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RESEARCH ARTICLE

Health Risks of Heavy Metals in Surface Waters of Mogan Lake (Ankara, Türkiye) for Recreational and Residential Users

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Abstract: Mogan Lake is an important recreational center for the capital city Ankara, not only because of its ecological value but also because of the various recreational activities it offers. In this study, the levels of certain heavy metals (As, Cd, Cr, Cu, Ni, Pb, Hg, Zn, Fe) were determined in surface waters at three selected stations in Mogan Lake for individuals (adults and children) who are exposed to heavy metals detected in the lake water and use it for both residential and recreational purposes, health risks via ingestion and dermal contact were estimated as follows: a) Non-carcinogenic health risks (Hazard Quotient – HQ, Hazard Index – HI, and Total Hazard Index - THI), and b) Carcinogenic health risks (Total Cancer Risk – TCR = CRingestion + CRdermal) and Cancer Risk Index (CR). According to the research findings; a) Exposure to heavy metals does not pose non-carcinogenic health risks (THI < 1), b) The hazard index values for children (HIingestion and HIdermal) are higher than those for adults, c) Based on the TCR values for As, exposure to this metal through ingestion and dermal absorption does not pose a health risk for recreational users (TCR < 1×10^{-4}), while for residents, although it does not constitute a significant cancer risk, it is not entirely negligible (1.13×10^{-6} – 1.43×10^{-6}). In this context, monitoring especially arsenic (As) levels in the lake water should be considered an essential component of lake management, both to protect the health of residents and to ensure the sustainability of the lake's recreational potential.

Anahtar kelimeler:

Kanserojenik olmayan sağlık riskleri
Kanserojenik sağlık riskleri
Kanser risk indeksi
Yüzey suları
Mogan Gölü

Mogan Gölü (Ankara, Türkiye) Yüzey Sularındaki Ağır Metallerin Rekreasyonel ve Konut Kullanıcıları için Sağlık Riskleri

Öz: Mogan Gölü, yalnızca ekolojik değeri açısından değil, aynı zamanda sunduğu çeşitli rekreasyonel aktiviteler açısından da başkent Ankara için önemli bir dinlence merkezisidir. Bu çalışmada, Mogan Gölü'nde seçilen üç istasyon yüzey sularında belirli ağır metallerin (As, Cd, Cr, Cu, Ni, Pb, Hg, Zn, Fe) seviyeleri belirlenmiştir. Göl suyunun konut ve rekreasyon amaçlı kullanımı yoluyla bu ağır metallere maruz kalan yetişkinler - çocuklar için yutma ve deri teması yoluyla oluşan sağlık riskleri tahmin edilmiştir. Bu kapsamda; a) Kanserojenik olmayan sağlık riskleri (Tehlike Katsayısı – HQ, Tehlike İndeksi - HI, Toplam Tehlike İndeski - THI), b) Kanserojenik sağlık riskleri (TCR = CR_{yutma} + CR_{dermal}) ve Kanser Risk İndeksi (CR) saptanmıştır. Araştırma bulgularına göre; a) Mogan Gölü yüzey sularındaki ağır metallerin olumsuz kanserojenik olmayan sağlıksal etkilerinin olmadığı (THI < 1), b) Çocuk tehlike indeks değerlerinin ($HI_{ingestion}$ - HI_{dermal}) yetişkinlere göre daha yüksek olduğu, c) As'e ilişkin TCR değerine göre bu metale yutma ve dermal absorbsiyon yolu ile maruziyetin rekreasyonel kullanıcılar açısından sağlıksal bir tehdit oluşturmadığı (TCR < $1x10^{-4}$), yerleşik sakinlerin sağlığı açısından ise ciddi bir kanser riski oluşturmamakla birlikte riskin tamamen ihmal edilebilir seviyede ($1.13x10^{-6}$ - $1.43x10^{-6}$) olmadığı tespit edilmiştir. Bu bağlamda, gerek yerleşik sakinlerin sağlığının korunması ve gerekse gölün rekreaktif potansiyelinin devamlılığı açısından, göl sularında özellikle As düzeylerinin izlenmesi, göl yönetiminin önemli bir parçası olarak dikkate alınmalıdır.

Introduction

Heavy metals, one of the factors causing water pollution, have a wide range of sources compared to other pollutants and reach aquatic ecosystems not only through various anthropogenic sources such as industrial wastewater, mining activities, and untreated municipal wastewater, but also via natural processes such as weathering and erosion (Pulatsü & Topçu, 2015; Kianersi et al., 2025). Heavy metals in aquatic ecosystems can pose significant health risks to both humans (Briffa et al., 2020; Khushbu et al., 2022) and aquatic organisms (Vajargah,

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2021; Banaee, 2024) due to their toxicity, low biodegradability, and potential for bioaccumulation.

As a result of intense anthropogenic pressure, water pollution caused by heavy metals threatens aquatic environments and, consequently, human health. Heavy metals can have adverse health effects by posing both non-carcinogenic and carcinogenic risks to humans. Heavy metals can enter the human body through the consumption of contaminated food, inhalation, drinking polluted water, and dermal contact from agricultural, pharmaceutical, manufacturing, residential, and industrial sources. Exposure to contaminated water can cause acute or chronic health effects depending on the types of pollutants, the duration, and the level of exposure. Long-term exposure to heavy metals may lead to organ damage, developmental disorders, reproductive issues, and an increased risk of cancer (Mukherjee et al., 2021; Patel et al., 2021; Saravanan et al., 2024).

Rivers and lakes have been increasingly investigated for heavy metal pollution, and as these studies deepen, conventional methods for characterizing and assessing heavy metal contamination are becoming progressively inadequate to meet the needs of ecological environmental protection. Consequently, biotoxicological and human health assessments (Zhaoyong et al., 2015; Wang et al., 2024) are being used more frequently as complementary approaches to evaluate the impacts of heavy metal pollution in these aquatic systems. In this context, a common practice in health risk assessment is to determine the risk levels of heavy metals in water bodies based on established models and standards (USEPA, 2004; ATSDR, 2018; Yu et al., 2022).

Mogan Lake is one of the natural assets of Türkiye's capital city, Ankara, and an important recreational and tourism area for the urban population. Located in the Gölbaşı district, approximately 25 km from the city center, commercial fishing is prohibited in the lake. However, activities such as birdwatching, recreational fishing, rowing, sailing, and nature photography are carried out. The lake shores are heavily used for picnicking, especially on weekends. Intensive dry farming is practiced in the southern part of the lake and around the Çökek Marsh. Rapid and unplanned urbanization processes within the lake basin, along with increasing mining activities, have led the lake to be subjected to significant pollution pressure. The main causes of pollution in Mogan Lake include domestic wastewater, agricultural chemicals, pollutants transported by inflow waters, and solid waste (Anonymous, 2026). In this context, several studies have been conducted to determine the spatial and seasonal variations of heavy metals in the lake water–sediment system (Küçükosmanoğlu & Filazi, 2020; Binici et al., 2021; Binici & Pulatsü, 2022). This study, however, focuses on whether the surface waters of the lake pose a risk to human health in relation to heavy metal contamination. In this context, for surface waters at three selected stations in Mogan Lake, across two different periods and for residential and recreational receptors (adults and children), (a) non-carcinogenic health risk was evaluated using Hazard Quotient (HQ; via ingestion and dermal absorption), Hazard Index (HI), and Total Hazard Index (THI), and (b) carcinogenic health risk was assessed using Total Cancer Risk (TCR).

