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Original Article

Investigation of Health and Ecological Risks of Mercury in the Water and Sediments of the Dez and Karkheh Rivers, Iran

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Abstract

Background & Aims: Mercury is one of the metal pollutants that enter the environment due to human industrial activities and subsequently enter the human body, causing poisoning and carcinogenesis. The present research was aimed to determine mercury pollution in water and sediments of the Dez and Karkheh rivers in Khuzestan province, Iran.

Materials and Methods: In this research, 30 water samples and 30 sediment samples were collected from each station, and a total of 120 samples from the Dez River and 180 samples from Karkhe River were collected from two stations. Mercury measurement was performed by atomic absorption method and hydride system with the help of Perkin Elmer 4100 device.

Results: Analysis of variance showed that the amount of mercury in water (P=0.011) and sediments (P=0.023) exhibited a significant difference between the Dez River and Karkheh River (P<0.05). The highest Nimro index and pollution factor were observed at the second station of the Dez River, with values of 0.848 and 1.350, respectively, while the lowest values of these indices were found at the second station of the Karkhe River, at 0.092 and 0.012, respectively. The mercury in water quality index (MI), mercury pollution index (HPI), Contamination Factor (CF), and water pollution index (WPI) at the first station of the Dez River were higher than those at the other studied stations in both the Dez and Karkheh rivers. The highest and lowest values of the mercury metal risk index in water were 11.49 for children and 0.052 for adults, observed at the first and second stations of the Karkhe River, respectively.

Conclusion: The potential risk assessment indicated that there is a possibility of adverse effects on human health from exposure to mercury, even below the permissible limit for adult and child receptors. The pollution indicators suggested that mercury metal pollution in the sediments of the Dez and Karkheh rivers is low to moderate, indicating that the origin of mercury metal in these sediments is very low. However, the results of water pollution indicators revealed that the waters of the Dez and Karkheh rivers are polluted with mercury.

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1. Introduction

Mercury is a unique heavy metal found in nature in three forms: elemental, inorganic, and organic, each of which has its own toxicity profile [1]. At room temperature, elemental mercury exists as a liquid that has a high vapor pressure and is released into the environment as mercury vapor. Mercury also exists as a cation with univalent and divalent oxidation states [2]. Methylmercury is the most common organic compound found in the environment, formed as a result of the methylation of inorganic mercury by microorganisms in soil and water [3]. Mercury is a widespread environmental toxin and pollutant that causes drastic changes in the body's tissues and leads to a wide range of adverse health effects [4]. Animals, plants, and humans are exposed to different forms of mercury in the environment, [5] and cannot avoid exposure to one of the mercury compounds [6]. Mercury is used in the electrical industry (e.g., switches, thermostats, and batteries), dentistry (dental amalgams), and numerous industrial processes, including caustic soda production, nuclear reactors, antifungal agents for wood processing, solvents for reagents, pharmaceutical products preservatives, and petrochemical processes [7]. There has been an industrial demand for mercury in various manufacturing industries [8]. Humans are exposed to mercury through accidents, environmental pollution, food pollution, dental care, preventive medical practices, industrial and agricultural operations, and occupational operations [8]. The main sources of chronic and low-mercury exposure are dental amalgams and fish consumption. Mercury enters the water as a natural process of gas ejection from the Earth's crust as well as through industrial pollution [9]. Algae and bacteria change the mercury entering the waterways as methylmercury. Methylmercury then makes its way through the food chain to fish, shellfish, and eventually to humans [9]. Dental amalgams contain more than 50%

