Archives of Hygiene Sciences
Qom University of Medical Sciences

Winter 2022. Volume 11. Number 1

Research Paper

Geochemical Study of Heavy Metal Contamination of Shalmanrud River Sediments

Fariba Asghari[1], Mozhgan Salavati[1*], Saeid Hakimi Ssiabar[2], Fatemeh Shariati[2]

1. Department of Geology, Faculty of Science, Lahijan Branch, Islamic Azad University, Lahijan, Iran.
2. Department of Environment, Faculty of Science, Lahijan Branch, Islamic Azad University, Lahijan, Iran.

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Please cite this article as Asghari F, Salavati M, Hakimi Ssiabar S, Shariati F. Geochemical Study of Heavy Metal Contamination of Shalmanrud River Sediments. Archives of Hygiene Sciences. 2022; 11(1):73-90. http://dx.doi.org/10.32598/AHS.11.1.349.9

http://dx.doi.org/10.32598/AHS.11.1.349.9

Article info:

Received: 21 Sep 2021
Accepted: 31 Oct 2021
Publish: 01 Jan 2022

ABSTRACT

Background & Aims: Due to chemical stability, low degradation, and high bioaccumulation power at different levels of the food chain, heavy metals pose many ecological hazards to living organisms. Therefore, the present study investigated the concentrations of heavy metals As, Cr, Cu, Ni, Pb, V, and Zn and evaluated the ecological, carcinogenic, and non-carcinogenic risks of the sediments of the Shalmanrud river.

Materials and Methods: Nineteen samples were taken from 15 stations in summer 2021 as control and geochemical background to investigate the heavy metal contamination of the sediments of the Shalmanrud river. After preparation, the samples were chemically degraded using the ICPOES method with the digestion of four acids. Indicators of origin and contamination degree, including geoaccumulation index (Igeo), Enrichment Factor (EF), Pollution Load Index (PLI), Contamination Factor (CF), and Contamination degree (Cd), were calculated to assess the level of sediment contamination.

Results: Statistical results showed that the mean concentration of heavy metals increased as As <Cu <Ni <Pb <Cr <Zn <V. The order of heavy metals based on the mean of the Igeo index is Pb> Ni> Cu> V> Zn> Cr>As. The EF index for all studied metals except two samples of Pb metal was less than 1, which indicates the lack of human activity and geogenic concentration of heavy metals in the area due to the geological characteristics of the area. The Contamination Factor (CF) study showed that most samples are in the low to medium contamination class. The results of the Contamination degree (Cd) of most samples of Shalmanrud river showed a moderate contamination trend. Examination of the Pollution Load Index (PLI) showed that most samples were not polluted in the Shalmanrud river. The Ecological Risk (ER) index and Environmental Risk (ER) index of heavy metals indicated a low risk of heavy metals in the sediments of the Shalmanrud river.

Conclusion: The results of this study showed that the potential risk for cancer and non-cancerous diseases in children was higher than adults and by estimating the non-carcinogenic risk of all pathways (HI), Cr> As> Pb metals in the swallowing pathway and V> Ni> Cr metals were unauthorized in the study area and are hazardous to the health of residents around the Shalmanrud river. The study of contamination indices for Pb, Ni, and Cu metals showed a high level of contamination compared to other heavy metals in the area, which reflects the relatively heterogeneous distribution of these metals due to the geochemical diversity of geological units in the area and anthropogenic activities, such as agriculture, etc.

Keywords:

Heavy metals, Environmen, Pollution, Risk assessment, Carcinogenic risk

*** Corresponding Author:**
Mozhgan Salavati, PhD.
Address: *Department of Geology, Faculty of Science, Lahijan Branch, Islamic Azad University, Lahijan, Iran.*
Phone: *+98 (61) 33350163*
E-mail: *salavati1973@gmail.com*

1. Introduction

Pollutants from aquatic areas, such as heavy metals, are among the pollutants that increase the risk of death among humans. Because the high accumulation of heavy metals in these components can lead to severe ecological changes [1], what is even more worrying is the release and transport of heavy metals to sensitive population centers. Heavy metals are not biodegradable and can remain in sediments, soil, and dust for long periods, causing toxic impacts, such as cancer if they enter the human body. Cancer is the leading cause of death in developing countries of the world [2]. The increase in cancer may be due to aging or population growth, carcinogenic lifestyles, and especially environmental contamination. The origin of natural heavy metals in sediments is from parent rock weathering; thus, its concentration is strongly dependent on the composition of the parent rock. Geochemical base concentrations strongly depend on the mineralogical composition of the parent rock and the weathering processes that lead to sediment formation. Therefore, the geochemical composition of the parent rock can give an approximate estimate of the base levels of metallic elements in the soil. By comparing these surfaces with the amounts of metallic elements observed in the sediment, it is possible to detect the entry of these elements from human resources into the sediment. According to previous studies, one of the main sources of human exposure to environmental pollutants is fish consumption. Many elements, such as lead and zinc accumulate in the body of organisms, enter the food chain, and create possible health outcomes for the consumer [3]. According to the research by the International Agency for Research on Cancer (IARC), heavy metals are classified into three groups in terms of carcinogenicity to humans [4]. The first groups are metals and quasi-metals that are carcinogenic. The second group is metal compounds that are likely to cause cancer in humans. The third group is a compound that does not have carcinogenic properties in humans [5]. Among these metals, such as Cd, Cr, and Ni, and their compounds are among the first group, namely, human carcinogens, which its gastrointestinal and inhalation exposure can cause diseases, such as lung, liver, and kidney cancer [6].

As, Cd, and Pb are the most important heavy metals dangerous to humans. Cd and Pb poisoning is pretty common and harms humans. Affecting the body's defense mechanism and renal dysfunction is one of the most well-known toxic impacts of cadmium in humans causing Itai-Itai disease, which was first caused by consumption of rice contaminated with this metal and reported in Japan. These metals can also lead to long-term toxic impacts on biological systems and, in small amounts, may be transmitted to other organisms through the food chain. Low levels of Cu, Ni, and V are needed to produce red blood cells in the human body. Although high levels can be somewhat toxic, Ni does not seem to cause problems in the short term. However, it can cause weight loss, heart damage, irritation, and allergies [1].

Although the mean concentrations of metals, such as Cd, Cu, Cr, Ni, and V in the earth's crust are on average 0.11, 50, 100, 80, and 160 mg/kg, their geochemical dispersion in the environment naturally happens through weathering processes. In areas affected by human activities, the concentrations of these heavy metals in urban and industrial areas are not solely related to geological factors [6, 7]. Many studies have been performed to evaluate heavy metal contamination caused by various industrial activities using the indicators mentioned above, among which we can mention the study by Nematollahi et al. [8]. In this study, they dealt with trace elements in coastal sediments and the southern bed of the Caspian Sea. The results showed that the Sisangan recreation area was the most polluted place, and the carcinogenic risks of Pb and As in adults and Pb, Cd, and As in children were identified. Emenike et al. [9] evaluated the risk of human health by selecting toxic elements in the sediments of the Atuwara River, Nigeria. In this study, it was found that due to the risk factor of certain metals through swallowing, their potential risk was as follows: Co>> As>> Pb> Cr> Cd> Al> Ni> Cu> Zn> Fe in both seasons, respectively, and the risk of carcinogenesis for children through swallowing over the safe range was as follows: As, Cd, Cr, and Ni in both seasons. This result indicates the need for immediate measures to restore environmental quality to communities around the Atuwara River.

Although the presence of some metals (such as iron, manganese, Co, CU, and Zn) as nutrients in very low amounts are essential for the biological activities of living organisms, the findings show that marine ecosystem sediments contain huge amounts of environmental pollutants, such as Hg, Pb and Cd are potentially toxic and hazardous to aquatic environments, especially living organisms and their users [10, 11]. Among these, one of the environments that have been severely affected by severe contamination caused by human activities and, to some extent natural, are sediments in estuaries, coastal strips, and rivers [12, 13]. Therefore, the surface sediments of these areas have been used to accurately assess the contamination of heavy elements because the sediments constantly uptake pollutants and, as a result, are much more polluted than the water column [14]. In this study, the Shalmanrud river was considered, which originates from the heights in the east of Gilan and reaches the Caspian Sea at the estuary. In this area, agriculture, urban, and industrial wastewater (anthropogenic activity), and the existence of a large outcrop of various igneous rocks and metamorphism (geological factors), make the geogenic contamination, especially heavy metals in this river, possible. This contamination, in turn, can create problems for human health and life. Therefore, the study and assessment of the environmental risk of heavy metals in this ecosystem are very important. Due to the presence of benthic organisms (such as river bivalves and freshwater oysters) in the estuaries of these rivers, it is possible that the toxic contaminants in these rivers enter these organisms and then into the ecosystem cycle. The present study aimed to evaluate the geochemical contamination of heavy metals As, Cr, Cu, Ni, Pb, V, and Zn in the sediments of Shalmanrud river using geochemical accumulation indices (Igeo), Enrichment Factor (EF), Contaminant Factor (CF), Pollution Load Index (PLI), Contaminant degree (Cd), Ecological Risk (ER) assessment of heavy metals, Environmental Risk (ER) assessment, and their carcinogenicity and non-carcinogenicity indicators due to dermatology, inhalation, and gastrointestinal exposure on children and adults living nearby were studied. The results of this study can provide a proper assessment of the impacts of heavy metals entering the environment.

