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RESEARCH ARTICLE **ARAŞTIRMA MAKALESİ**

Ecological risk assessment of heavy metals after dredging in Mogan Lake, Turkey

Mogan Gölü'nde (Türkiye) sediment tarama ertesi ağır metallerde ekolojik risk değerlendirmesi

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Abstract: The lake management strategy of sediment dredging (removal) is periodically undertaken in shallow, eutrophic Mogan Lake, an important recreation area. This study aims to use certain indices - enrichment index (EF), contamination/pollution index (CF), degree of contamination (C_d), pollution load index (PLI), geoaccumulation index (I_{geo}), potential ecological risk index (Er^i), integrated ecological risk index (PER), and mean probable effect concentration quotient (mPEC-Q) - to evaluate the state of sediment pollution in the lake after dredging. With this in mind, after dredging was completed, two stations in the littoral zone were selected. Station I was located especially where it would be reached by wastewater from mineral processing facilities and domestic areas; and Station II, where it would be reached by residential and agricultural wastewater. Surface sediment samples were taken repeatedly in May and November 2020 using a sediment grabber. According to the study findings, a) Among the heavy metals studied (Hg, As, Cd, Cr, Pb, Ni, Cu, and Zn), Cu, As, and Cd were found to have the highest enrichment and contamination indices; b) The pollution load index (PLI) values (1.30-2.26) suggest heavy metal pollution in the sediment, and the geoaccumulation index (I_{geo}) values show intensive Pb contamination at both stations in both months; c) In terms of potential ecological risk index (Er^i), Cd was found to have a significant level of ecological risk index; d) The integrated risk index (PER) indicates that all heavy metals in the lake were present at moderate ecological risk levels. Ni and As were metals that had negative biological effects. The results indicate that a) Dredging is not a very effective tool for reducing pollution in the sediment; and b) As long as anthropogenic pollutants continue to enter the lake basin, sediment heavy metal levels should be routinely monitored, particularly those with ecological and biological effects on the sediment: Cu, Cd, Pb, Ni and As. It is predicted that the findings of this study will contribute to the sediment-focused monitoring efforts of organizations and local governments.

Keywords*:* Ecological risk assessment, ecological indices, sediment dredging, heavy metals, Mogan Lake

Öz: Rekreaktif öneme sahip ötrofik-sığ Mogan Gölü'nde, göl içi yönetim uygulamalarından biri olan sediment dredging (uzaklaştırımı) zaman zaman uygulanmaktadır. Bu çalışmanın amacı; sediment tarama sonrası, gölde sedimentin kirlenme durumunun bazı indekslerin -zenginleşme indeksi (EF), kontaminasyon/kirlilik indeksi (CF), kontaminasyon derecesi (C_d), kirlilik yük indeksi (PLI), jeoakümülasyon indeksi (I_{geo}), potansiyel ekolojik risk indeksi (Er^i), bütünleşik ekolojik risk indeksi (PER), ortalama olası etki konsantrasyonu oranı (mPEC-Q) - kullanımı ile değerlendirilmesidir. Bu amaçla gölde sediment tarama sonrası, litoral bölgede iki istasyon seçilmiştir. Bunlardan I. istasyon; özellikle maden işleme tesisleri ve evsel kaynaklı atık suların, II. istasyon; evsel atık ve tarımsal faaliyet kaynaklı atık suların ulaştığı bir konumda bulunmaktadır. Yüzey sediment örnekleri, 2020 yılının Mayıs ve Kasım aylarında sediment alma kepçesiyle tekerrürlü olarak alınmıştır. Araştırma bulgularına göre; a) Ele alınan ağır metaller (Hg, As, Cd, Cr, Pb, Ni, Cu ve Zn) içerisinde Cu, As, Cd en yüksek zenginleşme ve kontaminasyon faktörlerine sahip ağır metaller olarak saptanmıştır, b) Kirlilik yük indeksi (PLI) değerleri (1,30-2,26) sedimentin ağır metallerle kirlenmesini desteklemekte, jeoakümülasyon indeks (I_{geo}) değerleri ise, her iki istasyon ve ayda Pb bakımından yoğun kirlenme olduğuna işaret etmektedir, c) Potansiyel ekolojik risk faktörleri (Er^i) açısından, Cd önemli düzeyde potansiyel ekolojik riske sahip bulunmuştur, d) Bütünleşik ekolojik risk faktörleri (PER), gölde tüm ağır metaller bazında orta düzeyli bir ekolojik riski göstermektedir. Ni ve As ise biyolojik açıdan olumsuz etkileri olan metallerdir. Sonuçlar; a) Sediment tarama girişiminin, sedimentteki kirlenmenin indirgenmesi açısından çok etkin olmadığı, b) Göl havzasındaki antropojenik kirleticiler süregeldikçe, sedimentte ekolojik ve biyolojik anlamda önem arzeden başta Cu, Cd, Pb, Ni ve As olmak üzere ağır metal düzeylerinin rutin olarak izlenmesi gereği yönündedir. Bulguların, ilgili kurumların ve yerel yönetimin sediment odaklı izleme çalışmalarına katkı sağlayacağı öngörülmektedir.

