimed to determine the ecological risk of Lake Arin through an analysis using comprehensive indexes. Surface sediment samples (21) and bedrock samples (5) were collected from Lake Arin. The metal concentrations were obtained from the ICP-OES analysis values. Enrichment Factor (EF), Contamination Factor (CF), Geoaccumulation Index (Igeo) and Toxic Risk Index (TRI), Modified ecological risk index (mER) and Modified Potential Ecological Risk Index (m-PER) were calculated from the ICP-OES data. Our results reveal that the average concentration of the Lake Arin metals is Al > Fe > Mn > Zn > Ni > Co > Pb > Cd > As, in decreasing order. While moderate enrichment was determined for Ni, As and Zn, moderate contamination was detected only for Ni. It was determined there was no contamination in terms of Geoaccumulation Factor, and PER values showed low ecological risk. The second highest EF value belongs to As, which is thought to originate from the use of fossil fuels in the region. As a result of the ecological risk analysis of Lake Arin, it was determined that the metal levels were not at high levels and were not toxic.

**Keywords:** Sediment, Heavy metals, Ecological Risk, Pollution, Lake Arin

## Introduction

The shipping industry is an essential element of global trade and has a significant impact on the environment. This environmental impact is equivalent to the release of 1.2 billion tons of CO2 in 2020 and accounts for about 3% of total global greenhouse gas emissions. Flag states and port states, especially the International Maritime Organization (IMO), take preventive measures to control greenhouse gas emissions and issue strict regulations for this purpose. For this reason, the maritime industry focuses on green technologies that will not only reduce emissions from ships but also minimize the environmental impact of shipyards, organized industrial zones, and subsidiaries. Although national and international institutions and organizations and port and flag states have adopted IMO's targets for 2050 and beyond, a common international standard has not been determined for classification societies and green technologies in the maritime industry. The maritime industry on green technologies; it focuses on smart technologies such as energy efficiency, biodiversity, digitalization, automation, and robotic applications, as well as clean technologies and waste disposal systems.

The accumulation of heavy metals in wetland sediments of natural or anthropogenic origin is important because it is risky for human health and the ecological aspects. Therefore, the determination of these risks with ecological risk indexes is important for the sustainability of wetlands and the protection of many living things. One of the areas where these environmental problems occur most seriously is lakes. Lake sediments archive metals and organic matter from polluting sources within the lake basin.

Ecological risks arising from the accumulation of heavy metals in natural lakes and dams due to human influence in Turkey, as in the whole world, continue to increase their impact today. Industrial wastes, domestic and/or urban wastes, fertilizers used in agricultural activities, pesticides used for pest control, metals issuing from factory chimneys resulting from fossil fuel consumption, especially thermal power plants and cement factories, accumulate and enrich on the floor of lakes. The sediments at the bottom of lakes provide a food source for benthic organisms, thanks to the micronutrient trace elements they contain, and form a natural reservoir for many fish species living and feeding in the bottom waters. For this reason, it should not be forgotten that not only the lake waters, but also the sediments on the lake floor are of vital importance. Metals enriched in lake sediments by the mentioned anthropogenic activities cause toxic effects when they reach high concentrations. Because heavy metals cannot be metabolized easily in living organisms, they accumulate in the tissues of several living organisms, such as zooplankton and fish (Achary et al., 2017).

Many indices have been developed to evaluate the ratio of metals with potentially toxic effects and the level of ecological risk they cause. Enrichment factor (Sutherland, 2000; Vrhovnik et al., 2013; Brady et al., 2015), Contamination factor (Hakanson, 1980) and the Geoaccumulation index (Müller, 1969) are among these commonly-used indices, and natural and anthropogenic sources of elements are determined. Comprehensive ecological risk assessment is also carried out with the Modified ecological risk index (Hakanson, 1980), Modified potential ecological risk index (Hakanson, 1980; Brady et al., 2015), and Toxic risk index (Zhang et al., 2016).

The number of studies on ecological risks in lake sediments in Turkey has been increasing in the last decade. In studies focusing on the ecological risk in lake sediments, the existence of potential ecological risks was concretely determined, albeit at different rates (Kükrer et al., 2015; Kaya et al., 2017; Kükrer, 2017; 2018; Kükrer et al., 2019; 2020). In this study, the ecological risk analysis of Lake Arin, which is a high altitude lake located in a rural area in the Eastern Anatolian region of Türkiye, where anthropogenic pressure is low, is discussed.

## Materials and Methods

### *Study Area*

Lake Arin is located in the Adilcevaz district of Bitlis province and is separated from Lake Van by a coastal cordon of 1000 m in length and 4 km in height. Located at an altitude of 1658 m to the north of Lake Van (Hoşgören, 1994), this shallow lake has a surface area of 18 km$^2$ and maximum water depth of 6.8 m (Kamar, 2018). Lake Arin is a soda lake as it is surrounded by volcanic areas (Lahn, 1951). According to data from the Van Meteorology Station (38.4 N - 43.3 E), which is 1675 meters above sea level, the average annual temperature in the field is 14.9°C and the annual average precipitation is 388.5 mm, showing semi-arid, less humid (C1,B'1,s,b'2) climate type characteristics (Çelik et el., 2018).

### *Sampling and Analytical Procedures*

For the ecological risk analysis calculations, a total of 21 sediment samples were collected from the shallow lake floor on the northern shore of Lake Arin, proceeding counterclockwise (Fig. 1). In order to calculate the background values, 5 different volcanic rock samples were collected. Inductively Coupled Plasma Optical Emission Spectroscopy (ICP-OES) was used to determine the element concentrations in the samples. Total organic carbon in powdered samples was measured using the Walkley-Black titration method (Gaudette et al., 1974). Using a Scheibler calcimeter, a total of $CaCO_3$% content was determined by measuring the carbon dioxide gas released as a result of mixing approximately 0.2 g of sediment with 10% HCl by recording the instantaneous pressure and temperature conditions during the measurement in the laboratory, where the measurement was made (Schlicting and Blume, 1966).