2. Materials and Methods

Study area

The study area in this research was Shalmanrud river in Gilan province, which is geographically located between the coordinates with a longitude of 50 degrees and 21 minutes and latitude of 37 degrees and 15 minutes (Figure 1 and Table 1). Due to the passage of geological units with high geochemical diversity (alkaline to acidic rocks), the density of various agricultural lands around, and the existence of a water recreation area for citizens, this river is considered an important area to assess the extent of sediment contamination.

Geology of the area

Due to its morphological position and location, the Shalmanrud river has caused it to pass through several lithological units and geological formations. This matter has led to the passage of these units carrying a lot of rocks, minerals, and sediments. Perhaps the most important lithology that the Shalmanrud river flows through is the Kv2 unit, which is shown in pink on the geological map (Figure 2). This unit is the broadest in the study area, which includes a collection of submarine volcanic rocks with alkaline composition, sometimes medium, in the form of shear lava, pyroclastic rocks, lava with pillow construction, split, hyaloclastite, and lithic crystals tuffs with small interlayers of tuff shales that have locally nourishing basaltic dykes (microgabbro to micromonzogabro). This geological unit with acidic to alkaline composition due to high geochemical diversity and the presence of elements, such as Cr, Cu, Ni, As, in the distribution of heavy metals in the sediments of Shalmanrud river has a significant impact and creates environmental contamination.

Laboratory sampling and analysis

It is necessary to have sufficient information about the conditions of the area in order to determine the study stations. In this study, the quality of river sediments has been measured and controlled at 15 points (Figure 3). For this purpose, the general location of the area was first examined using a map. Then, by evaluating the available information, the stations in question were identified due to the exposure to the most contaminant caused by geogenic and anthropogenic activities. There were 15 stations on the Shalmanrud river in summer 2021.

According to the location of factories and cities along the river and according to the geological location of the area and access roads available to the river to evaluate and track heavy metals and mobility control factors and transport them downstream in the Shalmanrud river, systematic sampling was done from 15 different stations along the river pathway from different parts of upstream, middle and downstream of the river and its tributaries. In sampling, an attempt was made to sample from the upstream or less affected area and downstream at the mouth of the river and its outlet to the sea. Systematic sampling was performed at the exit points of cities and factories to investigate the impact of industrial and human characteristics in each part and compare it with upstream untouched types.

Samples of Shalmanrud river sediments were done by Peterson-Grab apparatus. Unlike seasonal changes in the density of soluble elements, these conditions do not govern bed sediments, and generally, the density of elements in bed sediments is not subject to climatic conditions. The weight of the samples taken from each sampling station was about 5 kg. They were then sieved to prepare the collected sediments at a temperature of 30-30°C. Drying, grinding, and splitting were performed to turn them into 200 mesh powder. The samples were then transferred to the Aria Chemistry Laboratory in Karaj. In order to deter-

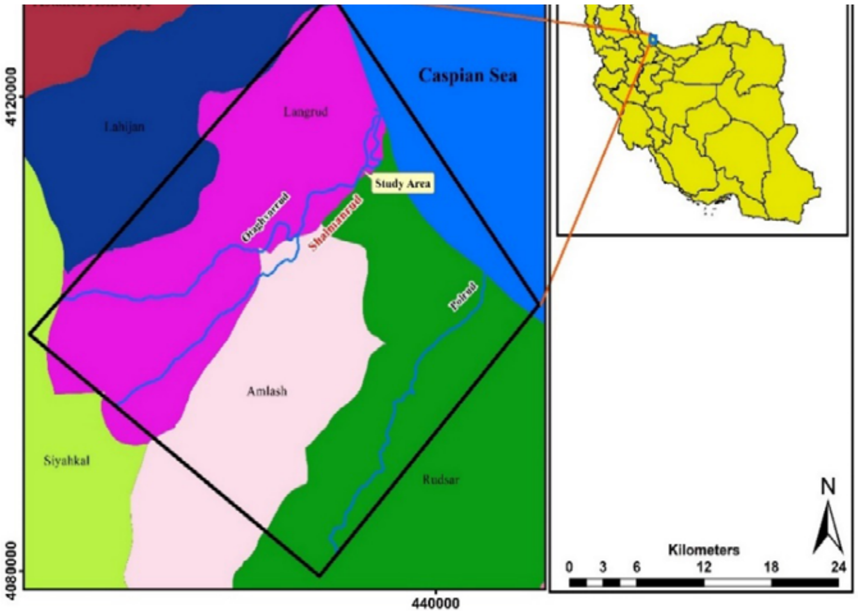

Figure 1. Geographical location of the study area

mine the composition of the studied sediments, they were analyzed by an ICPOES device with the digestion of four acids. The Van Veen model Grab apparatus collected sediment samples and stored them in the freezer until preparation. Samples were placed in plastic containers based on station number and replication (two replications and each replication included four combinations) and dried at room temperature. The dried sediments were crushed by a stone passed through a sieve with 230 mesh.

Environmental indicators

Geochemical Igeo Müller accumulation index

This method was used to evaluate the contamination of sediments with heavy metals, comparing the measured concentration of each heavy metal in the sample with its geochemical background concentration in the sediment. In order to determine the severity of contamination, the geoaccumulation index proposed by Muller [15] can be used. This index is indicated by the Igeo symbol and is calculated through the following Equation 1:

1. $Igeo=log_2\,[Cn/Bn\times1.5]$

Based on Igeo Müller Geoaccumulation Index (soil contamination intensity index), Cn is the concentration of the element in sediment, Bn is the concentration of the element in shale, 1.5 is the shale correction factor. In this formula, since the previous concentration of the element is not obtained through complete decomposition, the concentration of shale, which is a type of sedimentary rock, should be used. Because the mean concentration of elements in shale is lower than the mean concentration of elements in unpolluted sediments, it must be multiplied by 1.5 to balance it. According to this index and

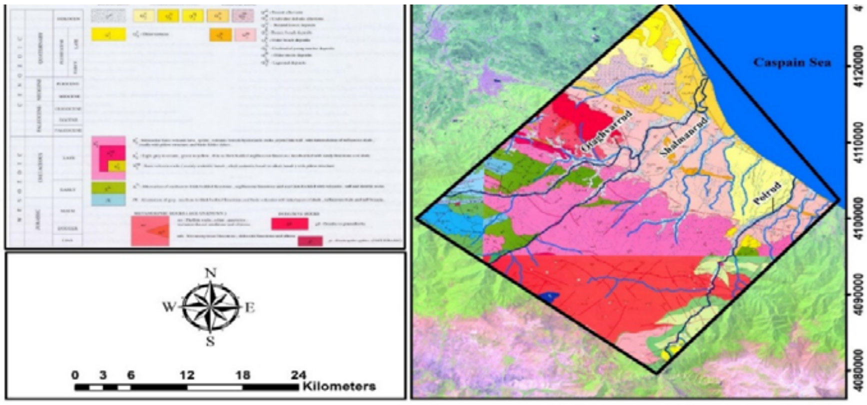

Figure 2. Geological map of the study area

Table 1. Sampling stations in the study area

Stations	Locations
SH-1	Shalmanrud under the Blordkan bridge
SH-2	Shalmanrud
SH-3	Shalmanrud
SH-4D	under the Kharshtem bridge before the crossroads
SH-4S	under the Kharshtem bridge before the crossroads
SH-5D	Shalmanrud before crossing with Chafjir
SH-5S	Shalmanrud before crossing with Chafjir
SH-6D	After Shalmanrud intersection and before the sea
SH-6S	After Shalmanrud intersection and before the sea
SH-7D	Shalmanrud outlet to the sea
SH-7S	Shalmanrud outlet to the sea
SH-8	Estuary of Shalmanrud river
SH-9	The confluence of the Ataqour River with the Shalmanrud of the Ataqour River
SH-10	From Shalmanrud, Amlash outlet under the Kharshtem bridge
SH-11	Downstream of Kahlestan Dam
SH-12	Down Samadi Tea Factory
SH-13	Under the Blordkan bridge
SH-14	Blordkan, Aghooz branch
SH-15	From Ataqour river

