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Original Article

Human Health Risk of Some Heavy Metals in the Surface Soil of Arak Plain

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Abstract

Background & Aims: Soil contamination with heavy metals is becoming a major environmental concern today. Therefore, the present study was conducted to evaluate the health risks of heavy metals in the surface soil of Arak plain.

Materials and Methods: Soil samples were collected by random sampling from 30 stations with three replications from a depth of 0-20 cm. After acidic digestion of the samples (HNO3: HclO4: HF=3: 2: 1), the concentrations of lead (Pb), zinc (Zn), copper (Cu), nickel (Ni), and cadmium (Cd) were determined by atomic absorption spectrometry. Finally, the carcinogenic and non-carcinogenic hazards of heavy metals in surface soils for human health were assessed through ingestion, inhalation, and dermal absorption using the method recommended by the EPA for children and adults.

Results: The results indicated that the average total concentrations of heavy metals of Pb, Zn, Cu, Ni, and Cd in the study area are 10.01, 13.83, 39.82, 43.41, and 11.9 mg/kg, respectively. The highest and lowest average daily dose (ADD) of elements in both age groups were related to Ni metal from the ingestion route and Cd metal from the inhalation tract, respectively. Further, the non-carcinogenic risk hazard quotient (HQ) of heavy metals in all three paths was less than 1. The results of the non-carcinogenic hazard index (HI) risk assessment of all three pathways separately for each metal and for both groups of children and adults showed metal values as Cu>Cd>Zn>Pb>Ni, respectively. In addition, the results of the carcinogenic risk index (RI) in the surface soil of Arak plain revealed that Ni and Pb have the highest and the lowest carcinogenic risk, respectively.

Conclusion: Finally, considering the size of the study area and proving the carcinogenic hazards and risks in the area, it is necessary and important to pay attention to health and environmental principles.

Keywords: Carcinogenicity tests, Absorption, Respiration, Eating, Metals, Heavy, Environmental pollution, Soil, Arak, Iran

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1. Introduction

Today, the environmental situation of the world is such that the people of one city or country are not safe from the effects of pollution in another city or country, so these cases make it necessary to pay attention to environmental pollution [1]. On the other hand, metal pollution is increasing every year, which ultimately leads to numerous risks to human, animal, and plant health. These metals are found in various sources such as chemical fertilizers, pesticides, herbicides, and insecticides. Moreover, due to the growth of industrial and development activities in different parts of the world, the production of industrial effluents and sewage sludge has increased, causing great concerns about the storage of these elements in the soil [2]. Heavy metals are naturally present in low concentrations in soil and rocks, but inappropriate human activities such as increasing industrial areas, traffic, agriculture, lack of land use management, increasing consumption of fossil fuels, and the like have led to increased emissions and concentrations of metal pollutants in our environment [3]. Most heavy metals are toxic even in extremely small amounts and can threaten the biological life of all living things on the planet [4]. Heavy metals accumulate in the tissues by entering the human body through three ways of respiration, ingestion, and dermal absorption and have harmful effects on human organs and vital systems such as the nervous system and blood circulation [5]. These toxic metals also interfere with the normal functioning of internal organs and cause adverse effects in some chronic diseases [4]. Since these elements are not metabolized in the human body and can accumulate in adipose tissue, muscles, bones, and joints, they lead to increased rates of diseases such as cancer [6]. Cancer is the leading cause of death in developed and developing countries worldwide [7]. The increase in cancer rates is due to several factors such as the increase in population age or population growth, wrong lifestyle, and exposure to various environmental pollutants. Recently, climate change to arid and semi-arid, reduction in water reserves, wind erosion, increasing industrial areas in cities, and

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their inappropriate location have led to an increase in pollution transmission that should be given serious attention [8].