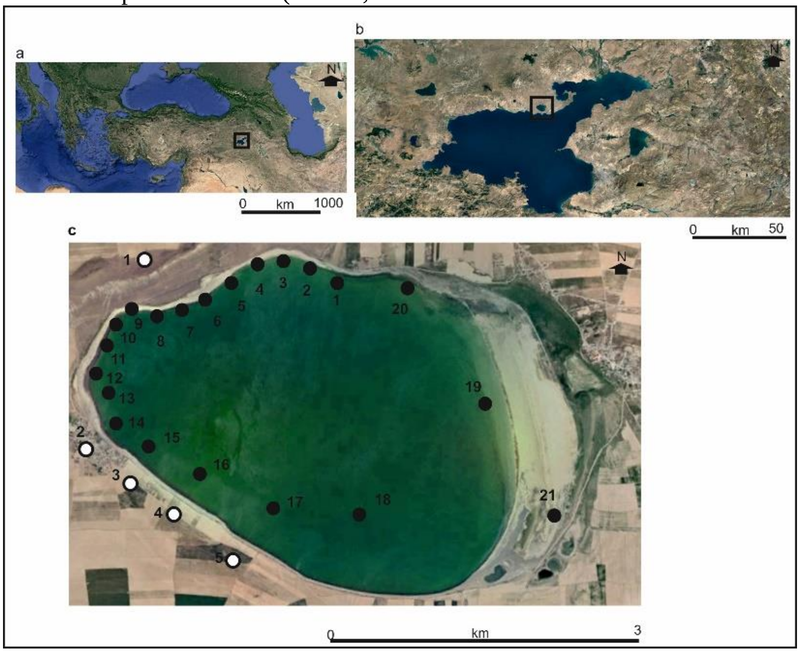


Fig. 1. (a-b) Location of Lake Arin. (c) Sampling sites on Google Earth image (last access: 04 June 2023; image date: 14 May 2022). Black dots indicate sediment sampling locations. White dots indicate locations of rock samples collected for background calculation.

### *Ecological Risk Indexes*

Five indexes, which are widely used to determine the ecological risk level due to metal accumulation in lake sediments, were applied in this study. These are Enrichment Factor (EF), Contamination Factor (CF), Geoaccumulation Index (Igeo) and Toxic Risk Index (TRI), Modified ecological risk index (mER), and Modified Potential Ecological Risk Index (m-PER). The explanations and evaluation criteria regarding the calculations are as follows:

### *Enrichment Factor (EF)*

In the EF calculation, which was made to accurately determine the density of pollutants accumulated in lake sediments by human influence, Al was considered one of the main components of the earth's crust used to minimize the margin of error associated with grain size in sediments (Zhang et al., 2007). The following formula is considered for calculation:

$$EF = \frac{\left(\frac{C_1}{Cre_f}\right)sample}{\left(\frac{B_1}{B_{ref}}\right)background} \quad \text{(Eq. 1)}$$

In this formula, Ci corresponds to the element concentration, and Cref corresponds to the concentration of the reference element used for normalization. The $B_i$ value is the regional background value of the element. Bref shows the background value of the reference element selected for normalization. In terms of EF classes, the following value ranges suggested by Sutherland (2000) were considered; EF < 2 deficiency to minimal enrichment, EF = 2 – 5 moderate enrichment, EF = 5 – 20 significant enrichment, EF = 20 – 40 very high enrichment, and EF ≥ 40 extremely high enrichments.

***Contamination Factor (CF) and Modified Degree of Contamination (mCD)***

The CF calculation applied to determine and classify the environmental effects or the degree of contamination in the studied sediments was obtained by dividing the present metal concentration by the background metal concentration (Hakanson, 1980). CF is calculated using the following formula:

CF = C_i / C_ni (Eq.2)

where Ci shows the element concentration, and Cni is the background value of the element.

Hakanson's (1980) classification was used for evaluation. The CF ranges considered are as follows; low contamination (CF<1), moderate contamination (1≤CF<3), high contamination (3≤CF<6) and very high contamination (CF>6).

As CF has some disadvantages in eliminating errors from grain size, mCd has been developed (Abrahim & Parker, 2008), which is calculated according to the following formula:

$$mCd = \frac{\sum_{i=1}^{n} CF}{n} \quad \text{(Eq.3)}$$

Here, CF is the contamination factor and n is the number of elements used in the analysis. mCd findings are evaluated as follows: mCd <1.5 nil to a very low, 1.5 < mCd <2 low, 2 < mCd <4 moderate, 4 < mCd <8 high, 8 < mCd <16 very high, 16 < mCd <32 extremely high, and mCd > 32 ultrahigh (Abrahim & Parker, 2008).

***Geoaccumulation Index (Igeo)***

The following formula was used in the Igeo calculation (Müller, 1969) to reveal the anthropogenic effect on the metal accumulation in the studied lake sediments:

$$I_{geo} = \log_2 \frac{Cm}{(Bm*1.5)} \quad \text{(Eq. 4)}$$

Here, C and B are the metal concentration and the background metal concentration, respectively. The Igeo values determined according to Müller (1969) were evaluated in the following value ranges; ($I_{geo} \leq 0$) unpolluted, ($0 < I_{geo} < 1$) unpolluted to moderately polluted, ($1 < I_{geo} < 2$) moderately polluted, ($2 < I_{geo} < 3$) moderately to strongly polluted, ($3 < I_{geo} < 4$) strongly polluted, ($4 < I_{geo} < 5$) strongly to very strongly polluted, and ($5 \leq I_{geo}$) very strongly polluted.

