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RESEARCH ARTICLE ARAŞTIRMA MAKALESİ

Evaluation of health risks from heavy metals in the creeks feeding Mogan Lake, Türkiye

Mogan Gölü'nü (Türkiye) besleyen derelerde ağır metallerden kaynaklanan sağlık risklerinin değerlendirilmesi

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Abstract: The non-carcinogenic and carcinogenic health risks arising from potential exposure to heavy metals pose a negative threat to human health. In this study, heavy metals (Hg, As, Cd, Cr, Pb, Ni, Cu, Zn) analyses were conducted in the waters of four creeks in the Mogan Lake Basin (Sukesen Creek, Başpınar Creek, Yavrucak Creek, Gölcük Creek) under anthropogenic pressure. In the water samples taken from the creeks that also contribute to Mogan Lake, which has significant recreational importance in the basin: a) The non-carcinogenic health risks (HQ) of exposure to heavy metals through ingestion and dermal routes were identified for adults and children, b) The total potential non-carcinogenic health risks for adults and children were determined using the hazard index (HI). The total HI (THI) value was calculated as the sum of individual HIs ($HI_{ingestion}$ + HI_{dermal}), c) Carcinogenic health risk (CR) values were calculated for three heavy metals (Cr, Ni and As). According to the findings: a) Ingestion HQ values were found to be higher in adults and children due to As compared to dermal HQ values. According to the HI values, there was a high level of non-carcinogenic health risk in terms of heavy metals in Sukesen, Başpınar, and Gölcük Creeks, varying according to the month and age group. However, for Yavrucak Creek, there has not been appeared to be a non-carcinogenic health risk for adults and children, b) According to the calculated HQ_{dermal} and HI_{dermal} values, there was no significant adverse health risk due to dermal exposure for adults and children, c) Children hazard index values were found to be higher than adult hazard index values, highlighting that children were at higher health risk most particularly when it comes to the considered heavy metals, d) The THI values for Sukesen and Başpınar Creeks indicated a significant non-carcinogenic health risk possibility for both adults and children in all sampled months. In Gölcük Creek, a serious non-carcinogenic health risk probability was observed for adults in April and for children during the sampling period, e) The calculated CR values for chromium, nickel, and arsenic indicated that the ingestion pathway poses a higher risk compared to the dermal route, expressing the likelihood of cancer incidence in adults and children. In the context of potential health hazards, to take administrative measures regarding heavy metal contamination, particularly in Başpınar and Sukesen Creeks, is important not only for the protection of public health but also for the sustainability of Mogan Lake.

Keywords: Heavy metals, health risk assessment, pollution, creeks, Mogan Lake

Öz: Ağır metallere potansiyel maruziyetten kaynaklanan kanserojenik olmayan ve kanserojenik sağlık riskleri, insan sağlığını olumsuz yönde tehdit etmektedir. Bu çalışmada, antropojenik baskı altındaki Mogan Gölü Havzası'ndaki dört dere (Sukesen Deresi, Başpınar Deresi, Yavrucak Deresi, Gölcük Deresi) sularında ağır metal (Hg, As, Cd, Cr, Pb, Ni, Cu, Zn) analizleri yapılmıştır. Havzadaki rekreaktif öneme sahip Mogan Gölü'nü de besleyen derelerden alınan su örneklerinde; a) Ağır metallere sindirim ve deriden emilim yoluyla maruz kalmanın, insan sağlığı üzerindeki kanserojenik olmayan riskleri (HQ) yetişkinler ve çocuklar bazında saptanmış, b) Yetişkinler ve çocuklarda toplam potansiyel kanserojenik olmayan sağlık riskleri tehlike katsayısı (HI) kullanarak belirlenmiştir. Toplam HI (THI) değeri; $HI_{sindirim}$ ile HI_{dermal} değerlerinin toplamından elde edilmiştir, c) Kanserojenik sağlık risk değerleri (CR) ise üç ağır metal (Cr, Ni ve As) için hesaplanmıştır. Bulgular doğrultusunda; a) $HQ_{sindirim}$ değerleri, As nedeniyle yetişkinler-çocuklarda, HQ_{dermal} değerlerinden daha yüksek bulunmuştur. HI kanserojenik sağlık değerine göre, Sukesen, Başpınar ve Gölcük Derelerinde ay ve yaş gruplarına göre değişmek üzere, ağır metaller açısından yüksek düzeyde kanserojenik olmayan sağlık riski söz konusudur. Yavrucak Deresi içinse yetişkinler-çocuklar açısından kanserojenik olmayan sağlık riski olası gözükmemektedir, b) Hesaplanan HQ_{dermal} ve HI_{dermal} değerlerine göre, yetişkinler-çocuklar açısından dermal yolla maruziyetten dolayı belirgin bir olumsuz sağlık riski bulunmamıştır, c) Çocuklar için tehlike katsayısı değerleri yetişkinler için tehlike katsayısı değerlerinden daha yüksek bulunmuş olup, özellikle dikkate alınan ağır metallere karşı çocukların daha fazla sağlıksal riskle karşı karşıya kaldıkları belirlenmiştir, d) Sukesen ve Başpınar Deresi'ne ilişkin THI değerleri; yetişkinler ve çocuklar için örnekleme yapılan tüm aylarda, Gölcük Deresi'nde, yetişkinler için nisan ayında, çocuklar içinse örnekleme periyodu esnasında ciddi düzeyde kanserojenik-olmayan sağlıksal risk olasılığını ortaya koymuştur, e) Krom, nikel ve arsenik için hesaplanan CR değerleri, sindirim yoluyla maruziyetin dermal yola göre daha riskli olduğunu ve yetişkinlerde-çocuklarda kansere yakalanma olasılığını ifade etmektedir. Potansiyel sağlık tehlikeleri bağlamında, özellikle Başpınar ve Sukesen Dere'lerinde ağır metal kontaminasyonuna ilişkin yönetsel tedbirlerin alınması, halk sağlığının korunması yanında Mogan Gölü'nün sürdürülebilirliği açısından da önem taşımaktadır.

Anahtar kelimeler: Ağır metaller, sağlık risk değerlendirmesi, kirlilik, dereler, Mogan Gölü

INTRODUCTION

Surface waters are among the water bodies most affected by water pollution. Heavy metals, which constitute a significant aspect of water pollution, are transported to water sources through various artificial means such as industrial, domestic, and agricultural wastewater as well as through natural sources and acid rain (Pulatsü and Topçu, 2015; Bat and Arıcı, 2018).