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elemental mercury [10]. Steam is a highly fat-friendly element and is effectively absorbed through the lungs and tissues covering the mouth. Once mercury enters the blood, it quickly crosses cell membranes [11]. The elemental mercury oxidizes after entering the cell and the divalent mercury cation becomes highly reactive. Methylmercury obtained from eating fish is easily absorbed in the gastrointestinal tract [12]. When mercury is absorbed, it has a very slow disposal rate. Much of what is absorbed is accumulated in the kidneys, nerve tissue and liver. All forms of mercury are toxic and their effects include gastrointestinal toxicity, neurotoxicity, and renal toxicity [7,10]. Carcinogenicity caused by metals has been a research topic of public health concern. In general, carcinogenicity has three stages of onset, promotion and progression and metastasis. While DNA mutations that can activate oncogenesis or inhibit tumor suppression have traditionally been thought of as important factors for the onset of carcinogenesis, recent studies have shown that other molecular events, such as transcription activation, signal transmission, oncogene amplification, and recombination also play significant roles. Studies have shown that mercury and other toxic metals affect cellular organelles and negatively affect their biological function [13,14]. The collected evidence also shows that reactive oxygen radicals play a major role in mediating metal-induced cellular responses and carcinogenesis [15-17]. The link between mercury exposure and carcinogenicity is highly controversial. While some studies have confirmed its genotoxic potential, others have not shown an association between mercury exposure and genotoxic damage [18]. However, laboratory studies suggest that susceptibility to DNA damage can be caused by cell exposure to mercury. These studies also show that mercury-induced toxicity and carcinogenicity may be specific to cells, organs or species [15,16,19]. In the country, several studies have been conducted on mercury concentrations in different environments, including water, sediments, plants, fish, and aquatic animals. Researchers identified industrial and anthropogenic sources of mercury and showed that humans are exposed to this toxic metal. [7,11,14]. Therefore, considering the health risks associated with mercury and its toxic and ecological effects on the environment, this study aimed to determine the levels of mercury contamination in the water and sediments of the Dez and Karkheh rivers in Khuzestan province, Iran.

2. Materials and Methods

Karkheh River catchment area with an area of about 43,000 square kilometers, is located between 46° and 57 min to 49° and 10 min of the Eastern longitude and 31° and 48 min to 34° and 58 min North latitude [20]. The sampling site of the Karkheh River in this study was located in Khuzestan province. The geographical location of the first station was within Karkheh National Park (32°, 4 min North latitude and 48° 13 min East longitude), the second station was in the downstream area of Alvan city (31°, 52 min North latitude and 48°, 20 min Eastern longitude) and the third station in the vicinity of the village of Barwaye (31°, 37 min North latitude and 48°, 35 min East longitude; Figure 1).

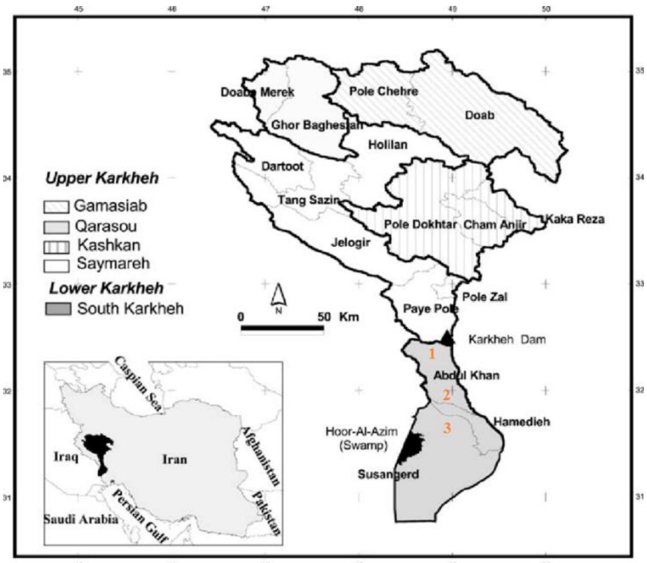

Figure 1. Geographical location of water and sediment sampling from Karkheh River [20]