***Modified ecological risk index (mER) and Modified Potential Ecological Risk Index (m-PER)***

mER is widely used to determine the individual ecological risk level of each metal, and mPER values, which are the indicator of the total potential ecological risk, are obtained by summing the mER values (Hakanson, 1980; Brady et al., 2015). The following formula is used in the mER calculation:

mER = EF x Tri (Eq.5)

Here, EF represents the enrichment factor and Tri represents the toxic risk coefficient of metals. The following value ranges were considered in the evaluation;mER < 40 low ecological risk, 40 ≤ mER < 80 moderate ecological risk, 80 ≤ mER < 160 significant ecological risk, 160 ≤ mER < 320 high ecological risk, and mER ≥ 320 very high ecological risk interpreted as risk (Hakanson, 1980).

mPER, the sum of the mER values of the metals, is calculated as follows:

$$mPER = \sum_{i=1}^{n} mER \quad \text{(Eq. 6)}$$

The value ranges considered in the interpretation of mPER values are; mPER <150 low ecological risk, 150 ≤ mPER <300 moderate ecological risk, 300 ≤ mPER <600 significant ecological risk, mPER ≥ 600 very high ecological risk (Hakanson, 1980).

***Toxic Risk Index (TRI)***

$The\ TRI_i$ which is used to determine the toxicity risk caused by each metal is formulated as follows (Zhang et al., 2016):

$$TRI_i = \sqrt{\frac{((C_i/TEL)^2 + (C_i/PEL)^2)}{2}} \quad \text{(Eq.7)}$$

In the formula, Ci is the metal concentration, TEL the threshold effect level, and PEL the probable effect level i (Macdonald et al., 1996). The sum of the individual 〖TRI〗_i values for metals gives the integrated TRI as:

$$TRI = \sum_{i=1}^{n} TRI_i \quad \text{(Eq.8)}$$

The following ranges were considered in the interpretation of TRI values; TRI ≤ 5: no toxic risk; 5 < TRI ≤ 10: a low toxic risk; 10 < TRI ≤ 15: a moderate toxic risk; 15 < TRI ≤ 20: a considerable toxic risk; and TRI > 20: a very high toxic risk.

## Results and Discussion

### *Distribution of Total Organic Carbon (OC), $CaCO_3$ and elements*

TOC values of the 21 sediment samples analyzed ranged between 9.69 and 19.12%. The average value is 16.3. The minimum, maximum and average values of $CaCO_3$, on the other hand, are 29.4 and 10.52, respectively. Comparing studies of other lake and dam sediments in Turkey, Lake Arin TOC values are considerably higher than those of several lakes, such as Aygır Lake (Kükrer, 2018) and Çıldır Lake (Kükrer et al., 2015) in Eastern Anatolia, Tortum Lake in the Eastern Black Sea region (Kükrer, 2016; Kaya et al., 2017), as well as Lake Gala (Öztura, 2021), and Küçükçekmece and Terkos in Thrace (Kükrer et al., 2019). The mean values (mg/kg) of the elements are as follows: Al > Fe > Mn > Zn > Ni Co > Pb > Cd > As (Table 1). The presence of Cu and Hg was not detected in the sediment samples. All metals except Pb and Cd were more-or-less detected at each sampling site. Pb was detected in only three sampling sites (5,16,17) while Cd was detected at sampling sites 17,18,20 and 21 (Table 1).

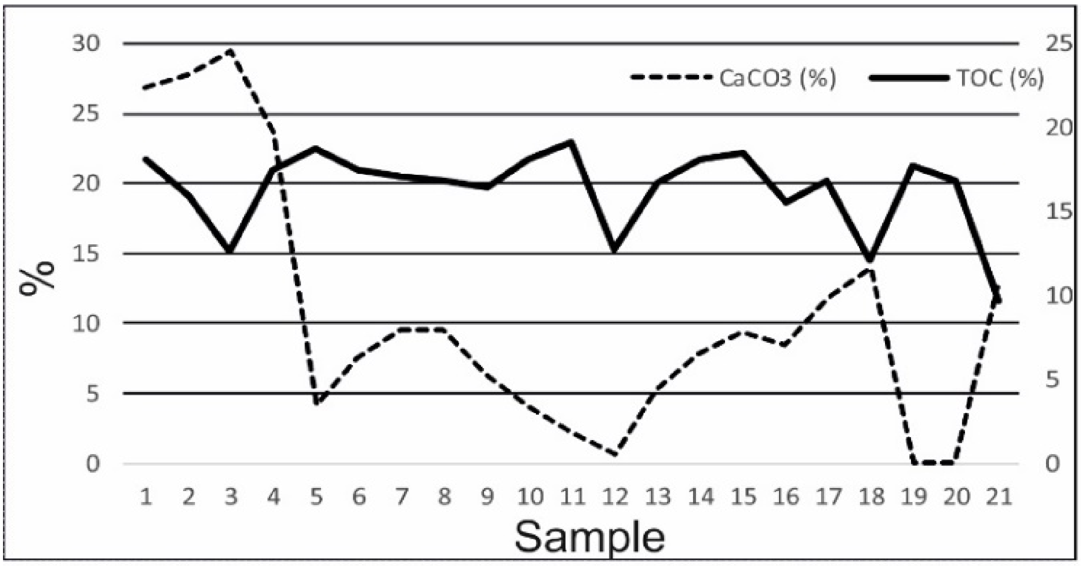


Fig. 2. Total OC and $CaCO_3$ distribution.