Uptake metals in aquatic ecosystems by humans through the ingestion of water, contact with water through the skin, and the consumption of fish and/or agricultural products irrigated with contaminated water. From a human health perspective, the estimation of risks arising from exposure to pollutants such as heavy metals in surface waters is of significant importance (Xiao et al., 2019; Joseph et al., 2022; Zhang et al., 2022). The contamination of surface and groundwater with heavy metals can result in cytotoxic, carcinogenic, and mutagenic effects of the heavy metals that enter the human body, particularly through ingestion. In more severe cases, it can lead to an increased risk of cancer development as a result of alterations in the expression patterns of various genes (Castresana et al., 2019). Carcinogenic and non-carcinogenic health risk assessments are based on methodologies that involve determining the concentration of heavy metals and evaluating the differences between groups, considering equations based on chronic exposure. For this purpose, hazard quotient (HQ), hazard index (HI), and carcinogenic risk (CR) data, which are developed as tools based on equations recommended by the United States Environmental Protection Agency (USEPA), are widely used. Methods for predicting the risk are continuously revised to characterize the accuracy and magnitude of the mentioned risk. Health experts focus on evaluating all pathways of exposure that humans experience after the release of chemicals into receiving waters, with particular emphasis on the ingestion of surface water when it is appropriate, as well as dermal exposure to this water (ATSDR, 2018). Due to the pollutants that widely reach the soil, plants, surface waters, and groundwater depending on the quality of water used today, health risk assessment studies on surface waters have gained momentum in our country, as well as worldwide, in recent years.

Mogan Lake is located within the 'Gölbaşı Special Environmental Protection Area,' which is one of the 15 designated protected areas in Türkiye. The lake is not only an important wetland and recreational area in its geography but also one of the significant natural habitats in the country in terms of its flora and fauna. In order to control the external pollution load on Mogan Lake, various rehabilitation and improvement works have been carried out on Sukesen Creek, which is the most important creek that passes through the town center and feeds the lake, as well as Tatlım, Kaldırım, and Gölcük Creeks located to the east. For the creeks that flow into Çökek Marsh within the basin area, some purification measures have been proposed as well. However, the development of the capital city, Ankara, and particularly the increasing population of Gölbaşı District located within the Gölbaşı Special Environmental Protection Area, have led to an increase in urbanization and industrial activities around the lake. Although agricultural areas are gradually shrinking due to urbanization, the use of chemical fertilizers and agricultural pesticides is still prevalent in the remaining agricultural lands. In addition to that, the increasing number of allotment gardens, especially in recent years, is among the factors that exert pressure on the lake ecosystem. Furthermore, the presence of numerous mining processing facilities around the lake, particularly andesite processing plants, is another factor contributing to the exposure of surface waters in the basin to heavy metal pollution. In this context, inevitably that any pollution that may occur in the water sources that feed the lake would have a negative impact on the entire wetland ecosystem.

The aim of this research is to assess the health risks faced by the population in the Mogan Lake Basin who are exposed to heavy metals in the creeks that flow into the lake, using various indices. For this purpose, two different groups, adults and children, were considered. The following values were determined: a) For the assessment of non-carcinogenic health risk: The Average Daily Doses (ADD) through ingestion and dermal absorption, hazard quotient (HQ), hazard index (HI), b) For the assessment of carcinogenic health risk: Cancer risks (CRs) and total cancer risks (TCR) values. It is believed that in addition to contributing to the development of rational strategies focused on heavy metal control about creeks in the context of public health, the findings will also play a role in the sustainability of the recreational Mogan Lake.

MATERIALS AND METHODS

Study area

The Mogan Lake, which is one of the important wetlands in our country nominated for Ramsar Site, has a significantly low groundwater supply, and the input of water mostly occurs during summers through irregularly flowing creeks, which often dry up. The most important of these creeks are Sukesen, Başpınar, Gölova, Yavrucak, Çolakpınar, Tatlım, Kaldırım, and Gölcük Creeks, located in the eastern and northwestern parts of the basin (Figure 1). The waters of Mogan Lake flow into Eymir Lake, which is entirely located within the Middle East Technical University (METU) campus, under the control of the regulator located in the northeast (Anonymous, 2017).

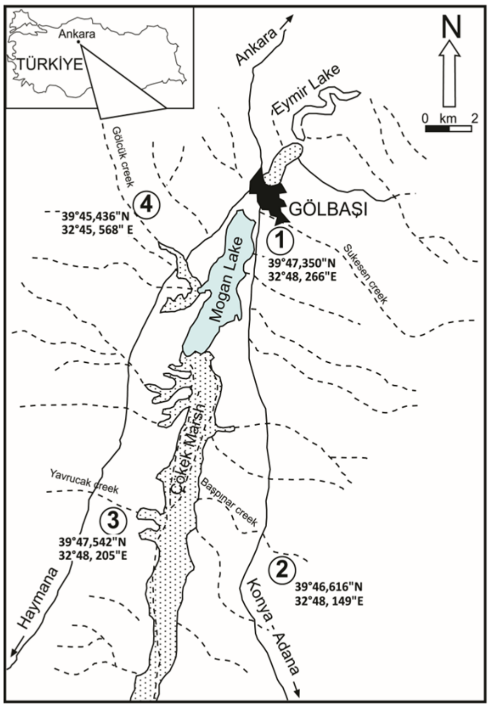

Figure 1. Study area and selected creeks

As shown in Figure 1, four creeks that contribute to the inflow of Mogan Lake and transport both point and non-point source pollutants to the lake. Wastewaters are broughtcome to the lake from stone quarries and residential areas in Sukesen Creek, from residential areas and agricultural activities in Başpınar Creek, from agricultural activities in Yavrucak Creek and Gölcük Creek.

Methods

Within the scope of the study, sampling was conducted three times from the creeks that feed Mogan Lake, in December 2022, February 2023, and April 2023. In determining the sampling times, months with a high probability of receiving heavy rainfall were taken into consideration based on previous meteorological data. The water samples were transported to the laboratory in a dark and cool environment. The heavy metal analysis of the water samples (Hg, As, Cd, Cr, Pb, Ni, Cu, Zn) was conducted in an accredited laboratory following the TS EN ISO 17294-1.24 standard. The analysis was performed with four replicates. Within the scope of the assessment of human health risk, the presence of a significant difference between adult and child health risk indices was determined using the non-parametric Wilcoxon test (Kolassa, 2020). The analysis was conducted using the SPSS 22 software package.

