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Examination of Concentrations of Five Heavy Metals in Soils Surrounding Sangan Iron Ore Mines and Impact on Human Health

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Abstract

The Heavy Metal (HM) contamination in surface soils poses significant environmental and health concerns near the mining operations. This study examined the concentrations and health risks of the five HMs lead (Pb), nickel (Ni), copper (Cu), arsenic (As), and iron (Fe) in soils surrounding the Sangan iron ore mines in eastern Iran. Sixty soil samples were collected at depths of 0-20 cm from sites adjacent to the mining area and one control site. The HM concentrations were compared to the global shale values. Soil contamination was quantified using the geo-accumulation index (Igeo). Health risks to the local residents were assessed using the US Environmental Protection Agency's Human Health Risk Evaluation Index. The analysis revealed that the lead concentrations near the mine exceeded the global shale standards, while the arsenic levels remained marginally below permissible limits established by global soil standards. The Igeo values indicated low to moderate the contamination levels for both Pb and As in the mining-adjacent areas. The risk assessment results showed that non-carcinogenic risk indices were within acceptable limits for both children and adults. However, arsenic posed a significant carcinogenic risk to adults through two exposure pathways: ingestion (3.36E-04) and dermal absorption (1.36E-04). These findings highlight the importance of implementing regular monitoring protocols for potentially hazardous elements in the mining region to prevent and mitigate pollution-related health risks.

1. Introduction

Mining is both a major driver of economic development and a significant source of environmental pollution with Heavy Metals (HMs) [1]. Mining plays a vital role in mineral production, but uncontrolled mining practices can pose health risks to the public and cause environmental problems [2, 3]. Given the ubiquitous and non-biodegradable nature of HMs; the negative effects persist for several decades or even longer [3]. HMs have toxic, long-lasting, and have accumulative properties, due to which, they could pose a serious threat to the plant, animal, and human health [4, 5]. While some HMs are essential for biological processes in trace amounts, excessive concentrations can be harmful to both the humans and the environment [6, 7, 8].

In the recent decades, contamination of soils with HMs near mining areas has become a global issue [9]. The soil HM pollution is difficult to tackle owing to its gradual nature, long-term persistence, and irreversibility [10, 11]. Consequently, HMs accumulate in the soil, and can enter the human body through various pathways such as ingestion, inhalation, dermal contact, and ingestion of foods grown in contaminated soil [3, 6, 7]. HMs may then induce various diseases; for example, increased blood pressure and cardiovascular problems due to lead exposure [12], kidney and brain damage from copper exposure [13, 14], liver disfunction, and respiratory diseases caused by iron exposure [15, 16], sensitivity and cardiac failure due to nickel exposure [17], and various health issues including birth defects,

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anemia, and decreased white blood cell count resulting from arsenic poisoning [18, 19]. There is also evidence that chronic exposure to low doses of carcinogenic HMs may cause many types of cancer [20, 21]. In general, the first step in assessing the extent and intensity of HM pollution in the soil around mines is to determine their concentrations [22]. Many researchers have conducted research on the HM pollution in different mining regions and the surrounding soils. Studies in Africa [4, 23 ,24], India [25], Iran [26, 27, 28], Mexico [29], and China [30, 31] have shown that the areas surrounding mines are often polluted by HMs originating from mining operations. Subsequently, health risk assessments can be conducted to evaluate the potential health effects of these elements in terms of cancerous and non-cancerous diseases [27].

In addition, the studies conducted in various mines in Iran showed that in the Zanjan province, both children and adults were subject to non-carcinogenic hazards, with children experiencing notably elevated risks. The chief pathways for exposure to HMs and the ensuing non-carcinogenic risks encompassed ingestion, inhalation, and dermal contact [3]. A study in the Qom province showed that the topsoil concentration of Mn, Cu, and Pb around the Venarj mine were increased due to the mining activities. The most negative environmental and health effects resulted from the higher concentration of Pb in the soil [4]. The results of the evaluation of six HMs (Cd, Mn, Cu, Fe, Pb, and Zn) in 102 soil samples conducted in the Kushk Pb-Zn mine in Bafq showed that geological activities were the most important sources of zinc, lead, and cadmium contamination. Iron, copper, and manganese were mainly controlled by geological sources and parent materials, and manganese concentrations were affected by fertilizers and agricultural soils [5]. In Sajzi plain of Isfahan, cadmium and lead showed a very low contamination level, and zinc showed a low contamination level. Also the ecological risk index was in the low-risk range for cadmium, lead, and copper. The environmental risk index for the three elements was less than 150, which showed a low-risk potential [6].

Health-risk assessment serves as an efficient method for assessing the potential negative health effects due to environmental hazards. Several methods have been proposed to estimate the risks posed by pollutants on the human health including assessment of cancer risk and non-cancerous disease risk [31, 32]. In recent years, the assessment of human health risks associated with HM contamination, particularly in soils of mining and industrial areas, has gained significant attention due to the carcinogenic and non-carcinogenic effects of these elements [17], [20], and [33]. Saha et al. [29] measured the concentrations of As, Cu, Fe, Mn, Pb, and Zn in the surface soil in Matehuala, Mexico. The mean concentrations were higher than the soil environmental quality standards of Mexico. As and Fe were found to pose considerable and moderate ecological risks, respectively. Health-risk evaluation indicated significant levels of carcinogenic risks for both adults and children, with higher risks for children. The study also showed that the main exposure pathways of As are ingestion and inhalation of soil particles. Li et al. [20] found that the concentrations of Ni, As, Cu, and Pb in the soil near an asbestos mine in China exceeded the soil threshold values. The results indicated higher ecological risks of HMs near the mine, as well as carcinogenic risks for children and adults. In another study in northwest Iran [3], the potential ecological risk of HMs in soil was considerable; both age groups (children and adults) were subject to non-carcinogenic hazards, with children encountering notably elevated risks. The study found that As posed carcinogenic risk to adults through ingestion and dermal contact. Any HM can be harmful, even at very low concentrations and short exposure times [3, 6]. It follows that the necessary protective measures need to be taken to reduce exposure and minimize the risk of exposure. The extensive mining industry in Iran has raised concerns about the negative environmental impacts of these activities, and their consequences for human health [34].