Table 1. Distribution of metals according to ICP-OES results (mg/kg).

| Sample | As (mg/kg) | Zn (mg/kg) | Pb (mg/kg) | Cd (mg/kg) | Co (mg/kg) | Ni (mg/kg) | Mn (mg/kg) | Fe (%) | Al (%) |
|---|---|---|---|---|---|---|---|---|---|
| **1** | 0.039 | 131.86 | - | - | 3.39 | 8.14 | 168.07 | 0.27 | 0.58 |
| **2** | 0.002 | 75.27 | - | - | 2.38 | 5.52 | 159.25 | 0.21 | 0.37 |
| **3** | 0.063 | 181.36 | - | - | 4.61 | 10.75 | 245.19 | 0.39 | 0.68 |
| **4** | 0.07 | 250.57 | - | - | 4.10 | 10.86 | 294.23 | 0.45 | 1.01 |
| **5** | 0.063 | 118.91 | 0.054 | - | 7.11 | 14.26 | 319.46 | 0.8 | 1.71 |
| **6** | - | 182.34 | - | - | 7.30 | 14 | 322.69 | 0.96 | 2.25 |
| **7** | 0.073 | 199.18 | - | - | 7.42 | 12.77 | 378.8 | 0.53 | 0.87 |
| **8** | 0.04 | 154.4 | - | - | 5.20 | 10.21 | 231.4 | 0.59 | 1.51 |
| **9** | 0.09 | 155.34 | - | - | 4.60 | 12.76 | 290.4 | 0.76 | 1.32 |
| **10** | 0.08 | 141.92 | - | - | 5.15 | 8.96 | 353.46 | 0.92 | 2.92 |
| **11** | 0.11 | 232.4 | - | - | 5.76 | 8.43 | 392.2 | 1.19 | 4.02 |
| **12** | 0.10 | 284.46 | - | - | 10.40 | 12.55 | 497.69 | 1.72 | 1.55 |
| **13** | 0.05 | 125.03 | - | - | 7.74 | 17.91 | 422.5 | 1.14 | 2.75 |
| **14** | 0.08 | 74.57 | - | - | 8.85 | 16.13 | 372.88 | 0.83 | 1.29 |
| **15** | 0.05 | 213.14 | - | - | 6.59 | 7.40 | 439.44 | 1.39 | 3.54 |
| **16** | 0.17 | 142.66 | 1.99 | - | 13.70 | 26.62 | 565 | 1.14 | 1.24 |
| **17** | 0.11 | 201.25 | 0.87 | 0.26 | 6.97 | 21.51 | 343.57 | 0.51 | 0.59 |
| **18** | 0.09 | 75.05 | - | 0.23 | 4.31 | 11.33 | 211.92 | 0.25 | 0.37 |
| **19** | 0.16 | 189.36 | - | - | 8.12 | 18.04 | 243 | 1.12 | 3.87 |
| **20** | 0.17 | 143.4 | - | 0.24 | 9.77 | 23.34 | 358.2 | 1.4 | 4.93 |
| **21** | 0.15 | 133.7 | - | 0.26 | 3.03 | 12.21 | 174.32 | 0.12 | 0.26 |
| **Average** | **0.08** | **162.19** | **0.97** | **0.24** | **6.5** | **13.5** | **323.03** | **0.79** | **1.79** |

Table 2. EF values of metals measured in Lake Arin.

| Sample | Zn | Ni | Mn | Fe | As | Co |
|---|---|---|---|---|---|---|
| **1** | **3.29** | **3.64** | 1.57 | 0.53 | 1.63 | 0.64 |
| **2** | **2.95** | **3.88** | **2.33** | 0.65 | 0.13 | 0.70 |
| **3** | **3.90** | **4.15** | 1.97 | 0.68 | **2.28** | 0.77 |
| **4** | **3.61** | **2.81** | 1.59 | 0.52 | 1.70 | 0.46 |
| **5** | 1.02 | **2.19** | 1.02 | 0.54 | 0.91 | 0.47 |
| **6** | 1.18 | 1.64 | 0.78 | 0.49 | 0.00 | 0.37 |
| **7** | **3.35** | **3.85** | **2.38** | 0.71 | **2.06** | 0.97 |
| **8** | 1.50 | 1.78 | 0.84 | 0.45 | 0.65 | 0.39 |
| **9** | 1.71 | **2.52** | 1.19 | 0.66 | 1.78 | 0.39 |
| **10** | 0.71 | 0.80 | 0.66 | 0.36 | 0.74 | 0.20 |
| **11** | 0.85 | 0.55 | 0.53 | 0.34 | 0.71 | 0.16 |
| **12** | **2.34** | **2.12** | 1.75 | 1.28 | 1.63 | 0.76 |
| **13** | 0.66 | 1.71 | 0.84 | 0.48 | 0.48 | 0.32 |
| **14** | 0.84 | **3.29** | 1.58 | 0.75 | 1.66 | 0.78 |
| **15** | 0.88 | 0.55 | 0.68 | 0.45 | 0.38 | 0.21 |
| **16** | 1.68 | **5.66** | **2.49** | 1.07 | **3.48** | 1.26 |
| **17** | **4.93** | **9.49** | **3.14** | 0.99 | **4.78** | 1.32 |
| **18** | **2.96** | **8.05** | **3.13** | 0.81 | **6.05** | 1.32 |
| **19** | 0.72 | 1.23 | 0.34 | 0.33 | 1.06 | 0.24 |
| **20** | 0.43 | 1.25 | 0.40 | 0.33 | 0.86 | 0.22 |
| **21** | **7.27** | **11.95** | **3.54** | 0.53 | **14.26** | 1.28 |
| **Average** | **2.22** | **3.48** | **1.55** | **0.61** | **2.24** | **0.63** |