Considering environmental and human health concerns related to heavy metals, the fundamental role of soil and its quality in human food security [2], its widespread contribution to the health of the earth's ecosystem, the two-way relationship between elements in nature, and pollutants' environmental issues [3], it is necessary to pay attention to the knowledge of the concentration of toxic elements as an important indicator in predicting the risks and diseases caused by these metals and also to determine their quality standards in the environment [6,8]. Numerous studies in Iran and the world have examined and measured the contamination of surface soils with heavy metals as well as carcinogenic and non-carcinogenic hazards in soils contaminated with heavy metals. One of the most important of these studies was conducted by Tepanosyan et al who examined the risks of surface soil contamination and the health risk of heavy metals in kindergartens in Armenia in 2017. The results of this study showed that most of these kindergartens have a non-carcinogenic risk for children [9]. In a study in 2018, Jamal et al assessed and distributed the health risk of heavy metals in soils around lead (Pb) and zinc (Zn) plants. The results showed that Pb is one of the most important pollutants with carcinogenic and non-carcinogenic risks in the study area [10]. A study by Rita et al and Adedeji in 2021 examined the effect of coal mining on drinking water quality at various water sources in Anambra, Nigeria. The results of this study revealed that the concentrations of chromium (Cr), copper (Cu), arsenic (As), cadmium (Cd), mercury, manganese, and Zn were within the allowable limits, and the effects of carcinogenic risk of metals on the water in the study area were reported to be very low [11]. A study was conducted in 2021 by Payandeh et al to investigate the risk of heavy metals in summer crops in Shushtar and Dezful on human health. The results of this study indicated that the carcinogenicity of Cd, Cr, and Pb metals in Shushtar products is more than the allowed limit [12]. In another study, Fouladi et al in 2021 assessed the health risk and determination of heavy metal contamination in barley grain in Khuzestan province. The results of this study suggested that the highest and lowest amounts of heavy metals in barley grain were related to Zn and Cr, respectively. The potential non-carcinogenic risk for children was also higher than that for adults [13].

The present study investigates the concentrations of heavy metals, including Pb, Zn, Cu, Ni, and Cd in the Arak plain region, and its purpose is to evaluate the indicators of carcinogenic and non-carcinogenic risk and health risks caused by these metals in the study area.

2. Materials and Methods

2.1. Study area

Markazi province with an area of about 29530 square kilometers is located in the western half of Iran, and the Arak watershed is located 260 km southwest of Tehran and northeast of the Zagros Mountains. This basin is almost circular and is located between longitudes 49-21 to 50° 19 East and 33.53 to 44° 34 North. The area of this catchment is estimated to be 5460 square kilometers, of which 2300 km^2 is the Arak plain. It is north-south direction surrounded by mountains and is located in the northeastern part of Arak. The seasonal and saline lake of Tuzlogel is the place of storage of sodium sulfate in this plain [14]. The area of Arak is 7178.98 square kilometers, and this city is the 18^{th} most populous city in Iran [15]. The city was selected as one of the industrial hubs of the country in the 1330s and received many immigrants during the industrialization period. This issue has also affected the trend of urban environmental pollution in Arak in recent decades [16]. In other words, Arak is among the most polluted metropolises in Iran. Factors such as population growth and, consequently, the increase in cars, the increase in the process of industrialization, and the construction of various factories have been effective in this regard [17].

2.2. Sample preparation and analysis

First, using random sampling distribution in a geographic information system, the proposed sampling locations in the study area were determined. Then, by correcting the position of each sampling place, the geographical position of each point to the device of the global positioning system was used to quickly reach the sampling place [18]. Thirty soil samples were taken from a depth of 0-20 cm with three replications at each station, stored in plastic bags, and then transferred to the laboratory of Malayer University [19,20]. The exact geographical location and characteristics of each station were recorded (Figure 1).

The collected samples were first dried in the open air or at room temperature (25°C) and passed through a 2 mm sieve. Then, about 50 g of soil was passed through a sieve of 0.149 mm, and about 1 g of soil sample was digested with acidic composition (HNO3: HclO4: HF = 3:2:1) in special containers at a temperature of 160°C. It was digested for 6 hours and finally brought to 50 mL volume with deionized water. Then, the concentration of heavy metals was measured by atomic absorption apparatus of the furnace (GFAAS, Shimadzu AA-670G, Japan). A control sample was considered to ensure the accuracy of the digestion operation and to eliminate the error caused by the sample preparation at each time of the digestion operation [21]. Moreover, to measure heavy metals by atomic absorption apparatus, the atomic absorption apparatus was calibrated first using standard solutions prepared by the German Merck Company, and then