Assessment of human health risks

- Non-carcinogenic health risk

To calculate the potential non-cancer health risk through ingestion and dermal exposure of surface water, child - adult were considered as the target groups. Parameters and their authoritative value used for exposure assessment of heavy metals through ingestion and dermal adsorption of waters are presented in Table 1. The Average Daily Doses (µg/ kg-day) through ingestion (ADD_i) and dermal (ADD_d) absorption were calculated using the following equation (1) and equation (2) as outlined by the US Environmental Protection Agency (USEPA, 2004).

$$ADD_i = C_w \times IR \times EF \times ED / BW \times AT \quad (1)$$

$$ADD_d = C_w \times SA \times K_p \times ET \times EV \times EF \times ED / BW \times AT \quad (2)$$

HQ is the ratio between exposure through individual pathways and the reference dose (RfD). The non-carcinogenic health quotient (HQ) of heavy metals through ingestion and dermal adsorption of water for the population in the area was calculated using the following Eq. (3):

$$HQ_{i/d} = ADD_{i/d} / RfD_{i/d} \quad (3)$$

Table 1. Input assumptions in used to calculate non-carcinogenic and carcinogenic human health risks due to metal exposure through ingestion and dermal pathways

Definitions	Symbols	Units	Values: Ingestion	Values: Dermal	References
Measured metal concentration	C_w	µg/ L			
Ingestion rate-adult	IR	L/day	2.2	-	USEPA (2004) Wang et al. (2017) Saleem et al. (2019)
Ingestion rate-child	IR	L/day	0.64	-	
Exposure time-adult	ET_a	h /event	1	0.58	
Exposure time-child	ET_c	h /event		1	
Exposure frequency	EF	days /year	350		USEPA (2004) Saleem et al. (2019)
Exposure duration-adult	ED_a	year	70	30	
Exposure duration-child	ED_c	year	6		
Conversion factor	CF	L/cm³	0.001		
Body weight-adult	BW_a	kg	70		
Body weight-child	BW_c	kg	20		
Average time-adult (365xED_a)	AT_{a-re}	days	25550		
Average time-child (365xED_c)	AT_c	days	2190		
Skin surface area-adult	SA_a	cm²	18000		
Skin surface area-child	SA_c	cm²	6600		
Dermal permeability coefficient	Kp	cm/h	Cd, As, Cu: 0.001; Pb: 0.0001; Ni:0.0002; Zn: 0.0006; Cr:0.002; Hg:0.001		USEPA (2004)
Ingestion reference dose	$R_fD_{ingestion}$	µg/ kg-day	Cr: 3; Ni: 20; Cu: 40; Zn: 300; As:0.3; Cd: 0.5; Hg: 0.3; Pb: 1.4		USEPA (2004) Qu et al. (2018)
Dermal reference dose	R_fD_{dermal}	µg/ kg-day	Cr: 0.075; Ni: 0.8; Cu: 8; Zn: 60; Cd: 0.025; As: 0.123 Hg: 0.3; Pb: 0.42		USEPA (2004) Kumar et al. (2019)
Cancer slope factor	CSF	µg/ kg-day	Cr: 0.0005; Ni: 0.0017; As: 0.0015		Mohammadi et al. (2019) Kumar et al. (2019)

The total potential non-carcinogenic risks were assessed by hazard index (HI), which was the sum of the HQs for each element in each exposure pathway (Eq. 4). Total HI (THI) for each receptor was calculated by summing the HIs in each exposure pathway (Eq. 5).

$$HI_{ingestion/dermal} = HQ_{Cr} + HQ_{Ni} + HQ_{Cu} + HQ_{Zn} + HQ_{As} + HQ_{Cd} + HQ_{Hg} + HQ_{Pb} \quad (4)$$

$$THI = HI_{ingestion} + HI_{dermal} \quad (5)$$

If the values of HI and THI > 1, indicates that there may be a potential for adverse non-carcinogenic health effects to occur, while HI and THI values < 1 indicate that non-carcinogenic health effects are not expected (USEPA, 2004).

- Carcinogenic health risk

The carcinogenic health risk (CR) was calculated for three metals (Cr, Ni and As) due to exposure to a potential carcinogen in this study. Potential carcinogenic risk possibilities that an individual may develop cancer over a lifetime of exposure are calculated by multiplying the $ADD_{i/d}$ and cancer slope factor (CSF) together (USEPA 1989, 2004). The slope factor (CSF) is a toxicity value that describes the association between dose and response (Table 1). The ADD of ingestion and dermal exposure of the above-mentioned carcinogens was considered in the calculation of total CR (TCR) for creeks. The CR and TCR were evaluated using the following equations Eqs. (6-8):

$$CR_{ingestion} = ADD_{ingestion} \times SF \quad (6)$$

$$CR_{dermal} = ADD_{dermal} \times SF \quad (7)$$

$$TCR = CR_{ingestion} + CR_{dermal} \quad (8)$$

A value of CR > 1.0×10^{-4} is considered unacceptable; 1.0×10^{-4} < CR < 1.0×10^{-6} is considered an acceptable range depending on the exposure conditions; CR<1.0×10^{-6} is considered not to have significant health effects (Mohammadi et al., 2019; Custodio et al., 2020).

RESULTS

The potential non-carcinogenic risks (HQ) and the total potential non-carcinogenic risks caused by different pathways (HI) for each creek, for adults and children, during the periods of December 2022, February 20023, and April 2023, were presented in Table 2,3,4,5.

In Sukesen Creek, during the three months of sampling, the values of the potential non-carcinogenic risks (HQ) related to ingestion were found to be greater than the values of dermal exposure (HQ_{dermal}) for both adults and children. Among the risk values of $HQ_{ingestion}$ and HQ_{dermal}, As has the highest contribution. In adults, values exceeding 1, indicating non-carcinogenic health risk, were observed for February and April. Similarly, in children, values above 1 were detected for all three months, indicating non-carcinogenic health risk.

Table 2. Heavy metal concentrations and non-carcinogenic (HQ and HI) risks of adults and children for Sukesen Creek