Material and Methods

Material

Study area

Mogan Lake is a natural dam lake formed behind alluvial barriers. With an average surface area of 5.6 km², Mogan Lake discharges into Eymir Lake, which has an area of approximately 1.25 km² in the northeast, through a wetland–marsh transitional zone extending 2 km from the southern part of the lake, via both surface and subsurface flow, and with an average elevation difference of about 5 meters. The Mogan–Eymir lakes and surrounding wetland–marsh areas constitute important bird habitats in Türkiye, having been proposed as a Ramsar site and serving as breeding, resting, and overwintering areas for 227 bird species. Of these species, 40 breed in the region, 30 are observed throughout the year, and the remainder are recorded during migration periods or only around the lake area (Anonymous, 2026).

Selection of the research stations

In this study, surface water samples were collected from stations selected to represent the pollution sources of Mogan Lake, based on previous studies. In this context, the characteristics of the selected stations are as follows:

Station I: The station where wastewater originating from quarry activities is intensely discharged;

Station II: The station is located closest to densely populated residential areas;

Station III: The station selected within the region where agricultural lands are predominant.

The study area and the locations of the selected stations are shown in Figure 1.

Methods

Surface water samples from Mogan Lake were collected at a depth of 30 cm during the dry period (August 2025) and the rainy period (December 2025), and subsequently transported to the laboratory under dark and cold conditions.

Laboratory work

Heavy metal analyses of the water samples were performed in an accredited laboratory with four replicates. For heavy metal (Hg, As, Cd, Cr, Pb, Ni, Cu, Zn, Fe) analyses, TS EN ISO 17294-1.2 was used. Non-carcinogenic health risks (Hazard Quotient (HQ; through ingestion and dermal absorption), Hazard Index (HI), Total Hazard Index (THI)) were estimated using Equations (1–6), while carcinogenic health risks (TCR = CR_ingestion + CR_dermal) were calculated using Equations (7–17); additionally, the USEPA (2024) Regional Screening Level

Calculator, developed to validate HQ and CR values for heavy metals, was also utilized. The equations used within the scope of the study are presented below, and the values and references considered in the calculations are provided in Table 1.

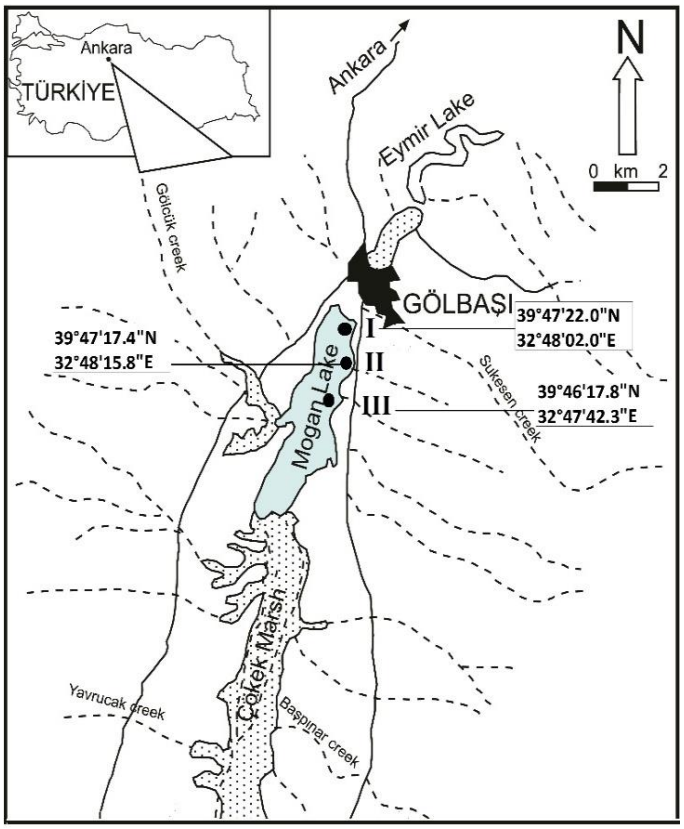


Figure 1. Mogan Lake and selected stations in the study area. Index map shows the geographical location of the study area within Ankara, Türkiye.

Non-carcinogenic risks for residential receptors

$$\text{HQingestion} = \frac{\text{Cw} \times \text{IRWres} \times \text{EFres} \times \text{ED}}{\text{BW} \times \text{ATres} \times \text{RfDo} \times 10^3} \quad (1)$$

$$\text{HQingestion} = \frac{\text{CCw} \times \text{SA} \times \text{Kp} \times \text{ETres} \times \text{EV} \times \text{EFres} \times \text{ED}}{\text{BW} \times \text{ATres} \times \text{RfDo} \times \text{GIABS} \times 10^6} \quad (2)$$

Non-carcinogenic risks for recreational receptors

$$\text{HQingestion} = \frac{\text{Cw} \times \text{IRWrec} \times \text{EFrec} \times \text{ED} \times \text{EV} \times \text{ETrec}}{\text{BW} \times \text{ATrec} \times \text{RfDo} \times 10^3} \quad (3)$$

$$\text{HQingestion} = \frac{\text{Cw} \times \text{SA} \times \text{Kp} \times \text{ETrec} \times \text{EV} \times \text{EFrec} \times \text{ED}}{\text{BW} \times \text{ATrec} \times \text{RfDo} \times \text{GIABS} \times 10^6} \quad (4)$$

$$\text{HI} = \sum \text{HQ}_s \quad (5)$$

$$\text{THI} = \text{HI}_{\text{ingestion}} + \text{HI}_{\text{dermal}} \quad (6)$$

When HI and THI are < 1, there are no non-carcinogenic health effects; however, if HI and THI are > 1, non-carcinogenic risk/adverse effects on human health are a cause for concern. (USEPA,2004).