The Dez River catchment has been passed through the folds of the middle Zagros and is geographically limited between 24° and 49°, 30° and 25° North latitude and 34°, 94 min, 35° and 89 min of Eastern longitude. The Dez River catchment as a Grade 3 basin is a subset of Karun Great Basin and is in the larger subdivision of the Persian Gulf and Oman Sea basin [21]. The sampling site of the Dez River water and sediments in this study was within the city of Dezful. The geographical location of the first station was within the limits of the State Park (32°, 24 min North latitude and 48°, 25 min East longitude) and the second station was within the limits of the Fifth Bridge of Dezful city (32°, 22 min North latitude and 48° and 22 min East longitude; Figure 2). From each station, water samples (n=30) and sediment samples (n=30) were collected, and a total of 120 water samples and sediments of the Dez River were collected from two stations, and 180 samples of water and sediments were collected from three stations in Karkheh River. For water samples, the Rotner sample bottle was sent to a depth of one meter and the water samples were poured into pre-sterilized bottles and transferred to the laboratory. The bottles were rinsed with distilled water solution and 2% nitric acid. Sediment sampling was performed using Ekman grab with a cross section of 225 cm area of 30-80 cm depth. Samples of sediment in bottles that were already sterilized with distilled water solution and 10% nitric acid were transferred to the laboratory [22].

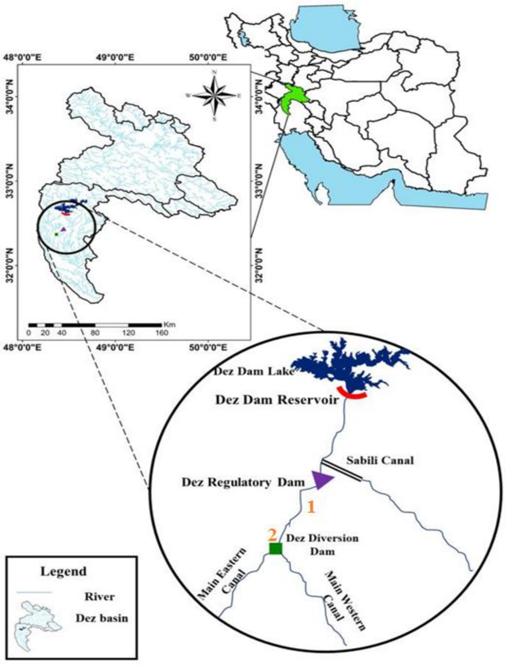

Figure 2. Geographical location of the Dez River water and sediment sampling from Dezful [21]

For chemical digestion of water samples and sediments, wet method was used [23]. Mercury was measured by atomic absorption and hydride system with the help of Perkin Elmer 4100. The detection limit of mercury by this atomic absorption device by cold vapor method was at ppb. In this device, the atomic absorption of LOD (Limits of detection) and LOQ (limits of quantification) were 0.015 and 0.005 µg/g, respectively [24]. The accuracy of the obtained data was evaluated using the Standard Reference Materials. At first, different standard concentrations of the elements were produced in five samples and after injection into atomic absorption device the calibration curve of the elements was plotted, and then the prepared samples were injected into the device and the concentration were read [25]. Mercury contamination in sediments was measured by the indices of pollution factor, Contamination Factor index (ER), enrichment factor, and geoaccumulation index. Contamination factor index was obtained using relation 1 in which Cn concentration of mercury in sediments and Co mean concentration of mercury in the earth's crust or shale (0.4 mg/kg). Based on the pollution factor, CF<1 is low pollution, 1≤CF<3 is moderate, 3≤CF<6 is high and CF≥6 is highly contaminated [26].

Relationship 1: $C_f = C_n \div C_o$

In this regard, CF is contamination factor, ecological risk: ER, risk index: RI, toxicity of heavy metals: TR is mercury toxicity coefficient.

Ecological risk is classified in five low risk levels of Er<40, moderate risk of 40≤Er<80, significant risk 80≤ ER<160, High Risk 160≤ER<320 and Very High Risk Er≥320. Biohazard Potential Index (RI) is classified as four categories of low-risk index RI<150, 150≤ RI<300, significant risk index 300≤RI<600 and Very High-Risk Index RI≥600 [26].

Relationship 2: $Er = TR \times CF$

Relationship 3: $RI = \sum Er$

Nemerow integrated pollution index (NIPI) from root of maximum sum (PI_{max}) and mean values (PI_{ave}) of mercury element divided by 2 were calculated (Relationship 4). This index is classified in five levels of pollution-free Nemro Integrated Pollution Index (NIPI)≤0.7, pollution warning line 0.7≤NIPI<1, low pollution level 1≤NIPI<2, average pollution level 2≤NIPI<3 and high pollution level NIPI≥3 [26].