Months	Heavy metals	Concentration (µg/L) (mean±SD)	$HQ_{ingestion}$		HQ_{dermal}	
			Adult	Child	Adult	Child
December	Cr	0.36±0.02	3.62×10^{-3}	4.91×10^{-3}	5.88×10^{-4}	4.05×10^{-3}
	Ni	3.45±0.40	5.20×10^{-3}	7.06×10^{-3}	5.29×10^{-5}	3.64×10^{-4}
	Cu	-	-	-	-	-
	Zn	0.21±0.07	2.11×10^{-5}	2.86×10^{-5}	1.29×10^{-7}	8.86×10^{-7}
	As	8.16±0.63	8.20×10^{-1}	1.11×10^{0}	4.07×10^{-3}	2.80×10^{-2}
	Cd	-	-	-	-	-
	Hg	-	-	-	-	-
	Pb	-	-	-	-	-
	$HI_{ingestion}$ - HI_{dermal}		8.20×10^{-1}	1.12×10^{0}	5×10^{-3}	3.20×10^{-2}
	THI	Adult	0.83×10^{0}			
		Child	1.16×10^{0}			
February	Cr	0.64±0.10	6.44×10^{-3}	8.73×10^{-3}	1.05×10^{-3}	7.20×10^{-3}
	Ni	3.51±0.66	5.29×10^{-3}	7.18×10^{-3}	5.38×10^{-5}	3.70×10^{-4}
	Cu	0.87±0.09	6.55×10^{-4}	8.90×10^{-4}	6.67×10^{-6}	4.59×10^{-5}
	Zn	0.71±0.04	7.13×10^{-5}	9.68×10^{-5}	4.35×10^{-7}	3.00×10^{-6}
	As	11.18±1.13	1.12×10^{0}	1.52×10^{0}	5.57×10^{-3}	3.83×10^{-2}
	Cd	0.18±0.08	1.08×10^{-2}	1.47×10^{-2}	4.41×10^{-4}	3.04×10^{-3}
	Hg	0.02±0.01	2.01×10^{-3}	2.73×10^{-3}	4.09×10^{-6}	2.81×10^{-5}
	Pb	0.08±0.03	1.72×10^{-3}	2.34×10^{-3}	1.17×10^{-6}	8.04×10^{-6}
	$HI_{ingestion}$ - HI_{dermal}		5.18×10^{-1}	1.56×10^{0}	1.0×10^{-3}	5.0×10^{-2}
	THI	Adult	0.52×10^{0}			
		Child	1.61×10^{0}			
April	Cr	0.76±0.07	7.65×10^{-3}	1.04×10^{-2}	1.24×10^{-3}	4.62×10^{-3}
	Ni	2.34±0.30	3.53×10^{-3}	4.79×10^{-3}	3.59×10^{-5}	1.33×10^{-4}
	Cu	1.54±0.0	1.16×10^{-3}	1.58×10^{-3}	1.18×10^{-5}	4.39×10^{-5}
	Zn	0.55±0.19	5.53×10^{-5}	7.50×10^{-5}	3.37×10^{-7}	1.25×10^{-6}
	As	14.14±0.0	1.42×10^{0}	1.93×10^{0}	7.05×10^{-3}	2.62×10^{-2}
	Cd	0.10±0.02	6.03×10^{-3}	8.18×10^{-3}	2.45×10^{-4}	9.11×10^{-4}
	Hg	0.03±0.02	3.01×10^{-3}	4.09x10-03	6.13×10^{-6}	2.28×10^{-5}
	Pb	0.87±0.15	1.87×10^{-2}	2.54×10^{-2}	1.27×10^{-5}	4.72×10^{-5}
	$HI_{ingestion}$ - HI_{dermal}		1.46×10^{0}	1.98×10^{0}	9.0×10^{-3}	3.0×10^{-2}
	THI	Adult	1.47×10^{0}			
		Child	2.01×10^{0}			

Table 3. Heavy metal concentrations and non-carcinogenic (HQ and HI) risks of adults and children for Başpınar Creek

Months	Heavy metals	Concentration (µg/ L) (mean±SD)	$HQ_{ingestion}$		HQ_{dermal}	
			Adult	Child	Adult	Child
December	Cr	0.29±0.04	2.92×10^{-3}	3.95×10^{-3}	4.74×10^{-4}	3.26×10^{-3}
	Ni	0.37±0.28	5.58×10^{-4}	7.57×10^{-4}	5.67×10^{-6}	3.90×10^{-5}
	Cu	-	-	-	-	-
	Zn	0.53±0.24	5.32×10^{-5}	7.23×10^{-5}	3.25×10^{-7}	2.24×10^{-6}
	As	17.94±1.45	1.80×10^{0}	2.45×10^{0}	8.94×10^{-3}	6.15×10^{-2}
	Cd	-	-	-	-	-
	Hg	-	-	-	-	-
	Pb	-	-	-	-	-
	$HI_{ingestion}$ - HI_{dermal}		1.81×10^{0}	2.45×10^{0}	9.03×10^{-3}	6.50×10^{-2}
	THI	Adult	1.82×10^{0}			
		Child	2.52×10^{0}			
February	Cr	2.18±0.23	2.19×10^{-2}	2.97×10^{-2}	3.57×10^{-3}	2.45×10^{-2}
	Ni	1.57±0.0	2.37×10^{-3}	3.21×10^{-3}	2.41×10^{-5}	1.66×10^{-4}
	Cu	0.63±0.21	4.75×10^{-4}	6.44×10^{-4}	4.83×10^{-6}	3.32×10^{-5}
	Zn	1.64±0.42	1.65×10^{-4}	2.24×10^{-4}	1.01×10^{-6}	6.92×10^{-6}
	As	26.39±1.85	2.65×10^{0}	3.60×10^{0}	1.32×10^{-2}	9.05×10^{-2}
	Cd	0.39±0.06	2.35×10^{-2}	3.19×10^{-2}	9.56×10^{-4}	6.58×10^{-3}
	Hg	0.07±0.02	7.03×10^{-3}	9.55×10^{-3}	1.43×10^{-5}	9.84×10^{-5}
	Pb	0.08±0.03	1.72×10^{-3}	2.34×10^{-3}	1.17×10^{-6}	8.04×10^{-6}
	$HI_{ingestion}$ - HI_{dermal}		9.93×10^{-1}	3.68×10^{0}	2.0×10^{-3}	1.20×10^{-1}
	THI	Adult	1.00×10^{0}			
		Child	3.80×10^{0}			
April	Cr	2.41±0.18	2.43×10^{-2}	3.29×10^{-2}	3.95×10^{-3}	1.46×10^{-2}
	Ni	2.00±0.68	3.01×10^{-3}	4.09×10^{-3}	3.06×10^{-5}	1.14×10^{-4}
	Cu	0.49±0.31	3.69×10^{-4}	5.01×10^{-4}	3.75×10^{-6}	1.40×10^{-5}
	Zn	0.33±0.05	3.32×10^{-5}	4.50×10^{-5}	2.02×10^{-7}	7.52×10^{-7}
	As	27.41±2.13	2.75×10^{0}	3.74×10^{0}	1.37×10^{-2}	5.08×10^{-2}
	Cd	0.01±0.01	6.03×10^{-4}	8.18×10^{-4}	2.45×10^{-5}	9.11×10^{-5}
	Hg	0.04±0.04	4.02×10^{-3}	5.46×10^{-3}	8.17×10^{-6}	3.04×10^{-5}
	Pb	0.55±0.19	1.18×10^{-2}	1.61×10^{-2}	8.03×10^{-6}	2.98×10^{-5}
	$HI_{ingestion}$ - HI_{dermal}		2.79×10^{0}	3.80×10^{0}	1.80×10^{-3}	7.0×10^{-2}
	THI	Adult	2.82×10^{0}			
		Child	3.86×10^{0}			

Additionally, it was determined that regardless of the metal, the children hazard index values ($HI_{ingestion}$ and HI_{dermal}) were higher than the adult hazard index values during all three months. Statistically, a significant difference was found between the children hazard index (HI) and adult hazard index (HI) values ($p < 0.05$). The THI-adult value was found to be above 1 in April, while the THI-child value was above 1 throughout all three months (Table 2). In this context, considering the heavy metals involved, there appear to be potential adverse health effects in terms of non-carcinogenic risks for adults in April and for children throughout all the sampled months.