*(Bold numbers show enrichment)*

Table 3. CF (Contamination Factor) and mCD (modified Degree of Contamination) values of metals measured in Lake Arin.

| Sample | Zn | Ni | Mn | Fe | As | Co | Al | mCD |
|---|---|---|---|---|---|---|---|---|
| **1** | 0.6 | 0.67 | 0.29 | 0.1 | 0.3 | 0.12 | 0.18 | 0.21 |
| **2** | 0.34 | 0.45 | 0.27 | 0.08 | 0.02 | 0.08 | 0.12 | 0.12 |
| **3** | 0.83 | 0.88 | 0.42 | 0.14 | 0.48 | 0.16 | 0.21 | 0.29 |
| **4** | **1.15** | 0.89 | 0.5 | 0.17 | 0.54 | 0.15 | 0.32 | 0.34 |
| **5** | 0.54 | **1.17** | 0.55 | 0.29 | 0.48 | 0.25 | 0.54 | 0.35 |
| **6** | 0.83 | **1.15** | 0.55 | 0.35 | 0 | 0.26 | 0.7 | 0.35 |
| **7** | 0.91 | **1.05** | 0.65 | 0.19 | 0.56 | 0.26 | 0.27 | 0.35 |
| **8** | 0.71 | 0.84 | 0.4 | 0.21 | 0.31 | 0.19 | 0.47 | 0.28 |
| **9** | 0.71 | **1.05** | 0.5 | 0.27 | 0.74 | 0.16 | 0.42 | 0.35 |
| **10** | 0.65 | 0.73 | 0.6 | 0.33 | 0.68 | 0.18 | 0.91 | 0.37 |
| **11** | **1.06** | 0.69 | 0.67 | 0.43 | 0.89 | 0.2 | **1.26** | 0.47 |
| **12** | **1.14** | **1.03** | 0.85 | 0.62 | 0.79 | 0.37 | 0.49 | 0.48 |
| **13** | 0.57 | **1.48** | 0.72 | 0.41 | 0.42 | 0.27 | 0.86 | 0.43 |
| **14** | 0.34 | **1.33** | 0.64 | 0.3 | 0.67 | 0.31 | 0.4 | 0.36 |
| **15** | 0.97 | 0.61 | 0.75 | 0.5 | 0.42 | 0.23 | **1.11** | 0.42 |
| **16** | 0.65 | **2.19** | 0.97 | 0.41 | **1.35** | 0.49 | 0.39 | 0.59 |
| **17** | 0.92 | **1.77** | 0.59 | 0.18 | 0.89 | 0.25 | 0.19 | 0.44 |
| **18** | 0.34 | 0.93 | 0.36 | 0.09 | 0.7 | 0.15 | 0.12 | 0.25 |
| **19** | 0.87 | **1.48** | 0.42 | 0.4 | **1.28** | 0.29 | **1.21** | 0.54 |
| **20** | 0.66 | **1.92** | 0.61 | 0.51 | **1.33** | 0.35 | **1.54** | 0.63 |
| **21** | 0.61 | **1.01** | 0.3 | 0.04 | **1.2** | 0.11 | 0.08 | 0.30 |
| **Average** | 0.73 | **1.11** | 0.55 | 0.28 | 0.66 | 0.23 | 0.56 | 0.38 |

* *(Numbers in bold show contamination)*

***EF results***

The EF is an index that is frequently used to determine the possible sources of metals, to determine the anthropogenic effect and its degree, and the varying values of the metals depending on the grain size differences, which are removed by normalization with Al. The mean enrichment factors of the metals studied in Lake Arin are Ni > As > Zn > Mn > Fe > Co in decreasing order. In general, the highest enrichment was found at sampling sites 17, 18 and 21. For Zn, moderate enrichment was found at the sampling sites 1,2,3,4,7,12,17 and 18 while significant enrichment is in question at sampling site 21. There was no or minimal enrichment at other sampling sites. For Ni, there is moderate enrichment at sampling sites 1,2,3,4,5,7,9,12,14 and significant enrichment at sampling sites 16, 17, 18 and 21. In other sampling sites, enrichment is absent or minimal (Table 2).

While Mn shows moderate enrichment in sampling sites 2,7,16,17,18,21, there is no enrichment or minimal enrichment in all the remaining sampling sites. While As shows moderate enrichment at sampling sites 3, 7, 16 and 17, it is significantly enriched at sampling sites 18 and 21. No enrichment / minimal enrichment was detected at other sampling sites. No enrichment / minimal enrichment was detected at all sampling sites for Fe and Co. According to the average data, moderate enrichment was determined for Zn, Ni and As. Moderate enrichment was detected for As (2.24) and the source of As in the sediment was determined to be anthropogenic, since the background value for As (0.13) was exceeded. As causes a moderate (2.24) enrichment in the studied sediment samples. Recent publications have suggested that the main anthropogenic sources of As are chemical fertilizers and fossil fuel use (Atabey, 2009). Anthropogenic As enrichment has been determined in relation to agricultural activities in both natural lakes (Şener and Şener, 2015) and dam sediments in Turkey (Kırmizigül, 2013; Fural, 2020). Ni is of lithological origin, as determined elsewhere (Kükrer et al., 2015).