Relationship 4: $\sqrt{\frac{PI_1^2 max + PI_1^2 ave}{2}}$

The geoaccumulation index (Igeo) was calculated based on the 5 relations that Cn is mercury concentration in sediments, Bn Hg content in the Earth's crust or shale (0.4 mg/kg) and a constant coefficient of 1.5. Based on this index, Igeo<0 uncontaminated, 0-1 uncontaminated to slightly contaminated, 2-1 slightly contaminated, 2-3 slightly infected to very contaminated, 4-3 highly contaminated, 4-5 highly contaminated and **>5** highly contaminated [27].

Relationship 5: $Igeo = \log_2 [C_n \div (1.5 \times B_n)]$

In assessing water quality, various indicators are used to assess the level of pollution and possible risks associated with heavy metals. One of the most commonly used indicators is the metal index (MI). The metal index was calculated using the 6 ratio in which **Ci** concentration of each metal is the maximum allowable concentration (MAC) (0.003 mg/L standard of drinking water quality in Iran) [28].

Relationship 6: $MI = C_i \div MAC$

The metal pollution index indicates the overall water quality and specific to heavy metals and was calculated by the relationship of 7 and 8 **HPI (**Heavy metal pollution index) indices, in which the **Qi** sub-index is calculated for the sample parameter of the element and the weight of **Wi** is assigned to the sample parameter of the element [29]. The weight of the parameter can be attributed based on its importance, which may be given between 0 and 1, it can also be considered with the standard value for each element or inverse ratio parameter, in which the weight parameter of 0.001 mercury was placed in relation to 7 [30].

Relationship 7: $HPI = \frac{\sum_{i=1}^{n} Wi\, Qi}{\sum_{i=1}^{n} Wi}$

In relation 8, **Mi** the amount of mercury in samples in µg/l, **Ii** and **Si** is ideal and standard concentrations of 0.01 and 0.06 mg/l for safe drinking water, respectively, which have been considered for the elements from the US Environmental Protection Agency (2009) and World Health Organization (WHO) (2011) for the elements [31, 32].

Relationship 7: $HPI = \frac{\sum_{i=1}^{n} Wi\, Qi}{\sum_{i=1}^{n} Wi}$

Relationship 8: $Qi = \sum_{i=1}^{n} \frac{|Mi - Ii|}{Si - Ii} \times 100$

Cumulative effects of metal on surface water are indicated by the degree of contamination which was calculated as 9 and 10 relationships in which C_{fi} shows the pollution factor for the sample water element.

In relation to 10, **Mi** the amount of sample element in µg/l and **Si** was the highest allowable concentration of mercury (0.006 µg/L of Iranian National Standard 1053). **Cd** is used to classify metal contamination in surface water as follows: **Cd** greater than 3 (high pollution), **Cd** in the range of 1–3 (medium pollution), and **Cd** less than 1 (low pollution) [33]. Ecological risk assessment and mercury risk index in sediments were calculated from relation 2 and 3 [34].

***Relationship 9*:** $Cd = \sum_{i=1}^{n} Cfi$

***Relationship 10*:** $Cf_i = \frac{Mi}{Si}$ –

The Water Pollution Index (WPI) is used in all types of water, and includes the control and monitoring of water pollution. A comparable number is given by this index about the lowest limit allowed for a particular poisonous element, calculated according to relation 11 [34], in which Ri is the Limit range for a particular element taken from the WHO (2011) and is the minimum acceptable standard limit [32].

