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Multi-index assessment of heavy metals and selenium contamination and ecological risk in drought-impacted Karataş lake sediments (Burdur-Türkiye)

by

Selda Tekin-Özan[1,*,a], Şule Özçelik[2,b]

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[1] *Süleyman Demirel University, Faculty of Engineering and Natural Sciences, Department of Biology, Isparta, Türkiye*
[2] *Independent Researcher, Isparta, Türkiye*

[a] *(https://orcid.org/0000-0002-8756-8859)*
[b] *(https://orcid.org/0000-0003-2938-7635)*

* Corresponding author: *seldaozan@sdu.edu.tr*

Abstract

Karataş Lake is a significant lake in Türkiye and completely dried up in 2021. In subsequent years, the lake intermittently retained water due to redirected water resources and increased precipitation. This seasonal study conducted between October 2019 and July 2020 investigated the concentrations of Cd, Cr, Cu, Fe, Mn, Mo, Ni, Zn, and Se in sediment samples collected from four stations. Metal concentrations were measured by an inductively coupled plasma optical emission spectrometer (ICP-OES). Pollution levels and possible sources were assessed using indices, including enrichment factor (EF), geoaccumulation index (I_{geo}), pollution load index (PLI), contamination factor (CF), contamination degree (CD), modified contamination degree (mCD), modified ecological risk (mER), and modified potential ecological risk (mPER). The levels of metals in sediments followed the order: Fe > Mn > Ni > Zn > Cr > Cu > Pb > Se > Mo > Cd. These results indicated considerable ecological risk, particularly associated with Ni and Se. Comparisons with sediment quality guidelines revealed the annual concentrations of Ni exceeded multiple threshold and effect levels. These findings emphasize the need for urgent management measures to regulate agricultural runoff, control water abstraction, and increase water input to protect Karataş Lake and ensure its long-term sustainability.

Key words: Karataş Lake, Heavy metal, Pollution indices, Sediment, Türkiye

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1. Introduction

Wetlands are one of the most important ecosystems on earth and are ecologically and economically important because they have rich biological diversity (Campbell & Reece, 2021). Wetlands have been polluted in recent years. Fecal and organic wastes, chemical and radioactive wastes, excessive use of pesticides and fertilizers, petroleum derivatives, detergents, waste heat, herbicides, nutrient salts, suspended solids, heavy metals, and power plants are the main causes of water pollution (Hu, 2000; Yarsan et al., 2000). Among these, the most common and dangerous pollutants are heavy metals (Censi et al., 2006; Vu et al., 2018). Heavy metals enter the aquatic systems through natural sources such as volcanic activities, atmospheric events, erosion, geological weathering, wind, bioturbation and anthropogenic activities such as mining, rapid industrialization, forest fires, urbanization, domestic wastes, agricultural runoff, and industrial wastes (Ali et al., 2019, 2022; Kabir et al., 2020; Proshad et al., 2019; Tekin-Özan et al., 2024; Zabir et al., 2016). Heavy metals are considered the major chemical pollutants and very dangerous for environment owing to easy bioaccumulation, persistence, bio toxicity characteristics, non-biodegradability and difficulty removing from water (Fan et al., 2020; Hossain et al., 2020; Khan et al., 2019; Liu et al., 2016, 2020; Nour et al., 2019; Vu et al., 2018; Zhang et al., 2019). Heavy metals, which enter the aquatic systems in different ways affect the water quality, precipitate into the sediment and accumulate in some living things such as fish, birds, and humans via food chain (Tepe, 2014; Zhao et al., 2017). The metals analyzed in the present study were selected because they are persistent, potentially toxic, and widely used as indicators of sediment contamination and ecological risk in aquatic ecosystems (Alloway, 2013; Buchman, 2008; Förstner & Wittmann, 1981).

Sediment consists of organic and inorganic waste particles at the lake bottom transported to the aquatic systems in different ways (Golterman et al., 1983). Sediment is the living, feeding, egg laying, and breeding area of the aquatic organisms. For this reason, sediment pollution affects the aquatic organisms directly or indirectly (Goyer, 1986; Kaushik et al., 2009; Xu et al., 2017). Sediment is the most important and sensitive indicator used to monitor pollutants in water (Şener et al., 2023a). It is known that after metals enter the aquatic systems, sediment serves as both a source and a sink (Algül & Beyhan, 2020). When heavy metals enter water, they precipitate by adhering to suspended particles and accumulate in the sediment (Dora, 2005). Changes in environmental parameters such as pH, redox potential, temperature, and salinity in the water column above the sediment cause heavy metals to be released back into the water column (Förstner & Wittmann, 1981; Mohanta et al., 2020; Pachana et al., 2010; Soares et al., 1999). When heavy metals are released from sediment to water, they cause secondary pollution in water and disrupt the ecological balance (Kennish, 1997; Niu et al., 2015). Heavy metals are five times more abundant in the sediment than in the water column (Goher et al., 2017).

Determining the levels of heavy metals in lake sediment doesn't help us detect toxic levels and sources of metals. For this reason, many indices have been developed to determine the degree of contamination and ecological risks of heavy metals in aquatic systems and are widely used by many scientists around the world (Ali et al., 2022; Çevik et al., 2009; Dai et al., 2018; El-Amier et al., 2017; Fındık & Turan, 2012; Guo et al., 2015; Niu et al., 2020; Özçelik & Tekin-Özan, 2024; Redwan & Elhaddad, 2022; Şener et al., 2023a; Tekin-Özan et al., 2024; Yuan et al., 2014; Yu et al., 2021). Özçelik and Tekin-Özan (2024) evaluated heavy metal pollution in Eğirdir Lake using some indices like EF, I_{geo}, and CF. Pb was at an extremely high enrichment level (EF > 40) in winter and autumn while at a very high enrichment level (EF = 20–40) in spring and summer. Eğirdir Lake was not polluted with Ni, Mo, Fe, Mn, Cu, Cr, and Zn in all seasons according to the I_{geo}. Depending on CF values of the Eğirdir Lake sediment in the moderately contaminated category (1 < CF < 3) with Cd and Pb, in the considerably contaminated category (3 < CF < 6) with Se in all seasons. Şener et al. (2023a) reported PLI values in Beyşehir Lake (Türkiye) between 0.649 and 0.976 and declared that the lake sediment does not carry a risk of heavy metal pollution. Şener et al. (2023a) calculated EF values of Beyşehir Lake's sediment and found that As, Cr, Cu, Ni, Pb, and Cd were at a significant enrichment level. In a study carried out in Beyşehir Lake, Zn, Pb, and Hg were in the low contamination category according to CF values (Şener et al., 2023a). In addition to indices, some sediment quality guidelines (SQGs) have been developed by MacDonald et al. (2000) to protect the living things in the freshwater systems.

The Lakes Region is an area located in the southwest of Türkiye and contains 36 wetlands, which are very important in terms of economic, ecological and tourism (Oruçoğlu & Beyhan, 2019). Of all, 16 of these wetlands dried out in the last 30 years, and 20 of them are facing drought and water shortage (Işıldar & Ercoşkun, 2021). Karataş Lake is an important lake located in the lakes region. Unfortunately, it completely dried up in 2021. In the following years, it was able to hold water from time to time thanks to both the redirection of water resources in the basin and increased precipitation (Doğru Haber, 2022; Tekin-Özan et al., 2024). However, more recent reports indicate that the lake has largely dried again by late 2025 due to ongoing drought conditions (Çağdaş Burdur, 2025), highlighting the continued vulnerability of the system. Karataş Lake is 20 km away from Tefenni District and located between 37° 23′ 9″ E and 29° 58′ 18″ N (Seçmen & Leblebici, 2008). It was formed as a result of tectonic effects (Senkul & Kalıpcı, 2019). The lake is located at an altitude of 1050–1070 m above sea levels (Turkish State Meteorological Service, 2024). The main waters flowing into the lake are Akçay, Bozçay, and Bademli Stream (Karamanlı Kaymakamlığı, 2019). There are many reed and grain fields around the lake (Kazancı, 1999). There were 121 bird species in and around the lake, 61 of which were water birds, and it was an important nesting and sheltering area for these birds (Karamanlı Kaymakamlığı, 2019). In the past years, although Karataş Lake was used for fishing activities, tourism, agriculture, and irrigation and has great ornithological importance, unfortunately its water has decreased in recent years and has dried out from time to time (Kazancı, 1999; Kurt, 2006; Tekin-Özan et al., 2024; Turkish State Meteorological Service, 2024; Yarar & Magnin, 1997). Karataş Lake has been accepted as 'Wildlife Protection Area' in 2006 by council of ministers (Ministry of Forestry and Water Management, 2017).