Anahtar kelimeler*:* Ekolojik risk tayini, ekolojik indeksler, sediment tarama, ağır metaller, Mogan Gölü

INTRODUCTION

Sediments play an important role as an accumulative environment for heavy metals in fresh- and saltwater ecosystems. In the same way that they can directly affect the benthic ecosystem, sediment heavy metals such as cadmium, mercury, lead, copper, and zinc accumulate in the food chain and can reach levels that threaten human health. Various methods have been developed recently to determine the degree of contamination in the sediment, protect the health of aquatic ecosystems, and facilitate ecological risk assessment. Accordingly, various indices are widely used in sediment contamination studies in freshwater, estuarine, and saltwater ecosystems, such as the enrichment, contamination (pollution), and geoaccumulation indexes, to shed light on potential sources (anthropogenic and/or natural) of heavy metals and their accumulation in the sediment (Wang and Feng, 2007; Hu et al., 2013; Liu et al., 2014; Ghaleno et al., 2015); potential-integrated ecological risk index, to determine the risk that heavy metals pose to human health and the health of aquatic ecosystems or their ecological sensitivity to heavy metals (Guo et al., 2010; Liu et al., 2014); and the mean probable effect concentration quotient, to obtain information on the biological effects of these metals (Kükrer, 2016; Tunca, 2016).

Having recreational importance and located in the Gölbaşı Special Environmental Conservation Area, Mogan Lake is a shallow eutrophic lake. It is under pressure from anthropogenic pollutants due to agricultural activity, residential use, industrial and mineral processing facilities, and various other sectors operating in the lake basin. It has been reported that there are 29 andesite processing facilities in Gölbaşı (24 factories and four workshops) and that in a 2006 inspection of these facilities, many were found to be discharging effluents, especially the watery mud produced while cutting stone, directly into the lake's tributaries without purification, and these facilities were fined. To eliminate anthropogenic pressure on the lake and its negative effects, certain management strategies have continued for nearly 15 years. One of these strategies, sediment dredging, that is, removing sediment from the lake bottom, is a management strategy undertaken on aquatic ecosystems under the threat of eutrophication. The local government reports that dredging mud from the lake bottom started in 2017 and ended in November 2018, with a total of 3,100,000 m^3 of sediment removed.

There has been a limited amount of research undertaken in Mogan Lake before (Olgun and Kocaemre, 2011; Benzer et al., 2013; Topçu and Kaya, 2017) and during (Küçükosmanoğlu and Filazi, 2020) dredging. These investigations will sequence the average metal concentrations in Mogan Lake sediment, examine seasonal and temporal fluctuations, and compare them to sediment quality criteria and TEL/PEL values. Only one of the preceding investigations (Topçu and Kaya, 2017) and two index estimations are available. This is the first study on heavy metal contamination of sediment carried out after lake sediment dredging. In addition, no study on dredging, which is an important in-lake management practice in our country's lakes, was found in the literature review. As a result, the findings highlight the significance of the research topic, particularly at Mogan Lake.

This study aimed to determine the state of post-dredging sediment heavy metal contamination in Mogan Lake using indices such as the enrichment index, contamination/pollution index, degree of contamination, pollution load index, geoaccumulation index, potential ecological risk index, integrated ecological risk index, and mean probable effect concentration quotient. The data obtained from the study will be used to create a roadmap for the development of rational strategies for lake management and to prepare the scientific groundwork for sediment management.

MATERIAL AND METHODS

Study area

Mogan Lake, long under intense anthropogenic pressure, is one of Turkey's important Ramsar candidate wetlands. The alluvial terrace lake, located in the Lower Ankara Creek Basin, 20 km south of Ankara on the Ankara-Konya road, is fed mostly by precipitation and by the waters of more than five small and large rivers (Anonymous, 2016).

Fieldwork

Two stations suitable for obtaining sediment samples and representing the sources of pollution were selected in the littoral zone of Mogan Lake (Figure 1). Station I was established in an area receiving wastewater from mineral processing facilities and domestic wastewater, and Station II in an area reached by domestic waste and agricultural wastewater.