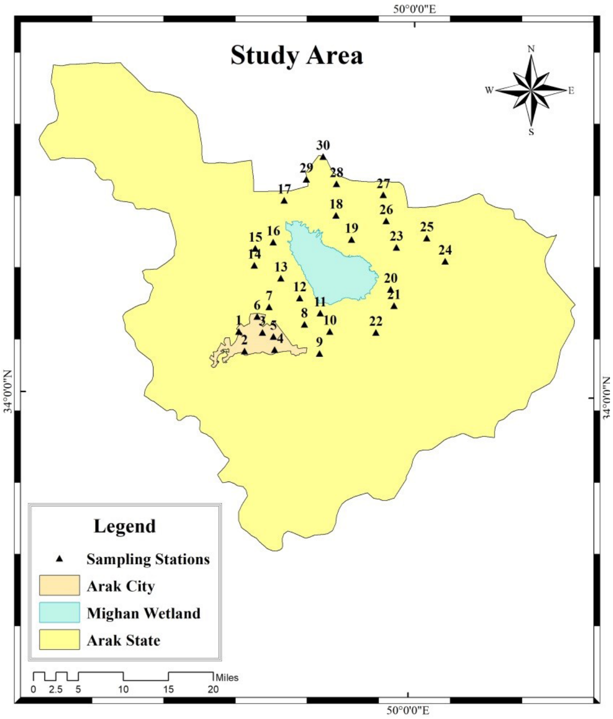

Figure 1. Arak Plain and sampling stations

samples were analyzed. The detection limit of the device for measuring Pb, Zn, Cu, Ni, and Cd was 1.923, 4.667, 4343.5, 0.981, and 1.913 mg/kg, respectively, and the recovery of the results was obtained to be in the range of 95-87%.

2.3. Data analysis

Statistical analysis of data was performed using SPSS and Excel software. First, the normality of the data was checked. Then, the concentrations of heavy metals measured in soil samples at different stations were compared, and finally, the correlation of the data was tested.

2.4. Carcinogenic and non-carcinogenic risk assessment

Assessing the health hazards of heavy metals based on the health risk index (RI) provided by the US Environmental Protection Agency (USEPA) is a multi-step process that was performed in two sections: the assessment of carcinogenic and non-carcinogenic hazards [22]. In the study of both carcinogenic and non-carcinogenic hazards, human exposure to metals from all three pathways of ingestion, inhalation, and dermal absorption was considered, and the values of average daily dose (ADD) in each of the pathways were calculated using their equations [22,23].

$$ADD_{ingestion} = C_{soil} \times \left(\frac{IngR \times EF \times ED}{BW \times AT}\right) \times 10^{-6} \qquad \text{Eq. (1)}$$

$$ADD_{inhalation} = C_{soil} \times \left(\frac{InhR \times EF \times ED}{PEF \times BW \times AT}\right) \times 10^{-6} \qquad \text{Eq. (2)}$$

$$ADD_{dermal} = C_{soil} \times \left(\frac{SA \times AF \times ABS \times EF \times ED}{BW \times AT}\right) \times 10^{-6} \qquad \text{Eq. (3)}$$

Where $ADD_{ingestion}$, $ADD_{inhalation}$, and ADD_{dermal} are the ADD of metals in mg/kg/d through ingestion, inhalation, and dermal absorption, respectively. C_{soil} is metal concentrations in soil (mg/kg), IngR and InhR represent ingestion and soil respiration rate (mg/day and m^2 per day), respectively, EF is the frequency of metal exposure (day per year), ED is the duration of exposure to exposed metals (years), and BW is the weight of the person exposed to metals (kg). In addition, AT depicts exposure time on the average amount of metals (days), PEF is the emission of metals from soil to air (m^2/kg), SA is the area of the dermal surface exposed to metals (cm^2), AF is the soil adhesion factor (mg/cm^2/d), and ABS is the dermal absorption factor (unit no) [24].

After calculating the daily metal uptake for each route, the non-carcinogenic hazard index (HI) risk of all routes for children and adults was determined by dividing the total ADD of each route by the reference dose of that metal toxicity based on the following equation [22,25]:

$$HI = \Sigma HQ = \Sigma\left(\frac{ADD_i}{RfD_i}\right) \qquad \text{Eq. (4)}$$

In this equation, hazard quotient (HQ) is the risk of non-carcinogenicity of metals in each pathway, ADD_i is the value of the ADD taken in each pathway of metal exposure (mg/kg/day), and RfD is the reference dose of metal toxicity in each pathway (mg/ kg/day). If $HQ \leq 1$, it is not incompatible with human health, and if $HQ \leq 1$, it has adverse and worrying effects on human health [21,26,27].