D: Deep; S: Surface

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according to Table 2, sediments are divided into seven groups in terms of contamination degree [15]:

Enrichment Factor (EF)

This index evaluated the possible anthropogenic impacts of the metal enrichment factor. The enrichment coefficient indicates the intensity of the impact of an external factor (mostly anthropogenic) on sediments, which is calculated from the following Equation 2 [16] :

$$2.\ EF=\frac{(Cx/Cref)_{Sample}}{(Cx/Cref)_{Background}}$$

Here, Cx is the reference concentration in the sediment samples, and Cref is the reference element. In this equation, the element Fe is used. The classification of the EF index is as follows (Table 3):

Contamination Factor (CF)

To further investigate how heavy metals are contaminated, a Contamination Factor (CF) was considered for all stations to elucidate the amount of heavy metal contamination at different stations. For this purpose, the amount of Contamination Factor (CF) was calculated by dividing the amount of density of the metal in the sediment sample by the mean shale content, according to which a CF greater than 1 (CF>1) indicates contamination and a CF lower than 1 (CF<1) indicates that the station is not contaminated with that metal element. Then, the amount of PLI was calculated [17] (Equation 3):

$$3)\ CF=\frac{C_m Sample}{C_m Background}$$

C_m sample is the density of heavy metal in the sediment sample, and C_m background is the amount of metal equiva-

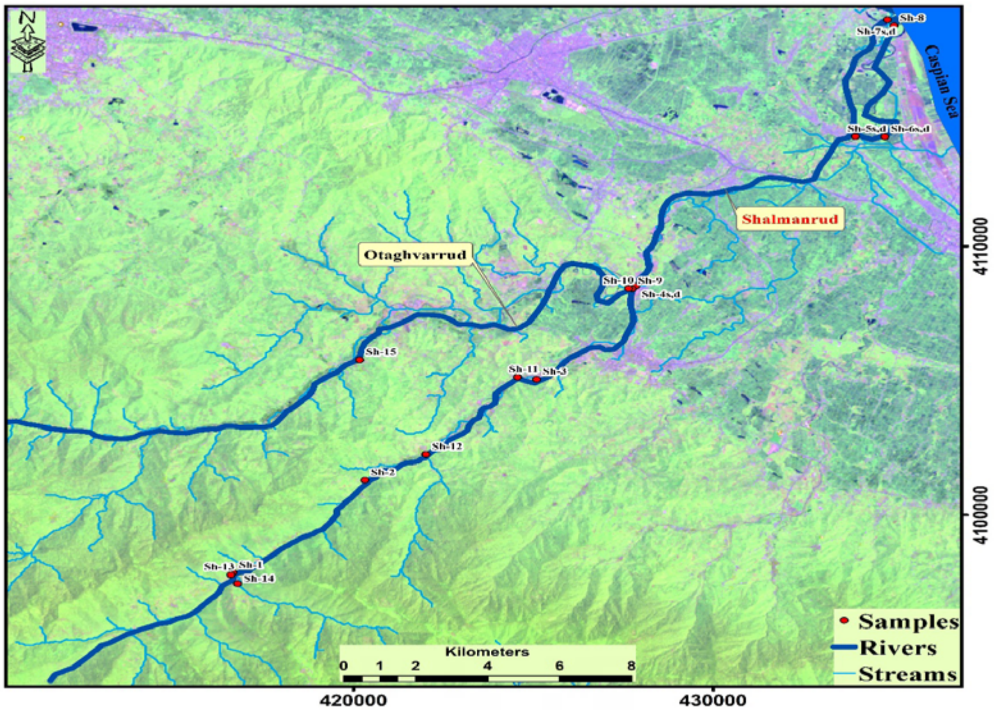

Figure 3. Location of sampling points in the Shalmanrud river

lent to the mean of surface rocks shown by Martin and Maybeck (1979). The CF classification is shown in Table 4 [17].

Pollution Load Index (PLI)

PLI was obtained from Equation 4 [18]:

4. $PLI=(CF1\times CF2\times CF3\times\ldots\times CFn)\ 1/n$

N is the number of heavy metals and CF is the contamination coefficient. Pollution load index higher than one (PLI>1) indicates contamination, less than one (PLI<1) indicates non-contamination, and contamination load factor close to one indicates density similar to the field.

Contamination degree (Cd)

Basically, the sum of the contamination coefficients of the studied pollutants expresses the general degree of sediment contamination, which is called Hakanson contamination degree, and is calculated according to Equation 5 and interpreted in Table 5 [19], where, n is the number of elements in a sampling station.

5. $Cd=\sum_{i=1}^{n} CF^{i}$

Table 2. Geoaccumulation index values used in determining sediment contamination

Contamination Intensity	Geoaccumulation Index (I_{geo})
Non-infected	Less than or equal to zero
Non-contaminated to a little infected	Zero to 1
Slightly infected	1 to 2
Slightly infected to very infected	2 to 3
Very infected	3 to 4
Very infected to severely infected	4 to 5
Severely infected	More than 5

Table 3. Equation between EF and degree of enrichment

Enrichment Factor (EF)	Enrichment Intensity
Less than 1	No enrichment
Between 1 and 3	Low enrichment
Between 3 and 5	Medium enrichment
Between 5 and 10	Relatively High Enrichment
Between 10 and 25	High enrichment
Between 25 and 50	Very High Enrichment
More than 50	extremely High Enrichment

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Ecological Risk (ER) and Environmental Risk (ER) of heavy metals in the study area

Hakanson first used the ecological risk assessment index to assess the risk of sediment contamination by heavy metals. Based on the degree of metal toxicity, various individuals have used modification methods, such as Wang et al. [20] and Yi et al. [21]. The two ER and RI indices are calculated according to Equations 6 and 7.

$$6.\ E_r^i=\frac{c^i}{c_0^i}\times T_r^i$$

$$7.\ RI=\sum_{i=2}^{n} E_r^i$$

In Equations 6 and 7, the ecological risk potential index and the amount of element measured in the studied sediment and the natural value (Background Value) are equal to the response factor of metal toxicity, respectively. In the present study, n was considered equal to the number of elements studied (equivalent to 7). According to Hakanson's approach, the toxicity response factor for As, Cr, Cu, Ni, Pb, and Zn metals is 10, 2, 5, 5, 5, and 1. It should be noted that this index is not set for element V. Table 6 shows the ecological and environmental risks of the studied heavy metals.

Carcinogenic and non-carcinogenic risk assessment

The health risk assessment method provided by the US Environmental Protection Agency (USEPA) was used [22] to assess the carcinogenic and non-carcinogenic risks of heavy metals in Shalmanrud sediments. Because the distance from the river to the nearest settlements and recreation centers is between 1 and 3 km, the people exposed to heavy metals were children and adults who lived in these centers. In the study of heavy metals' carcinogenic risks, children and adults' exposure to metals from all three pathways of swallowing, respiration, and skin uptake were considered. Given that the daily dose (concentration) exposure is expressed separately for each metal, the Average Daily Dose (ADD) values in each path were calculated using Equations 8-10.

$$8.\ ADD_{ingestion}=Csoil\,\frac{IngR\times EF\times ED}{BW\times AT}\times 10^{-6}$$

$$9.\ ADD_{inhalation}=Csoil\,\frac{InhR\times EF\times ED}{PEF\times BW\times AT}$$

$$10.\ ADD_{dermal}=Csoil\,\frac{SA\times AF\times ABS\times EF\times ED}{BW\times AT}\times 10^{-6}$$

Table 4. Contamination Factor (CF) and contamination level

Contamination Coefficient	Contamination Level
CF<1	Low contamination
1≤ CF <3	Moderate contamination
3≤ CF <6	Considerable contamination
CF >6	Very much contamination

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Table 5. Contamination degree (Cd) and level of contamination [19]

Contamination Degree	Contamination Level
6≥ Cd	Low contamination
12≥ Cd ≥6	Moderate contamination
24≥ Cd ≥12	Considerable contamination
Cd ≥24	Very much contamination

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$ADD_{ingestion}$, $ADD_{inhalation}$, and ADD_{dermal} are the mean daily uptake of metals (in milligrams per kilogram per day) through swallowing, inhalation, and dermal uptake. C is the concentrations of metals in soil (mg/kg), IngR and InhR are swallowing rate and soil respiration rate (mg/day and cubic meters per day), respectively. EF is the frequency of metal exposure (days per year), ED is the duration of exposure to metals (Years), BW is the weight of the person exposed to metals (kg), AT is the average time of exposure to any metals (days), PEF is the Metal-to-Air Emission Factor (cubic meters per kg) SA is the area of skin surface exposed to metals (square centimeters), AF is soil-to-skin adhesion factor (mg / cm/day), and ABS is skin uptake factor (no unit) [23].