Carcinogenic risks for residential receptors

$$\text{CRingestion} = \frac{\text{Cw} \times \text{IFWres} \times \text{CSFo}}{\text{BAT} \times 103} \quad (7)$$

$$\text{IFWres} \frac{\text{EFres} \times \text{EDa} \times \text{IRWres–a}}{\text{BWa}} + \frac{\text{EFres} \times \text{EDc} \times \text{IRWres–c}}{\text{BWc}} \quad (8)$$

$$\text{CRdermal} = \frac{\text{Cw} \times \text{Kp} \times 0.001 \times \text{ETevent–res} \times \text{DFWres} \times \text{CSFo}}{\text{AT} \times \text{GIABS} \times 10^3} \quad (9)$$

$$\text{ETevent–res} = \frac{\text{ETres–a} \times \text{EDa} + \text{ETres–c} \times \text{EDc}}{\text{ED}} \quad (10)$$

$$\text{DFWres} = \frac{\text{EVa} \times \text{EFres} \times \text{EDa} \times \text{SAa}}{\text{BWa}} + \frac{\text{EVc} \times \text{EFres} \times \text{EDc} \times \text{SAc}}{\text{BWc}} \quad (11)$$

Carcinogenic risks for recreational receptors:

$$\text{CRingestion} = \frac{\text{Cw} \times \text{IFWrec} \times \text{CSFo}}{\text{AT} \times 103} \quad (12)$$

$$\text{IFWrec} = \frac{\text{EVa} \times \text{ETrec–a} \times \text{EFrec} \times \text{EDa} \times \text{IRWrec–a}}{\text{BWa}} + \frac{\text{EVc} \times \text{ETrec–c} \times \text{EFrec} \times \text{EDc} \times \text{IRWrec–c}}{\text{BWc}} \quad (13)$$

$$\text{CRdermal} = \frac{\text{Cw} \times \text{Kp} \times 0.001 \times \text{ETevent–rec} \times \text{DFWrec} \times \text{CSFo}}{\text{AT} \times \text{GIABS} \times 103} \quad (14)$$

$$\text{ETevent– rec} = \frac{\text{ETrec–a} \times \text{EDa} + \text{ETrec–c} \times \text{EDc}}{\text{ED}} \quad (15)$$

$$\text{DFWrec} = \frac{\text{EVa} \times \text{EFrec} \times \text{EDa} \times \text{SAa}}{\text{BWa}} + \frac{-\text{EVc} \times \text{EFrec} \times \text{EDc} \times \text{SAc}}{\text{BWc}} \quad (16)$$

$$TCR = CR_{ingestion} + CR_{dermal} \quad (17)$$

$CR > 1.0\times10^{-4}$ is considered unacceptable, $1.0\times10^{-4} < CR < 1.0\times10^{-6}$ is considered an acceptable range depending on the exposure conditions, $CR<1.0\times10^{-6}$ is considered not to have significant health effects (USEPA, 1989).

Statistical analyses:

Within the scope of the study, the Kruskal–Wallis test was used to determine whether there was a statistically significant difference between adult and child health risk indices across stations during the dry and rainy periods (Kolassa, 2020). All statistical analyses were performed using SPSS 22.

Table 1. Variables used in health risk estimation of recreational (RC) and residential (RS) receptors; **A)** Definitions, symbols, units and values, **B)** Dermal permeability coefficient, reference dose, slope factor and gastrointestinal absorption coefficient for each element

A

Definitions	Symbols	Units	Values
Element concentration	C_w	µg/L	
Body weight-adult	BW_a	kg	70[a]
Body weight-child	BW_c	kg	15[a]
RS/RC exposure duration	ED	years	26[a]
RS/RC exposure duration-child	ED_c	years	6[a]
RS/RC exposure duration-adult	ED_a	years	20[a]
RS exposure frequency	EF_{res}	days/year	350[a]
RC exposure frequency	EF_{rec}	days/year	135[b]
RS exposure time-adult	$ET_{res\text{-}a}$	hours/event	0.71[a]
RS exposure time-child	$ET_{res\text{-}c}$	hours/event	0.54[a]
RC exposure time-adult	$ET_{rec\text{-}a}$	hours/event	2[b]
RC exposure time-child	$ET_{rec\text{-}c}$	hours/event	2[b]
RS/RC events-adult	EV_a	per day	1[c]
RS/RC events-child	EV_c	per day	1[c]
RS/RC skin surface area-adult	SA_a	cm^2	19652[a]
RS/RC skin surface area-child	SA_c	cm^2	6365[a]
RS water intake ratio-adult	$IRW_{res\text{-}a}$	L/day	2.5[a]
RS water intake ratio-child	$IRW_{res\text{-}c}$	L/day	0.78[a]
RC water intake ratio-adult	$IRW_{rec\text{-}a}$	L/day	0.11[d]
RC water intake ratio-child	$IRW_{rec\text{-}c}$	L/day	0.12[d]
RS averaging time-adult	$AT_{res\text{-}a}$	days	365 x ED = 9490 (non-carcinogenic)[a]
RS averaging time-child	$AT_{res\text{-}c}$	days	365 x ED_c = 2190 (non-carcinogenic)a
RC averaging time-adult	$AT_{rec\text{-}a}$	days	365 x ED_a (non-carcinogenic)[a]
RC averaging time-child	$AT_{rec\text{-}c}$	days	365 x ED_c (non-carcinogenic)[a]
RS water ingestion rate	IFW_{res}	L/kg	Age-adjusted[e]
RC water ingestion rate	IFW_{rec}	L/kg	Age-adjusted[e]
RS water dermal contact factor	DFW_{res}	cm^2 - event/kg	Age-adjusted[e]
RC water dermal contact factor	DFW_{rec}	cm^2 - event/kg	Age-adjusted[e]
RS water exposure time	$ET_{event\text{-}res}$	hours/event	Age-adjusted[e]
RC water exposure time	$ET_{event\text{-}rec}$	hours/event	Age-adjusted[e]
Life time	LT	years	70[a]
Averaging time	AT	days	365 × LT = 25550 (carcinogenic)[a]

B

Element	Dermal permeability constant (K_p; cm/h)	Oral reference dose (RfD_o; mg/kg-day)	Oral slope factor (CSF_o; mg/kg-day)	Gastrointestinal absorption (GIABS; unitless)
As	0.001[c]	0.0003[e]	1.5[e]	1[e]
Cr	0.002[c]	0.003[e]	0.5[e]	0.025[e]
Cu	0.001[c]	0.04[e]		1[e]
Fe	0.001[c]	0.7[e]		1[e]
Ni	0.0002[c]	0.02[e]	1.7[f]	0.04[e]
Pb	0.0001[c]	0.0014[e]	8.5[g]	1[e]
Zn	0.0006[c]	0.3[e]		1[e]

a-USEPA (2014), b- Site-specific, c) USEPA (2004), d) USEPA (2011), e) USEPA (2024), f - Kumar et al. (2019), g- Mohammadi et al. (2019)

Results

In the dry and rainy periods of the study, the potential non-carcinogenic risks (HQ) and the total potential non-carcinogenic risks caused by different exposure pathways (HI) for adults and children, based on three stations and separately for recreational and residential receptors, are presented in Tables 2–5. Our findings indicated that, Hg and Zn were below the detection limits at all stations during the dry period, while in the rainy period, Cd, Hg, and Pb at Stations I and II, and Cd, Hg, Pb, and Zn at Station III were found to be below the detection limits.