As it can be seen in Table 3, in Başpınar Creek, considering the $HQ_{ingestion}$ and HQ_{dermal} values for adults and children, the contribution of As is significant in the high non-carcinogenic risk. In all months, the $HQ_{ingestion}$ values were found to be higher than the HQ_{dermal} values. Except for February, the HI-adult values were found to be above 1, indicating non-carcinogenic health risk. Similarly, the HI-child values were also above 1 throughout the three months, indicating non-carcinogenic health risk. Indeed, this situation indicates an emerging health concern. Regardless of the specific metals, it was observed that the health risk values for children every month basis were higher than the health risk values for adults.

In Yavrucak Creek, during the sampled months, the $HQ_{ingestion}$ values were determined to be higher than the HQ_{dermal} values. For this creek, both the HI-adult and HI-child values were found to be below 1 (Table 4). Since the THI values for all months were found to be below 1 in comparison to the other three creeks, there is no significant adverse health effect on adults and children due to exposure to heavy metals through ingestion and dermal contact pathways. When considering the three-month period regardless of the specific metals, there is a significant difference ($p < 0.05$) in the health risk values between adults and children. However, no significant difference was observed ($p > 0.05$) between the measurements of HI-adult and HI-child.

Table 4. Heavy metal concentrations and non-carcinogenic (HQ and HI) risks of adult and child for Yavrucak Creek

Months	Heavy metals	Concentration (µg/ L) (mean±SD)	$HQ_{ingestion}$		HQ_{dermal}	
			Adult	Child	Adult	Child
December	Cr	0.58±0.00	-	-	-	-
	Ni	0.71±0.21	1.07x10^{-3}	1.45x10^{-3}	1.09x10^{-5}	7.49x10^{-5}
	Cu	-	-	-	-	-
	Zn	-	0	0	-	-
	As	1.28±0.31	1.29x10^{-1}	1.75x10^{-1}	6.38x10^{-4}	4.39x10^{-3}
	Cd	-	-	-	-	-
	Hg	-	-	-	-	-
	Pb	-	-	-	-	-
	$HI_{ingestion}$ - HI_{dermal}		1.30x10^{-1}	1.76 x10^{-1}	1.0 x10^{-3}	4.0 x10^{-3}
	THI	Adult	1.30 x10^{-1}			
		Child	1.80 x10^{-1}			
February	Cr	0.16±0.03	1.61x10^{-3}	2.18x10^{-3}	2.62x10^{-4}	1.80x10^{-3}
	Ni	0.45±0.16	6.78x10^{-4}	9.21x10^{-4}	6.90x10^{-6}	4.75x10^{-5}
	Cu	0.40±0.09	3.01x10^{-4}	4.09x10^{-4}	3.06x10^{-6}	2.11x10^{-5}
	Zn	0.36±0.11	3.62x10^{-5}	4.91x10^{-5}	2.21x10^{-7}	1.52x10^{-6}
	As	1.90±0.29	1.91x10^{-1}	2.59x10^{-1}	9.47x10^{-4}	6.52x10^{-3}
	Cd	0.05±0.03	3.01x10^{-3}	4.09x10^{-3}	1.23x10^{-4}	8.44x10^{-4}
	Hg	0.02±0.01	2.01x10^{-3}	2.73x10^{-3}	4.09x10^{-6}	2.81x10^{-5}
	Pb	0.02±0.02	4.31x10^{-4}	5.84x10^{-4}	2.92x10^{-7}	2.01x10^{-6}
	$HI_{ingestion}$ - HI_{dermal}		1.0 x10^{-1}	2.70 x10^{-1}	1.0 x10^{-4}	1.0 x10^{-2}
	THI	Adult	1.0 x10^{-1}			
		Child	2.80 x10^{-1}			
April	Cr	0.58±0.06	5.83x10^{-3}	7.91x10^{-3}	9.48x10^{-4}	3.52x10^{-3}
	Ni	2.50±0.11	3.77x10^{-3}	5.11x10^{-3}	3.83x10^{-5}	1.42x10^{-4}
	Cu	0.05±0.02	3.77x10^{-5}	5.11x10^{-5}	3.83x10^{-7}	1.42x10^{-6}
	Zn	0.18±0.04	1.81x10^{-5}	2.45x10^{-5}	1.10x10^{-7}	4.10x10^{-7}
	As	2.00±0.17	2.01x10^{-1}	2.73x10^{-1}	9.97x10^{-4}	3.70x10^{-3}
	Cd	0.02±0.01	1.21x10^{-3}	1.64x10^{-3}	4.90x10^{-5}	1.82x10^{-4}
	Hg	0.02±0.01	2.01x10^{-3}	2.73x10^{-3}	4.09x10^{-6}	1.52x10^{-5}
	Pb	0.95±0.12	2.05x10^{-2}	2.78x10^{-2}	1.39x10^{-5}	5.15x10^{-5}
	$HI_{ingestion}$ - HI_{dermal}		2.34x10^{-1}	3.20 x10^{-1}	2.0 x10^{-3}	1.0 x10^{-2}
	THI	Adult	2.40 x10^{-1}			
		Child	3.20 x10^{-1}			

As presented in Table 5, in Gölcük Creek, similar to the other three creeks, As holds significant importance when considering the ingestion and dermal exposure pathways. Although the $HQ_{ingestion}$ values were found to be higher than the HQ_{dermal} values, the $HQ_{ingestion}$ values for both children and adults, except for April, were below the non-carcinogenic health risk level of 1. Similar to the above three creeks, the health risk values for children were relatively higher compared to the health risk values for adults. Regardless of the specific metals, similar to the other creeks, no significant difference was found between the measurements of HI-adult and HI-child in Gölcük Creek ($p > 0.05$). According to the THI values, except for April, the heavy metals do not pose a significant non-carcinogenic health risk in terms of potential adverse effects.

In the scope of the study, it was determined that the carcinogenic risk values ranged from 1.0x10^{-4} to 1.38x10^{-3} for adults and from 1.30x10^{-4} to 1.88x10^{-3} for children. CR and TCR values ranging from 10^{-6} to 10^{-4} represent the probability of developing cancer within a lifespan of 70 years. Especially for Başpınar Creek, the data for the month of April were found to be significantly above the acceptable carcinogenic risk range. As shown in Figure 2, during the sampling months, the ∑CR child values in all four creeks were found to be higher than the ∑CR adult values. This finding indicates that children are more vulnerable to carcinogenic risks compared to adults when exposed to heavy metals in creek waters.