After calculating the daily uptake of metals for each path, the non-carcinogenic risk index (Hazard Quotient, HQ) of all pathways for industrial workers, children, and adults will be determined by dividing the total ADDi of each path by the reference value of the metal toxicity (Equation 11). In Equation 4, HQ is the non-carcinogenic risk of heavy metals in each path, RfDi is the reference value of metal toxicity in each path (mg/kg.day). If HQ≤1, no unacceptable effects will occur and if it is HQ<1, adverse and worrying impacts on human health will observe. This index is calculated from Equations 11 [24]:

$$11.\ HQ=\sum\frac{ADDi}{RfDi}$$

The value of the cumulative non-carcinogenic risk index (HI) of total heavy metals for industrial workers, adults, and children is obtained according to Equation 12 [25]:

$$12.\ HI=\sum HQ=\sum\frac{ADDi}{RfDi}$$

Carcinogenic risk assessment in each of the three pathways will be performed using Equation 13 [25]:

$$13.\ Risk\ (RI)=\sum ADD_i\times SF_i$$

In Equation 13, RI is the risk of carcinogenicity, ADD_i is daily metal uptake values in each of the metal exposure pathways (mg/kg/day), and SF_i is the cancer risk factor per metal exposure unit (mg/kg/day) [25].

3. Results

The results of the analysis of the samples are shown in Table 7. Descriptive statistics of the concentration of heavy metals (except Fe) measured in Shalmanrud sediments as a minimum, maximum, mean, median, in milligrams per Kg is summarized in Table 7. Among the heavy metals measured, the highest concentration (MAX) of metals in the soil of the study area was related to Pb with 595 mg/kg, and the lowest (MIN) was related to As with 2.39 mg/kg (Table 8). The concentrations

Table 6. Ecological risk classification of heavy metals [19]

Ecological and Environmental Risks	Risk Index (RI)	Ecological Risk of Heavy Metals	E^i_r
Low risk	150≥RI	Low risk	$40\geq E^i_r$
Medium risk	300≥RI≥150	Medium risk	$80\geq E^i_r\geq 40$
High risk	600≥RI≥300	Considerable risk	$160\geq E^i_r\geq 80$
Too high risk	RI≥600	High risk	$320\geq E^i_r\geq 160$
-	-	Very high risk	$E^i_r\geq 320$

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Table 7. Results of analysis of samples of the Shalmanrud river

Samples (mg/kg)	As	Cr	Cu	Ni	Pb	V	Zn
Sh-1	4.57	44.46	73.11	58.29	6.91	161.04	112.63
Sh-2	5.80	74.36	82.5	72.04	11.61	135.95	117.35
Sh-3	2.72	42.27	60	51.81	8.18	148.63	105
Sh-4d	6.16	53.65	69.75	57.68	12.07	163.65	130.12
Sh-4s	4.99	64.33	64.33	57.07	8.30	170.18	117.26
Sh-5d	7.20	60.09	49.17	50.26	12.01	134.4	102.71
Sh-5s	6.88	52.35	41.25	42.83	11.10	117.40	95.192
Sh-6d	9.80	40.17	27.26	25.82	11.47	88.95	67.43
Sh-6s	8.38	48.72	36.54	33.22	37.65	97.44	81.941
Sh-7d	8.39	17.06	21.33	18.49	9.95	49.78	51.209
Sh-7s	6.83	19.64	20.62	17.67	8.83	52.05	49.10
Sh-8	12.1	119	57	73	137	169	97
Sh-9	18.9	188	108	116	595	179	129
Sh-10	3.1	122	64	59	47	154	68
Sh-11	4.6	174	57	107	173	216	129
Sh-12	3.8	109	45	81	17	181	112
Sh-13	3.2	142	45	75	14	170	90
Sh-14	2.4	81	48	55	155	197	117
Sh-15	5.8	311	43	135	38	234	128

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Table 8. Descriptive statistics of heavy metal concentrations in the sediments of the Shalmanrud and global shale [26]

Metal (mg/kg)	As	Cr	Cu	Ni	Pb	V	Zn	Fe
MIN	2.4	17.06	20.62	17.67	6.91	49.78	49.1	18651.87
MAX	18.9	311	108	135	595	234	130.12	60600
AVER	6.66	92.79	53.31	62.43	69.16	148.39	99.99	40456.82
STEV	3.9	72.15	21.47	31.38	137.93	49.71	25.93	11361.52
VAR	15.28	5205.83	461.06	985.31	19025.08	2472.04	672.84	129084276.1
CV (%)	58.7	77.75	40.27	50.27	199.42	33.5	25.93	28.0830
KUR	4.64	3.56	1.06	0.46	12.89	0.03	-0.51	-0.23
SKEW	1.87	1.72	0.68	0.75	3.43	-0.54	-0.72	-0.14
Shale Aver	13	90	45	50	20	130	95	4700

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Table 9. Results of CF, Cd, and PLI of sediments of the Shalmanrud river

Samples	CF_As	CF_Cr	CF_Cu	CF_Ni	CF_Pb	CF_V	CF_Zn	Cd	PLI
Sh-1	0.35	0.49	1.62	1.16	0.34	1.23	1.18	6.40	0.77
Sh-2	0.44	0.82	1.83	1.44	0.58	1.04	1.23	7.40	0.95
Sh-3	0.20	0.46	1.33	1.03	0.40	1.14	1.10	5.70	0.68
Sh-4d	0.47	0.59	1.55	1.15	0.60	1.25	1.36	7.00	0.912
Sh-4s	0.38	0.71	1.42	1.14	0.41	1.30	1.23	6.62	0.84
Sh-5d	0.55	0.66	1.09	1.00	0.60	1.03	1.08	6.03	0.83
Sh-5s	0.52	0.58	0.91	0.85	0.55	0.90	1.00	5.34	0.74
Sh-6d	0.75	0.44	0.60	0.51	0.57	0.68	0.70	4.29	0.60
Sh-6s	0.64	0.54	0.81	0.66	1.88	0.74	0.86	6.15	0.81
Sh-7d	0.64	0.18	0.47	0.36	0.49	0.38	0.53	3.09	0.41
Sh-7s	0.52	0.21	0.45	0.35	0.44	0.40	0.51	2.91	0.40
Sh-8	0.93	1.32	1.26	1.46	6.85	1.3	1.02	14.15	1.54
Sh-9	1.45	2.08	2.4	2.32	29.75	1.37	1.35	40.74	2.65
Sh-10	0.23	1.35	1.42	1.18	2.35	1.18	0.71	8.44	1.01
Sh-11	0.35	1.93	1.26	2.14	8.65	1.66	1.35	17.36	1.66
Sh-12	0.29	1.21	1	1.62	0.85	1.39	1.17	7.54	0.96
Sh-13	0.24	1.57	1	1.5	0.7	1.30	0.94	7.27	0.90
Sh-14	0.18	0.9	1.06	1.1	7.75	1.51	1.23	13.74	1.15
Sh-15	0.44	3.45	0.9	2.7	1.9	1.8	1.34	12.60	1.51

CF: Contamination Factor; Cd: Contamination degree; PLI: Pollution Load Index.

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of heavy metals presented in Table 1 increased by their mean respectively as follows: As<Cu<Ni<Pb<Cr<Zn<V.

Findings from the results of calculating the amount of geoaccumulation index (Igeo) are given in Figure 4. Based on this index, the highest value was obtained for Pb, and the lowest was obtained for As. The mean of geoaccumulation index (Igeo) of heavy metals in Shalmanrud river sediments was as follows: Pb (0.89) > Ni (0.713) > Cu (0.711) > V (0.67) > Zn (0.60) > Cr (0.25) > As (-0.58), respectively.

Figure 5 shows the results of the EF study. The mean of EF of heavy metals in the sediments of Shalmanrud river was as follows: Pb (0.40)>Ni (0.14)>Cu (0.137)>V (0.0132)>Zn (0.122)>Cr (0.11)>As (0.59). According to Figure 5, the amount of EF obtained for all studied metals except two samples of Pb metal was less than one, which indicates the lack of anthropogenic activities and geogenic concentration of heavy metals in the area due to the geological characteristics of the area. Two samples of Pb metal, which showed a higher amount of EF, can be due to anthropogenic activities in the area, such as agricultural activities and the entry of sewage and fertilizers into the Shalmanrud river.