For recreational receptors, in both the dry and rainy sampling periods, child $HQ_{ingestion}$ values and child THI values were found to be higher than those of adults. Likewise, in both periods, $HQ_{ingestion}$ values were higher than dermal exposure (HQ_{dermal}) values. During the dry period, within the $HQ_{ingestion}$ risk values, As contributed the most (maximum values for child and adult were 1.05×10^{-3} and 2.10×10^{-4}, respectively), while within the HQ_{dermal} risk values Cd showed the highest contribution (child: 4.07×10^{-4}; adult: 2.69×10^{-4}). Based on THI values in the dry period, Station I, where quarry-related wastewater reaches the system, exhibited a higher risk compared to the other stations (child: 1.67×10^{-3}; adult: 5.94×10^{-4}) (Table 2). While THI values for the dry period were higher than those of the wet period at Stations I and II, they showed similar trends at Station III (Table 3).

During the rainy period, As made a significant contribution to both $HQ_{ingestion}$ and HQ_{dermal} risk values, while Cd, which had the highest contribution to HQ_{dermal} in the dry period, was not detected in this period. In addition, Station III, which has the highest likelihood of receiving agricultural runoff, showed comparatively lower risk levels than the other stations (child: 1.55×10^{-3}; adult: 4.00×10^{-4}) (Table 3).

For recreational receptors, no statistically significant differences were observed in health risk indices among stations for both adults and children during the dry period ($p > 0.05$). In the wet period, however, health risk indices for both adults and children showed statistically significant differences among stations ($p < 0.05$). According to post hoc tests, these differences were observed between adult and child health risk indices measured at Station I and those obtained from Stations II and III, as well as between measurements from Station II and those from Station III. Nevertheless, all values being below 1 indicate that non-carcinogenic health risks for recreational receptors are at negligible levels.

For residential receptors, during the dry sampling period, $HQ_{ingestion}$, HQ_{dermal}, and THI values for children were found to be higher than those for adults across all stations. Among the investigated metals, As within $HQ_{ingestion}$ (maximum values for child and adult were 8.99×10^{-3} and 6.18×10^{-3}, respectively) and Cd within HQ_{dermal} (child and adult maximum values were 2.85×10^{-4} and 1.91×10^{-4}, respectively) contributed more significantly to the total non-carcinogenic health risk compared to other metals. The higher THI values observed at Station II, which is closest to residential areas, compared to the other stations, support the conclusion that residential areas pose a potential risk for both metals (Table 4).

For this category, during the rainy sampling period, $HQ_{ingestion}$, HQ_{dermal}, and $THI_{ingestion-dermal}$ values for children were found to be higher than those for adults at all stations, similar to the dry period (Table 5). In addition, As remained the dominant contributor to both $HQ_{ingestion}$ and HQ_{dermal}. However, it is noteworthy that Cd, which showed the highest contribution to HQ_{dermal} during the dry period, was not detected in the rainy period. Based on total hazard index values in the rainy period, surface waters at Station III, which is closest to agricultural activity areas, exhibited higher risk levels compared to the other stations for both children and adults. Considering Tables 4–5, $HQ_{ingestion}$ values were consistently higher than HQ_{dermal} values. Furthermore, the absence of Cd and Pb during the rainy

period appears to be a contributing factor to the substantially lower THI (child–adult) values observed at Stations II and III compared to those of the dry period. For residential receptors, no statistically significant differences were found among stations in terms of $HI_{ingestion}$ values for both adults and children during the dry period ($p > 0.05$).

Table 2. Heavy metal concentrations and non-carcinogenic (HQ and HI) risks of adult and child for dry season for recreational receptors

Stations	Metals	Concentration (µg/ L) (mean±SD)	$HQ_{ingestion}$		HQ_{dermal}	
			Child	Adult	Child	Adult
I	As	53.15±1.22	$1.05x10^{-3}$	$2.06x10^{-4}$	$1.36x10^{-4}$	$8.97x10^{-5}$
	Cd	1.62±0.14	$1.92x10^{-5}$	$3.77x10^{-6}$	$4.07x10^{-4}$	$2.69x10^{-4}$
	Cr	2.61±1.92	$5.15x10^{-6}$	$1.01x10^{-6}$	$2.18x10^{-5}$	$1.44x10^{-5}$
	Cu	1.65±0.39	$2.44x10^{-7}$	$4.79x10^{-8}$	$2.59x10^{-6}$	$1.71x10^{-6}$
	Fe	15.78±2.27	$1.33x10^{-7}$	$2.62x10^{-8}$	$3.54x10^{-8}$	$2.34x10^{-8}$
	Ni	3.35±0.16	$9.92x10^{-7}$	$1.95x10^{-7}$	$6.58x10^{-6}$	$4.35x10^{-6}$
	Pb	4.37±070	$1.85x10^{-5}$	$3.63x10^{-6}$	$3.26x10^{-7}$	$2.16x10^{-7}$
	$HI_{ingestion}$ - HI_{dermal}		$1.09x10^{-3}$	$2.15x10^{-4}$	$5.74x10^{-4}$	$3.80x10^{-4}$
	THI	Child		$1.67x10^{-3}$		
		Adult		$5.94x10^{-4}$		
II	As	54.09 ± 1.94	$1.07x10^{-3}$	$2.10x10^{-4}$	$1.38x10^{-4}$	$9.13x10^{-5}$
	Cd	1.54 ± 0.09	$1.83x10^{-5}$	$3.59x10^{-6}$	$3.88x10^{-4}$	$2.57x10^{-4}$
	Cr	2.00 ± 3.00	$3.94x10^{-6}$	$7.74x10^{-7}$	$1.67x10^{-5}$	$1.11x10^{-5}$
	Cu	1.56 ± 0.18	$2.31x10^{-7}$	$4.53x10^{-8}$	$2.45x10^{-6}$	$1.62x10^{-6}$
	Fe	11.81 ± 0.88	$9.98x10^{-8}$	$1.96x10^{-8}$	$2.65x10^{-8}$	$1.75x10^{-8}$
	Ni	4.06 ± 0.25	$1.20x10^{-6}$	$2.36x10^{-7}$	$7.96x10^{-6}$	$5.26x10^{-6}$
	Pb	4.71 ± 0.54	$1.99x10^{-5}$	$3.91x10^{-6}$	$3.52x10^{-7}$	$2.33x10^{-7}$
	$HI_{ingestion}$ - HI_{dermal}		$1.11x10^{-3}$	$2.18x10^{-4}$	$5.53x10^{-4}$	$3.66x10^{-4}$
	THI	Child		$1.66x10^{-3}$		
		Adult		$5.84x10^{-4}$		
III	As	53.71 ± 0.94	$1.06x10^{-3}$	$2.08x10^{-4}$	$1.37x10^{-4}$	$9.07x10^{-5}$
	Cd	1.22 ± 0.07	$1.45x10^{-5}$	$2.84x10^{-6}$	$3.07x10^{-4}$	$2.03x10^{-4}$
	Cr	1.53 ± 2.12	$3.02x10^{-6}$	$5.94x10^{-7}$	$1.28x10^{-5}$	$8.49x10^{-6}$
	Cu	0.36 ± 0.15	$5.38x10^{-8}$	$1.06x10^{-8}$	$5.71x10^{-7}$	$3.78x10^{-7}$
	Fe	155.68 ± 53.43	$1.32x10^{-6}$	$2.59x10^{-7}$	$3.49x10^{-7}$	$2.31x10^{-7}$
	Ni	4.65 ± 0.43	$1.37x10^{-6}$	$2.70x10^{-7}$	$9.11x10^{-6}$	$6.03x10^{-6}$
	Pb	0.40 ± 0.21	$1.69x10^{-6}$	$3.33x10^{-7}$	$2.99x10^{-8}$	$1.98x10^{-8}$
	$HI_{ingestion}$ - HI_{dermal}		$1.08x10^{-3}$	$2.12x10^{-4}$	$4.67x10^{-4}$	$3.09x10^{-4}$
	THI	Child		$1.55x10^{-3}$		
		Adult		$5.22x10^{-4}$		