Notably, the Sangan iron ore mines in the Khaf county, eastern Iran, are among the largest mining operations in the region. Iron ore extraction and mining operations contribute to the release of HMs including As, Cu, Ni, Pb, and Fe into the environment; thus we studied the soil concentrations of these metals. In this region, mining operations, coupled with the geological composition of the region, have resulted in geomorphological disturbances, and increased potential for soil and water pollution [9]. Moreover, mining waste and the deposition of airborne particles in the vicinity of crushers and machinery contributes to the dispersion of pollutants. Smaller particles are particularly prone to dispersal by prevalent winds such as the 120-day Sistan winds, and pose a significant threat to soils and public health [34]. This necessitates urgent research to assess the concentration of HMs including Pb, As, Fe, Cu, and Ni in the soil and to evaluate the associated health risks, while considering different exposure pathways such as ingestion, inhalation, and dermal absorption for both adults and children in the areas surrounding the Sangan iron ore mine in eastern Iran.

2. Materials and Methods

2.1. Studied area

The Sangan iron ore mine is situated in eastern Iran, with geographical coordinates of 60°22'28" east and 34°27'22" north. This iron ore deposit is renowned for its grade of 54% [35], low phosphorus content, and vast reserve of iron, making it one of the most important iron mines in eastern Iran [28, 36]. The deposit originated from volcanic intrusions in the Khaf-Kashmar-Bardskan belt. It mainly consists of magnetite, along with other iron ores such as hematite, limonite, and goethite, as well as sulfur minerals including pyrite, chalcopyrite, marcasite, and pyrrhotite [37]. The dominant wind pattern in the region is the 120-day Sistan winds blowing from the northeast to the southwest, leading to dusty conditions on many days, particularly in spring and autumn. Figure 1 illustrates the geographical location of the studied area and sampling points.

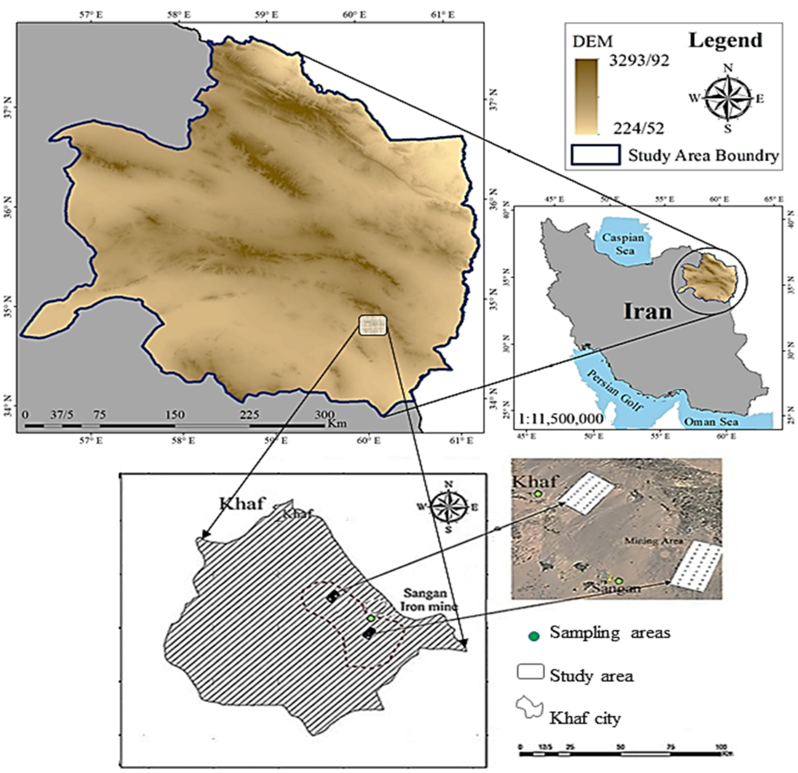

Figure 1. Geographical location of the studied area and sampling points.