Surface (0-20 cm) sediment samples were taken repeatedly with a Ekman grab at both stations in May and November 2020. Sediment samples were delivered to the laboratory in dark nylon bags and a cold environment.

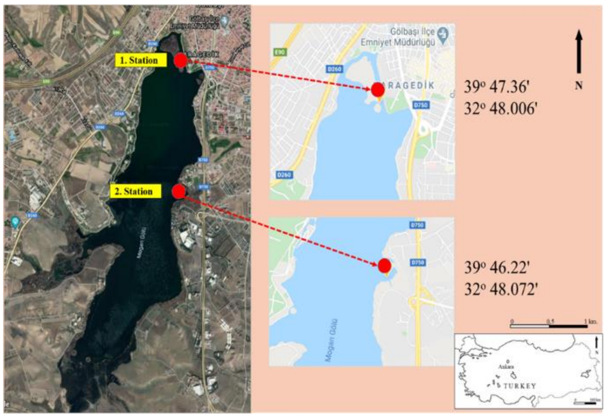

Figure 1. Research area and location of stations (Binici et al., 2021)

Laboratory work

Chemical analyses were performed at the Central Laboratory of Middle East Technical University. Experimental procedures were carried out according to the in-house laboratory methods based on the EPA 6020B method. Sediment samples were dried at 105˚C for 2 hours before digestion. Digestion procedures were carried out with an Anton Paar Multiwave 3000 microwave digestion system (Rotor type 8SXF100).

1. Approximately 0.3 g sample was weighed in a microwave digestion vessel.

2. 4 ml HNO_3, 2 ml HCl and 3 ml HF were added to the vessels, and sample and blanks were digested (Instrument parameters: Power 200 W, ramp 5 min, hold 5 min [step 1]; Power 1000 W, ramp 5 min, hold 15 min [step 2]).

3. Complexation was performed using 18 ml boric acid (Instrument parameters: Power 800 W, ramp 5 min, hold 15 min).

4. Sample/blanks were diluted to a final volume of 50 ml with de-ionized water.

Hg, As, Cd, Cr, Pb, Ni, Cu, and Zn levels were determined using Inductively Coupled Plasma Mass Spectrometry (ICP-MS, Perkin Elmer NexION 350D). NIST SRM 8704 Buffalo River Sediment is used for quality assurance and control. The CAS numbers of the acids used during the chemical analyses are 7697-37-2, 7647-01-0, and 7664-39-3, for HNO_3, HCL, and HF, respectively.

The formulas and references for risk assessment of heavy metals and pollution levels per EF, CF, Er^i, PERI, PLI, and mPEC−Q are presented in Tables 1 and 2, respectively.

Table 1. Risk assessment of heavy metals

The contamination level of heavy metals	**Symbols**	**References**
Enrichment index $EF= C_i/C_x \div B_n/B_x$	C_i= Measured metal concentration C_x= Geochemical background values of measured (Fe or Al) B_n= Geochemical background values of measured metal* B_{ref}= Geochemical background values of metals (Fe or Al)	Sutherland (2000) Rudnick and Gao (2014) Goher et al. (2017)
Contamination index $CF= C_i/ C_n$ Pollution load index $PLI=(CF_1 x CF_2 x CF_n)^{1/n}$	Ci= Measured metal concentration Cn*= Geochemical background values of metals n= Number of measured metal	Rudnick and Gao (2014) Suresh et al. (2012)
Geo-accumulation index $Igeo = \log_2(C_n/1,5 \times B_n)$	C_n= Measured metal concentration B_n= Geochemical background values of the metal (n)	Ghaleno et al. (2015)
Toxic effects of metals	**Symbols**	**References**
Potential risk index $Er^i = T_r^i x C_i/C_n$ Potential ecological risk index $PERI=\sum Er^i$	T_r^i: Response) index (Hg=40, Cd=30, As=10, Cu=Pb=Ni=5, Cr=2, Zn=1)	Guo et al. (2010) Hakanson (1980) Liu et al. (2014)
Combined biological effects of metals	**Symbols**	**References**
Mean probable effect concentration quotient $mPEC\text{-}Q= \sum_{i=1}^{n} (C_i/PEC_i)/n^{**}$ $TU= C_i/PEC_i$	C_i= Measured metal concentration PEC = Mean probable effect concentration n=Total metal number TU= Toxic unit	Long et al. (2006) Yang et al. (2014)