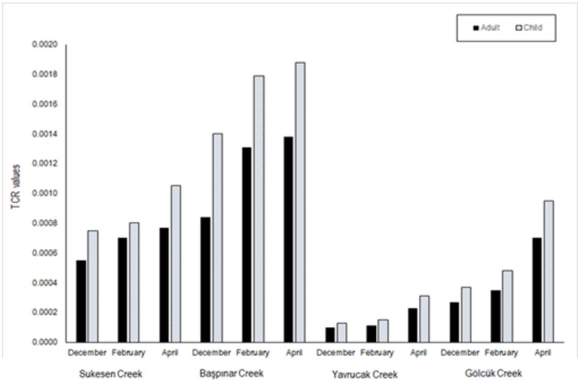

Figure 2. Total carcinogenic values for adults and children at each creek

Table 5. Heavy metal concentrations and non-carcinogenic (HQ and HI) risks of adult and child for Gölcük Creek

Months	Heavy metals	Concentration (µg/L) (mean±SD)	$HQ_{ingestion}$		HQ_{dermal}	
			Adult	Child	Adult	Child
December	Cr	-	-	-	-	-
	Ni	0.80±0.14	1.21×10^{-3}	1.64×10^{-3}	1.23×10^{-5}	8.44×10^{-5}
	Cu	-	-	-	-	-
	Zn	-	-	-	-	-
	As	5.11±0.10	5.13×10^{-1}	6.97×10^{-1}	2.55×10^{-3}	1.75×10^{-2}
	Cd	0	-	-	-	-
	Hg	0	-	-	-	-
	Pb	0	-	-	-	-
	$HI_{ingestion}$ - HI_{dermal}		3.0×10^{-3}	6.90×10^{-1}	3.0×10^{-3}	2.0×10^{-2}
	THI	Adult	6.0×10^{-3}			
		Child	0.72×10^{0}			
February	Cr	0.25±0.0	2.51×10^{-3}	3.41×10^{-3}	4.09×10^{-4}	2.81×10^{-3}
	Ni	3.06±0.0	4.61×10^{-3}	6.26×10^{-3}	4.69×10^{-5}	3.23×10^{-4}
	Cu	0.75±0.07	5.65×10^{-4}	7.67×10^{-4}	5.75×10^{-6}	3.96×10^{-5}
	Zn	0.50±0.07	5.02×10^{-5}	6.82×10^{-5}	3.06×10^{-7}	2.11×10^{-6}
	As	4.22±0.38	4.24×10^{-1}	5.76×10^{-1}	2.10×10^{-3}	1.45×10^{-2}
	Cd	0.21±0.07	1.27×10^{-2}	1.72×10^{-2}	5.15×10^{-4}	3.54×10^{-3}
	Hg	0.02±0.01	2.01×10^{-3}	2.73×10^{-3}	4.09×10^{-6}	2.81×10^{-5}
	Pb	0.06±0.04	1.29×10^{-3}	1.75×10^{-3}	8.76×10^{-7}	6.03×10^{-6}
	$HI_{ingestion}$ - HI_{dermal}		2.70×10^{-1}	6.10×10^{-1}	4.0×10^{-3}	2.0×10^{-2}
	THI	Adult	2.70×10^{-1}			
		Child	0.63×10^{0}			
April	Cr	0.06±0.02	6.03×10^{-4}	8.18×10^{-4}	9.81×10^{-5}	3.65×10^{-4}
	Ni	2.98±0.15	4.49×10^{-3}	6.10×10^{-3}	4.57×10^{-5}	1.70×10^{-4}
	Cu	0.04±0.01	3.01×10^{-5}	4.09×10^{-5}	3.06×10^{-7}	1.14×10^{-6}
	Zn	0.02±0.01	2.01×10^{-6}	2.73×10^{-6}	1.23×10^{-8}	4.56×10^{-8}
	As	12.02±0.91	1.21×10^{0}	1.64×10^{0}	5.99×10^{-3}	2.23×10^{-2}
	Cd	0.31±0.07	1.87×10^{-2}	2.54×10^{-2}	7.60×10^{-4}	2.83×10^{-3}
	Hg	0.01±0.01	1.00×10^{-3}	1.36×10^{-3}	2.04×10^{-6}	7.59×10^{-6}
	Pb	0.61±0.19	1.31×10^{-2}	1.78×10^{-2}	8.90×10^{-6}	3.31×10^{-5}
	$HI_{ingestion}$ - HI_{dermal}		1.24×10^{0}	1.69×10^{0}	7.0×10^{-3}	3.0×10^{-2}
	THI	Adult	1.25×10^{0}			
		Child	1.72×10^{0}			

DISCUSSION

In this study, the hazard index (HI) value was obtained by summing up the total potential health risks (HQs from ingestion and dermal contact exposure pathways) caused by heavy metals. Within the scope of the study, ingestion hazard quotient ($HQ_{ingestion}$) values were found to be higher than dermal absorption hazard quotient (HQ_{dermal}) values. In different studies, it was reported that the non-carcinogenic health risk values associated with metal ingestion were higher than the risk values associated with dermal exposure (Wu et al., 2009; Wang et al., 2017; Qu et al., 2018; Castresana et al., 2019; Mohammadi et al., 2019; Varol and Tokatlı, 2023). According to our findings, non-carcinogenic risks associated with water ingestion were identified in the other creeks, particularly in April, for both children and adults, except for Yavrucak Creek. It is possible that individuals exposed to the water of these creeks may experience adverse health effects However, Kutlu and Sarıgül (2023) reported that they found all HQ and HI values to be below 1 in surface water samples taken from the Munzur River area (Ramsar Site) in Türkiye for both adults and children.

According to our study, As has been determined as the heavy metal with the highest contribution in the HI ingestion pathway, which is in line with similar findings reported in different research studies. For example, Wu et al. (2009) reported that in surface water samples from the Yangtze River in China, all metals except As were found to have Hazard Quotient values below 1. Xiao et al. (2019) on the other hand, indicated a potential hazard by finding high $HQ_{ingestion}$ and $HI_{ingestion}$ values for As in a river water sample from the Lös Plateau in China. In their study, Kumar et al. (2019), examined the heavy metal content of surface waters worldwide and found that As was the main pollutant in terms of ingestion-dermal exposure hazard quotients for both adults and children. According to Custodio et al. (2020), the waters from rivers exposed to mining impacts in the Central Andes of Peru showed higher hazard indexes, determined by the ingestion of heavy metals, including As, exceeding the threshold value ($HI_{ingestion} > 1$). The findings of the present study align with the results reported by Li and Zhang (2010) in their study on surface water samples from the Upper Han River. They found that As posed a greater risk to human health, with a hazard quotient (HQ) exceeding the threshold value of 1, and identified it as the most significant pollutant causing non-carcinogenic and carcinogenic concerns, especially in children, with a carcinogenic risk greater than 10^{-4}. Our findings parallel the results reported by Varol (2019) for Keban Dam Lake, where he found that As contributed to approximately 70% of the hazard index (HI) through the ingestion pathway for both residential and recreational receptors. Additionally, our findings align with the study conducted by Tokatlı and Ustaoğlu (2020) on the Meriç River Delta, where they identified As as the most hazardous toxicant.