Table 3. Heavy metal concentrations and non-carcinogenic (HQ and HI) risks of adult and child for rainy season for recreational receptors

Stations	Metals	Concentration (µg/ L) (mean±SD)	$HQ_{ingestion}$		HQ_{dermal}	
			Child	Adult	Child	Adult
I	As	58.22 ± 1.88	$1.15x10^{-3}$	$2.26x10^{-4}$	$1.49x10^{-4}$	$9.83x10^{-5}$
	Cr	0.98 ± 0.74	$1.93x10^{-6}$	$3.80x10^{-7}$	$8.20x10^{-6}$	$5.42x10^{-6}$
	Cu	0.52 ± 0.57	$7.75x10^{-8}$	$1.52x10^{-8}$	$8.22x10^{-7}$	$5.44x10^{-7}$
	Fe	267.33 ± 86.61	$2.26x10^{-6}$	$4.44x10^{-7}$	$5.99x10^{-7}$	$3.97x10^{-7}$
	Ni	5.13 ± 0.35	$1.52x10^{-6}$	$2.98x10^{-7}$	$1.01x10^{-5}$	$6.66x10^{-6}$
	Zn	1.61 ± 0.31	$3.18x10^{-8}$	$6.25x10^{-9}$	$5.06x10^{-9}$	$3.35x10^{-9}$
	$HI_{ingestion}$ - HI_{dermal}		$1.15x10^{-3}$	$2.27x10^{-4}$	$1.68x10^{-4}$	$1.11x10^{-4}$
	THI	Child			$1.32x10^{-3}$	
		Adult			$3.38x10^{-4}$	
II	As	63.20 ± 1.15	$1.25x10^{-3}$	$2.45x10^{-4}$	$1.61x10^{-4}$	$1.07x10^{-4}$
	Cr	1.77 ± 0.15	$3.49x10^{-6}$	$6.86x10^{-7}$	$1.48x10^{-5}$	$9.81x10^{-6}$
	Cu	0.73 ± 0.67	$1.08x10^{-7}$	$2.13x10^{-8}$	$1.15x10^{-6}$	$7.61x10^{-7}$
	Fe	420.57 ± 36.96	$3.56x10^{-6}$	$6.98x10^{-7}$	$9.43x10^{-7}$	$6.24x10^{-7}$
	Ni	5.88 ± 0.19	$1.74x10^{-6}$	$3.42x10^{-7}$	$1.15x10^{-5}$	$7.64x10^{-6}$
	Zn	1.48 ± 0.21	$2.92x10^{-8}$	$5.74x10^{-9}$	$4.65x10^{-9}$	$3.07x10^{-9}$
	$HI_{ingestion}$ - HI_{dermal}		$1.26x10^{-3}$	$2.47x10^{-4}$	$1.90x10^{-4}$	$1.26x10^{-4}$
	THI	Child			$1.45x10^{-3}$	
		Adult			$3.72x10^{-4}$	
III	As	67.51 ± 1.47	$1.33x10^{-3}$	$2.62x10^{-4}$	$1.72x10^{-4}$	$1.14x10^{-4}$
	Cr	2.41 ± 0.20	$4.76x10^{-6}$	$9.36x10^{-7}$	$2.02x10^{-5}$	$1.34x10^{-5}$
	Fe	612.04 ± 35.08	$5.17x10^{-6}$	$1.02x10^{-6}$	$1.37x10^{-6}$	$9.08x10^{-7}$
	Ni	6.31 ± 0.18	$1.87x10^{-6}$	$3.66x10^{-7}$	$1.24x10^{-5}$	$8.18x10^{-6}$
	$HI_{ingestion}$ - HI_{dermal}		$1.34x10^{-3}$	$2.64x10^{-4}$	$2.06x10^{-4}$	$1.36x10^{-4}$
	THI	Child			$1.55x10^{-3}$	
		Adult			$4.00x10^{-4}$	

Table 4. Heavy metal concentrations and non-carcinogenic (HQ and HI) risks of adult and child for dry season for residential receptors

Stations	Metals	Concentration (µg/ L) (mean±SD)	$HQ_{ingestion}$		HQ_{dermal}	
			Child	**Adult**	**Child**	**Adult**
I	As	53.15±1.22	$8.83x10^{-3}$	$6.07x10^{-3}$	$9.49x10^{-5}$	$6.35x10^{-5}$
	Cd	1.62±0.14	$1.62x10^{-4}$	$1.11x10^{-4}$	$2.85x10^{-4}$	$1.91x10^{-4}$
	Cr	2.61±1.92	$4.34x10^{-5}$	$2.98x10^{-5}$	$1.53x10^{-5}$	$1.02x10^{-5}$
	Cu	1.65±0.39	$2.05x10^{-6}$	$1.41x10^{-6}$	$1.81x10^{-6}$	$1.21x10^{-6}$
	Fe	15.78±2.27	$1.12x10^{-6}$	$7.72x10^{-7}$	$2.48x10^{-8}$	$1.66x10^{-8}$
	Ni	3.35±0.16	$8.36x10^{-6}$	$5.74x10^{-6}$	$4.60x10^{-6}$	$3.08x10^{-6}$
	Pb	4.37±070	$1.56x10^{-4}$	$1.07x10^{-4}$	$2.28x10^{-7}$	$1.53x10^{-7}$
	$HI_{ingestion}$ - HI_{dermal}		$9.21x10^{-3}$	$6.32x10^{-3}$	$4.02x10^{-4}$	$2.69x10^{-4}$
	THI	Child	$9.61x10^{-3}$			
		Adult	$6.59x10^{-3}$			
II	As	54.09 ± 1.94	$8.99x10^{-3}$	$6.18x10^{-3}$	$9.66x10^{-5}$	$6.47x10^{-5}$
	Cd	1.54 ± 0.09	$1.54x10^{-4}$	$1.06x10^{-4}$	$2.71x10^{-4}$	$1.82x10^{-4}$
	Cr	2.00 ± 3.00	$3.32x10^{-5}$	$2.28x10^{-5}$	$1.17x10^{-5}$	$7.83x10^{-6}$
	Cu	1.56 ± 0.18	$1.94x10^{-6}$	$1.33x10^{-6}$	$1.71x10^{-6}$	$1.15x10^{-6}$
	Fe	11.81 ± 0.88	$8.41x10^{-7}$	$5.78x10^{-7}$	$1.85x10^{-8}$	$1.24x10^{-8}$
	Ni	4.06 ± 0.25	$1.01x10^{-5}$	$6.95x10^{-6}$	$5.57x10^{-6}$	$3.73x10^{-6}$
	Pb	4.71 ± 0.54	$1.68x10^{-4}$	$1.15x10^{-4}$	$2.46x10^{-7}$	$1.65x10^{-7}$
	$HI_{ingestion}$ - HI_{dermal}		$9.36x10^{-3}$	$6.43x10^{-3}$	$3.87x10^{-4}$	$2.59x10^{-4}$
	THI	Child	$9.75x10^{-3}$			
		Adult	$6.69x10^{-3}$			
III	As	53.71 ± 0.94	$8.93x10^{-3}$	$6.13x10^{-3}$	$9.60x10^{-5}$	$6.42x10^{-5}$
	Cd	1.22 ± 0.07	$1.22x10^{-4}$	$8.38x10^{-5}$	$2.15x10^{-4}$	$1.44x10^{-4}$
	Cr	1.53 ± 2.12	$2.55x10^{-5}$	$1.75x10^{-5}$	$8.99x10^{-6}$	$6.01x10^{-6}$
	Cu	0.36 ± 0.15	$4.54x10^{-7}$	$3.12x10^{-7}$	$4.00x10^{-7}$	$2.68x10^{-7}$
	Fe	155.68 ± 53.43	$1.11x10^{-5}$	$7.62x10^{-6}$	$2.44x10^{-7}$	$1.63x10^{-7}$
	Ni	4.65 ± 0.43	$1.16x10^{-5}$	$7.95x10^{-6}$	$6.38x10^{-6}$	$4.27x10^{-6}$
	Pb	0.40 ± 0.21	$1.43x10^{-5}$	$9.80x10^{-6}$	$2.10x10^{-8}$	$1.40x10^{-8}$
	$HI_{ingestion}$ - HI_{dermal}		$9.11x10^{-3}$	$6.26x10^{-3}$	$3.27x10^{-4}$	$2.19x10^{-4}$
	THI	Child	$9.44x10^{-3}$			
		Adult	$6.48x10^{-3}$			