* Background concentration of the metals (μg/g): Hg:0,05; Cr: 92; Ni:47; Cu:28; Zn:67; As:4,8; Cd:0,09; Pb: 17 (Rudnick and Gao, 2014)
** PEC_i values: Hg:0,486; Cr:90; Ni:36; Cu:197; Zn:315; As:17; Cd:3,53; Pb:91,3 (MacDonald et al., 2000)

Table 2. Pollution levels as per EF, CF, Er^i, PERI, PLI, and mPEC−Q value

EF value	**Ecological risk**	**CF value**	**Ecological risk**	**I_{geo} classes**	**Ecological risk**
EF<2	Depletion to mineral	CF<1	Low	0	Unpolluted
2≤EF<5	Moderate	1≤CF≤3	Moderated	1	Unpolluted moderated
5≤EF<20	Significant	3<CF≤6	Considerable	2	Moderated polluted
20≤EF<40	Very high	CF>6	Very high	3	Moderated to high polluted
EF≥40	Extremely high			4	Highly polluted
				5	Highly to extremely polluted
				>5	Extremely polluted

Er^i classes	**Er^i value**	**Ecological risk**	**PERI classes**	**PERI value**	**Ecological risk**
1	Er^i <40	Low	1	PERI <150	Low
2	40<Er^i <80	Moderate	2	150< PERI <300	Moderate
3	80<Er^i <160	Appreciable	3	300< PERI <600	Considerable
4	160<Er^i <320	High	4	600>PERI	Very high
5	320>Er^i	Serious			

PLI value	**Ecological risk**	**mPEC−Q value**	**Ecological risk**
PLI>1	Polluted	mPEC−Q <0.1	Low priority
PLI<1	Non-polluted	0.1< mPEC−Q<1	Low-medium priority
		mPEC−Q >0.1	High priority

RESULTS

Enrichment index (EF)

Enrichment index (EF) values for the metals measured in the sediment of Mogan Lake were determined by month and station: for Station I, Cu>Cd>As>Pb>Zn>Ni>Cr>Hg, in descending order. While Cu levels at Station I were highest in November, indicating a near moderate enrichment level, minimal enrichment was seen for Hg at the same station, also in November (Figure 2). Enrichment indexes for the metals at Station II were found to be Pb>Hg>As>Cd>Cu>Cr>Zn>Ni, in descending order. While Pb and Hg showed moderate enrichment levels in November, Hg showed minimal enrichment in May (Figure 2). Taking general averages into account, enrichment index values were: Cu>Cd>As>Pb>Hg>Cr>Zn>Ni.

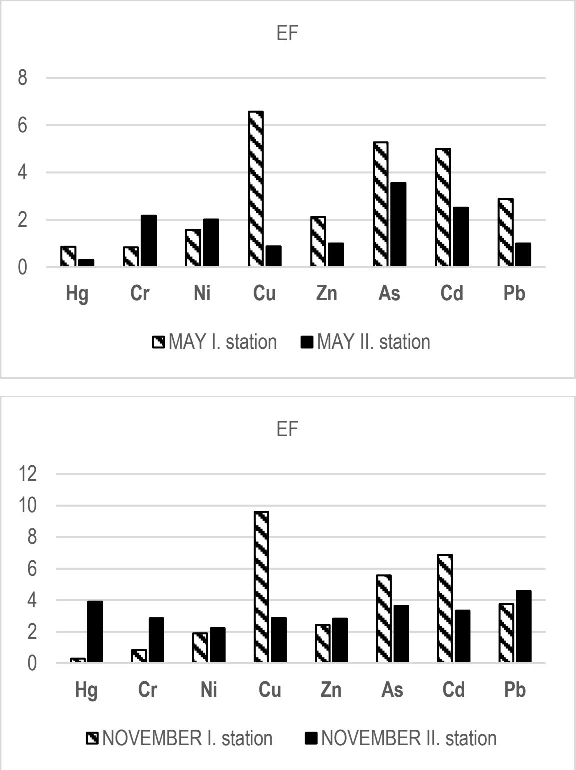

Figure 2. Sediment enrichment indexes at the station I and II in May and November

Contamination (pollution) index (CF)

Sediment contamination index values in Mogan Lake, without considering month and station, were arrayed as Cu>As>Cd>Pb>Hg>Cr>Zn>Ni. High levels of As contamination was found at both stations; for Cd, high contamination levels were detected at Station I. and moderate levels at Station II.; for Pb and Zn, moderate levels were detected at Station I and low levels at Station II; for Cr, moderate levels were detected only at Station II; for Ni, moderate levels were detected at both stations; and for Hg, low levels were detected at both stations (Figure 3).