In this study, dermal contact hazard quotient (HQ_{dermal})values were found to be <1 in all the creeks and sampling months, which is consistent with the findings of Mazel et al. (2022) for Loutété River in Southeast Congo, where they reported a HQ_{dermal} lower than 1 for all heavy metals. Varol (2019) indicated in his study conducted in Keban Dam Lake that Cr contributed approximately 79% to the HI for both residential and recreational receptors through the dermal contact pathway. In our study, Cr was identified as the second heavy metal contributing to the HQ_{dermal} value, following arsenic, including the December.

In this study, it was determined that regardless of the metal, the hazard index values ($HI_{ingestion}$ and HI_{dermal}) for children were higher than those for adults in all three sampling months. This result is consistent with the findings of a study (Varol 2019; Canpolat et al., 2020) that reported higher health risks for children compared to adults based on the HQ, HI, and THI values determined for Keban Dam Lake (Türkiye). In the study conducted by Saleem et al. (2019) in three freshwater reservoirs in Pakistan during three seasons (pre-monsoon, monsoon, and post-monsoon), it was indicated that Cr, Cd, Co, Pb, and Ni were associated with particularly high risks ($HI_{ingestion}$ > 1) for children. In a study conducted by Castresana et al. (2019) evaluating the health risks of the local population exposed to pollution in the Atoyac River (Mexico), the hazard index (HI) results were found to be higher in children due to the consumption of drinking water during the dry season, which is consistent with our research findings.

Different countries have reported carcinogenic risk (CR) values above the acceptable level of 10^{-4} for potential cancer risks associated with arsenic in surface waters (Qu et al., 2018; Shil and Singh 2019; Zhang et al., 2022; Selvam et al., 2022). In some studies conducted in our country, specifically in dam lakes and rivers, the carcinogenic risk values for As and Cr are below the target risk level of 1×10^{-4} (Canpolat et al., 2020; Varol et al., 2021; Kutlu and Sarıgül 2023). In our study, the cancer index values for Cr, Ni, and As were found to be higher than the range of 1×10^{-6} and 1×10^{-4} recommended by USEPA (1989, 2004) for both adults and children in all months and creeks. In this context, it has been determined that Cr, Ni, and As are potential heavy metals that have negative effects on health. Kumar et al. (2019) and Mohammadi et al. (2019) have also reported that heavy metals such as Cr, Ni, and Cd, in addition to As, exhibit values that can be considered as high risk for cancer formation through ingestion compared to dermal exposure. In addition, our finding that the carcinogenic risk values arising from oral exposure in children are higher than those in adults is consistent with the findings reported by Castresana et al. (2019), Custodio et al. (2020) and Joseph et al. (2022).

CONCLUSION

Water pollution caused by heavy metals as a result of intense anthropogenic pressure poses a threat to aquatic environments and consequently human health. Heavy metals can cause significant adverse effects on human health by serving as both non-carcinogenic and carcinogenic risk factors. In this study, hazard quotient (HQ) values were determined through ingestion and dermal pathways in four major streams that feed Lake Mogan, for both adults and children. The potential positive and negative health effects of heavy metals were evaluated based on exposure through these two pathways. Based on the findings, it was determined that As was the primary contaminant posing the highest risk to human health. According to the HQ-ingestion pathway values, while the heavy metals posing the highest risk after As vary among the creeks and months, it has been observed that Cr has a significant contribution in the HQ-dermal pathway after As, specifically in Sukesen, Başpınar, and Yavrucak Creeks. According to the $HI_{ingestion}$ and HI_{dermal} values, the children hazard index values were found to be higher than the adults hazard index values, indicating that children are exposed to higher health risks, particularly related to the considered heavy metals. The total hazard index (THI) values, considering the selected heavy metals in Sukesen and Başpınar Creeks for all sampled months in both adults and children, as well as in Gölcük Creek specifically for children in April, revealed that heavy metals pose a significant risk to the health of both adults and children. Based on the THI data, the ranking of the studied creeks in terms of potential adverse health effects is as follows: Sukesen Creek > Başpınar Creek > Gölcük Creek > Yavrucak Creek. The possible reason why Yavrucak Creek is ranked last may be that it is under less pressure than other creeks in terms of residential areas. The carcinogenic risk values determined for Cr, Ni, and As reflect a high risk of cancer for adults and particularly for children, indicating that the ingestion pathway is more risky compared to the dermal route.

Based on the study findings, it was determined that the heavy metals in Sukesen, Başpınar, and Gölcük Creeks in the Mogan Lake Basin pose a risk to human health and may contribute to the emergence of adverse health effects. In this context, considering the necessity of protecting public health, measures should be developed to reduce heavy metal contamination in the surface waters of the basin, especially in the mentioned creeks. Administrative measures regarding the sources of pollution in the lake basin are not only important for protecting human health but also for the sustainability of the lake ecosystem.

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AUTHORSHIP CONTRIBUTION

All authors took part in a part of the article and contributed to the design of the research, collection and writing of the article.

CONFLICT OF INTEREST

The authors declare that they have no conflict of interest.

ETHICAL STATEMENT

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.

REFERENCES

Anonymous (2017). Lakes and Wetlands Action Plan, 2017-2023. Republic of Türkiye Ministry of Agriculture and Forestry General Directorate of Water Management. Ankara (in Turkish).

ATSDR (2018). Agency for Toxic Substances and Disease Registry. Exposure Dose Guidance for Dermal and Ingestion Exposure to Surface Water. Atlanta, GA: U.S. Department of Health and Human Services, Public Health Service, Sept 25.

Bat, L., & Arıcı, E. (2018). Heavy metal levels in fish, molluscs, and crustacea from Turkish seas and potential risk of human health. In Holban AM, Grumezescu AM. (Eds.), *Handbook of Food Bioengineering, Food Quality: Balancing Health and Disease* (pp. 159-196). Elsevier, Academic Press.

Canpolat, Ö., Varol, M., Öztekin, Ö., Okan, C., Eris, K.K., & Çaglar, M. (2020). A comparison of trace element concentrations in surface and deep water of the Keban Dam Lake (Turkey) and associated health risk assessment. *Environmental Research*, 110012. https://doi.org/10.1016/j.envres.2020.110012

Castresana, G.P., Roldán, E.C., Suastegui, W.A.G., Perales, J. S.L.M., Montalvo, A.C., & Silva, A.H. (2019). Evaluation of health risks due to heavy metals in a rural population exposed to Atoyac River pollution in Puebla, Mexico. *Water*, *11*, 277. https://doi:10.3390/w11020277

Custodio, M., Cuadrado, W., Peñaloza, R., Montalvo, R., Ochoa, S. & Quispe, J. (2020). Human Risk from Exposure to Heavy Metals and Arsenic in Water from Rivers with Mining Influence in the Central Andes of Peru. *Water*, 12, 1946. https://doi:10.3390/w12071946

Joseph, A., Edet, U., Iwok, E., & Ekanem, S. (2022). Health implications of the oral and dermal exposure to heavy metals in borehole water from a poorly remediated Ikot Ada Udo community, Akwa Ibom State, South-South Nigeria. *Scientific African*, *8*, e01416. https://doi.org/10.1016/j.sciaf.2022.e01416 2468-2276

Kolassa, J. E. (2020). *An introduction to nonparametric statistics*. Chapman and Hall/CRC Press.