However, measurements of HI_{dermal} (child and adult) and THI (child and adult) showed statistically significant differences across stations. This variation was observed between Station I and Station III, as well as between Station II and Station III. During the rainy period, the differences in health risk indices among stations for both adults and children were also found to be statistically significant ($p < 0.05$). According to post hoc (pairwise comparison) tests, these statistical differences were identified between the adult and child health risk indices estimated for Station I and the values obtained from Stations II and III. Similarly, statistically significant differences ($p < 0.05$) were observed between the adult and child health risk indices of Station II and the estimated values for Station III. However, since all values were below the threshold of 1, exposure to these metals does not pose a significant non-carcinogenic health risk for residential receptors.

Table 5. Heavy metal concentrations and non-carcinogenic (HQ and HI) risks of adult and child for rainy season for residential receptors

Stations	Metals	Concentration (µg/ L) (mean±SD)	$HQ_{ingestion}$		HQ_{dermal}	
			Child	Adult	Child	Adult
I	As	58.22 ± 1.88	$9.68x10^{-3}$	$6.65x10^{-3}$	$1.04x10^{-4}$	$6.96x10^{-5}$
	Cr	0.98 ± 0.74	$1.63x10^{-5}$	$1.12x10^{-5}$	$5.74x10^{-6}$	$3.84x10^{-6}$
	Cu	0.52 ± 0.57	$6.53x10^{-7}$	$4.48x10^{-7}$	$5.75x10^{-7}$	$3.85x10^{-7}$
	Fe	267.33 ± 86.61	$1.90x10^{-5}$	$1.31x10^{-5}$	$4.20x10^{-7}$	$2.81x10^{-7}$
	Ni	5.13 ± 0.35	$1.28x10^{-5}$	$8.78x10^{-6}$	$7.04x10^{-6}$	$4.71x10^{-6}$
	Zn	1.61 ± 0.31	$2.68x10^{-7}$	$1.84x10^{-7}$	$3.54x10^{-9}$	$2.37x10^{-9}$
	$HI_{ingestion}$ - HI_{dermal}		$9.73x10^{-3}$	$6.68x10^{-3}$	$1.18x10^{-4}$	$7.88x10^{-5}$
	THI	Child	$9.84x10^{-3}$			
		Adult	$6.76x10^{-3}$			
II	As	63.20 ± 1.15	$1.05x10^{-2}$	$7.21x10^{-3}$	$1.13x10^{-4}$	$7.55x10^{-5}$
	Cr	1.77 ± 0.15	$2.94x10^{-5}$	$2.02x10^{-5}$	$1.04x10^{-5}$	$6.95x10^{-6}$
	Cu	0.73 ± 0.67	$9.13x10^{-7}$	$6.27x10^{-7}$	$8.05x10^{-7}$	$5.39x10^{-7}$
	Fe	420.57 ± 36.96	$3.00x10^{-5}$	$2.06x10^{-5}$	$6.60x10^{-7}$	$4.42x10^{-7}$
	Ni	5.88 ± 0.19	$1.47x10^{-5}$	$1.01x10^{-5}$	$8.08x10^{-6}$	$5.41x10^{-6}$
	Zn	1.48 ± 0.21	$2.46x10^{-7}$	$1.69x10^{-7}$	$3.25x10^{-9}$	$2.18x10^{-9}$
	$HI_{ingestion}$ - HI_{dermal}		$1.06x10^{-2}$	$7.27x10^{-3}$	$1.33x10^{-4}$	$8.89x10^{-5}$
	THI	Child	$1.07x10^{-2}$			
		Adult	$7.35x10^{-3}$			
III	As	67.51 ± 1.47	$1.12x10^{-2}$	$7.71x10^{-3}$	$1.21x10^{-4}$	$8.07x10^{-5}$
	Cr	2.41 ± 0.20	$4.01x10^{-5}$	$2.76x10^{-5}$	$1.41x10^{-5}$	$9.47x10^{-6}$
	Cu	0.00 ± 0.00	$0.00x10^{0}$	$0.00x10^{0}$	$0.00x10^{0}$	$0.00x10^{0}$
	Fe	612.04 ± 35.08	$4.36x10^{-5}$	$2.99x10^{-5}$	$9.61x10^{-7}$	$6.43x10^{-7}$
	Ni	6.31 ± 0.18	$1.57x10^{-5}$	$1.08x10^{-5}$	$8.66x10^{-6}$	$5.79x10^{-6}$
	$HI_{ingestion}$ - HI_{dermal}		$1.13x10^{-2}$	$7.77x10^{-3}$	$1.44x10^{-4}$	$9.66x10^{-5}$
	THI	Child	$1.15x10^{-2}$			
		Adult	$7.87x10^{-3}$			

In many studies on this subject, CR values exceeding the range of 10^{-6} to 10^{-4} are considered to represent the probability of developing cancer over a 70-year lifetime. In this study, five heavy metals—As, Cd, Cr, Ni, and Pb—were considered in the estimation of TCR values. For both the dry and rainy periods, the carcinogenic risk values estimated for surface waters were below 1×10^{-4}, indicating that there is no carcinogenic health threat for recreational receptors. During the dry period, As was identified as the dominant contributor to $CR_{ingestion}$, a component of carcinogenic risk (TCR), at all stations; this was followed by Pb at Stations I and II and by Ni at Station III. For CR_{dermal}, As was again the primary contributing metal, followed by Cd at Stations I and II and Ni at Station III (Figure 2).

