

Heavy Metal Pollution in Surface Soils of Ahvaz, Iran, Using Pollution Indicators and Health Risk Assessment

Afsaneh Borojerdnia^a , Maryam Mohamadi Rozbahani^{a*} , Ahad Nazarpour^b , Navid Ghanavati^c , Khoshnaz Payandeh^c 

^a Department of Environmental Sciences, Ahvaz Branch, Islamic Azad University, Ahvaz, Iran

^b Department of Geology, Ahvaz Branch, Islamic Azad University, Ahvaz, Iran

^c Department of Soil Sciences, Ahvaz Branch, Islamic Azad University, Ahvaz, Iran

*Correspondence should be addressed to Dr Maryam Mohamadi Rozbahani, Email: Mmohammadirozbahani@yahoo.com

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Background & Aims of the Study: Heavy metals are among the most dangerous environmental pollutants entering the air, water, and soil through human and natural activities with the potential of poisoning, pathogenicity, and carcinogenicity to living organisms and humans. The current study aimed to determine the contamination of heavy metals, including lead, zinc, copper, arsenic, chromium, and cadmium, in the surface soils of Ahvaz, Iran, using pollution indicators and health risk assessment.

Materials and Methods: Sampling of surface soils in Ahvaz with 227 soil samples was performed in August 2017 based on the regular networks of 1 × 1 km. The measurement of heavy metals was carried out by inductively coupled plasma optical emission spectrometry.

Results: The mean concentrations of Pb, Zn, Cu, Cr, Cd, and As in the surface soils of Ahvaz were reported as 180.99, 88.61, 185.13, 101.59, 5.63, and 8.97 mg/kg, respectively. Based on the contamination factor (CF), pollution index (PI), geoaccumulation index (Igeo), and ecological risk, the highest levels of pollution were related to Cd and Pb, and the lowest level was associated with Cr. The enrichment factor (EF) of heavy metals showed moderate contamination of Cr, high contamination levels of Cu, Cd, and As, and very high contamination levels of Pb and Zn. According to the Nemro Integrated Pollution Index (NIPI), 3% and 55% of the surface soils of Ahvaz showed high and low levels of pollution, respectively. The daily absorption of heavy metals through ingestion in children and adults was higher than that through respiration and dermal contact. The highest risk index was related to Cr and As through ingestion for children, and the lowest risk index was associated with Zn through respiration in adults.

Conclusion: The levels of As, Cr, and Cd in the surface soil of Ahvaz were higher than the Iran soil standard values; however, the levels of Pb, Zn, and Cu were lower. Based on the CF, PI, Igeo, and ecological risk, the surface soils were highly contaminated with Cd and Pb. According to the EF, Pb and Zn showed the highest levels of contamination. Based on the NIPI, the pollution of heavy metals was reported at low levels. The highest and lowest values of metals carcinogenicity were related to Cr in children and Pb in adults, respectively.

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Background

Among the most important soil contaminants are heavy metals reducing soil quality, thereby decreasing its optimal performance. Heavy metals are a group of metals and quasi-metals the small amounts of which are toxic and dangerous (1, 2). Heavy metals in the soil can directly enter the human body through ingestion and respiration after reaching the earth surface through precipitation, polluted water and soil sources, and plant structures (3, 4).

Arsenic, lead, and cadmium are toxic elements and the most dangerous environmental pollutants not playing a role in biological interactions in the human body and causing hemoglobin biosynthesis, anemia disorders, hypertension, kidney damage, abortion, nervous system disorder, brain damage, and reduction of learning ability in children (5). Zinc and copper play a role in biological processes based on their amounts and are among the essential elements for biological reactions; however, the increased bioaccumulation of these two metals in body tissues causes their high toxicity (6). High levels of chromium cause stomach ulcers, respiratory problems, weakened immune systems, kidney and liver damage, lung cancer, and mortality in humans (7, 8).

In a study carried out in Zahedan, Iran, Cd, Cr, Cu, Ni, Pb, and Zn were reported with the average concentrations of higher than the background concentrations (in suburbs). The highest metal concentrations were obtained in commercial and high-traffic areas (9). The average concentrations of Pb, Zn, Ni, Cr, except Cu and V, in the soil of parks in Ahvaz, Iran, are reported as several times higher than the background levels. According to the average enrichment factor (EF) and pollution index (PI), Ni, Zn, and Pb are highly polluted. The highest average geoaccumulation index (Igeo) is related to Ni, Zn, and Pb. Based on the evaluation of the Nemro Integrated Pollution

Index (NIPI), 100% of the samples had a high level of contamination (7).

Based on the evidence, the pollution of heavy metals in the street dust of Ahvaz was reported at a very high level, and areas with high population density, traffic congestion, and industrial activities are severely contaminated with heavy metals (10). The examination of Cd, Pb, Cr, Ni, Zn, Cu, Hg, and Co in the soil of the northern plateau in Spain showed that 54.61% of the soil in the study area has moderate to low pollution. In addition, 22.31% of the soil had moderate pollution, and 21.54% of the samples were free from pollution (11). The concentrations of heavy metals in the surface soils of Ibadan Industrial City in Nigeria have been reported as $Mg > Cr > Pb > Cu > Cd > Co > Ni$. All the samples were heavily contaminated based on the contamination factor (CF), pollution load index (PLI), EF, and PI (12). In the soils of Ijebu-Ode, Nigeria, the carcinogenic risk of Cu, Mn, Pb, and Zn for children and Mn, Pb, and Zn for adults was higher than their acceptable level (13).

The calculations of the CF and Igeo determined that the soil samples collected from Urabi fields in El Obour, Egypt, are not contaminated with Cr, Cu, and Pb; however, they are significantly contaminated with Cd and highly contaminated with As. Integrated pollution calculation index, PLI, pollution degree, and potential environmental risk index showed that soil samples have been contaminated with the studied heavy metals. High CF values of As and Cd demonstrated that these two elements play a major role in the high pollution of the soil (14).