***Relationship 11*:** $WPI = (M_i - Min_i) / Ri$

Health risk assessment of mercury in the water of the Dez and Karkheh rivers was done by the U.S. Environmental Protection Agency (EPA) method. For this purpose, the average daily dose of mercury was calculated according to the measured amount of mercury [12, 35]:

***Relationship 12*:** Average Daily Dose (mg/Kg/day) =

$$\frac{Ci \times IR \times EF \times ED}{BW \times AT}$$

In this regard, Average Daily Dose (**ADD**) of the amount of mercury absorption in the body per day through water intake (mg/kg body weight per day), **Ci** concentration of mercury in water (mg/li), intake rate (IR) Daily water consumption rate (1 liter per day for children and 2.2 liters per day for adults), Body Weight (BW) (70 kg for an adult and 14.5 kg for children),

EF (Exposure Frequency is 365 days per year), Average Time (**AT**) 365 days per year, and Exposure Duration (**ED**) is exposure time by the duration of exposure is 70 years [36]. The Hazard Index was calculated by comparing the estimated ADD of mercury with its reference dose (R_{FD}). If the risk is 1 or less than 1 (i.e., daily intake less than the reference dose), it indicates that no significant health risk is due to water intake [13, 35].

***Relationship 13*:** $HI = ADD / R_{FD}$

In relation to 14 of the mercury risk unit for carcinogenic effects (0.00005 mg/kg) and non-carcinogenic effects (0.0003 mg/kg) [35], the determined risk ratio was calculated relative to the specific concentration of mercury metal in water for native residents.

In this regard, **ADD** the amount of mercury absorption in the body per day through water intake (mg/kg BW per day) and **Ur** is a risk unit which is determined as a risk factor that depends on the available concentration. The risk unit accepts the correct value according to the type of element and the effect of the carcinogenic risk or the target hazard quotient [35]:

Relationship 14: **CR = ADD×Ur**

Mercury concentration in water and sediments was analyzed by SPSS software (version 22). Tables and calculations of indicators of pollution and health risk were performed using Excel 2007 software. The mean of data was used to compare the significant difference with the confidence range of 95% (P=0.05) using one-way ANOVA. T-test was used to compare the mean concentration of potential toxic elements in water and Karkheh River sediments with national and global standards.

3. Results

Analysis of variance showed that mercury concentration in water and sediments of studied stations in the Karkheh River was not significantly different (P>0.05). Although no significant difference was observed between Hg metal in the sediments of the first and second stations of the Dez River (P>0.05), a significant difference was seen in the amount of this toxic element in the water of the Dez River (P<0.05).

Statistical comparison of mercury content in water and sediments between Dez River and Karkheh River showed a significant difference (P<0.05). Mercury concentration in water and sediments of the Dez River was higher than the Karkheh River (P<0.05; Table 1).

Mercury metal pollution indices in sediments showed that the amount of pollution factor, geo index, NIPI and ER index in sediments of two Dez River stations were higher than the Karkheh River. The highest indices Nemro and pollution factors in the second station of the Dez River were 0.848 and 1.350, respectively. Additionally, the lowest indices were 0.092 and 0.012, respectively in the second station of the Karkheh River. The ecological risk index of sediments of the Dez and Karkheh rivers was 105.40 and 3.56, respectively (Table 2).

Mercury quality index in water **(MI)**, mercury pollution index **(HPI)**, pollution factor **(CF)** and **WPI** were higher in the first station of the Dez River compared to other studied stations in the Dez River and Karkheh River. Furthermore, the degree of contamination **(Cd)** in Dez River was higher than the Karkheh River. In the Karkheh River, mercury quality index in water **(MI)**, mercury pollution index **(HPI),** pollution factor **(CF)** and **WPI** were higher in the third station than the first and second stations (Table 3).

The highest and lowest values of mercury risk index in water were 11.49 for children and 0.052 for adults in the first and second stations of the Karkheh River.

The mercury risk index of water consumption for children in the Dez and Karkheh rivers was higher than 1 and for adults in the Dez River was higher than the Karkheh River. The mercury risk index in Dez River water was higher than 1 for adults and lower than 1 in the Karkheh River. The carcinogenic and carcinogenic risk of mercury in the water of the Dez River was higher than Karkheh River and for children was more dangerous than adults (Table 4).