The value of total non-carcinogenic HI of total metals for both groups of adults and children was obtained according to the following equation [28]:

$$HI = HQ\ (contamination1) + HQ\ (contamination2) + HQ\ (contamination) \qquad \text{Eq. (5)}$$

The metals considered in this study have non-carcinogenic effects, while Pb, Ni, and Cd cause both carcinogenic and non-carcinogenic effects. Therefore, carcinogenic RI in each of the three pathways was performed only for these three metals using the following equation:

$$RI\ (Risk\ Index) = \Sigma\ (ADD_i \times SF_i) \qquad \text{Eq. (6)}$$

In this equation, RI is carcinogenicity risk, ADD_i represents ADD values in each of the metal exposure pathways (mg/kg/day), and SF_i is cancer risk factor per unit of metal exposure (mg/kg/d) [26,29].

The constant values required for equations 1 to 6 for adults and children are given in Table 1.

3. Results

3.1. Statistical analysis results

The results of this study indicated that the average concentrations of heavy metals, including Pb, Zn, Cu, Ni, and Cd in the study area are 10.01, 13.83, 39.82, 43.41, and 9.11 mg/kg, respectively. The highest mean concentration was related to Ni, and the lowest mean concentration was obtained for Cd in the study area. Table 2 presents a summary of the results obtained from the statistical description of the data for the concentration of heavy metals in the surface soil of Arak plain.

Table 1. Values of required parameters in carcinogenic and non-carcinogenic risk assessment [26-28]

Parameter	Unit of measurement	Children	Adults
IngR	mg/d	200	100
InhR	m^3/d	7.63	12.8
EF	day/year	350	350
ED	year	6	24
BW	kg	15	55.9
AT	days	365 × ED	365 × ED
PEF	m^3/kg	$10^9 \times 1.36$	$10^9 \times 1.36$
SA	cm^2	1600	4350
AF	mg/cm/d	0.2	0.7
ABS	-	0.001	0.001
SF	per (mg/kg/d)	Pb (4.2×10^{-2}) Ni (8.4×10^{-1}) Cd (6.3×10^{-1})	
RfD ingestion	mg/kg/d	Zn (0.3) Ni (0.02) Cd (0.001)	Pb (0.0035) Cu (0.04)
RfD inhalation	mg/kg/d	Zn (3×10^{-1}) Ni (2.06×10^{-2}) Cd (1×10^{-3})	Pb (3.52×10^{-3}) Cu (4.02×10^{-2})
RfD dermal	mg/kg/d	Zn (6×10^{-2}) Ni (5.4×10^{-3}) Cd (1×10^{-5})	Pb (5.25×10^{-4}) Cu (1.2×10^{-2})

Note. IngR: Ingestion rate; InhR: Inhalation rate; EF: Exposure frequency; ED: Exposure duration; BW = Body weight; AT: Averaging time; SA: Surface area; AF: Adhesion factor; ABS: Dermal absorption factor; SF: Slope factor; RfD: Reference dose; Pb: Lead; Ni: Nickel; Cd: Cadmium; Zn: Zinc; Cu: Copper.

Table 2. The concentration of heavy metals in the surface soil of Arak plain (mg/kg)

Metal	Average	Minimum	Maximum	Coefficient of Variation	Standard Deviation
Pb	10.01	3.97	18.32	37.00	3.70
Zn	39.82	10.98	196.93	21.16	25.67
Cu	41.43	13.30	64.40	28.35	11.75
Ni	13.83	2.37	70.43	10.18	8.86
Cd	9.11	5.14	22.63	42.91	3.91

Note. Pb, Lead; Zn, Zinc; Cu, Copper; Ni, Nickel; Cd, Cadmium.

The normality of the results was tested by the Kolmogorov-Smirnov test ($P > 0.05$), and the homogeneity of data ($P > 0.05$) was evaluated by the Levene's test. One-way analysis of variance was also used to compare the concentrations of heavy metals in soil samples at different stations. Correlations between dependent and independent variables were also analyzed using Pearson tests for normal data and Spearman tests for abnormal data.

The results of the statistical analysis demonstrated that only the data obtained from Pb samples were normal ($P > 0.05$), and the data obtained from other metals after normalization were analyzed by the Leven test. All elements except Cu were homogeneous ($P > 0.05$). After examining the normality and homogeneity of the data, the Duncan test was used for Pb, Zn, Ni, and Cd to compare the concentration of heavy metals in soil samples at different stations, and Dunnett T3 was used for Cu. The results of the Duncan and Dunnett T3 test showed that the concentration of heavy metals studied in most sampling stations has a significant difference. Finally, the results of the Pearson's correlation test revealed (99% probability) a positive and significant correlation ($P < 0.01$) between the concentrations of Pb with Cd, Zn with Cu and Cd, Cu with Zn and Cd, Ni with Cd, and Cd with Pb, Cu, and Ni.