Kumar, V., Parihar, R.D., Sharma, A., Bakshi, P., Singh Sidhu, G.P., Bali, A.S., Karaouzas, I., Bhardwaj, R., Thukral, A.K., Gyasi-Agyei, Y., & Rodrigo-Comino, J. (2019). Global evaluation of heavy metal content in surface water bodies: A meta-analysis using heavy metal pollution indices and multivariate statistical analyses. *Chemosphere*, *236*, 124364. https://doi.org/10.1016/j.chemosphere.2019.124364

Kutlu, B., & Sarıgül, A. (2023). The assessment of health risk from heavy metals with water indices for irrigation and the portability of Munzur Stream: A case study of the Ovacık area (Ramsar site), Türkiye. *Oceanological and Hydrobiological Studies*, *52*(1), 111-123. https://doi.org/10.26881/oahs-2023.1.09

Li, S., & Zhang, Q. (2010). Risk assessment and seasonal variations of dissolved trace elements and heavy metals in the Upper Han River, China. *J. Hazard Mater.*, *181*, 1051-1059. https://doi.org/10.1016/j.jhazmat.2010.05.120

Mazel, I.G., Mpissi, D., Flora, Z., Mafoumba, B., Claude, J., & Laurent, M. (2022). Health Risk Assessment of Heavy Metals in the Water of the Loutété River, Mfouati District, Southeast Congo. *Journal of Geoscience and Environment Protection*, *10*, 77-86. https://doi.org/10.4236/gep.2022.1012006

Mohammadi, A.A., Zarei, A., Majidi, S., Ghaderpoury, A., Hashempour, Y., Saghi, M.H., Alinejad, A., Yousefi, M., Hosseingholizadeh, N., & Ghaderpoori, M. (2019). Carcinogenic and non-carcinogenic health risk assessment of heavy metals in drinking water of Khorramabad, Iran. *MethodsX*, 6, 1642–1651. https://doi:10.1016/j.mex.2019. 07.017

Pulatsü, S., & Topçu, A. (2015). Review of 15 years of research on sediment heavy metal contents and sediment nutrient release in inland aquatic ecosystems, Turkey. *Journal of Water Resource and Protection*, *7*, 85-100. https://doi.org/10.4236/jwarp.2015.72007

Qu, L., Huang, H., Xia, F., Liu, Y., Dahlgren, R. A., Zhang, M., & Mei, K. (2018). Risk analysis of heavy metal concentration in surface waters across the rural-urban interface of the Wen-Rui Tang River, China. *Environmental Pollution*, *237*, 639-649. https://doi.org/10.1016/j.envpol.2018.02.020 0269-7491

Saleem, M., Iqbal, J., & Shah, M.H. (2019). Seasonal variations, risk assessment and multivariate analysis of trace metals in the freshwater reservoirs of Pakistan. *Chemosphere*, *216* 715-724. https://doi.org/10.1016/j.chemosphere.2018.10.173

Selvam, S., Jesuraja, K., Roy, P.D., Venkatramanan, S., Khan, R., Shukla, S., Manimaran, D., & Muthukumar, P. (2022). Human health risk assessment of heavy metal and pathogenic contamination in surface water of the Punnakayal estuary, South India. *Chemosphere*, *298*, 134027. https://doi.org/10.1016/j.chemosphere.2022.134027

Shil, S., & Singh, U. K. (2019). Health risk assessment and spatial variations of dissolved heavy metals and metalloids in a tropical river basin system. *Ecological Indicators*, *106*, 1-12. https://doi.org/10.1016/j.ecolind.2019.105455

Tokatlı, C., & Ustaoğlu, F. (2020). Health risk assessment of toxicants in Meriç River delta wetland, Thrace region, Turkey. *Environmental Earth Sciences*, *79*(18), 426. https://doi.org/10.1007/s12665-020-09171-4

USEPA. (1989). Risk Assessment Guidance for Superfund Volume I: Human Health Evaluation Manual (Part A), interim final, Office of Emergency and Remedial Response. EPA/540/1-89/002

USEPA. (2004). Risk Assessment Guidance for Superfund Volume I: Human Health Evaluation Manual (Part E, Supplemental Guidance for Dermal Risk Assessment) Final. OSWER 9285.7-02EP.July 2004.

Varol, M. (2019). Arsenic and trace metals in a large reservoir: seasonal and spatial variations, source identification and risk assessment for both residential and recreational users. *Chemosphere*, *228*, 1–8. http://dx.doi.org/10.1016/j.chemosphere.2019.04.126

Varol, M., Karakaya, G., & Sünbül, M. R. (2021). Spatiotemporal variations, health risks, pollution status and possible sources of dissolved trace metal (loid)s in the Karasu River, Turkey. *Environmental Research*, *202*, 111733. https://doi.org/10.1016/j.envres.2021.111733

Varol, M., &Tokatlı, C. (2023). Evaluation of the water quality of a highly polluted stream with water quality indices and health risk assessment methods. *Chemosphere*, *311*, 137096. https://doi.org/0.1016/j.chemosphere.2022.137096

Wang, J., Liu, G., Liu, H., & Lam, P.K.S. (2017). Multivariate statistical evaluation of dissolved trace elements and a water quality assessment in the middle reaches of Huaihe River, Anhui, China. *Science of the Total Environment*, *583*, 421-431. http://dx.doi.org/10.1016/j.scitotenv.2017.01.088

Wu, B., Zhao, D.Y., Jia, H.Y., Zhang, Y., Zhang, X.X., & Cheng, S.P. (2009). Preliminary Risk Assessment of Trace Metal Pollution in Surface Water from Yangtze River in Nanjing Section, China. *Bulletin of Environmental Contamination and Toxicology*, *82*, 405-409. http://dx.doi.org/10.1007/s00128-008-9497-3

Xiao, J., Wang, L., Deng, L. & Jin, Z. (2019). Characteristics, sources, water quality and health risk assessment of trace elements in river water and well water in the Chinese Loess Plateau. *Science of the Total Environment*, *650*, 2004-2012. https://doi.org/10.1016/j.scitotenv.2018.09.322

Zhang, Z., Guo, Y., Wu, J., & Su, F. (2022). Surface water quality and health risk assessment in Taizhou City, Zhejiang Province (China). *Exposure and Health*, 14, 1–16. https://doi.org/10.1007/s12403-021-00408-6