Heavy metal pollution in Karataş Lake was investigated by some researchers in different years (Başyiğit & Tekin-Özan, 2013; Kaya, 2021; Kır et al., 2006; Oruçoğlu & Beyhan, 2019; Tekin-Özan et al., 2024). Kır et al. (2006) carried out a study about heavy metal contamination in organs of *Scardinius erythrophthalmus* living in Karataş Lake. Another study carried out 2010–2011, aimed to determine heavy metal levels in water, sediment, and some organs such as liver, muscle, and gill of *Sander lucioperca* living in Karataş Lake (Başyiğit & Tekin-Özan, 2013). At the end of the study, they reported that the levels of metals in sediment were listed as follows: Fe > Mn > Ni > > Zn > Cr > Cu > Se > Pb > Mo > Cd. Metal levels in sediment increased in autumn and decreased in spring. They emphasized that metal levels in sediment may have decreased in spring due to water circulation. Oruçoğlu and Beyhan (2019) published an article which was focus on some metal levels (Zn, Cr, Mn, Fe, Cu, Co, Ni, Al, As, Mo, B, Ti, Vn, and Ba) in water of Karataş Lake. They determined that the lake water was in I. water quality class. In a study carried out in Karataş Lake in 2019, water, sediment and *Carassius carassius* samples were taken from the lake and the concentrations of Pb, Cr, Cd, Cu and Zn were investigated (Kaya, 2021). Pb and Cd in the lake sediment were below the analysis limit. They found Cr levels between 10.66 mg · kg^{-1} and 275.25 mg · kg^{-1}, Cu levels between 1.78 mg · kg^{-1} and 42.81 mg · kg^{-1} and Zn levels between 4.60 mg · kg^{-1} and 67.60 mg · kg^{-1}. According to EF, it was determined that Cr was significantly enrichment levels and Cu and Zn were moderate enrichment level. The results of the I_{geo} show that the sediment of Karataş Lake are not contaminated with heavy metals except for Cr. In another study carried out in the same period as this study, some heavy metal levels in water of Karataş Lake were determined (Tekin-Özan et al., 2024). They stated that analyzed metals sorted as Cd < Mo < Cr < Cu < Mn < Zn < Ni < Fe and generally, heavy metals were increased in autumn and decreased in spring. In that study some indices such as Water Quality Index (WQI), Heavy Metal Pollution Index (HPI) and Heavy Metal Evaluation Index (HEI) were calculated to determine heavy metal pollution degree of Karataş Lake. Based on WQI results, lake water quality was classified as good in autumn, winter, and spring but in the poor category in summer, however, HPI and HEI values are in the low contamination category.

The main purpose of this study is to determine the concentrations of some heavy metals in the sediment of Karataş Lake seasonally. Wetlands in our country and around the world are in danger of extinction due to some reasons such as drought, global warming, and climate change. Heavy metals are the most common form of chemical pollution in water and have toxic effects (Vu et al., 2018). Therefore, in order to protect human health, aquatic environment, and ecological balance, heavy metal pollution in lakes need to be investigated and ecological risks need to evaluated (Xu et al., 2017). Karataş Lake dried up completely in 2021, and its water level increased and decreased from time to time in the following years. Since the water barrier between the lake sediment and the atmosphere is low, the metals in the lake sediment are in direct contact with the atmosphere. For this reason, we think that the accumulated metal in the sediment may be dangerous for the lake's environment, the animals, plants, and people living around the lake. The results determined in this study will be a guide for the removal of metal from the sediment, the return of more water to the lake and the sustainability of the lake. In this study, some indices such as EF, I_{geo}, PLI, CF, CD, mCD, mER, and mPER index calculated to determine the heavy metal pollution level in Karataş Lake.

2. Materials and methods

2.1 Sample collection and analysis

Totally four sites were selected to determine some heavy metals and selenium pollution of Karataş Lake and this study was carried out between October-2019 and July-2020 as seasonally. When determining the sites, some criteria such as completely surrounding the lake and equal distances between the sites were taken into considerations. In addition to these, factors such as accessibility, suitability of land conditions and regions where macrophytes are dense also helped site selected. The 4th site is located at the entrance of Bademli Stream and the 2nd site is located next to the irrigation canal coming out of the lake. The location of the lake in our country and the stations are shown in Figure 1.

Sediment samples were taken with the help a stainless steel hand space at depths of 30–50 cm and transferred to the laboratory with sample containers. 2 days before the fields studies, the polypropylene bottles to be used during the fields work were soaked in 10% nitric acid solution overnight and then rinsed with tap water and washed with pure water (Boyd & Tucker, 1992; Zhao et al., 2012). The collected sediment samples were dried at room temperature for 7 days, sieved and fraction smaller than 63 µm was obtained. Metals tend to accumulate in the fine grain size fractions of sediments (Ackermann et al., 1983; Förstner & Salomons, 1980; Horowitz, 1985). As the grain size in the sediment decreases, the surface area, surface load and organic matter content increases accordingly (Förstner & Wittmann, 1981; Horowitz, 1985; Jones & Bowser, 1978). In metal pollution studies, fractions such as silt and clay with grain sizes smaller than 63 µm are recommended. Because these fractions are the most effective carriers of natural and anthropogenic components and can be transported over long distances. Fractions of this grain size contain metals in higher concentrations and in homogeneous distributions (Balkıs & Algan, 2005). After the sieving process, the sediment samples were kept in the oven to dry completely. About 0.2 g of dried sediment samples were taken, digested with 5 mL HNO_3 (65%, Merck, Darmstadt, Germany) and kept at room temperature for 24 hr. The samples were heated at 120°C until their colored vapors disappeared and they were completely mineralized. After cooling, 1 ml of H_2SO_4 (95%–97%, Merck, Germany) was added to bottles. Samples were transferred to polypropylene containers and the solutions were made up to 25 mL with distilled water. Then 1–2 drops HNO_3 were added and kept 4ºC until analysis (United Nations Environment Programme [UNEP], 1984).

2.2 Quality control and analytical method

The accuracy of the analysis was controlled by using HISS 1 certified standard reference material (Marine Sediment Reference Material for Trace Elements and Other Constituents, National Research