2.2. Sampling and soil analysis

Samples of surface soil were systematically collected at sixty sampling sites in undisturbed rangelands (locations with minimal disturbance by human activities), covering 20 km^2. The sampling sites were selected using a grid pattern with a distance of 500 m between sites, and the sampling depth ranged from 0 to 20 cm [7, 22]. The remaining thirty samples were obtained from the control area within a 10 km^2 area situated approximately 35 km away from the mines. The selection of these locations was based on the prevailing winds in the studied area, which blow from the northeast to the southwest. The sampling strategy aimed to cover a large portion of the studied area to capture the variability of the soils in the region. The samples were collected and stored in labeled re-sealable plastic bags, with each bag containing approximately 1 kg of soil. The samples were then numbered for identification before further analysis. Subsequently, the samples were transported to the central laboratory of Ferdowsi University of Mashhad for analysis. In the laboratory, each soil sample was dried at room temperature, powdered, and sieved through a 2 mm sieve to ensure a consistent particle size. The samples were digested using the aqua regia method according to ISO-11466 [38]. Aqua regia was prepared by mixing nitric acid (HNO_3) with hydrochloric acid (HCl) in a 1:3 ratios. This method is a standard approach in environmental soil studies, taking into account factors such as extraction efficiency, acid consumption, equipment requirements, and ease of digestion [39]. To measure the levels of HMs in the samples, a plasma-optical sensing spectrometer (ICP-OES, SPECTRO ARCOS-76004555) was utilized. Inductively coupled plasma-optical emission spectrometry (ICP-OES) can measure the concentration of elements in the solid samples. In this technique, electrons of different elements are excited in a plasma environment and emit light, allowing for highly accurate and precise measurement of metal concentrations [8, 40]. Throughout the study, the concentrations of all metals were expressed as milligrams per kilogram (mg/kg) based on dry weight.

2.3. Data analysis

To assess the levels of HMs in the mining and control areas, the concentrations of HMs were compared with the average concentrations found in the World Average Shale (WAS) [41]. Due to the long history of industrialization in the area, obtaining base or background concentrations at lower depths was not feasible. The extent of HM pollution was evaluated using the geo-accumulation index (I_{geo}). This index, developed by Muller (1969) [42], is widely utilized in studies of soil contamination by HMs [17, 20, 22]. I_{geo} is a useful tool for evaluating the accumulation of HMs in soil, as it helps distinguish natural fluctuations from changes caused by the human activities. I_{geo} provides insights into the HM pollution in the environment [42]. This index is derived as follows:

$$I_{geo} = \log_2[C_n/(1.5 \times B_n)] \tag{1}$$

where, C_n refers to the concentration of metal n in the sample, and B_n represents the geochemical background concentration of the metal. The WAS values were adopted as the background values as follows: Fe = 47200, Ni = 68, Pb = 20, Cu = 45, and As = 13 mg/kg, according to Turekian and Wedepohl (1961) [41]. The factor 1.5 represents possible differences in the background concentrations and minor anthropogenic influences [42]. Table 1 provides the classification of pollution levels from A to G based on I_{geo} [43].

Table 1. Classification of pollution level-based Igeo [43].

Value	$I_{geo} \leq 0$	$0 < I_{geo} \leq 1$	$1 < I_{geo} \leq 2$	$2 < I_{geo} \leq 3$	$3 < I_{geo} \leq 4$	$4 < I_{geo} \leq 5$	$I_{geo} > 5$
Classification of the amount of pollution	Unpolluted	Unpolluted to moderately polluted	Moderately polluted	Moderately to strongly polluted	Strongly polluted	Strongly to extremely polluted	Extremely polluted
Class	class 0	class 1	class 2	class 3	class 4	class 5	class 6
Code	A	B	C	D	E	F	G

2.4. Human health risk assessment

To evaluate potential health impacts on residents including both carcinogenic and non-carcinogenic effects, we applied the methodology outlined by the USEPA. This comprehensive evaluation examines exposure to toxic elements in surface soil through three primary pathways: oral consumption, skin exposure, and respiratory intake [44, 45, 46]. For non-carcinogenic health effects, we employed the Hazard Quotient (HQ). This value is computed by taking the Average Daily Dose (ADD), measured in mg/kg/day, and dividing it by the reference dose (RFD)—a safety threshold indicating the maximum exposure level considered safe for human health. Equations 2-4 provide the formulas for calculating the ADD across all three exposure routes (ingestion, inhalation, and dermal contact), while Equation 5 shows how to derive the HQ value.

$$ADD_{ing\text{-}soil} = \frac{c \times INGR \times CF \times EF \times ED}{BW \times AT} \tag{2}$$

$$ADD_{inh\text{-}soil} = \frac{c \times INHR \times EF \times ED}{REF \times BW \times AT} \tag{3}$$

$$ADD_{dermal\text{-}soil} = \frac{c \times SA \times CF \times AF \times ABS \times EF \times ED}{BW \times AT} \tag{4}$$

$$HQ = \frac{ADD}{RFD} \tag{5}$$

Furthermore, the total Hazard Index (HI) was utilized to determine the overall hazard index for non-cancer diseases. HI is calculated using Eq. 6 by summing the HQ for all pathways (HQ_{ing}, HQ_{inh}, and HQ_{dermal}).

$$HI = \sum_{i:1}^{N} HQ = HQ_{ing} + HQ_{inh} + HQ_{dermal} \tag{6}$$

HQ < 1 or HI < 1 indicate that there is no likelihood of adverse health effects, even for sensitive groups. Conversely, values larger than 1 suggest potential adverse health effects [47, 48, 49]. Health risk can be evaluated using the values provided in Table 2.

Table 3 presents the RFD and Cancer Slope Factors (CSFs) for As, Cu, Ni, Pb, and Fe.

Table 2. Values of different parameters used in risk assessment.

Parameter	Definition (unit)	Values		Reference
		Children	Adults	
C	Concentration of heavy metal in soil (mg/kg)	-	-	-
IngR	Ingestion rate (mg/day)	200	100	[21], [50, 51]
InhR	Inhalation rate (m^3/day)	10	20	[21], [51]
PEF	Particle emission factor (m^3/kg)	$\times 10^9$	1.3×10^9	[22], [51]
SA	Exposed skin area (cm^2)	2100	5800	[51]
AF	Soil adherence factor (mg/cm^2)	0.2	0.07	[50, 51]
ABS	Dermal absorption factor (unit less)	0.1	0.1	[14], [51]
ED	Exposure duration (year)	6	30	[51]
EF	Exposure frequency (day/year)	350	350	[14], [50, 51]
BW	Average body weight (kg)	15	70	[27], [50, 51]
AT	Average time (day)			[23], [51]
	For carcinogens	365 × 70	365 × 70	
	For non-carcinogens	365 × ED	365 × ED	
CF	Conversion factor (kg/mg)	10^{-6}	10^{-6}	[46], [50, 51]

Table 3. RFD and CSF for As, Cu, Ni, Pb, and Fe [52, 53, 54].