Considering residential receptors, in both the dry and rainy periods, carcinogenic risk values associated with metals other than As (Cr, Ni, Cd, and Pb) were found to be below the target risk level of 1.0×10^{-4}; therefore, no adverse effects on human health are expected. TCR values for As were found to be in the range of $1.0\times10^{-4} < CR < 1.0\times10^{-6}$, indicating an acceptable level depending on exposure conditions. The maximum TCR value for As was recorded at Station I in the dry period (1.13×10^{-6}), while in the rainy period it was observed at Station III (1.43×10^{-6}). Both values indicate a "very low but acceptable risk level." In both the dry and wet periods, As was identified as the dominant contributor to $CR_{ingestion}$ and CR_{dermal} at all stations. In the dry period, the second major contributor to TCR after As was Pb, whereas in the rainy period, it was Ni (Figure 2). Statistical analysis revealed that TCR values showed significant differences both between periods and among stations ($p < 0.001$). TCR values were higher in the wet period compared to the dry period, and the highest carcinogenic risk value was observed at Station III, where agricultural runoff is likely to be the primary source of contamination.

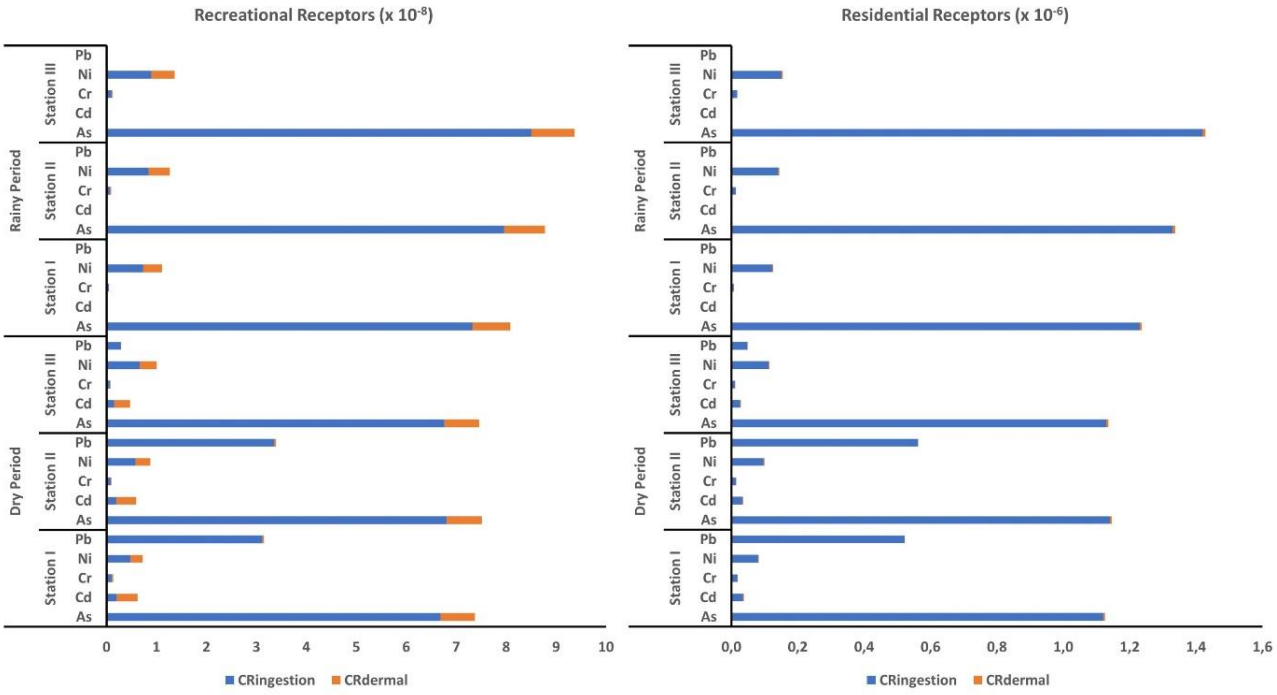


Figure 2. Variation of carcinogenic risk values for recreational (A) and residential (B) receptors depending on stations and periods

Discussion

Heavy metals, which are among the factors causing water pollution, are considered systemic toxic substances that can lead to multiple organ damage as well as teratogenic and carcinogenic effects. In particular, heavy metal risk levels, which are a critical issue affecting the safety of drinking water resources, have been addressed in various studies (Saleem et al., 2019; Fahimah et al., 2024; Wang et al., 2024). It has also been reported that the waters of Uluabat Lake (Şener et al., 2023) and Lake İznik (Şener et al., 2025) in Türkiye may cause both carcinogenic and non-carcinogenic health problems. In this study, the eutrophic and shallow Mogan Lake was selected as the study area; however, in terms of water quality, it is far from being a drinking water source and primarily serves residential and recreational functions.

Numerous studies in recent years have demonstrated that the assessment of heavy metal-related health risks in rivers and lakes has become an essential component of aquatic environmental management. The concentrations of Cr, Ni, Cu, Zn, As, Cd, Hg, Pb, and Fe in the surface

waters of Mogan Lake were determined, and non-carcinogenic health risks were estimated for residential and recreational receptors. Within the scope of the study, the estimated total non-carcinogenic health risk values for residential and recreational receptors (children and adults) during both dry and rainy periods were found to be below the threshold value of 1. Accordingly, it can be stated that exposure to the aforementioned metals is unlikely to pose a potential health risk to residents or recreational users of the lake. However, the estimated total hazard index (THI > 1) values for the Sukesen, Başpınar, and Gölcük streams feeding Mogan Lake indicate a high level of non-carcinogenic health risk (Pulatsü & Latifi, 2023). In this study, particularly during the rainy period, THI values for residential receptors showed statistically significant variation across sampling stations for both adults and children ($p < 0.05$), reaching their maximum at Station III, where agricultural wastewater inputs are received (child: 1.15×10^{-2}; adult: 7.87×10^{-3}), and at Station II, which is located closest to residential areas (child: 1.07×10^{-2}; adult: 7.35×10^{-3}). Under current conditions, although exposure to heavy metals in lake surface waters does not pose a significant non-carcinogenic health risk for residential receptors, it is likely that human health risk values may be adversely affected in the future if wastewater inputs originating from residential settlements and agricultural activities in the watershed continue.