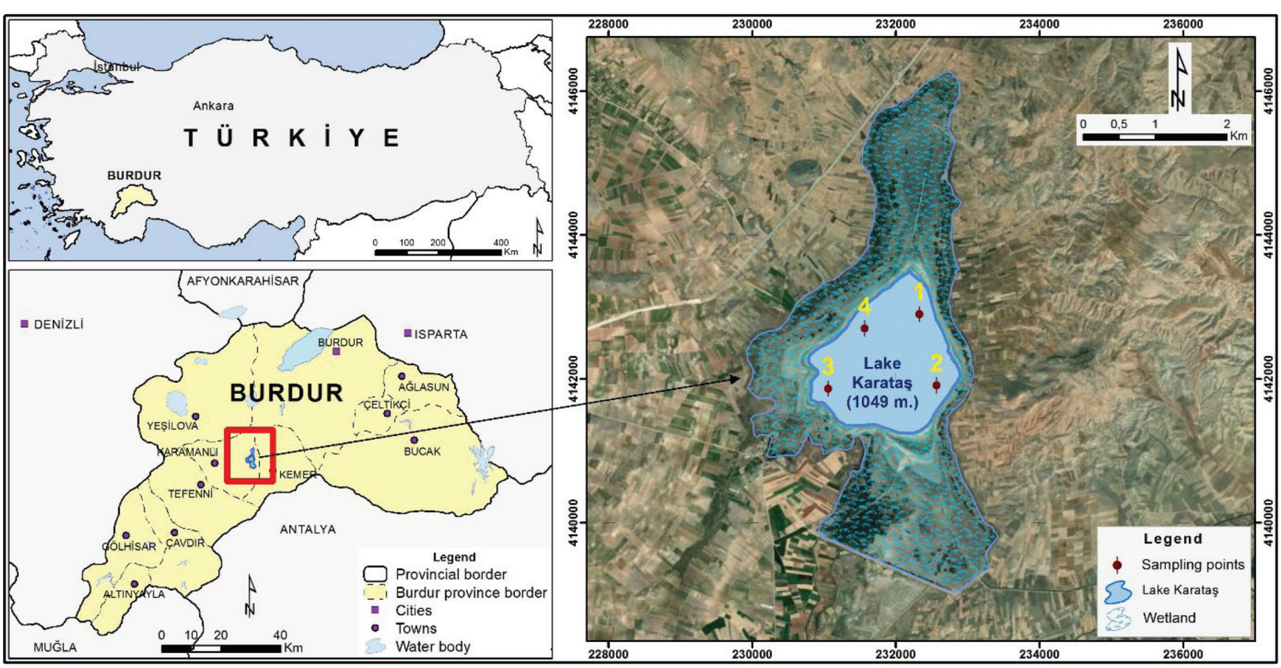

Figure 1

Location map of Karataş Lake (Tekin-Özan et al., 2024).

Council Canada). Blank solution was used to determine the actual concentration of metals. Blank and standard reference materials were also prepared as above and analyzed 3 times to determine accurate results. Before analysis, all glassware was washed with distilled water, soaked 20% nitric acid overnight, and air-dried (Pandiyan et al., 2021). The recoveries for investigated metals of the standard reference samples ranged from 87% (Cd) to 107% (Cr) (Table 1).

Analysis were performed by using inductively coupled plasma optical emission spectrometer (ICP-OES) (Agillent 5110) (Agilent Technologies, Inc., Santa Clara, CA, USA). This method can analyze many metals simultaneously. It also provides fast, reliable, accurate and precise results (Tampushi et al., 2022). All samples were analyzed in triplicate for Cd, Cr, Cu, Fe, Mn, Mo, Ni, Pb, Se and Zn. The laboratory stated that the average of three analyzes results as the final result of each element.

Table 1

Concentrations of metals found in certified reference material HISS-1 from the National Research Council, Canada.

Metals	HISS 1 certified	HISS 1 observed	Recovery (%)
Cd	0.024 ± 0.009	0.021 ± 0.03	87
Cr	30.0 ± 6.8	32.10 ± 2.35	107
Cu	2.29 ± 0.37	2.40 ± 0.21	104
Fe	-	-	-
Mn	66.1 ± 4.2	62.85 ± 1.36	95
Mo	-	-	-
Ni	2.16 ± 0.29	2.25 ± 1.10	104
Pb	3.13 ± 0.40	3.02 ± 0.02	96
Se	0.050 ± 0.007	0.046 ± 0.1	92
Zn	4.94 ± 0.79	4.70 ± 0.25	95

2.3 Assessment of heavy metal pollution in lake sediment

EF, I_{geo}, CF, PLI, CD, mCD, mER index, and mPER index were calculated to determine and evaluate the heavy metal pollution level in Karataş Lake.

2.3.1. EF

It is important to determine whether metals in aquatic environments originate from natural structures or anthropological effects. EF is used to determine the level of anthropological impact on the heavy metal level in the sediment. In this method, normalization is performed using a reference element. This element must be stable in the Earth's crust, must not deteriorate with decomposition or transport, and must be an element that can be found in fine-grained materials. Aluminum, iron, lithium, manganese, rubidium, and zircon are used as reference elements (Ackermann, 1980; Chen et al., 2007; Feng et al., 2004; Rodríguez-Barroso et al., 2009).

Aluminum was used as normalizer in this study because it is the most abundant metal in the earth's crust, is relatively inert, is not significantly affected by diagenetic processes and strong redox reactions in the sediment and its content is generally not affected by anthropogenic sources (Charlesworth & Service, 2000; Schropp & Windom, 1988).

EF value was calculated using the following formula (Buat-Menard & Chesselet, 1979);

$EF = (C_n/C_{ref})_{sample}/(B_n/B_{ref})_{referans}$

C_n: The concentration of the element in the analyzed sample

C_{ref}: Concentration of the reference element (Al) in the analyzed sample

B_n: Average level of element in shale according to Mason (1966)

B_{ref}: Average level of reference element (Al) in shale according to Mason (1966)

Sediment quality classes according to EF results are given in Table 2.

2.3.2. I_{geo}

In order to determine the level of metal pollution in the sediment, I_{geo} was calculated by comparing the heavy metal levels detected in the sediment samples with pre-industrialization values. The I_{geo} was developed by Muller (1969) and the following formula is used to determine this index.

$I_{geo} = \log_2 (C_n/(1,5 X B_n))$

C_n: Metal concentrations in the analyzed sediment

B_n: The reference value of the measured metal

Factor (1.5) is used as basic matrix correction due to lithogenic variations. I_{geo} is evaluated based on seven different pollution classes (Muller, 1969, 1981) (Table 2).

2.3.3. CF

CF is one of the methods used to determine heavy metal pollution degree in lake sediment (Hakanson, 1980). It was calculated using the below formula:

$CF = C_{metal}/C_{background}$

C_{metal}: Metal concentration in sediment

C_o: Average metal concentration in shale (Mason, 1966)

The classes of the CF are given Table 2.

Table 2

Classification of used indices for lake sediment.

Indices	Pollution class	
EF	EF < 2	No or minimal enrichment
Yongming et al. (2006)	EF = 2–5	Moderate enrichment
	EF = 5–20	Significant enrichment
	EF = 20–40	Very high enrichment
	EF > 40	Extremely high enrichment
I_{geo}	$I_{geo} < 0$	Unpolluted
(Muller, 1969, 1981)	$0 < I_{geo} < 1$	Unpolluted-moderately polluted
	$1 < I_{geo} < 2$	Moderately polluted
	$2 < I_{geo} < 3$	Moderately strongly polluted
	$3 < I_{geo} < 4$	Strongly polluted
	$4 < I_{geo} < 5$	Strongly very strongly polluted
	$I_{geo} > 5$	Very strongly polluted
CF	CF < 1	Low pollution
Hakanson, 1980	1 ≤ CF ≤ 3	Moderate pollution
	3 ≤ CF ≤ 6	Considerable pollution
	CF ≥ 6	High pollution
CD	Cd < 6	Low contamination degree
Hakanson (1980)	6 ≤ CD ≤ 12	Moderate contamination degree
	12 ≤ Cd < 24	Considerable contamination degree
	CD ≥ 24	Very high contamination degree
mCD	mCD < 1.5	Very low pollution
Abrahim & Parker (2008)	1.5 < mCD < 2	Low pollution
	2 < mCD < 4	Moderate pollution
	4 < mCD < 8	High pollution
	8 < mCD < 16	Very high pollution
	16 < mCD < 32	Extremely high pollution
	mCD > 32	Ultra-high pollution
PLI	PLI = 0	Perfect
Tomlinson et al. (1980)	PLI = 1	Presence of pollutant at base level
	PLI > 1	Progressive pollution
mER index	mER < 40	Low potential ecological risk
Brady et al. (2015), Hakanson (1980)	40 ≤ mER ≤ 80	Moderate potential ecological risk
	80 ≤ mER ≤ 160	Significant potential ecological risk
	160 ≤ mER ≤ 320	High potential ecological risk
	mER ≥ 320	Very high potential ecological risk
mPER index	mPER < 150	Low ecological risk
	160 ≤ mPER < 300	Moderate ecological risk
Hakanson (1980)	300 ≤ mPER < 600	Significant ecological risk
	mPER ≥ 600	Very high ecological risk

EF, enrichment factor; $I_{geo,}$ geoaccumulation index; CF, contamination factor; CD, contamination degree; mCD, modified contamination degree; PLI, pollution load index; mER, modified ecological risk; mPER, modified potential ecological risk.