Elements	RfD_{ing} (mg/kg-day)	RfD_{Dermal} (mg/kg-day)	RfD_{Inh} (mg/kg-day)	CSF_{ing} $(mg/kg\text{-}day)^{-1}$	CSF_{Dermal} $(mg/kg\text{-}day)^{-1}$	CSF_{Inh} $(mg/kg\text{-}day)^{-1}$
AS	3.00E-04	3.00E-04	3.00E-04	1.50E+00	1.50E+00	1.50E+01
Cu	3.700E-02	2.40E-02	-	-	-	-
Ni	2.00E-02	5.60E-03	-	-	-	-
Pb	3.60E-03	-	-	8.50E-03	-	4.20E-02
Fe	7.00E-1	-	-	-	-	-

Carcinogenesis risk (CR) represents the likelihood of any type of cancer developing during a person's life as a result of contact with pollutants, which can be calculated using Equations 7 and 8 [46]. CR < 1×10^{-6} indicates negligible risk, while larger values indicate higher risk and potential carcinogenesis in humans. CR values in the 1×10^{-6} to 1×10^{-4} range indicate moderate levels of risk that may be considered tolerable for human health.

$$\text{Risk (CR)} = \sum_{i:1}^{N} \text{ADD} \times \text{CSF} \tag{7}$$

$$\text{Total Risk} = \sum_{i:1}^{N} \text{RISK} = \text{RISK}_{ing} + \text{RISK}_{inh} + \text{RISK}_{dermal} \tag{8}$$

3. Results and Discussion

The concentrations of HMs in samples are presented in Table 4. The mean levels are also compared with their average concentrations in WAS [41].

Table 4. HM concentration in soil samples (mg/kg).

Elements	Mining area			Control area			Shale
	Minimum	Maximum	Mean	Minimum	Maximum	Mean	
As	9.4	18.9	12.7	7.6	9.9	8.5	13
Cu	18.3	46.4	25.5	11.5	21.3	15.9	45
Ni	19.1	49.3	34.5	17.5	40.7	32.1	68
Pb	21.9	95.7	48.6	13.1	24.5	16.9	20
Fe	29200	62400	38860	24400	37200	29110	47200

The area adjacent to the mine (experimental group) is located 5 kilometers from the Sangan mine, where magnetite is the dominant mineral. Due to its magnetic properties, magnetite disrupts the Earth's magnetic fields in the surrounding area. This region was selected based on expert opinion, local residents, and field observations to minimize errors in the pollutant concentration measurements. The average concentrations of HMs in soil samples near the mine are ranked as follows: arsenic < copper < nickel < lead < iron. A similar trend is observed in the control area. Given that the mine is an iron ore mine, the elevated iron concentrations in both areas are expected.

The average As, Cu, Ni, Pb, and Fe levels in the mining area were 12.7, 25.5, 34.5, 48.6, and 38860 mg/kg, respectively. In contrast, the control area exhibited the average concentrations of 8.5, 15.9, 32.1, 16.9, and 29110 mg/kg, respectively. The highest average concentration among the elements in the mining area was observed for Fe (38860 mg/kg), while the lowest concentration was found for As (12.7 mg/kg). In the control area, the highest average concentration belonged to Fe (29110 mg/kg), while the lowest concentration was recorded for As (8.5 mg/kg). Comparison with the WAS levels indicated that the concentration of Pb in the area close to the mines (48.6 mg/kg) surpassed the maximum standard for WAS (20 mg/kg). Moreover, the concentration of As in the mining area (12.7 mg/kg) was close to the permissible limit set by WAS (13 mg/kg). The concentrations of the other elements in both areas were below the maximum standard for WAS. As seen in Table 4, the mean levels of HMs in the soil samples from both areas followed the order As < Cu< Ni < Pb < Fe. Considering that the nearby mine in an iron ore mine, it is expected that the concentration of Fe would be relatively high in both areas. Figure 2 provides a visual comparison of HM concentrations in both areas, in relation to WAS.