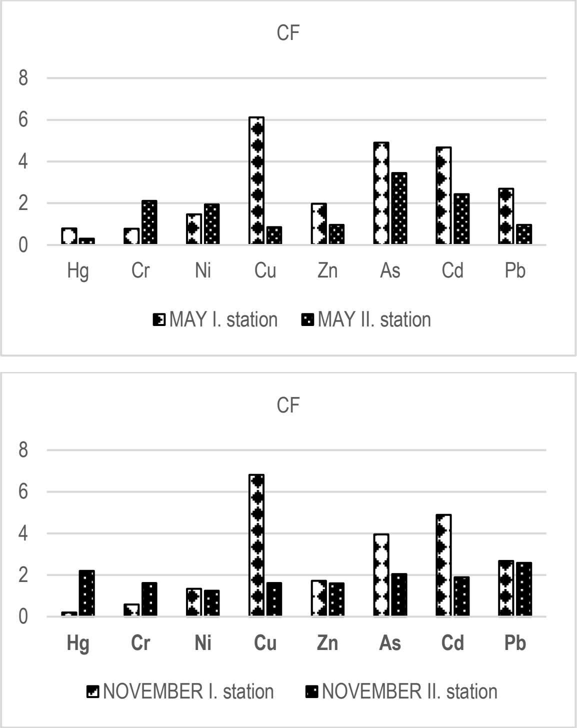

Figure 3. Sediment contamination indexes at the station I and II in May and November

Degree of contamination (pollution) (C_d) and pollution load index (PLI)

An extremely high degree of contamination (C_d) was determined in May at Station I, at 23.42 13.04 mg kg^{-1} dry w and a moderate degree at Station II, at 13.04 mg kg^{-1} dry w. Similarly, in November, while C_d at Station I was found to be extremely high at 22.2 mg kg^{-1} dry w, this value was found to be moderate at Station II, at 14.8 mg kg^{-1} dry w. In light of this data, the C_d levels determined in both months at Station I proved to be extremely high.

PLI values for May were calculated as 2.26 at Station I and 1.30 at Station II, while the values for November were 1.77 at Station I and 1.81 at Station II. Ghaleno et al. (2015) reported that, PLI values of <1 indicate the absence of contamination, and that values greater than 1 indicate advanced pollution. The PLI values of >1 recorded in Mogan Lake point to heavy metal contamination in the sediment.

Geoaccumulation index (I_{geo})

Evaluating the geoaccumulation index by station, values for Station I were recorded as Pb>Cu>As>Cd>Zn>Ni>Hg>Cr, and for Station II, as Pb>As>Cd>Hg>Cr>Ni>Cu>Zn, in decreasing order. In both months at both stations, Pb was determined to have high contamination levels, while Cu had moderate levels in May and higher than moderate levels in November at Station I; and As values for May at both stations and Cd values for the same month at Station I had moderate levels of contamination. The other metals were not detected at levels showing contamination (Figure 4).

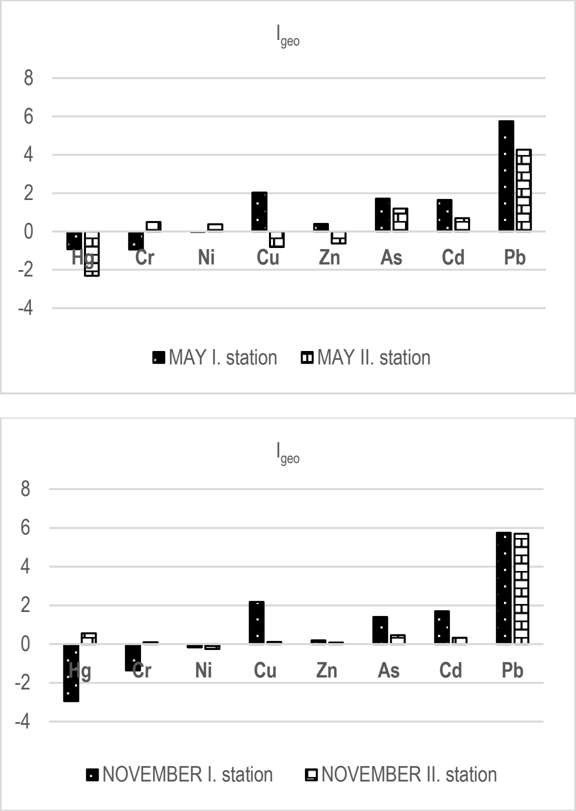

Figure 4. Sediment geoaccumulation indexes at stations I and II in May and November