2.3.4. CD

The CD is the sum of the CF values of heavy metals (Hakanson, 1980). Its formula was given below. CD categories were shown in Table 2.

$$C_d = \sum_{i=1}^{n} C_F^i$$

CF: Contamination factor

2.3.5. mCD

Geochemical normalization is not performed when calculating CF. Therefore, CF has some disadvantages in terms of eliminating grain size errors. mCD was developed to eliminate this disadvantage (Abrahim & Parker, 2008). It is calculated with the following formula. mCD classes were given in Table 2.

$$mCD = \frac{\left[\sum_{i=1}^{n}\left(C_F^i\right)\right]}{n}$$

CF: Contamination factor
n: Number of elements analyzed

2.3.6. PLI

PLI is used to determine sediment quality according to heavy metals and was calculated by the formula below (Tomlinson et al., 1980). Sediment quality classes were given in Table 2.

$PLI = \sqrt[n]{(CF_1 \; X \; CF_2 \; X \ldots\ldots\ldots X \; CF_n)}$
CF: Contamination factor
n: Metal number

2.3.7. mER index and mPER index

mER index is used to determine individual ecological risk levels of metals (Brady et al., 2015). mPER index was calculated by summing the mER values. In previous years, CF results were used to calculate mER index and mPER index (Hakanson, 1980). However, since geochemical normalization is not performed in CF calculations, errors caused by grain size are not minimized. For this reason, mER and mPER were developed in which EF data were used in the calculations (Brady et al., 2015).

mER index and mPER index were calculated with the following formula. The results were evaluated according to Table 2.

$mER = EF \times Tr_i$
EF: Enrichment factor
Tr_i: Toxic risk coefficient of metals

$$mPER = \sum_{i=1}^{n} mER$$

2.3.8. SQG

SQG are used to evaluate sediment quality and ecological risks posed by heavy metals to the aquatic life (Hübner et al., 2009). MacDonald et al. (2000) suggested a consensus-based SQG to evaluate the ecological effects of metals. Six threshold values were used in this study (MacDonald et al., 2000).

1. Lowest effect level (LEL): Sediments are considered to be clean to marginally polluted. No effects on the majority of sediment-dwelling organisms are expected below this concentration (Persaud et al., 1993).
2. Threshold effect level (TEL): Represents the concentration below which adverse effects are expected to occur only rarely (Smith et al., 1996).
3. Minimal effect threshold (MET): Sediments are considered to be clean to marginally polluted. No effects on the majority of sediment-dwelling organisms are expected below this concentration (EC & MENVIQ, 1992).
4. Severe effect level (SEL): Sediments are considered to be heavily polluted. Adverse effects on the majority of sediment-dwelling organisms are expected when this concentration is exceeded (Persaud et al., 1993).
5. Probable effect level (PEL): Represents the concentration above which adverse effects are expected to occur frequently (Smith et al., 1996).
6. Toxic effect threshold (TET): Sediments are considered to be heavily polluted. Adverse effects on sediment-dwelling organisms are expected when this concentration is exceeded (EC & MENVIQ, 1992).

2.4. Statistical analysis

All statistical analyses were performed with SPSS 22.0 program (SPSS, Inc., Chicago, IL, USA). The results determined from the sites were combined on a seasonal basis and minimum, maximum and standard deviation (SD) values were calculated. One-Way analysis of variance (ANOVA) and Duncan Multiple Range Test were used to compare heavy metal levels seasonally (Duncan, 1955; Fisher, 1928). The relationship was considered statistically significant at $p < 0.05$.

3. Results and discussion

3.1 Heavy metals and Se levels in sediment

Some heavy metals and Se levels seasonally in sediments (arithmetic mean, minimum, maximum and SD) were given in Table 3. All metals determined in all seasons except Se in winter. In a study conducted in the same period, it was determined that Pb and Se in water of Karataş Lake were below detection limit (BDL). These results show that the heavy metal concentrations in the sediment are higher than the water and heavy metals precipitate into the sediment. The total levels of heavy metals and Se in sediment samples observed as: Fe > Mn > Ni > Zn > Cr > Cu > Pb > Se > Mo > Cd. Başyiğit and Tekin-Özan (2013) determined Se in all seasons in Karataş Lake sediment. Also, they found that the highest metal was Fe and the lowest was Cd. Similar results were found in Beyşehir Lake (Şener et al., 2023a), Uluabat Lake (Şener et al., 2023b), Eğirdir Lake (Özçelik & Tekin-Özan, 2024), Avşar Dam Lake (Öztürk et al., 2009), Bafa Lake (Algül & Beyhan, 2020), Manzala Lake (Redwan & Elhaddad, 2022), Oymapınar Dam Lake (Tekin-Özan, 2021). Iron is the most abundant element on earth and in other resources, and the most frequently used transition metal in the biosphere. It is one of the basic components of cells and plays a role in many physiological activities (Kappler & Straub, 2005; Usero et al., 2004). Cd accumulates very slowly in sediment. It also not found in the organic fraction for low adsorption constant (Baron et al., 1990; Kerrison et al., 1988). Therefore, Cd was the least accumulated metal in the sediment.

The minimum and maximum metal values of Cd, Cr, Cu, Fe, Mn, Mo, Ni, Pb, Se, and Zn in Karataş Lake sediment are presented Table 3. To evaluate the overall metal burden of the lake, the annual mean values of each metal are also provided in same table. When compared with findings from Beyşehir Lake (Şener et al., 2023a) and Eğirdir Lake (Özçelik & Tekin-Özan, 2024), the concentrations obtained in the present study fall within the broad ranges reported for these systems, although some metals exhibited noticeable differences among lakes. These differences may be due to the topographic structure of the lakes, their morphological characteristics, the density and diversity of living things in the lake, and the difference and density of pollutants entering the lake (Tekin-Özan et al., 2024). Some factors such as the development of agriculture and industry, the increase in the use of fertilizers and pesticides due to this development, mining activities, fossil fuel burning, and sewage waste may also be the reason for the different metal levels in the different lake sediments (Li et al., 2022; Ma et al., 2013).

To better compare the metal burden in Karataş Lake with other freshwater systems, the annual mean concentrations of Cd, Cr, Cu, Fe, Mn, Mo, Ni, Pb, Se and Zn in the present study were evaluated together with previously reported values for Karataş, Beyşehir and Eğirdir lakes (Table 4). Among these studies, Başyiğit and Tekin-Özan (2013) reported seasonal sediment concentrations for Karataş Lake between July 2010 and April 2011. In addition to that, the average values of metals in Karataş Lake sediment are as follows: 0.11 mg · kg^{-1}—0.25 mg · kg^{-1} for Cd, 13.82 mg · kg^{-1}—53.13 mg · kg^{-1} for Cr, 13.88 mg · kg^{-1}—32.27 mg · kg^{-1} for Cu, 4244.9 mg · kg^{-1}—8116.2 mg · kg^{-1} for Fe, 228.15 mg · kg^{-1}—352.92 mg · kg^{-1} for Mn, 0.015 mg · kg^{-1}—0.68 mg · kg^{-1} for Mo, 47.16 mg · kg^{-1}—203.92 mg · kg^{-1} for Ni, 0.54 mg · kg^{-1}—1.13 mg · kg^{-1} for Pb, 1.21 mg · kg^{-1}—4.38 mg · kg^{-1} for Se and 12.92 mg · kg^{-1}—45.004 mg · kg^{-1} for Zn. When compared with average values of our and other study carried out between July 2010 and April 2011 by Başyiğit and Tekin-Özan (2013), it was determined that the levels of all metals except Se increased. During this 11-year period, heavy metals can enter the water from different sources such as agricultural activities, marble mining activities, domestic, and other anthropogenic activities. Additionally, the water level of the lake decreased during this period. Therefore, metals may have increased in the sediment due to decreased circulation. The decrease in selenium may be related to the increasing macrophyte density. Although selenium is harmful to plants at high concentrations, it may be beneficial at low concentrations. It can improve plants' tolerance to UV-induced oxidative stress, delay senescence, and promote the growth of senescent seedlings. It has recently been shown that selenium can regulate the water status of plants under drought conditions (Topuz & Topal, 2021). These patterns indicate that Karataş Lake currently exhibits a particularly pronounced enrichment of Ni and Zn in its sediments compared with other major lakes in the region.