3.2. Consequences of carcinogenic and non-carcinogenic risk

Tables 3 and 4 present ADD of metals and their non-carcinogenic risks in each of the pathways separately for children and adults, respectively.

The highest and lowest ADD absorption of elements in both age groups were related to Ni in the ingestion pathway and Cd in the inhalation tract, respectively. The ADD of all elements in the studied age groups in the ingestion route was higher than that in the inhalation and dermal absorption routes. The daily absorption of metals in the ingestion and inhalation tract was higher for children than for adults, while in the dermal absorption pathway, it was higher for adults than for children. The non-carcinogenic HQ of heavy metals in all three pathways indicated that all metals have a non-carcinogenic hazard of less than 1. Furthermore, the highest and lowest risk of non-carcinogenicity in all elements studied in all pathways and in both age groups are related to the ingestion pathway in children and the inhalation tract in adults, respectively, and the non-carcinogenic risk in ingestion > inhalation > dermal absorption was observed for all elements. Additionally, in all elements, non-carcinogenic risk in children was observed to be higher than that in adults in ingestion and inhalation tract and greater in children than in adults in dermal absorption.

The total non-carcinogenic hazard (ΣHQ) of heavy

Table 3. Average daily dose of metals via three pathways of ingestion, inhalation, and dermal absorption by children and adults in the surface soil of Arak Plain (mg/kg/d)

Metal	ADD Ingestion		ADD Inhalation		ADD Dermal	
	Adults	Children	Adults	Children	Adults	Children
Pb	17.26×10^{-6}	127.98×10^{-6}	1.61×10^{-9}	3.58×10^{-9}	0.50×10^{-6}	0.20×10^{-6}
Zn	23.84×10^{-6}	176.82×10^{-6}	2.23×10^{-9}	4.95×10^{-9}	0.69×10^{-6}	0.28×10^{-6}
Cu	68.65×10^{-6}	509.10×10^{-6}	6.41×10^{-9}	14.26×10^{-9}	1.99×10^{-6}	0.80×10^{-6}
Ni	71.43×10^{-6}	529.68×10^{-6}	6.67×10^{-9}	14.83×10^{-9}	2.07×10^{-6}	0.83×10^{-6}
Cd	15.71×10^{-6}	116.47×10^{-6}	1.47×10^{-9}	3.26×10^{-9}	0.46×10^{-6}	0.18×10^{-6}

Note. ADD, average daily dose; Pb, Lead; Zn, Zinc; Cu, Copper; Ni, Nickel; Cd, Cadmium.

Table 4. Non-carcinogenic (HQ) risk of metals in three pathways of ingestion, inhalation, and dermal absorption by children and adults in the surface soil of Arak Plain

Metal	HQ (ingestion)		HQ (inhalation)		HQ (dermal)	
	Adults	Children	Adults	Children	Adults	Children
Pb	4.93×10^{-3}	36.57×10^{-3}	0.46×10^{-6}	1.02×10^{-6}	0.10×10^{-2}	0.04×10^{-2}
Zn	7.95×10^{-5}	58.94×10^{-5}	0.74×10^{-8}	1.65×10^{-8}	0.12×10^{-4}	0.05×10^{-4}
Cu	17.16×10^{-4}	127.27×10^{-4}	1.59×10^{-7}	3.55×10^{-7}	1.66×10^{-4}	0.66×10^{-4}
Ni	35.71×10^{-4}	264.84×10^{-4}	3.24×10^{-7}	7.20×10^{-7}	0.38×10^{-3}	0.15×10^{-3}
Cd	15.71×10^{-3}	116.47×10^{-3}	1.47×10^{-6}	3.26×10^{-6}	0.46×10^{-1}	0.18×10^{-1}

Note. HQ, Hazard quotient; Pb, Lead; Zn, Zinc; Cu, Copper; Ni, Nickel; Cd, Cadmium.

metals can also be seen in Table 5. According to the results of this table, the highest non-carcinogenic risk in both adult and pediatric groups is observed in Ni in the ingestion pathway, and the lowest non-carcinogenic risk in both adult and pediatric groups is seen in Ca in the inhalation tract. Further, the total non-carcinogenic risk of heavy metals for the sum of all three pathways of ingestion, respiration, and dermal absorption for both age groups confirms this conclusion.