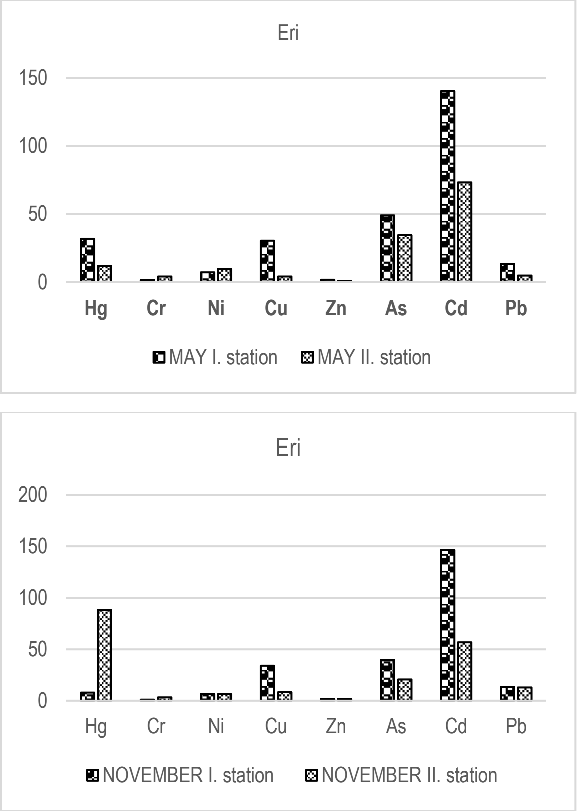

Figure 5. Sediment potential ecological risk indexes at the station I and II in May and November

Findings on the toxic effects of metals

Potential ecological risk index (Er^i)

Arranged according to the calculated ecological risk indices, the metals at Station I are as follows: Cd>As>Cu>Hg>Pb>Ni>Zn>Cr. While Cd had a significant potential ecological risk in both months, As had a moderate ecological risk in May at the same station (Figure 5).

Integrated ecological risk index (PER)

The highest value for the integrated ecological risk index (PER) for the metals was recorded in May at Station I (276.14 mg kg^{-1}), in the moderate ecological risk category. Likewise, in November, as PER values at both stations were at 150≤PER<300, a moderate ecological risk was determined.

Findings on the combined biological effects of metals

Toxic unit (TU)

From a standpoint of toxic units, Ni and As values in May at Station I were higher than those for November, with low values for the other metals. At Station II, Ni and Cr had high values, with those in May higher than those seen in November.

Mean probable effect concentration quotient (mPEC-Q)

The highest and lowest $\sum$TU values were reported at Station II, in May and November, respectively. The mean probable effect concentration ratio values of lake sediment are determined for May and November respectively; as 0,76-0,68 for me and as 0,79-0,65 for II. There is a high priority for this index.

DISCUSSION

Within the scope of sediment pollution studies, as in many places in the world, many studies have been undertaken in different parts of Turkey using ecological indices in lakes with extremely different hydrographic and nutrient levels.

In a study on Kalimanci Lake in Macedonia, Vrhovnik et al. (2013) found surface sediment enrichment index values of between 0.12-590.3 and reported significant Cd, Pb, Zn, and As sediment contamination. In the study in Mogan Lake, sediment enrichment index values varied between 0.21-6.98; and especially Cu sediment values showed significant enrichment in May and November at Station I. At the same station in Mogan Lake, Zn and Pb were at moderate enrichment levels; and in fact, it is known that wastewater from mineral processing plants reaches this station.

In Veeranam Lake (India), Suresh et al. (2012) reported average PLI values of 2.03 (1.18-4.09) and stated that the lake sediment was significantly contaminated. Likewise, in this study, the lake sediment was found to be contaminated by heavy metals and taking the average PER value of 238.79 (196.86-266.31) into account, it was shown that the lake is facing a moderate ecological risk. The finding in Mogan Lake that sediment Hg and Cd posed a significant potential ecological risk in some months and at some stations is in concordance with the finding at Veeranam Lake that sediment Cd from metals processing plants, agriculture, and residential areas poses a high ecological risk. Similarly, results from studies in China at Dalinouer Lake (Hou et al., 2013), East Lake (Liu et al., 2014), and 35 other surface sediment studies (Yang et al., 2014) show that Cd was the heavy metal posing the highest potential risk, are in parallel with the findings of the study conducted in Mogan Lake.