It was determined that Cd (0.45 mg · kg^{-1}), Cu (25.83 mg · kg^{-1}), Pb (3.35 mg · kg^{-1}), Se (2.92 mg · kg^{-1}) and Zn (144.15 mg · kg^{-1}) were highest in summer and Cr (97.44 mg · kg^{-1}), Fe (27011.72 mg · kg^{-1}), Mn (515.83 mg · kg^{-1}), Mo (0.80 mg · kg^{-1}) and Ni (312.99 mg · kg^{-1}) in spring. Cd (0.19 mg · kg^{-1}), Cr (68.17 mg · kg^{-1}), Ni (211.72 mg · kg^{-1}) were lowest in

Table 3

The concentrations (mg · kg^{-1}) of some heavy metals and Se in Karataş Lake's sediment.

Season	Cd	Cr	Cu	Fe	Mn	Mo	Ni	Pb	Se	Zn
Autumn	0.08–0.33 0.19 ± 0.10[a*]	16.90–103.74 68.17 ± 39.69[a]	5.91–18.03 12.76 ± 5.45[a]	6629.49–23 327.41 18 074.59 ± 7737.08[a]	143.96–540.26 367.35 ± 172.62[a]	0.36–0.97 0.60 ± 0.27[a]	49.04–324.30 211.72 ± 129.26[a]	0.54–3.57 2.35 ± 1.28[ab]	1.11–1.39 1.20 ± 0.12[b]	54.53–75.06 68.60 ± 9.65[a]
Winter	0.23–0.62 0.40 ± 0.16[a]	20.37–136.33 73.45 ± 56.93[a]	5.71–15.28 11.54 ± 4.49[a]	7906.09–23 633.99 16 914.47 ± 7956.36[a]	167.82–575.60 362.07 ± 181.52[a]	0.13–0.83 0.42 ± 0.32[a]	68.57–422.22 246.41 ± 195.09[a]	0.28–1.18 0.67 ± 0.46[a]	BDL[**]	53.80–106.30 75.18 ± 24.10[a]
Spring	0.13–0.57 0.37 ± 0.18[a]	53.86–161.25 97.44 ± 51.34[a]	12.40–38.37 24.41 ± 10.80[a]	23 334.75–33 640.99 27 011.72 ± 4613.09[a]	378.83–607.52 515.83 ± 104.58[a]	0.52–1.14 0.80 ± 0.25[a]	118.53–575.79 312.99 ± 200.30[a]	2.43–3.00 2.77 ± 0.30[ab]	1.11–1.68 1.40 ± 0.28[ab]	70.40–130.90 104.09 ± 30.81[a]
Summer	0.17–0.65 0.45 ± 0.22[a]	39.95–104.41 75.79 ± 30.07[a]	15.30–43.54 25.83 ± 12.51[a]	15 301.18–25 791.46 22 274.31 ± 4750.72[a]	391.32–563.52 464.21 ± 86.71[a]	0.19–0.98 0.51 ± 0.34[a]	136.94–316.23 258.59 ± 83.08[a]	1.76–5.84 3.35 ± 2.18[b]	1.48–4.05 2.92 ± 1.31[c]	72.94–308.56 144.15 ± 110.22[a]
Annual Mean	0.35	78.71	18.63	21 068.77	427.37	0.58	257.42	2.28	1.38	98.00

*Means with the same superscript in the same row are not significant different according to Duncan's multiple range test ($p < 0.05$).
**BDL.
BDL, below detection limit.

autumn, and Cu (11.54 mg · kg^{-1}), Fe (16914.47 mg · kg^{-1}), Mn (362.07 mg · kg^{-1}), Mo (0.42 mg · kg^{-1}), Pb (0.67 mg · kg^{-1}), Se (< BDL), and Zn (75.18 mg · kg^{-1}) in winter (Table 3). There is no significant relationship among seasons for Cd, Cr, Cu, Fe, Mn, Mo, Ni, and Zn (> 0.05). Statistical differences were found for Pb levels in winter and summer between the other seasons (<0.05). In Eğirdir Lake sediment, Cd and Mn were highest in autumn, Cr, Cu, Mo, and Ni in winter, Fe, Pb, Se, and Zn were in summer. Cd and Mo were lowest in summer, Cr, Cu, Fe, and Ni were in spring, Mn, Pb, and Se were in winter, Zn were in autumn (Özçelik & Tekin-Özan, 2024). Şener et al. (2023a) studied concentrations of heavy metals in sediment of Beyşehir Lake and reported that Cr, Zn, Pb, Cd, and Mn were highest in summer, Cu in spring, Ni in autumn, and Fe in winter. Cr, Zn, Pb, Cd, and Mn were lowest in spring, Cu and Fe in autumn, and Ni in winter. The heavy metal levels in Yeniçağa Lake sediment, Mo, Ba, Cr, Mn, Co, and Ni levels were highest in April 2008 (Saygı & Yiğit, 2012). In a previous study conducted by Başyiğit and Tekin-Özan (2013) to determine heavy metal levels in Karataş Lake sediment, researchers found that Cd, Fe, Ni, and Se were highest in winter, Cr, Cu, and Mn in autumn, Mo and Zn in summer, and Pb in spring. Cd, Cr, Cu, Fe, Mn, Ni, and Zn were lowest in spring, Mo and Pb in winter and Se in summer. In this study, generally, heavy metal levels increased in summer and spring and decreased in autumn and winter.

Metals have a strong affinity for particles and due to this affinity they are trapped by suspended matter of sediment in lakes and tend to sink to the bottom. Sediment acts as both source and sink for heavy metals (Dauvalter, 1998; Luorna, 1990; Wang et al., 2003). As the temperature increased in spring, the rainfall increased, and the snow began to melt, water entered the lake from different sources. These waters bring pesticides, agricultural fertilizers with them (Sancer & Tekin-Özan, 2016). However, the water level of the lake decreased due to local people drawing water to irrigate grain and apple orchards (Tekin-Özan et al., 2024). Circulation is either very reduced or absent due to decrease in water level. The increase of some heavy metal levels in summer can be due to evaporating, increasing of dying living things in lake, summer stagnation, and decreasing of rains (Başyiğit & Tekin-Özan, 2013; Özçelik & Tekin-Özan, 2024). Heavy rain and snow can cause a decrease in heavy metal levels in winter and autumn (Gülcü-Gür & Tekin-Özan, 2017).

3.2 Assessment of contamination degree

To determine the heavy metal pollution degree in sediment, EF, I_{geo}, PLI, CF, CD, mCD, mER index, and mPER index were calculated.

Table 4

Comparison of annual mean concentrations (mg · kg^{-1}) of heavy metals and Se in Karataş Lake sediment (this study) with values reported for Karataş, Beyşehir, and Eğirdir Lakes in previous studies.