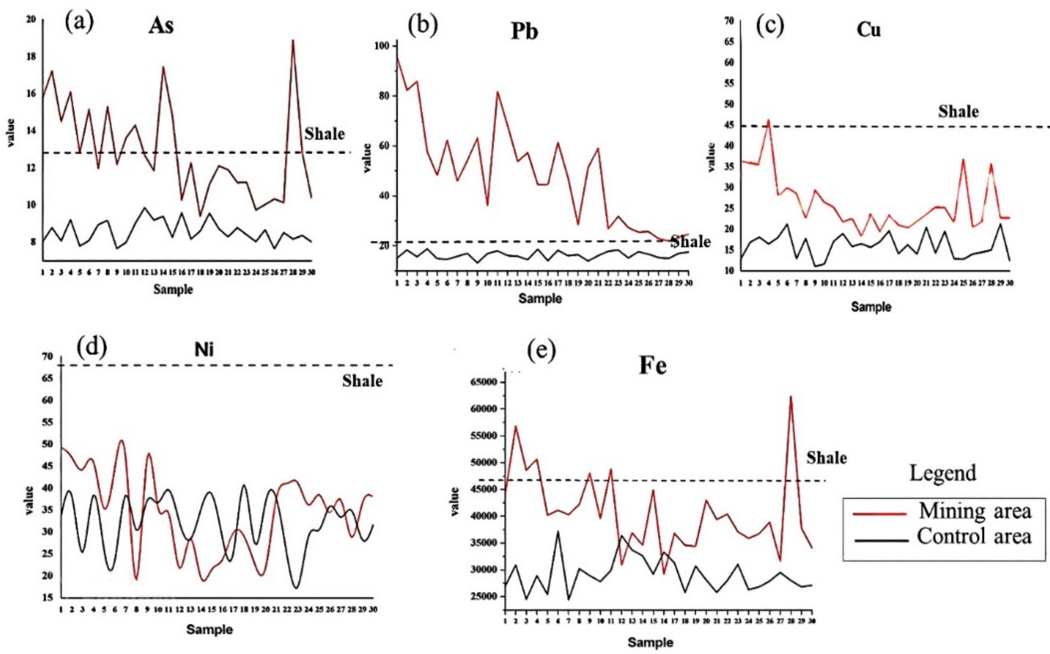

Figure 2. Comparison of concentrations in the mining and control area with WAS (mg/kg): (a) As; (b) Pb; (c) Cu; (d) Ni; (e) Fe.

In the nickel element diagram, all samples show lower concentrations than the global shale levels, and exhibit minimal fluctuations. The uniformity in nickel concentrations between the area adjacent to the mine and the control area can be attributed to the type of mineralization and the lack of its influence on increasing the nickel levels.

The area adjacent to the mines exhibits a higher concentration and pollution with arsenic compared to the control area (Figure 2a), particularly in sampling sites that are closer to the mines. This increase in concentration can be attributed to the mining activities, which are known to cause As pollution [9]. All samples from the mining area show higher Pb concentrations than WAS (Figure 2b). In contrast, the Pb concentration was lower than WAS in the control area, except for two samples. Figure 2b clearly highlights the intensity of the Pb concentration in the area near the mine, indicating potential contamination. Cu concentration in the mining area was higher compared to the control area (Figure 2c). With the exception of one sample from the mining area, all samples in both areas exhibit lower Cu concentrations than WAS. This suggests that the mining activities have influenced Cu concentration but have not exceeded the global average levels. All samples had Ni concentrations lower than the global average values (Figure 2d). The fluctuations in Ni concentrations are relatively small, indicating the low Ni content in local minerals [9, 10]. Given the predominance of iron minerals, higher soil concentrations of Fe are expected. Fig. 2e, displays the concentration of Fe at sampling sites, revealing higher concentrations at the sampling sites closer to the mines. The observed Fe contamination aligns with previous studies by [10], and [16]. These findings are consistent with previous research such as [34], which reported elevated Pb levels in the region due to mining and the associated activities. The study also found that the concentration of Ni was lower than the global average. Additionally, studies conducted in southern China by [31] and in a mining area in Armenia by [11] report the increased concentrations of Pb, Cu, and Fe, which were attributed to the mining activities, and were deemed hazardous to the human health.

A comparative study on water quality in India by [25] indicated that iron ore tailings commonly contain harmful elements such as Hg, Fe, Cu, Pb, and As. These findings are consistent with our observations, suggesting an increase in the HM concentrations, particularly Pb and As, near industrial and mining areas. In general, mining activities such as iron ore extraction has significant negative effects on soil and water quality [24, 15, 33].

3.1. Geo-accumulation index (I_{geo})

In this study, I_{geo} was employed to assess the accumulation of HMs in the mining and control areas. According to the classification of I_{geo}, samples from the mining area varied from unpolluted (code A) to moderately polluted (code C) for Pb and from unpolluted to moderately pollute for As (code B). Minimum soil accumulation (code A) was observed for the other elements in both areas.

The mean I_{geo} values for As, Cu, Ni, Pb, Fe in areas near the mine and the control area were 0.25, -1.43, -1.6, 1.85, -0.8, and -1.18, -2, -1.6, -0.8, -1.2, respectively. I_{geo} for Pb in the mining area, with an average value of 1.85, indicates a moderate degree of contamination. In the area adjacent to the mine, the average value of 0.25 for As suggests a low level of contamination. The geo-accumulation indices for As, Cu, Ni, Pb, and Fe in the control area indicate no contamination (Figure 3).

A study conducted by [9] around the Khaf iron ore mine reported an average I_{geo} of 0.6 for As and 0.12 for Fe, indicating moderate pollution (code B). Ni and Cu had average I_{geo} values of -0.82 and -1.25, respectively, indicating no pollution. However, the average I_{geo} value for Pb (-1.3) suggested no pollution, which differs from the results of this study. In a study conducted by [17] in southwestern China, the geo-accumulation index for Pb in the soil ranged from unpolluted (code A) to moderately polluted (code C). These results align with the results of the current study. Additionally, the I_{geo} index in Angoran mine in Iran showed high levels of As and Ni pollution, while no Cu pollution was detected [22]. They also observed that human activities, specifically mining, influenced the distribution and spread of these elements. This aligns with the impact of anthropogenic factors including mining on the increased concentration of HMs in the samples taken adjacent to the mine, leading to contamination and soil degradation. Overall, the use of the I_{geo} index in this study provides valuable insights into the contamination levels for different elements, and confirms the influence of mining activities on HM accumulation in the studied area.