Table 6 presents the results of the non-carcinogenic HI risk assessment of all three pathways for each metal for both children and adults. According to the results of this table, the values of non-carcinogenic risk of all pathways for both children and adults have the highest values for Cu > Cd > Zn > Pb > Ni, respectively.

The results of carcinogenic RI of heavy metals in the surface soil of the study area are in accordance with Table 7. According to this table, Ni has the highest carcinogenic risk, and Pb has the lowest carcinogenic risk in the surface soil of the Arak plain.

4. Discussion

Soil and vegetation have special ecological functions in the environment, including the regulation of water flow, nutrients, temperature, and various gases. The soil has a highly complex structure and different characteristics [3,4,15]. Among the many and varied contaminants in the soil, heavy metals are regarded as one of the most important contaminants because they reduce soil quality, thus reducing its optimal performance. Soil, on the other hand, is an important entry point for heavy metals in terrestrial ecosystems [15,30,31].

Table 5. Total non-carcinogenic risk (HQ) of metals in the three pathways of ingestion, inhalation and dermal uptake in the surface soil of Arak Plain

Metal	(Children and adults) ΣHQ (ingestion)	(Children and adults) ΣHQ (inhalation)	(Children and adults) ΣHQ (dermal)
Pb	41.50×10^{-3}	1.48×10^{-6}	0.13×10^{-2}
Zn	66.89×10^{-5}	2.39×10^{-8}	0.16×10^{-4}
Cu	144.44×10^{-4}	5.14×10^{-7}	2.32×10^{-4}
Ni	300.55×10^{-4}	10.44×10^{-7}	0.54×10^{-3}
Cd	132.18×10^{-3}	4.73×10^{-6}	0.64×10^{-1}

Note. HQ, Hazard quotient; ΣHQ, total non-carcinogenic hazard quotient; Pb, Lead: Zn, Zinc; Cu, Copper; Ni, Nickel; Cd: Cadmium.

Table 6. Risk of total non-carcinogenicity (HI) of heavy metals in the surface soil of Arak Plain

Metals	HI
Pb	41.52×10^{-3}
Zn	68.50×10^{-3}
Cu	1467.71×10^{-3}
Ni	30.60×10^{-3}
Cd	196.19×10^{-3}
Sum of metals	1804.52×10^{-3}

Note. HI, Hazard index; Pb, Lead; Zn, Zinc; Cu, Copper; Ni, Nickel; Cd, Cadmium.

Table 7. Carcinogenic hazard (RI) of heavy metals in the surface soil of Arak Plain

Metal	Risk
Pb	6.13×10^{-6}
Ni	507.38×10^{-6}
Cd	8.71×10^{-6}

Note. RI: Risk index; Pb: Ni: Nickel; Cd: Cadmium.