The results of the CF study showed that most of the samples are in the category of low to medium contamination coefficient (Table 9) For V and Ni metals, 14 samples showed medium contamination and five samples showed low contamination, for Zn and Cu, 13 and 11 samples showed medium contamination and six and eight stations showed low contamination, for Pb, four samples showed considerable contamination, three sam-

Table 10. Ecological Risk (ER) and Environmental Risk (ER) of heavy metals in the sediments of the Shalmanrud river

Samples	ER_As	ER_Cr	ER_Cu	ER_Ni	ER_Pb	ER_V	ER_Zn	RI
Sh-1	3.522024	0.988024	8.123752	5.829341	1.729042	0	1.185629	20.19218
Sh-2	4.465636	1.652582	9.166667	7.204225	2.90493	0	1.23536	25.39404
Sh-3	2.097902	0.939394	6.666667	5.181818	2.045455	0	1.105263	16.93124
Sh-4d	4.738939	1.192412	7.750678	5.768293	3.018293	0	1.369705	22.46861
Sh-4s	3.843738	1.429769	7.148847	5.707547	2.075472	0	1.234359	20.20537
Sh-5d	5.544715	1.335541	5.463576	5.02649	3.004967	0	1.081213	20.37529
Sh-5s	5.298996	1.163462	4.583333	4.283654	2.776442	0	1.002024	18.10589
Sh-6d	7.541439	0.892754	3.028986	2.582609	2.869565	0	0.70984	16.91535
Sh-6s	6.448914	1.082774	4.060403	3.322148	9.412752	0	0.862593	24.32699
Sh-7d	6.456187	0.37931	2.37069	1.849138	2.489224	0	0.53902	13.54455
Sh-7s	5.256982	0.436508	2.291667	1.767857	2.209821	0	0.516917	11.96284
Sh-8	9.307692	2.644444	6.333333	7.3	34.25	0	1.021053	59.83547
Sh-9	14.53846	4.177778	12	11.6	148.75	0	1.357895	191.0662
Sh-10	2.384615	2.711111	7.111111	5.9	11.75	0	0.715789	29.85684
Sh-11	3.538462	3.866667	6.333333	10.7	43.25	0	1.357895	67.68846
Sh-12	2.923077	2.422222	5	8.1	4.25	0	1.178947	22.6953
Sh-13	2.461538	3.155556	5	7.5	3.5	0	0.947368	21.61709
Sh-14	1.846154	1.8	5.333333	5.5	38.75	0	1.231579	53.22949
Sh-15	4.461538	6.911111	4.777778	13.5	9.5	0	1.347368	39.15043
Total	96.67701045	39.18141859	112.5441532	118.62312	328.5359621	0	19.99981745	-

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ples showed moderate contamination, and 12 samples showed low contamination samples, for Cr, one sample showed significant contamination, six samples showed medium contamination samples, and 12 samples showed low contamination samples, and finally, one sample showed low contamination sample and 18 samples showed low contamination for As (Figure 6). According to Table 9, Contamination degrees (Cd), five samples showed low contamination, nine samples showed moderate contamination, three samples showed considerable contamination, and two samples showed very high contamination. In general, most of the samples of the Shalmanrud river show a moderate contamination trend.

In general, according to Table 10, the study of PLI of heavy metals in the study area shows that six samples are polluted and 13 samples are not polluted in the Shalmanrud river.

Ecological risk assessment of heavy metals in the study area

The results of the ecological risk study of heavy metals are shown in Figure 7 and Table 10. The results of the ecological risk study of these findings show that all the samples studied, except for samples Sh-9 and Sh-11 for Pb metal in terms of ER of heavy metals, are in the low-risk category. In addition, the trend of changes in the overall risk of each metal in the area was as follows: Pb> Ni> Cu> As> Cr> Zn, respectively. The highest and lowest risks are related to the metals Pb and Zn, respectively. Also, according to Table 10, the findings of

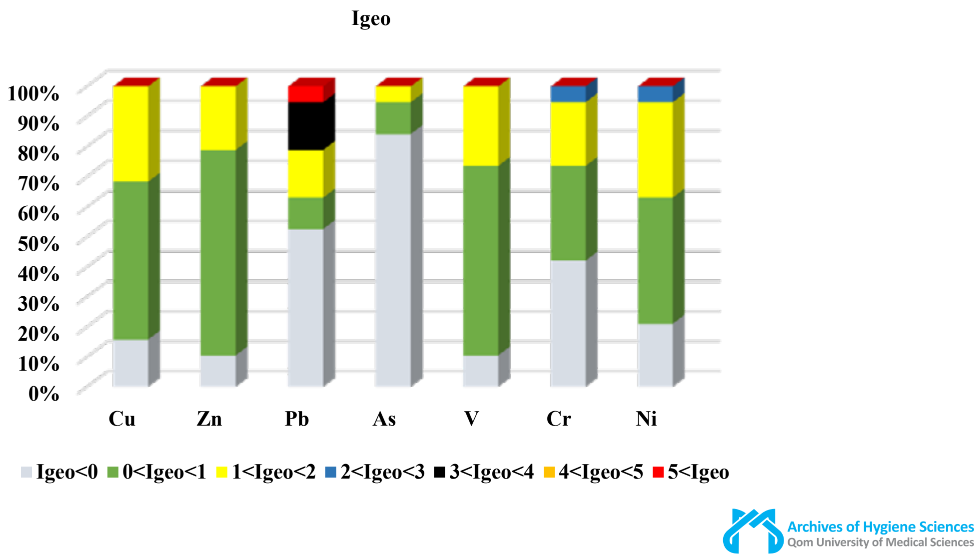

Figure 4. Geoaccumulation index values (Igeo) of the studied metals in the sediments of Shalmanrud river

environmental risk assessment of heavy metals showed that according to the obtained values (less than 150), the environmental risk of these metals was low.

Carcinogenic and non-carcinogenic risk

The health risk assessment of exposure to heavy metals in Shalmanrud sediments from the three main pathways of swallowing, respiration, and skin uptake for children and adults is presented in Table 11. According to the HQ results, in the age group of children and adults, all the studied metals were swallowed>dermal uptake>respiration, respectively. Also, the amount of HQ in the skin uptake, respiration, and swallowing pathways was higher for children than adults. The highest amount of HQ was related to chromium metal through the swallowing pathway for both age groups. HQ study of heavy metals in all three pathways of swallowing, skin uptake, and respiration is estimated to be less than one; thus, it will not threaten human health. According to Table 12, the non-carcinogenic risk index (HI) values of the total uptake pathways in the age group of children are higher than adults. This issue indicates that children are more exposed to heavy metals than adults. HI of the total uptake pathways in the age groups of children and adults are presented in Table 11 and Figure 8. The heavy metals' carcinogenic risk assessment results are presented separately for children and adults in Table 12 and Figure 9.

Examination of the non-carcinogenic risk (HQ) of heavy metals in each pathway indicates that most metals except As (children), Cr (children and adults), and lead (children) in the swallowing pathway and Cr (adults) in

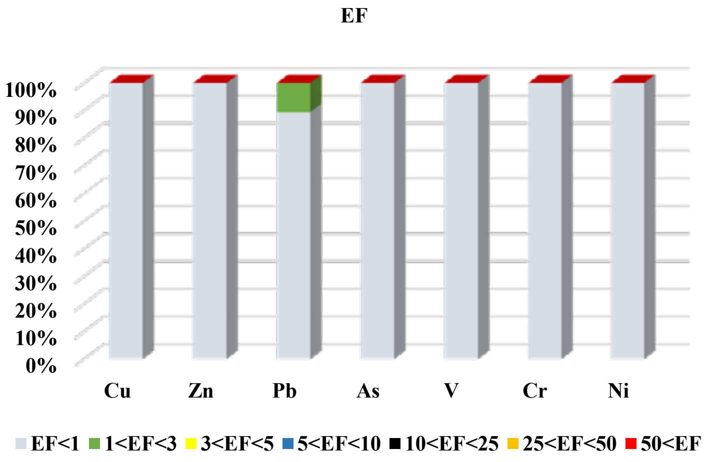

Figure 5. Enrichment Factor (EF) values of the studied metals in the sediments of Shalmanrud river