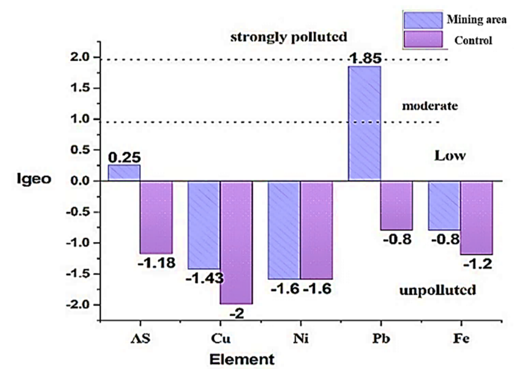

Figure 3. Average I_{geo} for samples from the mining and control areas.

3.2. Non-carcinogenic risk of HMs

The extent of risk from HMs directly correlates with their quantity consumed daily [51]. We calculated ADD to evaluate non-cancer health impacts among both child and adult populations, examining soil samples from mining-adjacent areas through three exposure routes: ingestion, inhalation, and skin contact. Since the control region showed no HM contamination, risk calculations were omitted for those samples. Table 5 displays the calculated the ADD figures for both age groups. Among adults, iron showed the highest ADD value, with nickel, lead, copper, and arsenic following in the descending order. The results for children revealed iron and lead to be at the highest levels, followed by nickel, copper, and arsenic. This data suggests that exposure to contaminated soil containing these five heavy metals poses health concerns for both demographic groups. The notably elevated ADD values for iron across both populations indicates that this particular metal might contribute most significantly to the overall health implications of HM exposure.

Table 5. ADD values for non-cancerous disease risk for adults and children in the mining area.

Absorption Pathways	ADD (mg/kg/day)									
	Adults					Children				
	As	Cu	Ni	Pb	Fe	As	Cu	Ni	Pb	Fe
Ingestion (ADD_{ing})	1.74E-05	3.50E-05	4.74E-05	6.66E-05	5.32E-02	1.63E-04	3.27E-04	4.42E-04	6.22E-04	4.97E-01
Inhalation (ADD_{inh})	2.68E-09	2.44E-09	7.29E-09	1.03E-08	8.19E-06	6.25E-09	1.26E-08	1.70E-08	2.397E-08	1.91E-05
Dermal (Add_{dermal})	7.07E-06	1.42E-05	1.92E-05	2.70E-05	2.16E-02	3.41E-05	6.85E-05	9.28E-05	1.31E-04	1.04E-01
Total	2.45E-05	4.92E-05	6.66E-05	5.56E-05	7.48E-02	1.97E-04	3.96E-04	5.35E-04	7.53E-04	6.01E-01

HQ and HI for the samples taken from the mining area are presented in Table 6. The HQ and HI values below 1 do not indicate a health risk, while greater values indicate non-carcinogenic health risk [42]. HQ and HI for all five HMs were below 1 for both children and adults, indicating no risk of non-cancerous diseases (Table 6). However, the HQ values for Pb and Fe via ingestion and the HQ values for As via ingestion and dermal absorption were close to 1, which indicates that these HMs were likely to expose children and adults to health hazards in the future. Overall, the ingestion pathway posed the greatest risk, followed by dermal absorption and inhalation (HQ_{ing} > HQ_{derm} > HQ_{inh}) for all HMs in the studied area.

Figure 4 presents HI values for adults and children. Pb, As, and Fe represented the greatest non-carcinogenic risk for children. The greatest non-carcinogenic risk to adults was posed by As, followed by Fe, Pb, Ni, and Cu. The greatest non-carcinogenic risk to children was presented by Fe, followed by As, Pb, Ni, and Cu.

Table 6. HQ and HI for adults and children based on soil samples taken from the mining area.

Absorption Pathways	Hazard Quotient (HQ)									
	Adults					Children				
	As	Cu	Ni	Pb	Fe	As	Cu	Ni	Pb	Fe
Ingestion	5.80E-02	9.46E-04	2.37E-03	1.85E-02	7.60E-02	5.42E-01	8.83E-03	2.21E-02	1.73E-01	7.00E-01
Inhalation	8.93E-06	-	-	-	-	2.08E-05	-	-	-	-
Dermal	2.36E-02	5.92E-04	3.43E-03	-	-	1.14E-01	2.86E-03	1.66E-02	-	-
HI	8.16E-02	1.54E-03	5.80E-03	1.85E-02	7.60E-02	6.56E-01	1.17E-02	3.87E-02	1.73E-01	7.00E-01

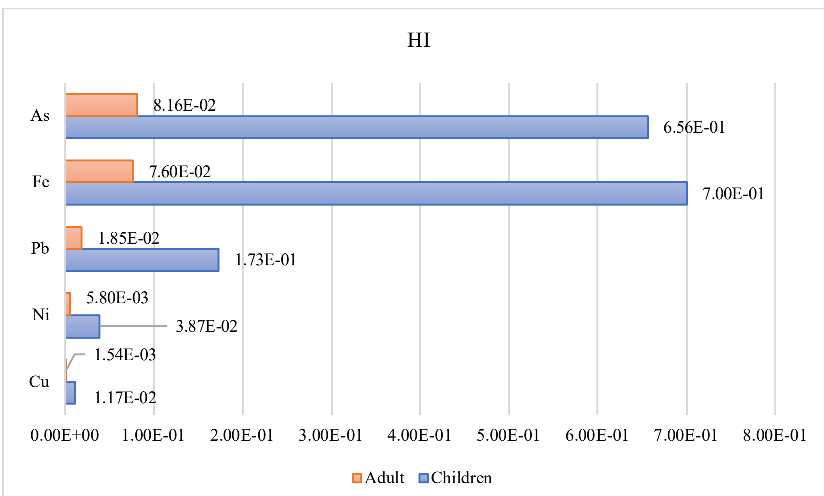

Figure 4. HI for adults and children.