Metal	This study	Başyiğit and Tekin-Özan (2013) (Karataş Lake)	Kaya (2021) (Karataş Lake)	Şener et al. (2023a) (Beyşehir Lake)	Özçelik and Tekin-Özan (2024) (Eğirdir Lake)
Cd	0.35	0.20	0		0.61
Cr	78.71	37.06	164.89	78.58	14.43
Cu	18.63	21.95	25.86	42.87	14.20
Fe	21 068.77	6968.60	-	19 765.22	10 357.88
Mn	427.36	306.40	-	1510.30	330.09
Mo	0.58	0.21	-	-	1.09
Ni	257.43	131.81	-	56.27	25.49
Pb	2.28	0.88	0	12.01	41.38
Se	1.38	2.83	-	-	2.38
Zn	98.00	28.17	41.61	48.20	35.37

3.2.1. EF

In Table 5 and Figure 2, the values of EF index were presented. Pb in all seasons and Mo in summer were at minimum enrichment level (EF < 2). Cu in autumn and winter, Mo in autumn, winter, and spring, Fe in winter and summer were at moderate enrichment level (EF = 2–5). Cd, Cr, Mn, and Zn in all seasons, Fe in autumn and spring, Cu in spring and summer were at significant enrichment level (EF = 5–20). Se in autumn, winter and spring, Ni in summer were at very high enrichment level (EF = 20–40). Ni in autumn, winter, and spring, Se in summer were at extremely high enrichment level (EF > 40). Özçelik and Tekin-Özan (2024) calculated EF values of Eğirdir Lake's sediment and found that Pb was at an extremely high enrichment level (EF > 40) in autumn and winter, and at very high enrichment level (EF = 20–40) in summer and spring. Cr was at a significant enrichment level (EF = 5–20) in autumn and winter, and a minimum enrichment level (EF < 2) in summer and spring. Fe was at significant enrichment level (EF = 5–20) in autumn and winter, at moderate enrichment level (EF = 2–5) in summer and minimum enrichment level (EF < 2) in spring. Cu, Mn, and Ni were at a significant enrichment level (EF = 5–20) in autumn and winter, while at a moderate enrichment level (EF = 2–5) in summer and spring. In another study, it was determined that Cu and Zn were in moderate enrichment levels (EF = 2–5) and Cr was in the significant enrichment level (EF = 5–20) in Karataş Lake's sediment (Kaya, 2021). If the EF value varies between 0.5 and 1.5, it is known that metals originate from Earth's crust or natural weathering processes (Zhang & Liu, 2002). If EF value is greater than 1.5, it is thought that some of metals come from anthropogenic activities such as urbanization, agricultural activities, fossil fuels, industrialization, different living things, and different pollution sources (Islam et al., 2015; Klerks & Levinton, 1989; Zhang & Liu, 2002). It can be seen that all EF values are greater than 1.5, except for the value of Pb in winter. We can say that pollutants enter Karataş Lake from different sources.

3.2.2. I_{geo}

The I_{geo} values were presented in Table 5 and Figure 3. Karataş Lake was not polluted with Cr, Cu, Fe, Mn, Mo, and Pb in all seasons, while Cd and Zn were present in all seasons except summer (I_{geo} < 0). Se in all seasons except summer, Cd and Zn in summer levels in the unpolluted-moderately polluted class (0 < I_{geo} < 1). Ni in all seasons and Se in summer were in moderately polluted class (1 < I_{geo} < 2). Özçelik and Tekin-Özan (2024) reported that Eğirdir Lake was not polluted with Cr, Cu, Fe, Mn, Mo, Ni, and Zn (I_{geo} < 0) in all seasons, and Se was in the moderately polluted class(1 < I_{geo} < 2) in all seasons. In Beyşehir Lake, I_{geo} values for Cr, Cu, Ni, Zn, Pb, Cd, Hg, Fe, and Al indicated that the sediment was in unpolluted class (Şener et al., 2023a).

3.2.3. PLI

As seen Figure 4, PLI values varied between 0.525 and 0.836. If the PLI value is >1, it indicates that there is heavy metal pollution in the environment; if it is <1, it indicates that there is no heavy metal pollution (Tomlinson et al., 1980). Karataş Lake sediments showed no pollution (PLI < 1) for all metals in all seasons.

Table 5

EF, I_{geo} and CF of Karataş Lake's sediment by seasons.

	EF				(I_{geo})				CF			
	Autumn	Winter	Spring	Summer	Autumn	Winter	Spring	Summer	Autumn	Winter	Spring	Summer
Cd	8.960	18 133	14.085	15.024	−1.23	−0.15	−0.27	0.009	0.639	1.343	1.242	1.509
Cr	10 519	10 539	13 543	8592	−0.98	−0.87	−0.47	−0.83	0.758	0.816	1.083	0.842
Cu	3824	3421	5556	5610	−2.40	−2.54	−1.46	−1.38	0.284	0.257	0.543	0.574
Fe	5208	4763	6400	4722	−1.96	−2.06	−1.39	−1.66	0.383	0.358	0.572	0.472
Mn	5799	5652	6483	5401	−1.79	−1.81	−1.30	−1.45	0.432	0.426	0.607	0.546
Mo	3335	2171	3714	1972	−2.68	−3.21	−2.28	−2.92	0.234	0.162	0.308	0.198
Ni	42 941	46 793	59 200	38 371	1.05	1.27	1.61	1.34	3.114	3.624	4.603	3.308
Pb	1563	0.443	1559	1600	−3.67	−5.47	−3.43	−3.15	0.118	0.034	0.139	0.168
Se	29 563	33 887	27 187	45 657	0.41	0.63	0.63	1.61	2.006	2.337	2.317	4.603
Zn	10 533	10 913	11 863	14 532	−1.05	−0.92	−0.45	0.01	0.722	0.791	1.096	1.517

EF, enrichment factor; I_{geo}, geoaccumulation index; CF, contamination factor.

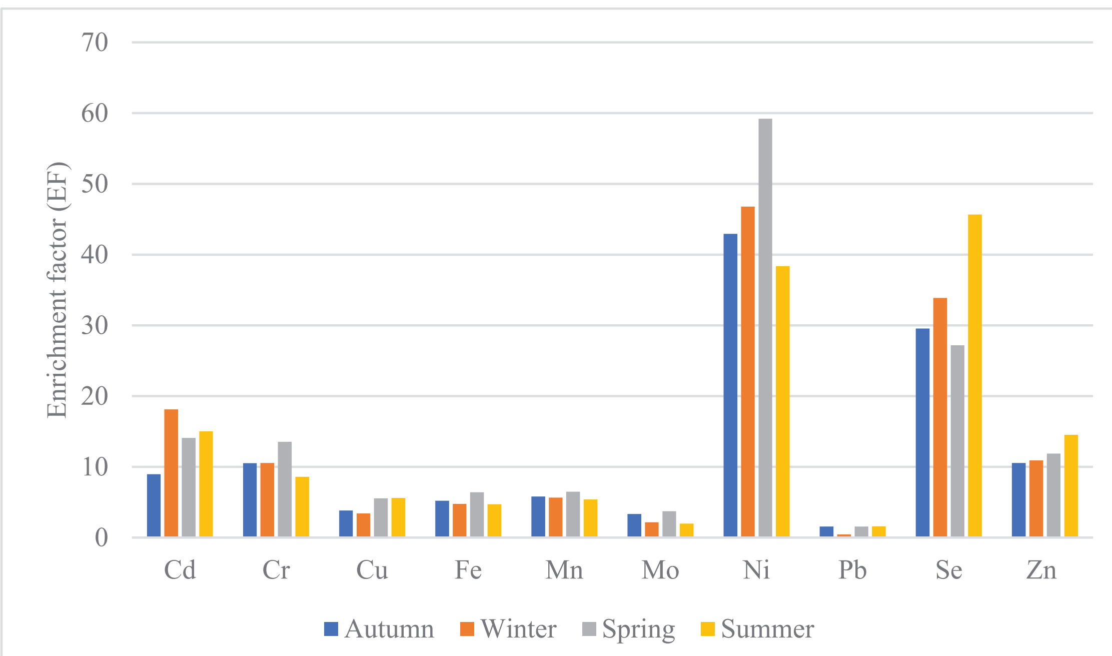

Figure 2

EF of Karataş Lake's sediment. EF, enrichment factor.