In this study, the highest amount of ADD was related to the Ni in the ingestion tract, and the lowest was related to the Cd in the respiratory tract. According to the USEPA standard, if ADD is higher than the RfD value in each route, the risk of non-carcinogenic metals in that route is higher than allowed (HQ > 1) and is incompatible with human health. Due to the low daily absorption of Ni compared to the RfD value of its toxicity for both groups of adults and children in the ingestion path, it will not have harmful consequences for human health. According to the USEPA standard, if the non-carcinogenic risk of heavy metals in each pathway is more than one, that element may have adverse effects on human health [26,32]. According to the results of this study, none of the heavy metals in ingestion, inhalation, and dermal absorption pathways had HQ values higher than one in any of the age groups of adults and children, which according to the study area (multiple urban and rural areas), indicates a safe condition for the non-carcinogenic risk of heavy metals studied in Arak Plain. However, the highest risk of non-carcinogenicity was observed in the pathways of ingestion > respiration > dermal absorption for all elements, respectively. In all elements, the non-carcinogenic risk was more observed in children than in adults in ingestion and respiratory tract, and it was more observed in adults than in children in dermal absorption. The results of the present study were similar to those of Tao et al in 2015. They found that the risk of exposure to heavy metals for children in the ingestion pathway was higher than that in other pathways, and its numerical values were higher in children than in adults [33]. The results of non-carcinogenic HI risk assessment of the three pathways separately for each group and for both children and adults showed that HI has the highest values for Cu > Ca > Zn > Pb > Ni, respectively. However, some differences were observed between the results of this study and studies by Chabukdhara and Nema in 2013. Chabukdhara and Nema examined the effects of carcinogenic and non-carcinogenic hazards in industrial areas of India. The results of their study suggested that the risk of non-carcinogenicity for both groups of adults and children in the soil of these industrial areas is in the form of Zn, Ca, Cu, Ni, manganese, Pb, and Cr, which can be due to the type of industrial activity or soil and rock type of the study area [34]. The results of carcinogenic RI of heavy metals in the surface soil of the study area showed that Ni has the highest carcinogenic risk and Pb has the lowest carcinogenic risk in the surface soil of the Arak plain. Furthermore, in a study conducted in 2020, Ehtemae et al assessed the ecological risk potential and human health of some heavy metals in street dust in Ilam and found that Pb has the lowest risk of carcinogenicity in street dust, which is in line with the results of the present study [35]. Additionally, in another study in 2020, Sheikhi and Forghani Tehrani investigated the concentration and health RI of potentially toxic elements in the agricultural soils of Aleshtar plain in Lorestan province. They found that intake of Ni through swallowing by adults and through skin contact by young children is associated with carcinogenic risk, and Ni has a high risk for carcinogenesis in this study area. The results of this study are also consistent with the present study [36].

Conversely, the results of the current study are different from those of a study conducted by Yang et al in 2018. They found that the highest amount of HI was related to the Pb, and the highest amount of absorption was in the age group of children [37].

In general, according to the EPA standard, this risk is negligible if the RI of carcinogenicity is less than the risk 1×10^{-6} (one in every one million people). However, if the RI of carcinogenesis is higher than 1×10^{-4}, it is unauthorized and dangerous to human health. The RI of carcinogenicity within 1×10^{-4} and 1×10^{-6} also indicates the permitted risk under controlled conditions [24,36]. According to this standard, in the present study, the values of carcinogenic RI are more than both ranges (i.e., 1×10^{-4} and 1×10^{-6}), indicating the presence of unofficial amounts of Pb, Ni, and Cd in the surface soil of Arak plain, which shows that human health in both age groups of adults and children is at risk. These results were consistent with those of studies by Li et al [38]. They also found that the levels of Ca carcinogenic risk in the study area were highly critical for the age group of children provided by the EPA [38]. Other similar studies such as those of Zhao et al in 2012 showed that the risk of carcinogenicity for Ca was higher than that of EPA [39]. In another study conducted by Qing et al, it was found that the lowest risk of carcinogenicity in adults and children was related to Zn in the study area [40]. In addition, a study was conducted by Łukasik et al in 2021 to investigate the health risks of mineral slag in Siechnice, Poland. The results revealed that the amounts of heavy metals such as Zn, Cu, Pb, iron, and Cr were all above the allowable level. Moreover, all the studied metals had a carcinogenic risk, and the highest risk route for adults and children was observed through swallowing [41]. Another study by Alasfar and Isaifan in 2021 measured the environmental and health hazards of heavy metals in regional agricultural soils in Qatar. The results of this study showed that the concentrations of Pb, As, Cd, Cr, Cu, and Ni in the collected soil samples are much higher than those of world standards. Further, only As metal had a non-carcinogenic risk for children, and As, Cr, and Ni metals had the highest carcinogenic risks for both adults and children. In addition, swallowing was reported to be the most important mode of exposure [8].

5.Conclusion

The results of non-carcinogenic hazard risk assessment of all three metal pathways for children and adults indicated that Cu > Cd > Zn > Pb > Ni had the highest risk values, respectively. In addition, the results of carcinogenic RI of these metals showed that Ni and Pb have the highest and the lowest carcinogenic risk in the surface soil of Arak plain, respectively. The assessment of the health risks of heavy metals in surface soils indicated the carcinogenic and non-carcinogenic risks of heavy metals for the health of children and adults and the current situation. Although less attention has been paid to the intake of heavy elements through ingestion, and inhalation of the soil as well as dermal absorption, these studies with the potential to report risk to all sections of society, especially children, can be extremely important. The present study demonstrated that carcinogenic hazards and risks in the study area, attention to health principles while complying with environmental principles, and respect for environmental laws are more important than ever.

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Competing Interests

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