3.3. Non-carcinogenic risk of HMs

ADD values for Fe, Ni, Pb, Cu, and As were calculated according to Table 2 based on three absorption pathways (ingestion, inhalation and dermal absorption). Table 7 provides the ADD for adults and children in mg/kg/day.

Table 8 presents the CR for As and Pb. The CR values in the 1×10^{-6}-1×10^{-4} range are acceptable for human health [51]. Based on the results, the CR for As exposure is higher than the acceptable limit through ingestion (CR = 3.36 × 10^{-4}) and dermal absorption (CR = 1.36 × 10^{-4}), indicating high risk of cancer as a result of exposure. Adults do not face any health risks from Pb exposure through ingestion (CR = 2.43×10^{-7}), inhalation (CR = 1.85×10^{-10}), or dermal absorption as the CR values were below the threshold. CR for children was below the threshold for all HMs.

Table 7. ADD values for carcinogenic risk for adults and children based on soil samples taken from the mining area.

Absorption Pathways	ADD (mg/kg/day)									
	Adults					Children				
	As	Cu	Ni	Pb	Fe	As	Cu	Ni	Pb	Fe
Ingestion (ADD_{ing})	7.46E-06	1.50E-05	2.03E-05	2.86E-05	2.28E-02	1.39E-05	2.80E-05	3.79E-05	5.33E-05	4.26E-02
Inhalation (ADD_{inh})	1.15E-09	2.31E-09	3.12E-09	4.39E-09	3.51E-06	5.36E-10	1.08E-09	1.46E-09	2.05E-09	1.64E-06
Dermal (Add_{dermal})	3.03E-06	6.09E-06	8.24E-06	1.15E-05	9.26E-03	3.90E-06	5.87E-06	7.96E-06	1.12E-05	8.94E-03
Total	1.05E-05	2.11E-05	2.85E-05	4.01E-05	3.21E-02	1.78E-05	3.39E-05	4.59E-05	6.45E-05	5.15E-02

Table 8. CR for adults and children based on the soil samples taken from the mining area.

Absorption Pathways	**CR**									
	Adults					**Children**				
	As	**Cu**	**Ni**	**Pb**	**Fe**	**As**	**Cu**	**Ni**	**Pb**	**Fe**
Ingestion	3.36E-04	-	-	2.43E-07	-	2.09E-05	-	-	4.53E-07	-
Inhalation	5.17E-07	-	-	1.85E-10	-	8.04E-09	-	-	8.61E-11	-
Dermal	1.36E-04	-	-	-	-	4.39E-06	-	-	-	-
Total Risk	4.73E-04	-	-	2.43E-07	-	2.53E-05	-	-	4.53E-07	-

The CR for As was 4.13×10^{-9} in the study by [30], which indicated acceptable concentrations (1×10^{-6} < CR < 1×10^{-4}) for the human health. They also found the CR for all elements to be within the acceptable range, in contrast to the present study. In another study in southwest China, non-carcinogenic disease risk was significant for children (HI > 1), but not for adults (HI < 1) [17]. The risk of cancerous diseases associated with iron ore mining was reported to be acceptable for children and adults. Moreover, their findings indicated that the HM contamination of soil presents a threat to the health of the humans and the environment. Another study reported an acceptable carcinogenic risk for children and adults [31]. The researchers found that the mining industry poses the greatest health risk through non-cancerous diseases, and that the carcinogenic risk is mainly due to the impact of the As produced during long-term production and transportation activities in the mining industry. Our findings do not agree with the results obtained by [31]. Based on the present study, the non-carcinogenic risk for children and adults was acceptable, but As posed carcinogenic risk to adults through ingestion and dermal contact. In a study in southern Iran, children faced greater non-carcinogenic risk than adults for all selected elements through ingestion, inhalation, and dermal absorption [27].

A study conducted on a mining area in Armenia [11] found that the risk of non-carcinogenic diseases caused by Pb was greater than 1 for adults (HQ/HI > 1); and that Fe, Cu, and Pb posed a significant risk to children. The study conducted by [47] in China reports similar results for As. Children are more at risk than adults as they tend to eat non-food items, suck on their fingers, and have poor awareness of hygiene in outdoor environments [27, 44, 47].

In general, children are more sensitive to the non-carcinogenic health risks. A study in northeastern Iran showed that the non-carcinogenic risk posed by As, Cu, Ni, and Pb was acceptable through dermal contact and involuntary ingestion but unacceptable through inhalation [54]. They report that the HI values for all collected soil samples were higher than the acceptable limit (HI > 1), which is contrary to the present study. Also the carcinogenic risk posed by Pb was acceptable for the dermal absorption and ingestion pathways, but unacceptable for inhalation. Similarly, CR for Pb exposure through inhalation was high. HMs such as lead and arsenic can potentially increase the risk of cancer in humans. Therefore, long-term exposure to low levels of toxic elements such as As can cause cancer [27, 44].