Table 1. Mercury concentration in water (mg/L) and sediments (mg/kg) of the Dez and Karkheh rivers from Khuzestan province

River	Sample	Station	Mean±SD	Sig	P^{*}	Sig	P^{**}
Dez	Water	1	0.137±0.025	P<0.05	0.025	P<0.05	0.011
		2	0.097±0.030				
	Sediment	1	0.514±0.124	P>0.05	0.088		
		2	0.540±0.345				
Karkheh	Water	1	0.005±0.067	P>0.05	0.645	P<0.05	0.023
		2	0.005±0.033				
		3	0.010±0.087				
	Sediment	1	0.011±0.066	P>0.05	0.225		
		2	0.005±0.052				
		3	0.020±0.055				

* Significant level in the studied stations of each river (confidence level 95).
** Significant level of water and sediments between the two rivers (confidence level 95).

Table 2. Mercury metal pollution indicators in the sediments of the Dez and Karkheh rivers

River	Station	Mean	CF	Er	RI	Igeo	NIPI
Dez	1	0.514	1.285	51.40	105.40	- 0.067	0.840
	2	0.540	1.350	54		- 0.045	0.848
Karkheh	1	0.011	0.027	1.08	3.56	- 1.736	0.122
	2	0.005	0.012	0.48		- 2.079	0.092
	3	0.020	0.050	2		- 1.477	0.156

CF: Contamination Factor; Er: Ecological risk; RI: Risk Index; Igeo: Index of Geoaccumulation;
NIPI: Nemro Integrated Pollution Index

Table 3. Environmental pollution indicators of mercury in the water of the Dez and Karkheh rivers

River	Station	Mean	MI	HPI	CF	WPI	Cd
Dez	1	0.137	45.66	254	21.83	43	36.99
	2	0.097	32.33	174	15.16	32	
Karkheh	1	0.005	1.66	10	0.17	1.33	1
	2	0.005	1.66	10	0.17	1.33	
	3	0.010	3.33	0	0.66	1.33	

MI: Metal Index; HPI: Heavy metal Pollution Index; CF: Contamination Factor;
WPI: water pollution index; Cd: Contamination degree

Table 4. Health risk assessment of mercury in the water of the Dez and Karkheh rivers

River	Station	Mean	ADD		HI		CR		THQ	
			Ch.	Ad.	Ch.	Ad.	Ch.	Ad.	Ch.	Ad.
Dez	1	0.137	0.009	0.004	3.14	1.43	45Ч10^{-7}	20Ч10^{-7}	27Ч10^{-6}	12Ч10^{-6}
	2	0.097	0.006	0.003	2.22	1.01	30Ч10^{-7}	15Ч10^{-7}	18Ч10^{-6}	9Ч10^{-7}
Karkheh	1	0.005	0.0003	0.00015	11.49	0.052	15Ч10^{-8}	75Ч10^{-8}	9Ч10^{-8}	45Ч10^{-8}
	2	0.005	0.0003	0.00015	11.49	0.052	15Ч10^{-8}	75Ч10^{-8}	9Ч10^{-8}	45Ч10^{-8}
	3	0.010	0.006	0.00031	2.22	0.104	30Ч10^{-7}	15.5Ч10^{-7}	18Ч10^{-6}	93Ч10^{-8}

Ch: Children; Ad: Adult; ADD: Average Daily Dose; HI: Hazard Index; CR: Carcinogenic Risk; THQ: Target Hazard Quotien

4. Discussion

Mercury is among the most dangerous pollutants that has attracted widespread attention due to its significant toxicity and bio-magnification and rotates through the atmosphere, water and soil in different forms to different parts of the world. High levels of mercury exposure cause damage to the brain, kidneys and fetus. Its effects on brain function may cause irritability, shyness, tremor, changes in vision or problems with hearing and memory [2,13].

In this study, a statistical comparison of mercury content in water and sediments between Dez River and Karkheh River showed that concentration of this metal in water and sediments of the Dez River was higher than Karkheh River (P<0.05). Reducing river water due to drought and climate change on the one hand and discharge of urban, industrial and especially agricultural effluents to Dez River on the other hand, has faced the water quality of the Dez River with a serious challenge. In Dez River, there are three types of pollution caused by municipal and rural wastewaters, agricultural wastewater, and industrial wastewater [36].