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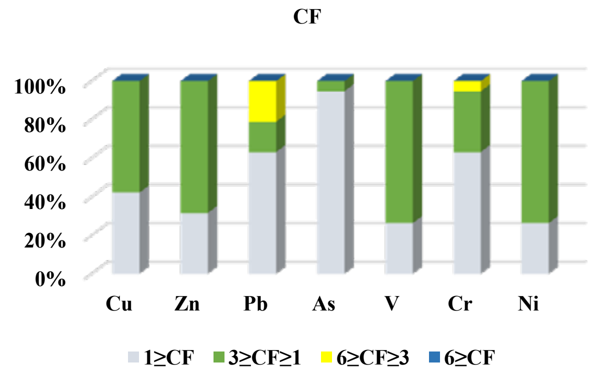

Figure 6. Contamination Factor (CF) of the studied metals in the sediments of Shalmanrud river

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the skin pathway had more than one non-carcinogenicity. The highest HQ was observed for Cr in the swallowing pathway and children. Also, the highest amount of HQ for both groups was assigned to Cr metal in the swallowing pathway. The risk of non-carcinogenicity (HQ) of each metal uptake pathway in the swallowing pathway was higher for children than adults, in the dermal uptake pathway for adults than in children, and in the respiratory pathway except in the case of Cu for children more than adults. The results of the non-carcinogenic risk assessment of all three pathways (HI) for each metal are shown separately for children and adults in Figure 8. According to this chart, the non-carcinogenic risk values of the total As, Cr, Cu, Ni, Pb, V, and Zn uptake pathways (HI) are 5.47, 8.35, 0.34, 0.79, 4.97, 0.03, and 0.08 for children and adults 0.78, 2.26, 0.05, 0.11, 0.79, 0.005 and 0.013, respectively.

The study of heavy metals' carcinogenic risk in Shalmanrud sediments showed that the three metals of Cr, Ni, and V have the highest carcinogenic risk among other metals and in children. Then, Ni (children and adults), Cu (children), and a low amount of Zn (children) have a carcinogenic risk, which can be ignored due to the low amounts of these metals (Figure 9).

Basically, the origin of environmental contamination is various in aquatic systems, and these pollutants enter aquatic systems through different ways and processes. Therefore, assessing contamination conditions in these ecosystems to prevent, control, and warn human communities is of great importance. In the meantime, one of the methods to assess the contamination conditions in the environment is to analyze and study them in the area's sediments. Due to the existence of natural and artificial resources for heavy metal contamination by Cr, As, Pb, V, and Ni in Shalmanrud sediments, which are affected by various agricultural and industrial effluents along with the impact of natural resources, especially the use of surrounding rivers of the area and the particular

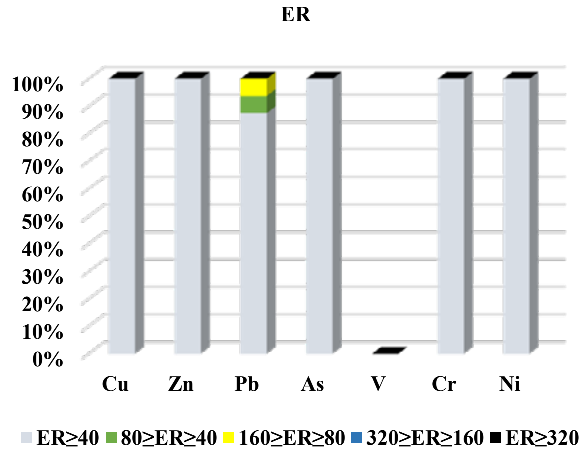

Figure 7. Ecological Risk (ER) study of the studied metals in the sediments of the Shalmanrud river

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Table 11. Results of HQ index of heavy metals in the sediments of Shalmanrud river

Metal	$HQ_{Ingestion}$		$HQ_{Inhalation}$		HQ_{Dermal}	
	Children	Adults	Children	Adults	Children	Adults
As	5.458142621	0.732308938	0.00014817	6.66999E-05	0.021300069	0.054387335
Cr	7.712974063	1.034835518	0.022695133	0.010216393	0.617037925	1.575537077
Cu	0.340190546	0.045642739	9.49537E-06	4.27442E-06	0.00181435	0.004632738
Ni	0.792716789	0.106357351	2.15892E-05	9.71855E-06	0.004697581	0.011994746
Pb	4.927188169	0.661071758	0.00013743	6.1865E-05	0.052556674	0.134197567
V	0.038020847	0.005101187	2.51582E-09	5.33457E-11	6.08334E-07	1.55331E-06
Zn	0.084693192	0.01136313	2.37577E-06	1.06947E-06	0.000677546	0.001730036

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geological conditions of the area, the contamination of these metals in the sediments of the area is inevitable. On the other hand, since many living organisms are in contact with bed sediments or live in them in aquatic ecosystems, sediments can act as an important path in the exposure of aquatic organisms to pollutants. Therefore, standards have been developed for sediments that can be used to grade contaminated sediments and predict the potential for adverse impacts on aquatic animals in contact with these sediments. Therefore, to determine the contamination of surface sediments in the study area with heavy metals, their mean concentration was compared with the Canadian Sediment Quality Guidelines (SQGs). The SQGs are used to assess the degree of contamination and evaluate the impact of pollutants on living organisms [26, 27].

In Table 13, the SQGs are compared with the two sediments Threshold Effect Concentrations (TEC) and Probable Effect Concentration (PEC), which indicate the impact concentration threshold and probable impact concentration, respectively, and were compared with the sediments of the Shalmanrud river. According to the SQGs, Cr, Cu, Ni, and Pb metals are higher than the TEC standard, and only Ni metal in the sediments of the Shalmanrud river is higher than the PEC standard. Therefore, all metals except As and Zn are on the verge of contamination, and if the contamination continues to increase, it can have negative impacts on living things in the future.

4. Discussion

Based on the Müller Geochemical Accumulation Index (Igeo), the quality of sediments for most of the studied

Table 12. Results of HI and RI index of heavy metals of Shalmanrud river sediments

Metal	RI		HI	
	Children	Adults	Children	Adults
As	0.000247656	3.41869E-05	5.47959086	0.786762973
Cr	0.009734169	0.001343719	8.352707121	2.620588988
Cu	0	0	0.342014391	0.050279751
Ni	0.013339324	0.00184138	0.797435959	0.118361815
Pb	0.000725476	0.000100146	4.979882273	0.79533119
V	0.038082747	0.005256998	0.038021458	0.00510274
Zn	0	0	0.085373114	0.013094236

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Table 13. Comparison of heavy metal concentrations in Shalmanrud river sediments in comparison with TEC and PEC standards [27]

Metal (mg/kg)	As	Cr	Cu	Ni	Pb	V	Zn
Study area	6.66	92.97	53.31	62.43	69.16	148.39	99.99
TEC	9.79	43.4	31.6	22.7	35.8	-	121
PEC	33	111	149	48.6	128	-	459

TEC: Threshold Effect Concentrations; PEC: Probable Effect Concentration

metals shows from non-contaminated to slightly contaminated (Figure 5). It can be stated that the highest accumulation coefficient for Pb metal has occurred in the sediment samples of the area, considering the geoaccumulation index's mean and the percentage of classes of this index. The high Pb geoaccumulation index compared to other elements and its high rate compared to the mean Pb in the mean of shale (Table 8) indicate the impact of various geogenic and anthropogenic activities on increasing and wide changes in its concentration in the area.

The results of EF of all metals showed that all the studied metals in the area are geogenic, and their accumulation in the sediments of the Shalmanrud river is geogenic. It can be stated that the highest enrichment coefficient for Pb metal has occurred in the sediment samples of the area, considering the mean of the geoaccumulation index and the percentage of classes of this index. The high mean of Pb enrichment index compared to other metals indicates the effect of various human activities on increasing its concentration in the area.

The CF results showed that all samples are in the low to medium contamination category. Thus, Pb and Cr metals showed the highest contamination coefficient among metals. The mean CF of heavy metals in Shalmanrud river sediments was as follows: Pb (3.45)>Ni (1.24)>Cu (1.18)>V (1.14)>Zn (1.05)>Cr (1.03)>As (0.50), respectively. Also, the findings of the Cd of the studied metals in different stations showed that most of the samples have a moderate contamination degree. PLI is a standard system for detecting contamination that allows the comparison of contamination rates between different sites and at different times. This index allows researchers to make a general assessment of the toxicity status of the contribution of several metals in a sediment sample. The PLI results showed that six samples are contaminated and 13 samples are not contaminated in the sediments of the Shalmanrud river. This issue indicates low contamination of the area to heavy metals. The results of Cd and PLI showed that the Sh-8 station located downstream and Sh-9 station, which is the intersection of Ataqourrud and Shalmanrud, were more contaminated.