According to Cheng et al. (2015), mercury is the heavy metal with the greatest ecological hazard in the surface sediments of 16 Chinese lakes, followed by Cd, As, Pb, Cu, Ni, Cr, and Zn. Heavy metals were sequenced as Cd>As>Cu>Pb>Zn in a study conducted by Singh and Upadhyay (2012) in Lake Ramgarh (Upper India), and the average potential ecological risk factor was calculated to be 76.53 (moderate contamination). According to Yin et al. (2011), the potential ecological risk index in the surface sediment of Lake Taihu (China) is moderately polluted, with Cd being the greatest and Hg being the second ecological risk factor. Yuan et al. (2014) discovered that Cd is the heavy metal in the most significant risk group in the sediment of Lake Dianchi (China), a hypereutrophic plateau lake, and that Cr has a very low potential ecological risk index, which is consistent with the data from Lake Mogan. Given the endurance of pollutant inflows from the Lake Mogan basin, long-term monitoring of cadmium in lake sediment is unavoidable for the preservation and maintenance of sediment quality, in this context.

Mamat et al. (2016) reported that Cd, Hg, and Pb were determined to be at low/partially severe contamination levels, while Zn, As, Cr, Ni, and Cu were determined to be at uncontaminated/low contamination levels, based on the enrichment factor and geoaccumulation index value in the Bosten Lake surface sediment located in the arid region of Northwest China. The results partly corroborate the previous observation that Cu, As, and Cd are the most abundant enrichment factors in Lake Mogan sediment. Waheshi et al. (2017) reported that Pb and Cu are not contaminated in Lake Edku sediment according to their I_{geo} values, and the I_{geo} value for Pb was found to be maximum in Lake Mogan. Guo et al. (2018) revealed that 18 lake surface sediments in the Tibetan plateau exhibit moderate contamination in terms of Cd and As, according to the Er^i and I_{geo} indices of the sediment. While the Lake Mogan data partially overlapped with the values of Guo et al. (2018), they were determined to be consistent with As showing moderate-high contamination in terms of both indices. It has been observed that the use of pesticides and chemical fertilizers in agricultural activities causes As contamination in the surface sediment of Lake Dali (North China) (Xu et al., 2019). Given the contamination factors (2.05-3.45) of Mogan Lake Station II, it appears that agricultural wastes could reach this station and contaminate it.

Fan et al. (2019), in a study conducted on Shitang Lake (China), first defined sediment dredging areas using the geoaccumulation index (I_{geo}) and the potential risk index (RI). According to the geoaccumulation index values calculated in the study, it was determined that the sediment was more than moderately contaminated, at Station I in May and November by Cu, and at Station II in November by As. Accordingly, although it may be possible to say that suitable months and locations exist for the aforementioned heavy metals in terms of sediment dredging activities in Mogan Lake since the resultant area would be quite small, this approach, unfortunately, does not appear to be suitable for use in the lake.

According to Imran et al. (2020), elevated I_{geo} and EF values discovered for As, Fe, and Cd in the surface sediment of Lake Keenjhar (Pakistan) are produced by human activity in the lake's surroundings. According to Zhang et al. (2013), the geoaccumulation index (I_{geo}) of six heavy metals in Lake Yangzonghai (China) sediment is Cu>As>Cr>Zn>Mn>Pb in general, with copper reaching a value of 2.42. In the foreground, Pb and Cu were determined in terms of I_{geo} values on the overall average basis of the Lake Mogan sediment, with the maximum I_{geo} value for copper reaching 2.18 at Station I in November. According to Zhang et al. (2013) concluded that potential sources of Pb, Zn, As, and Cr in the sediment are created by human activities such as industry, mining, and tourism, which are also effective contributors in sediment contamination in Lake Mogan.

The finding that average bed sediment Cu, Zn, Ni, Mn, and As values in Kovada Lake were reported to be greater than the shale value, means that values for these elements in Kovada Lake indicated low or moderate enrichment (Şener and Şener, 2015), in parallel to the enrichment index values for the heavy metals other than Cr and Cd in the sediment of Mogan Lake. While Kükrer et al. (2015), reported the potential risk index of two metals, Cd and Hg, in the sediment of Çıldır Lake (Ardahan), in this study, Cd in the sediment of Mogan Lake was also shown to pose a significant potential ecological risk.

While sediment samples from Seyfe Lake, whose sole anthropogenic source is an agricultural activity, were classified according to the geoaccumulation index as moderately polluted in regards to As (Bölükbaşı and Salman Akın, 2016), sediment As in Mogan Lake reached its maximum value (2.64) in November at Station II, indicating contamination above moderate levels.

Similarly, while all sediment geoaccumulation index data in Mogan Lake, except for Cu values for May and November at Station I and As values for November at Station II, indicate a contaminated or moderately contaminated state, in Uluabat Lake (Bursa), according to the geoaccumulation index (I_{geo}), the sediment is moderately contaminated (Hacısalihoğlu and Karaer, 2016).