Effluents in residential areas, such as Zibashahr, Dezful, and Chamegolak are the main sources of pollution in Dez River and the major part of industrial wastewater from the Mianrud,, Haft Tappeh, and sugarcane side industries, as well as agricultural drains in downstream areas enter the Dez River [37].

Also, rice cultivation by farmers in the summer and the presence of aquaculture a high volume of agricultural wastewater pollution and dissolved salts to enter the Dez River.[38]. In various studies, it has been reported that the origin of both chemical and physical pollutant parameters in Karkheh River is man-made. This is due to dam construction, the existence of different industries near the Karkheh River, and indiscriminate water harvesting for agricultural purposes, which creates unsuitable conditions [39,40]. Many researchers have reported that mercury released from natural sources (e.g., volcanic eruptions, geothermal and weathering activities of mother rocks, and man-made activities, i.e., combustion of fossil fuels, metal extraction, and industrial resource emissions) enter water ecosystems mainly through rivers and atmospheric sediments [5,11]. The sediment contamination factor showed that the sediments of the Dez River had moderate contamination of mercury and the Karkheh River had low contamination. The Nemro pollution index indicated that Karkheh River sediments were unpolluted, whereas Dez River sediments were at a pollution alert level. In addition, the land-accumulation index showed that the sediments of the Dez and Karkheh rivers were not polluted. Ecological risk assessment of sediments showed that sediments of the Dez River had moderate ecological risk and Karkheh River sediments had very low ecological hazard in terms of mercury metal. Biohazard index of mercury metal in Dez and Karkheh rivers sediments indicated little potential for aquatic environmental hazard in these two rivers. Considering the existence of some industrial and agricultural sources of pollutants in the vicinity of the Dez and Karkheh rivers, it seems that the origin of mercury metal in them is very low, and all indicators showed that mercury metal pollution in sediments of the Dez and Karkheh rivers is low to moderate. In a study on Sefidrud River sediments, it was reported that mercury metal chemistry is very complex and it is difficult to predict the changes of this pollutant in aquatic environments [1]. Sediments are considered as reservoirs of pollutants and storage places and environmental changes [8]. When mercury enters the river, horizontal transition and vertical division occur simultaneously. The horizontal concentration process is carried out during the hydrological slope for the long haul, at the same time, vertical allocation between environments is also carried out, and finally mercury is deposited on the sediments [3, 5]. Reports indicate that discharge of industrial effluents and industries adjacent to water and agricultural resources of watershed and atmospheric sediment are the main sources of mercury in river and lake sediments [4]. The metal index is a water quality index that evaluates overall pollution levels based on the concentration of different metals compared to their respective MAC values. Higher metal concentrations than its MAC value indicates poor water quality. In this study, mercury values in Dez and Karkheh rivers were higher than 1. If the value of the MI exceeds 1, it acts as a warning threshold. When the MI is less than 1, it indicates the suitability of water to drink, which indicates compliance with safety standards. On the other hand, when the MI exceeds 1, it indicates that water is unsuitable for drinking due to high metal concentrations, indicating potential health risks. The metal index threshold limit of 1 serves as a critical danger threshold, highlighting the point at which water quality changes from drinkable to non-potable. This threshold is an important determinant in assessing the safety and suitability of water for human consumption [28]. The mercury emission index (HPI) was higher than 100 in Dez River water and it was lower than 100 in Karkheh River. The HPI value is equal to 100 threshold values at which harmful results are likely, while a value below 100 indicates low contamination by the elements. If the HPI value is greater than 100, it indicates that water is not suitable for use [30]. Water pollution index in Dez and Karkheh rivers was higher than 1. If WPI is higher than 1, the water is contaminated n times and should be diluted with water of the best quality within the acceptable range. If the WPI is in the range of 1-0, this water is acceptable for specific purposes. If the WPI is less than 0, this water is of good quality [32]. The results of water pollution index showed that the water of Dez and Karkheh rivers are contaminants with mercury. The Gamsiab River is the main upstream branch of the Karkheh River, which passes through Kermanshah and Hamedan provinces. Due to the presence of villages, abundant livestock farming, and industrial wastewater in the vicinity of this river, it is moderately polluted in terms of quality [41,42]. Therefore, it can be inferred that this river upstream can provide conditions for the pollution of the Karkheh River downstream.