***CF results***

According to the CF analyses performed to identify the sources of metals in the Lake Arin sediments, the CF values are Ni > Zn > As > Al > Mn > Fe > Co, in decreasing order. In general, the largest CF value was determined at the 16th sampling site (2.19). In terms of Zn, moderate contamination was detected at sampling sites 4, 11 and 12, and low contamination was detected at other stations. Ni shows moderate contamination at sampling sites 5,6,7,9,12,13,16,17,19,20 and 21, and low contamination at other stations. As shows moderate contamination at four sampling sites (16,19,20 and 21) and low contamination in other samples (Table 3). Similarly, in terms of Al, moderate contamination was detected at four sampling sites (11, 15, 19 and 20) and low at other stations. While Mn, Fe and Co metals indicate low contamination in all stations, it was determined that a moderate contamination range was reached in some stations in terms of Al, As, and Zn values, and there was generally low contamination, except for Ni. Although moderate contamination was detected for Ni (1.11), the Ni source in the sediment was not anthropogenic but of natural origin, since the background value for Ni (12.13) was not exceeded (Table 3). Ni can be found in high concentration in volcanic rocks. Since volcanic rocks cover a large area in the Lake Arin basin, moderate enrichment of Ni may be lithological. Thus, while the lithological background value for Ni was (12.3), the enrichment ratio for the sediment samples was found to be (1.11). Lake Arin is a wetland without intensive agricultural activities around it, and the CF data obtained does not pose a risk.

***Igeo index results***

Igeo analyses performed to evaluate the pollution level created by the metals in the Lake Arin sediments and whether the metal sources are natural or anthropogenic (Meng and Li, 1985) revealed that all values are negative, suggesting that the lake is not polluted in terms of Zn, Ni, Co, Mn, Fe, As and Al (Table 4). Lake Arin is a relatively isolated lake without dense settlement, intensive agriculture or industrial activities around it. Therefore, when these features are taken into consideration, they are compatible with the data obtained in terms of the Igeo index. Consistent with previous studies (Kükrer, 2016, 2017, 2018; Kaya et al., 2017), high altitude lakes are not polluted as they are far from residential areas, industrialization and agricultural activities, and therefore they are not exposed to agricultural or industrial waste discharges.

***TRI (Toxic Risk Index), mPER (Modified Potential Ecological Risk index) and mCd (modified Degree of Contamination) results***

Results obtained from TRI, mPER and mCED index calculations are presented in Table 5. As is known, toxic ecological risk is an important ecological risk index that determines the toxic effect limits of metals based on toxicological experimental studies and determines the concentration thresholds at which they begin to become harmful. As seen in Table 5, there is no risk for TRI in Lake Arin (TRI $\leq$ 5 no toxic risk). The PER index (Hakanson, 1980) values, which are used to reach predictions about the potential toxic effects of metals accumulated in the sediment on the ecosystem, explain the presence of low ecological risk in both sampling sites and average values (PER<150 low ecological risk). Similarly, since mCd values are well below 1, there is a very low risk (mCd <1.5 is very low; Abrahim and Parker, 2008).

**Conclusion**

Heavy metal contents and their potential ecological risk were studied in sediment samples collected from 21 selected sampling sites in Lake Arin. Moderate enrichment was detected for Ni, As and Zn and moderate contamination for Ni. Ecological risk values calculated for each metal were generally below the limit values. The PER value indicated moderate ecological risk in one sampling site and low ecological risk in other sites, while low ecological risk emerged compared to the mean. The second highest EF value belongs to As. It is thought that the source of As originates from the use of fossil fuels used in the region. We conclude that the metals studied in Lake Arin are not presently in concentrations that may pose a risk to the ecosystem.

## Acknowledgements

This research includes the results of the postgraduate thesis of the first author and was supported by Çanakkale Onsekiz Mart University Scientific Research Projects Unit, within the scope of the graduate thesis project coded SYL-2021-3802. We thank Şakir Fural for his valuable support with the ecological risk index calculations.

Table 4. Igeo values of metals measured in Lake Arin.

| Sample | Zn | Ni | Mn | Fe | As | Co | Al |
|---|---|---|---|---|---|---|---|
| 1 | -1.32 | -1.17 | -2.38 | -3.94 | -2.32 | -3.67 | -13.83 |
| 2 | -2.12 | -1.73 | -2.46 | -4.3 | -6.61 | -4.19 | -14.35 |
| 3 | -0.86 | -0.77 | -1.84 | -3.38 | -1.63 | -3.19 | -13.35 |
| 4 | -0.39 | -0.75 | -1.58 | -3.18 | -1.48 | -3.36 | -13.52 |
| 5 | -1.46 | -0.36 | -1.46 | -2.37 | -1.63 | -2.57 | -12.72 |
| 6 | -0.85 | -0.38 | -1.44 | -2.11 | 1.62 | -2.53 | -12.68 |
| 7 | -0.72 | -0.52 | -1.21 | -2.96 | -1.42 | -2.51 | -12.66 |
| 8 | -1.09 | -0.83 | -1.92 | -2.81 | -2.29 | -3.02 | -13.17 |
| 9 | -1.08 | -0.52 | -1.6 | -2.45 | -1.02 | -3.19 | -13.35 |
| 10 | -1.21 | -1.03 | -1.31 | -2.17 | -1.15 | -3.04 | -13.2 |
| 11 | -0.5 | -1.12 | -1.16 | -1.8 | -0.75 | -2.88 | -13.04 |
| 12 | -0.4 | -0.54 | -0.82 | -1.27 | -0.92 | -2.02 | -12.17 |
| 13 | -1.39 | -0.02 | -1.05 | -1.87 | -1.85 | -2.45 | -12.61 |
| 14 | -2.14 | -0.18 | -1.23 | -2.31 | -1.16 | -2.26 | -12.41 |
| 15 | -0.62 | -1.3 | -1 | -1.58 | -1.85 | -2.69 | -12.85 |
| 16 | -1.2 | 0.55 | -0.64 | -1.86 | -0.16 | -1.62 | -11.78 |
| 17 | -0.7 | 0.24 | -1.35 | -3.03 | -0.75 | -2.61 | -12.76 |
| 18 | -2.13 | -0.69 | -2.05 | -4 | -1.1 | -3.29 | -13.45 |
| 19 | -0.79 | -0.02 | -1.85 | -1.89 | -0.23 | -2.38 | -12.53 |
| 20 | -1.19 | 0.36 | -1.29 | -1.56 | -0.17 | -2.12 | -12.27 |
| 21 | -1.29 | -0.58 | -2.33 | -5.07 | -0.32 | -3.8 | -13.95 |
| **Average** | -1.11 | -0.54 | -1.52 | -2.66 | -1.29 | -2.8281 | -12.98 |