The results of ecological risk and environmental risk of heavy metals showed that all samples except two samples for Pb metal have a low-class ecological risk. The mean of ER assessment of heavy metals in the sediments of the Shalmanrud river was as follows: Pb (17.29)>Ni (6.24)>Cu (5.92)>As (5.08)>Cr (2.06)>Zn (1.05), respectively. Also, the RI findings concerning the values obtained (less than 150) for the Shalmanrud river sediments showed that heavy metals' environmental risk

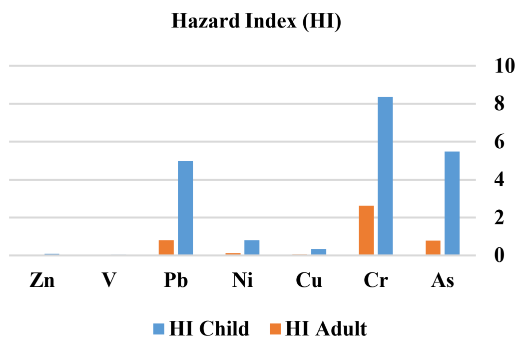

Figure 8. Cumulative non-carcinogenic risk of all heavy metal uptake pathways of Shalmanrud river sediments separately for adults and children

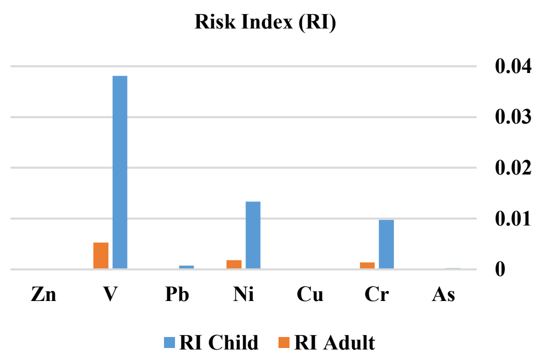

Figure 9. Risk of carcinogenicity of heavy metals in the sediments of the Shalmanrud River separately for adults and children

is low. According to the US Environmental Protection Agency, if the non-carcinogenic (HQ) risk of heavy metals is greater than one in each pathway, the toxicity of that element may have adverse impacts on human health [28]. In this study, Cr (children and adults), As (children), and Pb (children) in the swallowing pathway, and Cr (adults) in the respiratory pathway have such conditions. Considering that the amount of HQ in the swallowing pathway was higher than HQ in the respiratory and skin uptake pathways for all metals, the most important pathway for heavy metal exposure for children and adults is the swallowing pathway, which has been confirmed by Li et al. [29] and Qing et al. [30]. Yin et al. [31] showed that Cd contamination in river sediments is primarily derived from sewage purification and outflow based on the direction of river flow and the geochemical behaviors of the Cd isotope in nature.

This study further confirmed that Cd isotopes analysis could be a powerful tool for tracking the origin and destination of environmental Cd for multiple sources with similar Cd concentrations. Emenike et al. [9] found that according to the risk factor of certain metals through swallowing, the risks are as follows: Co >> As >> Pb> Cr> Cd> Al> Ni> Cu> Zn> Fe in both seasons, respectively. Furthermore, the risk of carcinogenicity for children through swallowing exceeded the safe range of As, Cd, Cr, and Ni in both seasons.

This result indicates the need for immediate measure to restore environmental quality to communities around the Atuwara river. In this study, it was found that the highest non-carcinogenic risk of total pathways (HI) in both children and adults is related to Cr, and the lowest is related to V. In this study, cumulative non-carcinogenic (HI) risk of Cr metals (adults and children) was more than one for Pb (children) and As (children). These values are very large and dangerous that have harmful outcomes, especially for children. In the present study, it was found that the risk of carcinogenicity in children is higher than in adults, which is consistent with the results of Qing et al. [30]. In general, according to the US Environmental Protection Agency standard, the risk is negligible if RI is less than 1×10-6 (one in a million people), while the RI is more than 1×10-4 and is unauthorized and dangerous to human health. The risk of carcinogenicity between the range of 1×10-6 and 1×10-4 indicates the acceptable risk under the conditions of control and supervision [32, 33]. In this study, the RI of V, Ni, and Cr in adults and children was above the critical level of 1×10-4.

5. Conclusion

Since many people live along the Shalmanrud river (Amlash, Shalman, and surrounding villages) and on the other hand, the water of this river is also used in agriculture, which can be imported to agricultural products, mainly rice, in the present study, the concentrations of heavy metals of As, Cr, Cu, Ni, Pb, V and Zn in the sediments of the Shalmanrud river were studied. In the end, the results showed that the highest and lowest concentrations for metals were obtained in terms of mg/kg dry weight, respectively. Comparison of metal concentrations in the studied sediments with the mean of global shale showed that the concentrations obtained were much higher for all metals except for As metal, which indicates that the sediments of Shalmanrud river are enriched with heavy metals due to the geological units of the area, which consist of alkaline rocks to the middle. High values of the mean of Igeo, EF, CF, and ER of Pb, Ni, and Cu metals due to the impact of geogenic activities more than anthropogenic activities indicate the concentration of these metals in the sediments of the Shalmanrud river in the area. Compared to sediment quality, the mean concentration of all metals except As and Zn was higher than TEC, and only Ni metal was higher than PEC. Therefore, the concentration of metals other than As and Zn is at the border of contamination, and Ni metal is in the state of contamination and can negatively impact biological communities, especially benthic animals. The study of ecological risk and environmental risk of heavy metals showed that all the studied samples are in the low-risk category in terms of ecological risk of heavy metals. Also, the findings of the environmental risk index of heavy metals showed that according to the obtained values, the environmental risk of the studied heavy metals in the Shalmanrud River is low.

The assessment results of the health risks of heavy metals in Shalmanrud sediments show that the risk of non-carcinogenicity of all pathways (HI) and the carcinogenic risk of these metals poses a serious threat to the health of children and adults. The results showed that the potential risk of cancer and non-cancer in children is higher than adults and by estimating the risk of total carcinogenicity (HI) of Cr> As> Pb and carcinogenic risk of metals V> Ni> Cr, respectively, are unauthorized in the study area and are hazardous to the health of residents.

Ethical Considerations

Compliance with ethical guidelines

All ethical principles are considered in this article. The participants were informed of the purpose of the research and its implementation stages. They were also assured about the confidentiality of their information and were free to leave the study whenever they wished, and if desired, the research results would be available to them.

A written consent has been obtained from the subjects. principles of the Helsinki Convention was also observed.

Funding

This research did not receive any grant from funding agencies in the public, commercial, or non-profit sectors.

Authors' contributions

Conceptualization and Supervision:Fariba Asghari and Mojgan Salavati; Methodology: Saeid Hakimi Asiabar; Investigation, Writing – original draft, and Writing – review & editing: All authors; Data collection: Mojgan salavati and Fariba Asghari; Data analysis: Fatemeh Shariati and Saeid Hakimi Asiabar; Funding acquisition and Resources: Fariba Asghari

Conflict of interest

The authors declared no conflict of interests.

Acknowledgments

The Vice-Chancellor for Research of the Islamic Azad University, Lahijan Branch, is appreciated.

References

[1] Xiao L, Liu J, Ge J. Dynamic game in agriculture and industry cross-sectoral water pollution governance in developing countries. Agricultural Water Management. 2021; 243:106417. [DOI:10.1016/j.agwat.2020.106417]

[2] Mullineaux ST, McKinley JM, Marks NJ, Scantlebury DM, Doherty R. Heavy metal (PTE) ecotoxicology, data review: Traditional vs. a compositional approach. Science of the Total Environment. 2021; 769:145246. [DOI:10.1016/j.scitotenv.2021.145246] [PMID]

[3] Tao C, Song Y, Chen Z, Zhao W, Ji J, Shen N, et al. Geological load and health risk of heavy metals uptake by tea from soil: What are the significant influencing factors? Catena. 2021; 204:105419. [DOI:10.1016/j.catena.2021.105419]

[4] Stewart BW, Wild CP. World Cancer Report 2014. Geneva: International Agency for Research on Cancer; 2014. https://books.google.com/books?id=OQHbngEACAAJ&dq

[5] Suvarapu LN, Baek SO. Determination of heavy metals in the ambient atmosphere. Toxicology and Industrial Health. 2017; 33(1):79-96. [DOI:10.1177/0748233716654827] [PMID]

[6] Mishra S, Bharagava RN, More N, Yadav A, Zainith S, Mani S, et al. Heavy metal contamination: An alarming threat to environment and human health. In: Sobti RC, Arora NK, Kothari R, editors. Environmental Biotechnology: For Sustainable Future. New York: Springer; 2019. pp. 103-125. [DOI:10.1007/978-981-10-7284-0_5]