3.2.4. CF

The CF values showed low pollution (CF < 1), moderate pollution (1 ≤ CF ≤ 3), and considerable pollution (3 ≤ CF ≤ 6) degrees in lake sediments (Table 5). Ni in all seasons and Se in summer were in the considerable pollution category (3 ≤ CF ≤ 6), Cd in winter, spring, and summer, Se in autumn, winter, and spring, Cr in spring, Zn in spring and summer were in moderate pollution category (1 ≤ CF ≤ 3). The other metals in all seasons were in low pollution category (CF < 1). The CF values of the heavy metals are sorted as follows Ni > Se > Cd > Zn > Cr > Mn > Fe > Cu > Mo > Pb. In the study carried out by Algül and Beyhan (2020) in Bafa Lake, heavy metals were ranked as Ni > Cd > Co > Cr > Pb > Fe > Mn > Cu > Zn according to the mean values of the CF. It was determined that Cu, Fe, Pb, and Zn were in moderate levels, Cr, As, Hg, Cd, and

Al were in high levels, Mn and Ni were in very high levels according to CF values in the sediment of İkizcetepeler Dam Lake (Fural et al., 2020). According to the CF results in the Gala Lake sediment, Pb, As, Cd, Cr, Ni, Zn, and Cu were in low contamination class in winter and summer (Öztura, 2023).

3.2.5. CD and mCD

The CD results were determined as 8.69 in autumn, 10.14 in winter, 12.51 in spring, and 13.73 in summer. These results show that Karataş Lake sediment falls into the moderate contamination degree in autumn and winter and the considerable contamination degree in spring and summer. The mCD for the four season in the range from 0.869 (autumn) to 1.373 (summer). All seasons can be classified into the very low pollution category. In a study conducted in Beyşehir Lake, sediment samples were taken from three different stations. According to the CD results, it was determined that the 2nd station was very high, the 1st station was quite high, and the 3rd station was medium contaminated. According to the mCD results, it is seen that the 1st and 2nd stations have medium level contamination, and the 3rd station has very low level contamination (Tunca, 2016).

3.2.6. mER index and mPER index

mER index and mPER index values are shown at Table 6. According to the results, the low potential ecological risk level was identified for Cr, Cu, Mn, Pb, and Zn in all seasons. While Ni was in the in high potential ecological risk class in all seasons, Cd was in the high potential ecological risk class in autumn and very high potential ecological risk class in other seasons. These results were also supported by the mPER index results. mPER values, which express the ecological risk level, varied between 540.13 and 834.89. It has been determined that there is a significant ecological risk in autumn and a very high ecological risk in other seasons.

3.2.7. SQG

Compared with SQG, the annual average concentrations of Ni in sediment exceeded the LEL, TEL, MET, TET, SEL, and PEL values (Table 7). Cr levels in sediment are above the LEL, TEL, and MET values, while Cu levels are above the LEL values. Cd, Zn and Pb were below all levels and the sediment was not polluted with these metals. In another study conducted in Karataş Lake, researchers stated that the Cr value exceeded the

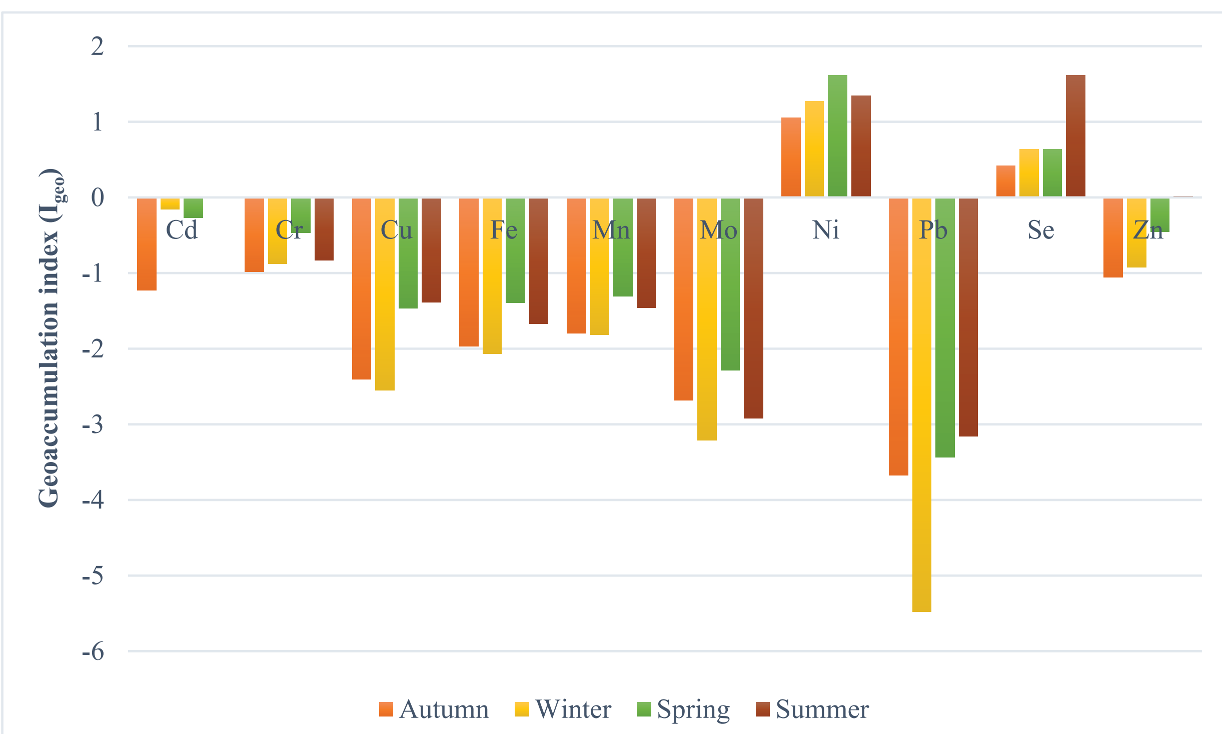

Figure 3

I_{geo} of Karataş Lake's sediment. $I_{geo,}$ geoaccumulation index.

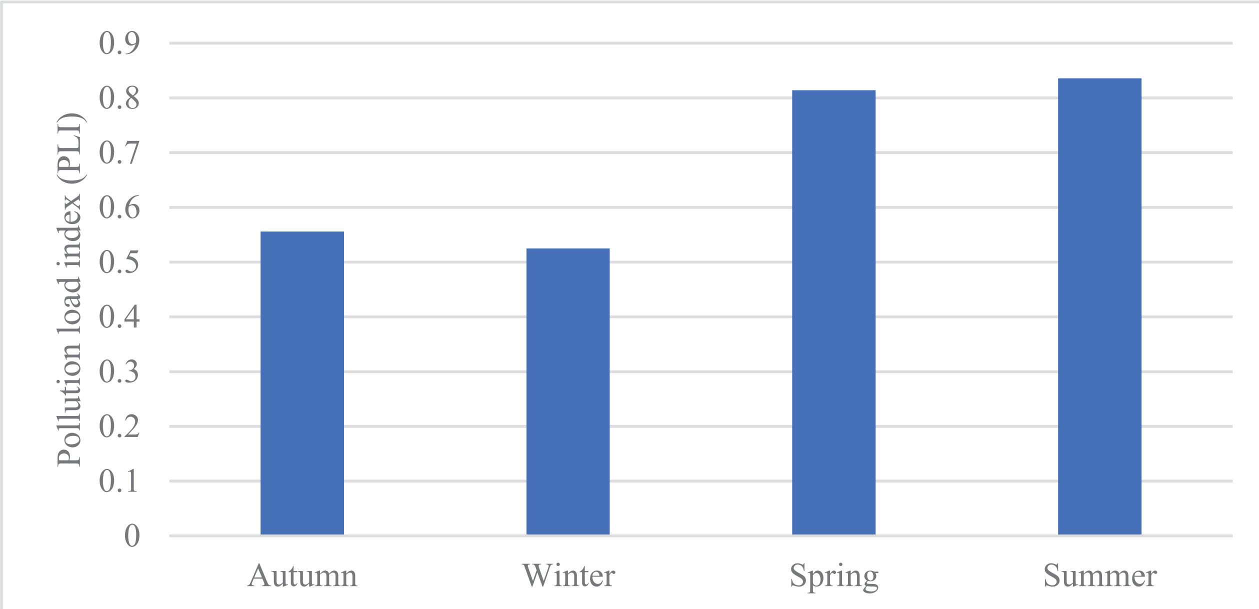

Figure 4

PLI of Karataş Lake sediment. PLI, pollution load index.