The results of this study are consistent with the findings reported for ten ponds located in the Saros Gulf (Türkiye), which is used as a source of irrigation and drinking water (Tokatlı & Varol, 2021), as well as for studies conducted at Doğancı Dam (Bursa, Türkiye) (Fural et al., 2022), where no non-carcinogenic health risk was identified for either adults or children. In the present study, the hazard index (HI) was calculated as the sum of the total potential health risks posed by heavy metals, derived from hazard quotients (HQs) through ingestion and dermal contact exposure pathways. In this context, for both considered periods, ingestion hazard quotient ($HQ_{ingestion}$) values were found to be higher than dermal absorption hazard quotient ($HQ_{dermal)}$ values for both recreational and residential receptors. Our findings are consistent with those of previous studies (Custodio et al., 2020; Varol & Tokatlı, 2023; Dippong et al., 2024), which reported that non-carcinogenic health risk values associated with metal ingestion are higher than those resulting from dermal exposure. For the four streams feeding Mogan Lake, the calculated $HQ_{ingestion}$ values for both adults and children, based on Hg, As, Cd, Cr, Pb, Ni, Cu, and Zn concentrations, were also found to be higher than the corresponding HQ_{dermal} values (Pulatsü & Latifi, 2023).

It has been reported that non-carcinogenic risk levels are higher for children compared to adults, indicating that children are exposed to a greater level of potential risk (Sharafi & Salehi, 2025; Pulatsü & Latifi, 2023). Similarly, in our study, for both recreational and residential receptors, child- $HQ_{ingestion}$ and child-THI values were found to be higher than those of adults during both dry and rainy sampling periods (Tables 2–5). This result is consistent with findings reported for the upstream–downstream sections of Keban Dam Reservoir (Türkiye) (Varol, 2019) and for water samples collected from both surface and deep zones of the reservoir (Canpolat et al., 2020), where higher HI values were observed for children compared to adults in both residential and recreational exposure scenarios. In addition, it has been reported that child hazard index values ($HI_{ingestion}$ and HI_{dermal}) for the streams feeding Mogan Lake are also higher than those for adults (Pulatsü & Latifi, 2023). Based on the findings for Mogan Lake, although non-carcinogenic health risks were found to be negligible, it can be stated that children's health is disproportionately more at risk compared to that of adults.

In our study, arsenic (As) was identified as the heavy metal contributing most significantly to the ingestion pathway of the hazard index (HI) for both residential and recreational receptors during the dry period. This finding is consistent with Kumar et al. (2019), who reported that As is the primary contaminant based on hazard quotients associated with ingestion and dermal exposure pathways for both adults and children. Furthermore, the significant contribution of As to the ingestion pathway has also been reported in studies conducted in Keban Dam Lake (for both residential and recreational receptors; Varol, 2019) and in the Meriç River Delta (Tokatlı & Ustaoğlu, 2020).

In our study, non-carcinogenic health indices for both recreational and residential receptors were found to be higher during the rainy period compared to the dry period. This result indicates that seasonal hydrological processes (i.e., precipitation) may alter the distribution of environmental pollutants and exposure dynamics. Increased rainfall and surface runoff are thought to enhance the transport of heavy metals into aquatic environments, thereby increasing the potential for receptor exposure through ingestion and dermal contact pathways. In this context, it is likely that the rainy period poses a greater threat to human health, particularly at stations receiving agricultural and residential wastewater inputs. However, conducting a greater number of sampling campaigns in both dry and wet seasons would strengthen the conclusion that seasonal risk variations should be taken into account for individuals living in residential areas and using recreational zones.

In our study, HQ_{dermal} values for both recreational and residential receptors were found to be below 1 (for both children and adults) during the dry period, and Cd was identified as the heavy metal with the highest contribution to this risk factor. In the rainy period, however, As was the metal contributing most significantly to dermal exposure for both residential and recreational receptors. Our findings are not consistent with Varol (2019), who reported that Cr made the highest contribution to the HI for both residential and recreational receptors via dermal exposure in Keban Dam Reservoir. However, they are in agreement with Pulatsü and Latifi (2023), who reported that As contributed most significantly to HQ_{dermal} values in the streams feeding the lake. In this context, arsenic appears to be the most important toxic element responsible

for non-carcinogenic health concerns in the surface waters of Mogan Lake.

In our study, the $CR_{ingestion}$ exposure risk value, which is one of the components of total carcinogenic risk values, was found to be higher than CR_{dermal}, and this result is in line with the finding of Pulatsü and Latifi (2023), who calculated that $CR_{ingestion}$ exposure for chromium, nickel, and arsenic in Mogan Lake inflow waters is more risky than CR_{dermal} exposure. Within the scope of the study, among the metals considered in terms of carcinogenic health risks (As, Cd, Cr, Ni, Pb), exposure to As was found to be below the target risk level of 1×10^{-4} and does not pose a hazard in terms of the health of recreational receptors. Our finding is consistent with the results reported by Canpolat et al. (2020) and Varol et al. (2021) for Keban Dam Reservoir.

For residential receptors, exposure to As in terms of carcinogenic health risks was determined to be at an "acceptable risk" level ($1.13 \times 10^{-6} – 1.43 \times 10^{-6}$). As, identified as the metal with the highest risk for residential receptors, is known to be the only carcinogen that can cause cancer through both respiratory and gastrointestinal exposure pathways. Considering its toxicity, the importance of arsenic exposure for public health (Mukherjee et al., 2021; Patel et al., 2021; Anonymous, 2024) and the need for further research and a continuous monitoring program to support effective public health management have been emphasized (Cheung et al., 2020). In our study, Pb and Ni, following As, were identified as metals with a higher potential to pose carcinogenic risk compared to Cr.

As a result, exposure to heavy metals (As, Cd, Cr, Cu, Ni, Pb, Hg, Zn, Fe) in the surface waters of Mogan Lake via ingestion and dermal pathways was found not to cause non-carcinogenic risks for recreational and residential receptors (both adults and children). For recreational and residential receptors during the dry period, arsenic (As) was identified as the primary contributor to the total risk (HI) for the $HQ_{ingestion}$ pathway, while chromium (Cr) was identified as the primary contributing metal for the HQ_{dermal} pathway. For recreational and residential receptors across both dry and wet periods, based on $HI_{ingestion}$ and HI_{dermal} values, hazard index values for children were found to be higher than those for adults, indicating that children are exposed to greater health risks from the considered heavy metals. The total carcinogenic risk (TCR) value for arsenic (As) in the surface waters of Mogan Lake suggests that exposure to this metal does not pose a serious cancer risk for residential receptors; however, the risk cannot be considered entirely negligible. In this context, long-term adverse health effects associated with arsenic exposure in residential receptors appear likely. In order to protect the health of local residents in the Mogan Lake basin and to sustain the lake's recreational potential, monitoring of heavy metal dynamics at the lake/basin scale would be appropriate.

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Conflicts of Interest

The authors declare that they have no conflict of interest.

Author Contributions

All authors took part in designing the research, collecting and writing the manuscript.

Ethics Approval

There are no ethical issues with the publication of this manuscript.

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