Dez River is also a recipient of various pollutants with the introduction of numerous industrial and agricultural pollutants [37]. Contaminants such as mercury in river water are absorbed through physical chemical uptake and biological absorption into particles in the water column. Because of gravity, the pollutant complex with particles down to the riverbed forms a sedimentary layer [12]. The index of mercury metal in the water of the Dez River was higher than 1 for children and adults. The risk index of the Karkheh River for children was also higher than 1. If the risk is equal to 1 or more than 1; then daily intake is higher than the reference dose, indicating that the perceived and health-related risk occurs as a result of water consumption [13]. Mercury is a highly toxic element due to its cumulative and stable properties in the environment and organisms [1]. Exposure to mercury; even in small amounts, can cause serious health problems. Previous assessments show that mercury has increased in the hair, blood, and urine samples of residents. Fetuses and infants are highly susceptible to mercury exposure, and this is associated with neurological effects [5,11]. Human exposure to mercury can occur through a number of pathways, including food and water intake, dental amalgams, mercury-containing vaccines, occupational and home use [3]. In other studies, in Ghana and Indonesia, adults had a lower level of risk index compared to children, indicating that children were more at risk of mercury exposure than adults [43،44], which is consistent with our findings. Both age groups are at risk of experiencing adverse effects of mercury exposure through multiple sources.

However, in this study, the risk of carcinogenicity and non-carcinogenesis in children was higher than that of the adults. This is due to the different proportions of the body where the amount of consumption is higher in children. Early stages of neural development, physiological structure, and immune systems put children at greater risk [7,8]. These results are consistent with previous studies conducted in Italy and Japan, where frequent exposure to mercury due to greater sensitivity in the early stages of brain development made young children more vulnerable to neurological changes than adults [9,10]. Toxic response factors of cadmium and mercury are significantly higher than other heavy metals, suggesting that exposure to mercury is more dangerous to human health, especially among young children [11]. The results obtained by Jimenez-Oyola et al. (2021) suggest that the greatest risk of exposure for adults and children to the mineral mercury found in contaminated waters is through accidental water ingestion [45]. The WHO also considers mercury to be one of the most harmful heavy metals for humans and the environment [13]. The study assessed mercury concentrations in sediments and surface waters of the Dez and Karkheh rivers and identified a potential risk to the health of residents of the study area. A possible risk assessment showed that there was a possibility of causing adverse effects on human health from exposure to mercury below the limit for adult and pediatric receptors. It was also found that the population of children doubled the level of carcinogenic risk and acceptable non-carcinogenic risk to assess definitive risk.

5. Conclusion

In this study, mercury concentrations in the sediments and surface waters of the Dez and Karkheh rivers were evaluated, and the potential hazard to the health of the inhabitants of the region was investigated. The risk assessment showed that the risk of adverse effects on human health from exposure to mercury was lower than the limit for both adult and pediatric populations. It was also found that, in the population of children, the level of carcinogenicity and acceptable non-carcinogenic risk was twice as high in the definitive risk assessment.

Human health risk assessment is a tool for estimating the risk faced by a population under certain conditions of exposure to one or more pollutants. Risk assessment can be conducted using Deterministic methods. The deterministic method uses a single value to represent input variables, leading to an estimate of risk for a studied population under conditions of specific exposure conditions to one or more pollutants. Pollution indicators showed that mercury metal contamination in the sediments of the Dez and Karkheh rivers is low to moderate; therefore, it seems that the origin of mercury in these rivers is very low. However, the results of water pollution indices indicated that the water in the Dez and Karkheh rivers is more contaminated than mercury metal.

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Competing Interests

There is no conflict of interest between the authors. The authors have observed all ethical considerations, including non-plagiarism, double publication, data distortion, and data fabrication in this article. They also reject any real or material conflict of interest that may affect the results or interpretation of the article.

Ethical Approval

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