**Table 5.** TRI, mPER and mCED values of metals measured in Lake Arin.

| Sample | Zn | Ni | As | Cd | mPER | Zn | Ni | As | TRI | mCd |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 3.29 | 18.2 | 16.35 | 19.23 | **57.06** | 0.79 | 0.27 | 0.0029 | **1.08** | **0.21** |
| 2 | 2.95 | 19.42 | 1.32 | 21.07 | **44.76** | 0.45 | 0.18 | 0.00015 | **0.64** | **0.12** |
| 3 | 3.9 | 20.74 | 22.79 | 23.13 | **70.57** | 1.09 | 0.36 | 0.0047 | **1.47** | **0.29** |
| 4 | 3.61 | 14.04 | 16.98 | 13.83 | **48.46** | 1.51 | 0.37 | 0.0052 | **1.89** | **0.34** |
| 5 | 1.02 | 10.93 | 9.05 | 14.18 | **35.18** | 0.71 | 0.48 | 0.0047 | **1.21** | **0.35** |
| 6 | 1.18 | 8.19 | 0 | 11.08 | **20.45** | 1.1 | 0.48 | 0 | **1.58** | **0.35** |
| 7 | 3.35 | 19.23 | 20.63 | 29.06 | **72.26** | 1.2 | 0.43 | 0.0054 | **1.65** | **0.35** |
| 8 | 1.5 | 8.91 | 6.52 | 11.78 | **28.71** | 0.93 | 0.35 | 0.003 | **1.29** | **0.28** |
| 9 | 1.71 | 12.61 | 17.79 | 11.85 | **43.97** | 0.93 | 0.43 | 0.0072 | **1.38** | **0.35** |
| 10 | 0.71 | 4.01 | 7.4 | 5.96 | **18.09** | 0.85 | 0.3 | 0.0066 | **1.17** | **0.37** |
| 11 | 0.85 | 2.76 | 7.1 | 4.85 | **15.56** | 1.4 | 0.28 | 0.0087 | **1.7** | **0.47** |
| 12 | 2.34 | 10.62 | 16.33 | 22.91 | **52.19** | 1.5 | 0.42 | 0.0077 | **1.94** | **0.48** |
| 13 | 0.66 | 8.56 | 4.82 | 9.55 | **23.59** | 0.75 | 0.61 | 0.004 | **1.37** | **0.43** |
| 14 | 0.84 | 16.45 | 16.59 | 23.32 | **57.2** | 0.45 | 0.55 | 0.0065 | **1.01** | **0.36** |
| 15 | 0.88 | 2.76 | 3.75 | 6.28 | **13.67** | 1.28 | 0.25 | 0.004 | **1.55** | **0.42** |
| 16 | 1.68 | 28.31 | 34.76 | 37.82 | **102.57** | 0.86 | 0.91 | 0.013 | **1.79** | **0.59** |
| 17 | 4.93 | 47.46 | 47.79 | 39.51 | **139.69** | 1.21 | 0.73 | 0.0087 | **1.96** | **0.44** |
| 18 | 2.96 | 40.23 | 60.46 | 39.71 | **143.35** | 0.45 | 0.38 | 0.0068 | **0.85** | **0.25** |
| 19 | 0.72 | 6.13 | 10.55 | 7.16 | **24.56** | 1.14 | 0.61 | 0.012 | **1.78** | **0.54** |
| 20 | 0.43 | 6.24 | 8.64 | 6.73 | **22.04** | 0.86 | 0.8 | 0.013 | **1.44** | **0.63** |
| 21 | 7.27 | 59.76 | 142.61 | 38.5 | **248.14** | 0.8 | 0.41 | 0.011 | **1.46** | **0.3** |
| **Average** | 2 | 17 | 22 | 19 | 61 | 1 | 0 | 0.01 | 1.439 | 0.4 |

**References**


Abrahim, G., Parker, R., (2008). Assessment of Heavy Metal Enrichment Factors and the Degree of Contamination in Marine Sediments from Tamaki Estuary, Auckland, New Zealand. *Environmental Monitoring and Assessment,* 136,227-223. https://doi.org/10.1007/s10661-007-9678-2.

Achary, M. S., Satpathy, K. K., Panigrahi, S., Mohanty, A. K., Padhi, R. K., Biswas, S., et al. (2017). Concentration of heavy metals in the food chain components of the nearshore coastal waters of Kalpakkam, southeast coast of India. Food Control 72:232–243.

Atabey, E. (2009). Arsenik ve Etkileri. Ankara: Maden Tetkik ve Arama Genel Müdürlüğü Yayınları,

Brady, J.P., Ayoko, G.A., Martens, W.N., & Goonetilleke, A. (2015). Development of a hybrid pollution index for heavy metals in marine and estuarine sediments. *Environmental Monitoring and Assessment,* 187.

Çelik, M.A., Kopar, İ., Bayram, H. (2018). Doğu Anadolu Bölgesi'nin Mevsimlik Kuraklık Analizi. *Atatürk Üniversitesi Sosyal Bilimler Enstitüsü Dergisi,* 22(3), 1741-1761.