[7] Rai PK, Lee SS, Zhang M, Tsang YF, Kim KH. Heavy metals in food crops: Health risks, fate, mechanisms, and management. Environment International. 2019; 125:365-85. [DOI:10.1016/j.envint.2019.01.067] [PMID]

[8] Nematollahi MJ, Keshavarzi B, Moore F, Vogt RD, Saravi HN. Trace elements in the shoreline and seabed sediments of the southern Caspian Sea: Investigation of contamination level, distribution, ecological and human health risks, and elemental partition coefficient. Environmental Science and Pollution Research. 2021; 28(43):60857-80. [DOI:10.1007/s11356-021-14678-9] [PMID]

[9] Emenike PC, Tenebe IT, Neris JB, Omole DO, Afolayan O, Okeke CU, et al. An integrated assessment of land-use change impact, seasonal variation of pollution indices and human health risk of selected toxic elements in sediments of River Atuwara, Nigeria. Environmental Pollution. 2020; 265(Pt B):114795. [DOI:10.1016/j.envpol.2020.114795] [PMID]

[10] Al-Taani AA, Batayneh AT, El-Radaideh N, Ghrefat H, Zumlot T, Al-Rawabdeh AM, et al. Spatial distribution and pollution assessment of trace metals in surface sediments of Ziqlab Reservoir, Jordan. Environmental Monitoring and Assessment. 2015; 187(2):32. [DOI:10.1007/s10661-015-4289-9] [PMID]

[11] Nagajyoti PC, Lee KD, Sreekanth TVM. Heavy metals, occurrence and toxicity for plants: A review. Environmental Chemistry Letters. 2010; 8(3):199-216. [DOI:10.1007/s10311-010-0297-8]

[12] Zhang L, Liao Q, Shao S, Zhang N, Shen Q, Liu C. Heavy metal pollution, fractionation, and potential ecological risks in sediments from Lake Chaohu (Eastern China) and the surrounding rivers. International Journal of Environmental Research and Public Health. 2015; 12(11):14115-31. [DOI:10.3390/ijerph121114115] [PMID] [PMCID]

[13] Veerasingam S, Venkatachalapathy R, Ramkumar T. Historical environmental pollution trend and ecological risk assessment of trace metals in marine sediments off Adyar estuary, Bay of Bengal, India. Environmental Earth Sciences. 2014; 71(9):3963-75. [DOI:10.1007/s12665-013-2781-5]

[14] Arias Almeida JC, Ramrez Restrepo JJ. Caracterización preliminar de los sedimentos de un embalse tropical: Represa La Fe (El Retiro, Antioquia, Colombia). Limnetica. 2009; 28(1):65-78. [DOI:10.23818/limn.28.05]

[15] Muller G. Index of geoaccumulation in sediments of the Rhine River. Geojournal. 1969; 2:108-18. https://scholar.google.com/scholar?q=Index+of+geoaccumulation+in=0,5

[16] Li Y, Zhou H, Gao B, Xu D. Improved enrichment factor model for correcting and predicting the evaluation of heavy metals in sediments. Science of the Total Environment. 2021; 755(Pt 1):142437. [DOI:10.1016/j.scitotenv.2020.142437] [PMID]

[17] Magni LF, Castro LN, Rendina AE. Evaluation of heavy metal contamination levels in river sediments and their risk to human health in urban areas: A case study in the Matanza-Riachuelo Basin, Argentina. Environmental Research. 2021; 197:110979. [DOI:10.1016/j.envres.2021.110979] [PMID]

[18] Zhang J, Shi Q, Fan S, Zhang Y, Zhang M, Zhang J. Distinction between Cr and other heavy-metal-resistant bacteria involved in C/N cycling in contaminated soils of copper producing sites. Journal of Hazardous Materials. 2021; 402:123454. [DOI:10.1016/j.jhazmat.2020.123454] [PMID]

[19] Hakanson L. An ecological risk index for aquatic pollution control. A sedimentological approach. Water Research. 1980; 14(8):975-1001. [DOI:10.1016/0043-1354(80)90143-8]

[20] Wang J, Liu W, Yang R, Zhang L, Ma J. Assessment of the potential ecological risk of heavy metals in reclaimed soils at an opencast coal mine. Disaster Advances. 2013; 6(S3):366-77. https://www1.cugb.edu.cn/uploadCms/file/20600/papers_upload/276.pdf

[21] Yi Y, Yang Z, Zhang S. Ecological risk assessment of heavy metals in sediment and human health risk assessment of heavy metals in fishes in the middle and lower reaches of the Yangtze River basin. Environ Pollution. 2011; 159(10):2575-85. [DOI:10.1016/j.envpol.2011.06.011] [PMID]

[22] EPA Publications Bibliography: Quarterly Abstract Bulletin. United States. U.S. Environmental Protection Agency; 1997. https://www.google.com/books/edition/EPA_Publications_Bibliography/VHguAAAAMAAJ?hl=en&gbpv=0

[23] Gupta N, Yadav KK, Kumar V, Krishnan S, Kumar S, Nejad ZD, et al. Evaluating heavy metals contamination in soil and vegetables in the region of North India: Levels, transfer and potential human health risk analysis. Environmental Toxicology and Pharmacology. 2021; 82:103563. [DOI:10.1016/j.etap.2020.103563] [PMID]

[24] Thongyuan S, Khantamoon T, Aendo P, Binot A, Tulayakul P. Ecological and health risk assessment, carcinogenic and non-carcinogenic effects of heavy metals contamination in the soil from municipal solid waste landfill in Central, Thailand. Human and Ecological Risk Assessment: An International Journal. 2021; 27(4):876-97. [DOI:10.1080/10807039.2020.1786666]

[25] Wu H, Xu C, Wang J, Xiang Y, Ren M, Qie H, et al. Health risk assessment based on source identification of heavy metals: A case study of Beiyun River, China. Ecotoxicology and Environmental Safety. 2021; 213:112046. [DOI:10.1016/j.ecoenv.2021.112046] [PMID]

[26] Meybeck MICHEL. Heavy metal contamination in rivers across the globe: An indicator of complex interactions between societies and catchments. Understanding Freshwater Quality Problems in a Changing World. 2013; 361:3-16. https://scholar.google.com/scholar?hl=en&as_sdt=0%2C5&qbtnG=

[27] Mohiuddin KM, Zakir HM, Otomo K, Sharmin S, Shikazono N. Geochemical distribution of trace metal pollutants in water and sediments of downstream of an urban river. International Journal of Environmental Science & Technology. 2010; 7(1):17-28. [DOI:10.1007/BF03326113]

[28] Li Z, Ma Z, van der Kuijp TJ, Yuan Z, Huang L. A review of soil heavy metal pollution from mines in China: Pollution and health risk assessment. Science of the Total Environment. 2014; 468-469:843-53. [DOI:10.1016/j.scitotenv.2013.08.090] [PMID]

[29] Li N, Kang Y, Pan W, Zeng L, Zhang Q, Luo J. Concentration and transportation of heavy metals in vegetables and risk assessment of human exposure to bioaccessible heavy metals in soil near a waste-incinerator site, South China. Science of the Total Environment. 2015; 521-522:144-51. [DOI:10.1016/j.scitotenv.2015.03.081] [PMID]

[30] Qing X, Yutong Z, Shenggao L. Assessment of heavy metal pollution and human health risk in urban soils of steel industrial city (Anshan), Liaoning, Northeast China. Ecotoxicology and Environmental Safety. 2015; 120:377-85. [DOI:10.1016/j.ecoenv.2015.06.019] [PMID]

[31] Yin X, Wei R, Chen H, Zhu C, Liu, Y, Wen H, Ma J. Cadmium isotope constraints on heavy metal sources in a riverine system impacted by multiple anthropogenic activities. Science of the Total Environment. 2021; 750:141233. [DOI:10.1016/j.scitotenv.2020.141233] [PMID]

[32] Wei X, Gao B, Wang P, Zhou H, Lu J. Pollution characteristics and health risk assessment of heavy metals in street dusts from different functional areas in Beijing, China. Ecotoxicology and Environmental Safety. 2015; 112:186-92. [DOI:10.1016/j.ecoenv.2014.11.005] [PMID]

[33] Hu X, Zhang Y, Ding Z, Wang T, Lian H, Sun Y, et al. Bioaccessibility and health risk of arsenic and heavy metals (Cd, Co, Cr, Cu, Ni, Pb, Zn and Mn) in TSP and PM2.5 in Nanjing, China. Atmospheric Environment. 2012; 57:146-52. [DOI:10.1016/j.atmosenv.2012.04.056]