In a study on Tortum Lake conducted by Kükrer (2016), low-moderate level contamination of the surface sediments was reported, and the highest EF values were found for Cd as a result of the use of fossil fuels in the region. As for PLI and PER values, the lake's low ecological risk due to heavy metals and the mPEC-Q values at 15-29% point to its being a primarily low-moderate area. In Mogan Lake, as the highest sediment EF value was for Cu, and PER values were between 196.86-266.31, this indicates that the heavy metals tested for had a moderate ecological risk; mPEC-Q values showed that the sediment might have been partially impacted by the combined biological effects of the metals.

In Beyşehir Lake (Konya), it has been put forth that the potential toxic effect of sediment As on lifeforms is at a serious level (Tunca, 2016). In Mogan Lake, Ni and As was reported to be the most significant heavy metals in terms of their negative biological impact.

According to the above-mentioned research conducted in various geographical regions of Turkey, heavy metal concentrations in sediment are unavoidably altered by natural or anthropogenic sources. Furthermore, it should be noted that no dredging activity has been carried out for improvement in any of these lakes.

Principal component analysis was used to characterize the types and contributions of heavy metals in the lake's pollutant sources within the scope of a study conducted by Binici et al. (2021) in Mogan Lake after dredging. The researchers observed that the variances in heavy metals originating from diverse anthropogenic sources reaching the lake also indicate the diversity and pressure of environmental pressure for heavy metal accumulation in the lake as a result of principal component analysis. Cu (0.826), As (0.962), and Cd (0.933) in the first basic component, which explains 40.063% of the total variance, in the first station where domestic wastewaters are discharged from the mine processing facilities in the two periods of sampling were quite high compared to the second station in the aforementioned study.

The maximum enrichment index (EF) for all three metals was established at the first station in this study, as were the contamination index values (CF) at the first and second stations. In this regard, both mineral processing-domestic wastewater and agricultural activities might be considered variables in the enrichment and contamination of the sediment with these metals. In the same study, Hg (0.936), Zn (0.831), and Pb (0.900) were shown to have higher positive charges than other heavy metals in the second basic component, which explains 31.625% of the total variation. The high potential ecological risk index (Er^i) value for Hg in November was determined in the present study, particularly at the second station, indicating that the mercury originates from domestic and agricultural wastewaters. Among the Cr (0.779) and Ni (0.935) in the third basic component, which explains 24,452 % variance, Cr was found to be higher in the second station, where domestic wastewater and wastewater from agricultural activities were reached, compared to the first station, in both months of sampling. When the toxic unit (TU) values for both metals are considered, domestic-agricultural wastes have a significant effect on the toxicity of the sediment. Although the interpretations of the indices differ, it is obvious that the heavy metal concentrations in the sediment (Hg, As, Cd, Cr, Pb, Ni, Cu, and Zn) are negatively affected by both point and non-point pollutant sources reaching the lake.

Although the location of the stations was different, within the scope of a study conducted on Mogan Lake before dredging (Topçu and Kaya, 2017), geoaccumulation index I_{geo} values lower than zero indicated extremely low pollution levels. Similarly, enrichment index values generally of <1 indicate a low pollution level. A stark increase can be seen between pre-dredging index values and those recorded in this study. When considering pre-dredging ecological index values, it does not seem possible to evaluate sediment removal as an effective strategy in Mogan Lake.

CONCLUSION

In light of the findings, suggestions regarding Mogan Lake are presented below:

-Sediments such as those in the example of Mogan Lake are important due to the accumulation of heavy metals in the sediment biota and the role they play in the transformation of metals. Heavy metal levels should routinely be monitored, especially for the lake's sustainability and due to the continuation of anthropogenic pollutants.

-Dredging depth appears to be the most important index in laying a foundation for the more effective utility and applicability of sediment dredging activity in the lake. If sediment removal is to be practiced from time to time in the lake, its cost, environmental effects, the process, and other indexes should be examined; the dredging areas should first be prioritized, and other topics such as the dredging technique should be considered. Moreover, monthly or more frequent surface sediment sampling is first of all important to determine dredging areas to maintain the lake's sustainability. Accordingly, it is thought that the findings of existing studies, at least as preliminary scientific data, will shed light on the way to determine dredging areas.

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AUTHOR CONTRIBUTIONS

All authors contributed equally.

CONFLICTS OF INTEREST

The author declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

ETHICS APPROVAL

There are no ethical issues with the publication of this manuscript

DATA AVAILABILITY

The authors confirm that the data that supports the findings of this study are available within the article. Raw data that support the finding of this study are available from the corresponding author, upon reasonable request.

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