4. Conclusions

The current research addressed the impact of industrial regions and iron ore mining on the contamination of soil with HMs. The research also investigated the possible health risks associated with living in mining areas and the soil pollution caused by mining activities. To assess the extent of contamination, the levels of As, Fe, Ni, Pb, and Cu were measured in an area near the mines and a control area. The concentrations of the HMs followed the order As < Cu < Ni < Pb < Fe in both areas. Comparing these concentrations with world average shale values indicated that Pb (48.6 mg/kg) and As (12.7 mg/kg) had higher concentrations than the world average and caused greater contamination in the areas close to the mines, particularly in areas nearest to the mining sites. The findings from the geo-accumulation index indicated a low to moderate level of Pb (1.85) contamination and a low level of As (0.25) contamination in the area near the mines. Assessing the health risk posed by HMs indicated that the total non-carcinogenic hazard index was within acceptable limits for adults and children through the ingestion, inhalation, and dermal absorption pathways (HI < 1). However, children were found to be more vulnerable than adults to the potential non-carcinogenic health risks posed by Pb (1.73E-01), As (6.56E-01), and Fe (7.00E-01). Carcinogenic risk assessment for adults indicated a probable risk of developing cancer due to As exposure through ingestion (3.36E-04) and dermal absorption (1.36E-04). On the other hand, Pb levels were deemed acceptable and safe for both children and adults (1×10^{-6} < CR < 1×10^{-4}). A notable contribution of this study is the calculation of the health risk for the local population in the studied area, which had not been previously done in Iran.

This information can be a valuable resource for further research on this subject. Given the health risks associated with As, it is strongly recommended to conduct additional research to evaluate the effects of mining and the associated activities on the HM levels in the soil and the health of individuals residing near the Sangan iron ore mines in Khaf, Iran. Furthermore, it would be beneficial to investigate dust contamination with HMs and assess the pathogenic potential in the studied area. In summary, further studies and comprehensive investigations are necessary to better understand the environmental and health implications of mining activities, particularly in relation to HM contamination. By conducting thorough research and implementing appropriate measures, it is possible to mitigate the potential risks and protect the well-being of individuals residing in mining areas.

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Conflict of Interest

The authors declare that there is not any conflict of interests regarding the publication of this manuscript. In addition, the ethical issues including plagiarism, informed consent, misconduct, data fabrication and/ or falsification, double publication and/ or submission, and redundancy has been completely observed by the authors.

Abbreviations

ABS	Absorption factor	**HQ**	Hazard quotient
ABW	Average body weight	**ICP- OES**	Inductively coupled plasma-optical emission spectrometry
ADD	Average daily dose	**I_{geo}**	Geo-accumulation index
AT	Average time	**InhR**	Inhalation rate
CF	Conversion factor	**mg/ kg/ day**	Milligrams per kilogram per day
CR	Carcinogenesis risk	**PEF**	Particle emission factor
CSF	Cancer slope factors	**RFD**	Reference dose
ED	Exposure duration	**SA**	Skin area
EF	Exposure frequency	**SAF**	Soil adherence factor
HCl	Hydrochloric acid	**USEPA**	United States Environmental Protection Agency
HI	Hazard index	**WAS**	World average shale
HMs	Heavy metals		

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بررسی غلظت پنج فلز سنگین در خاک‌های اطراف معادن سنگ آهن سنگان و تاثیر آن بر سلامت انسان

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کلمات کلیدی

آلودگی خاک
معدن سنگان
خطر سرطان‌زایی
عناصر سمی
فعالیت‌های معدنی

چکیده

آلودگی فلزات سنگین در خاک‌های سطحی، نگرانی‌های محیط زیستی قابل توجهی را در نزدیکی مناطق معدنی ایجاد می‌کند. این مطالعه غلظت و خطر سلامت انسان ناشی از پنج فلز سنگین همچون سرب، نیکل، مس، آرسنیک و آهن را در خاک‌های اطراف معادن سنگ آهن سنگان در شرق ایران بررسی کرد. تعداد ۶۰ نمونه خاک از عمق ۰-۲۰ سانتی‌متری از سایت‌های مجاور منطقه معدنی و یک سایت شاهد جمع‌آوری شد. غلظت فلزات سنگین با مقادیر شیل جهانی مقایسه شد. آلودگی خاک نیز با استفاده از شاخص زمین انباشت تعیین گردید. خطر سلامت ساکنان محلی با استفاده از شاخص ارزیابی خطر سلامت آژانس حفاظت از محیط زیست ایالات متحده ارزیابی شد. تجزیه و تحلیل نشان داد که غلظت سرب در مناطق مجاور معدن از استانداردهای جهانی شیل فراتر رفته است، در حالی که سطوح آرسنیک تا حدی کمتر از حد مجاز تعیین شده توسط استانداردهای جهانی خاک باقی مانده است. مقادیر شاخص زمین انباشت نیز سطوحی از آلودگی کم تا متوسط برای سرب و آرسنیک را در مناطق مجاور معدن نشان داد. نتایج ارزیابی خطر نشان داد که شاخص‌های خطر غیرسرطان‌زا هم برای کودکان و هم برای بزرگسالان در محدوده قابل قبولی قرار دارند. با این حال، آرسنیک از طریق دو مسیر قرار گرفتن در معرض خطر سرطان‌زایی قابل توجهی برای بزرگسالان ایجاد می‌کند بلع با مقدار (E-04۳.۳۶) و جذب پوستی با مقدار (E-041.۳۶). نتایج این تحقیق اهمیت اجرای قوانین نظارت منظم بر غلظت عناصر دارابی پتاسیل خطر در مناطق معدنی برای جلوگیری و کاهش خطر سلامت مرتبط با آلودگی را برجسته می‌کند.

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