Table 6

mER index and mPER index of Karataş Lake's sediment by seasons

	Autumn	Winter	Spring	Summer
Cd	268.8	543.99	422.55	450,72
Cr	21.03	21.07	27.08	17.18
Cu	11.47	17.10	27.78	28.05
Mn	5799	5652	6483	5401
Ni	214.70	233.96	296	191.85
Pb	7.81	2.21	7.79	8
Zn	10.53	10.91	11.86	14.53
mPER	540.13	834.89	799.54	715.73

mER, modified ecological risk; mPER, modified potential ecological risk.

SEL values, while the Cu and Zn values were below (Kaya, 2021). In this study, while it was determined that nickel pollution in the sediment was severe and could have negative effects on sediment-dwelling organisms, it was determined that Cd, Zn, and Pb was not effective on sediment-dwelling organisms.

4. Conclusions

Lakes are used by people in many areas, including drinking water, irrigation of agricultural lands, recreation, tourism, aquaculture, energy production, wastewater treatment, and flood and drought control. In recent years, the water level of lakes has been decreasing or drying up completely due to many reasons such as climate change, global warming, drought, unconscious use of water, detergents, fertilizers, pesticides, and livestock activities. Heavy metals are the most dangerous pollutants in wetlands and can enter freshwater systems from different sources and accumulate in different concentrations in all living things through the food chain. Türkiye is located in the Southeastern Europe and Eastern Mediterranean geography, which is a very critical region in terms of global warming, and this situation threatens the existence of lakes that are closed basins and are therefore more affected by climate change than seas and oceans (Işıldar & Ercoşkun, 2021). The Lakes Region is a large area that includes 36 lakes located in the southwest of our country. Karataş Lake is one of the most important lakes of the Lakes Region and was declared 'Wildlife Development Area' in 2006 (Ministry of Forestry and Water Management, 2017). The lake dried up completely in September-2021 due to some reasons such as lack of precipitation, climate change, drying of the sources feeding the lake or water supply. In following years, it was able to hold water from time to time thanks to both increased precipitation and the redirection of water resources in the basin. The sediment is in direct contact with the atmosphere because the water column between the sediment and the atmosphere disappears and

Table 7

SQG criteria values and current study results.

	LEL	TEL	MET	TET	SEL	PEL	Annual average results
Cd	0.6	0.596	0.9	3	10	3.53	0.35
Cr	26	37.3	55	100	110	90	78.71
Cu	16	35.7	28	86	110	197	18.63
Ni	16	18	35	61	75	36	257.42
Pb	31	35	42	170	250	91,3	2.28
Zn	120	123	150	540	820	315	98.20

SQG, sediment quality guidelines; LEL, lowest effect level; MET, minimal effect threshold; PEL, probable effect level; SEL, severe effect level; TEL, threshold effect level; TET, toxic effect threshold.

sometimes contains very little water. Therefore, it is very important to determine the heavy metal levels in the sediment of Karataş Lake.

In present study, some heavy metals (Cd, Cr, Cu, Fe, Mn, Mo, Ni, Pb, and Zn) and Se concentrations were determined seasonally (October-2019, January-2020, April-2020, July-2020). In addition, some indices such as EF, I_{geo}, PLI, CF, CD, mCD, mER index, and mPER index calculated to evaluate heavy metal pollution degree in Karataş Lake. SQG were used to determine sediment quality and evaluate its impact on living things. All metals were determined in all seasons except Se in winter. Fe and Mn were highest, and Cd was lowest. Since Fe, Mn, and Al are the most abundant metals in the Earth's crust, their high levels in lake sediment are expected (Şener et al., 2023b). It was determined that Cd, Cu, Pb, Se, and Zn were highest in summer, and Cr, Fe, Mn, Mo, and Ni in spring. Cd, Cr, and Ni were lowest in autumn, and Cu, Fe, Mn, Mo, Pb, Se, and Zn in winter. When the results of indices made to determine the degree and sources of heavy metal pollution of Karataş Lake sediment were evaluated together, it was determined that the lake was not polluted in terms of heavy metals according to PLI results. EF values indicate significant enrichment for Cd, Cr, Mn, and Zn in all seasons, for Fe in autumn and spring, for Cu in spring and summer, very high enrichment for Se in all seasons except summer and for Ni in summer, extremely high enrichment for Ni in all seasons except summer and for Se in summer. Depending on I_{geo} results, Ni in all seasons and Se in summer were in moderately polluted class. Similarly, Ni in all seasons and Se in summer were in the considerable pollution category ($3 \leq CF \leq 6$) according to CF values. According to CD results, Karataş Lake sediment falls into the moderate contamination degree in autumn and winter and the considerable contamination degree in spring and summer. Depending on the mCD results, all seasons can be classified into the very low pollution category. According to the mER index results, the low potential ecological risk level was identified for Cr, Cu, Mn, Pb, and Zn in all seasons. While Ni was in the in high potential ecological risk class in all seasons, Cd was in the high potential ecological risk class in autumn and the very high potential ecological risk class in other seasons. Compared with SQG, the annual average concentrations of Ni in sediment exceeded the LEL, TEL, MET, TET, SEL, and PEL values. Considering the results of all indices used in the study, it was determined that there was a serious risk in Karataş Lake, especially for Ni and Se. Nickel is found in very low levels in nature. However, nickel is released into the atmosphere by burning fuels, mining, and burning urban waste (Seven et al., 2018). The presence of marble quarries near Karataş Lake and the fact that the lake is located next to a highway with heavy traffic may explain the high amount of Ni in the lake. Selenium is the 66th rarest element in nature. Its average concentration in the Earth's crust is 0.05 ppm. The most important cause of Se pollution is solid waste landfills containing Se and agricultural products grown in the regions where these areas are located. It enters the food chain through these products and reaches the human body. Se is an important trace element for living things in low concentrations; however, it is toxic in high concentrations.

Even though the public people living around the lake are in direct contact with the lake due to agriculture, animal husbandry, and fishing, they do not foresee that the lake may dry up and they have very little knowledge and experience about lakes. Authorized institutions and the public should work together in lake conservation and sustainability. Tekin-Özan et al. (2024), carried out a study at same period to determine heavy metal pollution of water in Karataş Lake and give some suggestions to protect of the lake, its sustainability, prevent of re-drying, and preservation of ecological balance. Tekin-Özan et al. (2024), suggested that to investigate the past studies, to obtain information about the old state of the lake, to collect continuous data by repeating the studies, to evaluate both socio-economic and ecological aspects together, to determine of the future state of the lake through modeling studies, to study on the effects of marble quarries close to the lake. In addition, it has been recommend to constantly determine the water quality and eutrophication status through regular scientific studies, to avoid uncontrolled fishing, to carry out irrigation according to the water budget of the lake, to control the use of fertilizers and pesticides in agricultural activities, to prevent overgrowth of aquatic plants and solid waste pollution. Considering the results obtained in this study, it is seen that serious measures should be taken to protect the lake, prevent its re-drying, and ensure its sustainability.

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Author contribution

STÖ: methodology, investigation, validation, writing, original draft, visualization, calculation of indices, and funding acquisition. ŞÖ: calculation of indices, writing, review. All authors approved the final manuscript.

Competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

The data can be available upon request.

Ethics approval and consent to participate

Not applicable.

Consent for publication

Not applicable.

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