Fural, Ş. (2020). İkizcetepeler Baraj Gölü Çökellerinin (Balıkesir) Ekolojik Risk Analizi. Doktora Tezi. Balıkesir. Balıkesir Üniversitesi, Sosyal Bilimler Enstitüsü.

Gaudette, H., Flight., W, Toner, L., Folger, D., (1974). An Inexpensive Titration Method For The Determination Of Organic Carbon İn Recent Sediments. J*ournal of Sedimentary Research* (44), 249-253.

Hakanson, L. (1980). An ecological risk index for aquatic pollution control: A sedimentological approach. *Water Research, 14,* 975- 1001.

Hoşgören, M.Y. (1994). Türkiye Gölleri. *Türk Coğrafya Dergisi, 29,* 19-51.

Kamar, G., (2018). Palynology of Lake Arin (Eastern Anatolia, Turkey) deposits and its relation with water level change of Lake Van: Preliminary Findings. *Quaternary International,* 486, 83-88.

Kaya, H., Erginal, G., Çakır, Ç., Gazioğlu, C., Erginal, A., (2017) Ecological Risk Evaluatıon of Sediment Core Samples, Lake Tortum (Erzurum, NE Turkey) Using Environmental İndices. *International Journal of Environment and Geoinformatics,* 4(3), 227-239

Kırmızıgül, O. (2013). Gökçekaya Baraj Gölü Dip Sedimentinin Ağır Metal Düzeylerinin Belirlenmesi. Yüksek Lisans Tezi. Ankara: Gazi Üniversitesi, Fen Bilimleri Enstitüsü.

Kükrer, S. (2016). Tortum Gölü yüzey sedimentlerindeki metal birikiminin ekolojik indeksler yolu ile kapsamlı risk değerlendirmesi. *Türk Tarım-Gıda Bilim ve Teknoloji dergisi,* 4(12), 1185-1191.

Kükrer, S., (2017). Pollution Source, and Ecological Risk Assessment of Trace Elements İn Surface Sediments of Lake Aktaş, NE Turkey. *Human and Ecological Risk Assessment,* 7, 1629-1644.https://

Kükrer, S., (2018). Vertical and Horizontal Distribution, Source İdentification, Ecological and Toxic Risk Assessment of Heavy Metals İn Sediments of Lake Aygır, Kars, Turkey. *Environmental Forensics,* (19), 122-133.

Kükrer, S., Çakır, Ç. Kaya, H., Erginal, E. A., (2019). Historical Record of Metals in Lake Küçükçekmece and Lake Terkos (Istanbul, Turkey) Based on Anthropogenic İmpacts and Ecological Risk Assessment. *Environmental Forensics,* 4, 385-401.

Kükrer, S., Erginal A.E., Kılıç, Ş., Bay, Ö., Akarsu, T., Öztura, E., (2020). Ecological Risk Assessment of Surface Sediment of Çardak Lagoon Along a Human Disturbance Gradient. *Environmental Monitoring and Assessment,* 192 (3599).

Kükrer, S., Erginal, A. E., Şeker, S., Karabıyıkoğlu, M., (2015). Distribution and environmental risk evaluation of heavy metal in core sediments from Lake Çıldır (NE Turkey). *Environmental Monitoring and Assessment,* 187, 1-14.

Lahn, E. (1951)Bazı Türkiye Gölleri'nin Jeolojisi ve Jeomorfolojisi. *MTA Dergisi.* 41,71-83. Ankara.

MacDonald. DD., Carr, RS., Calder, FD., Long, ER., Ingersoll, CG. (1996) Development and Evaluation of Sediment Quality Guidelines For Florida Coastal Waters. *Ecotoxicology* 5:253-278.

Meng, X., and Li, S., (1985) Study on Background Value of Soil Environment of the Jilin Province. *Environ Science.* (40), 70-91.

Müller, G. (1969). Index of geo-accumulation in sediments of the Rhine river. *Geochem, J.,* 2,108 - 118.

Öztura, E. (2021), Trakya Bölgesindeki Seçilmiş Göllerde Antropojenik Kaynaklı Sediment Kirliliğinin Ekolojik Riskler Açısından Araştırılması (Küçük Çekmece Gölü, Durusu/Terkos Gölü, Gala Gölü, Mert Gölü), Doktora Tezi. Çanakkale: Çanakkale Onsekiz Mart Üniversitesi, Lisansüstü Eğitim Enstitüsü.

Schlicting, E., Blume, E., (1966). Bodenkundliches Practicum. Editor: Parey, VP Hamburg, 94.

Şener, Ş., Şener, E. (2015). Kovada Gölü (Isparta) Dip Sedimanlarında Ağır Metal Dağılımı ve Kirliliğin Değerlendirilmesi. Süleyman Demirel Üniversitesi Fen Bilimleri Enstitüsü, 19 (2), 86-96.

Sutherland, R. A. (2000). Bed Sediment-associated Trace Metals in Urban Stream, Oahu, Hawaii. *Environmental Geology, 39,* 611-627.

Vrhovnik, P., Šmuc, N. R., Dolenec, T., Serafimovski, T., Dolenec, M. (2013). An evaluation of trace metal distribution and environmental risk in sediments from the Lake Kalimanci (FYR Macedonia). *Environmental Earth Sciences, 70,*(2), 761–775.

Zhang, G., Bai, J., Zhao, Q. (2016). Heavy Metals in Wetland Soils Along a Wetland-forming Chronose Quence in the Yellow River Delta of China: Levels, *Sources and Toxic Risks. Ecological Indicators.*

Zhang, X., Shyy, W., Sastry, AM., (2007). Numerical Simulation of İntercalation- İnduced Stress İn Li-on Battery Electrote Particles. *Journal of the Electrochemical Society.* 154(10),A910.