Ahvaz has special conditions due to the rich resources of oil and gas, large metallic and nonmetallic industries, cellulose and electricity, and hot and humid weather conditions. In addition, high consumption of fossil fuels in industry, automobiles, and miscellaneous sources, such as seasonal dust, relatively high population density with urban traffic, and lack

of green space in the city and suburbs are the reasons for heavy metal pollution in the soil (15). Large industrial factories, such as oil and gas companies, and metal industries are the major sources of soil pollution in Ahvaz (16).

Materials & Methods

Sampling

The samples (n=227) of the surface soil were collected from a depth of 0-10 cm below the ground surface in June 2017 to avoid potentially toxic elements washed by rainwater (Figure 1). The map of Ahvaz was divided into 1 × 1 km networks, and a total of 227 regular networks were created using ArcGIS software (version 10.5). Each network in the city was then tracked using the Global Positioning System. The soil samples were collected and mixed from three scattered points in each network, and the composite samples were subsequently passed through a 2-mm mesh. In addition, eight soil samples as the control soils were collected from eight pits from a depth of 120 cm at four main directions and four

subdirections of the city in the uninhabited areas with no traffic (17).

After the removal of surface contaminants and separation of pebbles, plant roots, and other wastes, the collected samples were sieved through a 2-mm nylon net with a wooden spoon and dried in the air. In order to chemically digest the samples, they were placed in a polyethylene beaker, and a few drops of hydrochloric acid and 7 cc of hydrofluoric acid were added to the beaker. The samples were heated in a water bath at a temperature of 100°C until drying. After cooling the samples, 7 cc of nitric acid and hydrochloric acid were added to each sample, and they were heated on a water bath until drying. After the chemical digestion of all the samples, a completely clear solution was obtained by adding distilled water to each of them and gently heating them. All the samples were brought to a volume of 50 cc by 1N hydrochloric acid and then injected into the device (17). Zn, Cu, Pb, Cd, Cr, and As were measured by inductively coupled plasma optical emission spectrometry. Varian 710-ES (Varian, USA) was used for the pollution measurement of the heavy metals.

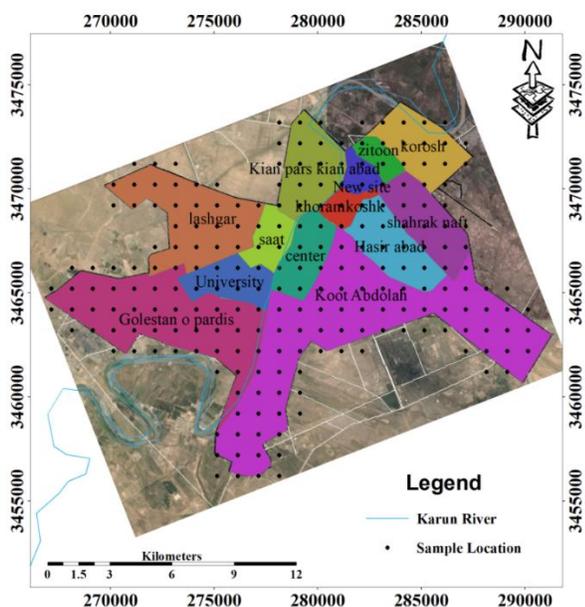


Figure 1) Location of surface soil sampling points in Ahvaz, Iran

Contamination Factor

The CF is the ratio of the concentration of each metal to the amount of the natural background concentration of that metal (Equation 1). Accordingly, $CF < 1$, $1 < CF < 3$, $3 < CF < 6$, and $CF \geq 6$ demonstrate low, moderate, high, and severe pollution, respectively (18).

Equation 1

$$CF = \frac{C_{\text{metal}}}{C_{\text{background}}}$$

Pollution Index

In the PI equation (Equation 2), C is the concentration of the studied element in soil samples; X_a is the heavy metal enrichment concentration threshold; X_c is the pollution low-level concentration threshold; X_p is the pollution high-level concentration threshold

Table 1) Threshold of contamination level of studied elements (19)

Element	Xa	Xc	Xp
Arsenic	15	25	30
Lead	35	250	500
Zinc	85	200	500
Copper	30	50	400
Chromium	90	200	300
Cadmium	0.15	0.30	1

(Table 1). The pollution levels according to the value of the PI were nonpollution ($PI \leq 1$), low pollution ($2 \geq PI > 1$), moderate pollution ($3 \geq PI > 2$), and high pollution ($PI > 3$) (19).

Equation 2 $PI = C/Xa \quad C \leq Xa$
 $PI = 1 + (C - Xa) / (Xc - Xa) \quad Xa < C \leq Xc$
 $PI = 2 + (C - Xc) / (Xp - Xc) \quad Xc < C \leq Xp$
 $PI = 3 + (C - Xp) / (Xp - Xc) \quad C > Xp$

Nemro Integrated Pollution Index

Based on this index, soil quality is classified into five levels of nonpollution ($NIPI \leq 0.7$), warning line of pollution ($0.7 < NIPI \leq 1$), low pollution ($1 < NIPI \leq 2$), moderate pollution ($2 < NIPI \leq 3$), and high pollution ($NIPI > 3$) (Equation 3) (19).

Equation 3
$$NIPI = \sqrt{\frac{PI_{i \max}^2 + PI_{i \text{ave}}^2}{2}}$$

Enrichment Factor

This factor indicates the intensity of anthropogenic impact (Equation 4). In this equation, EF is the enrichment factor; C_x is the measured element concentration in soil samples; C_{Ref} is the reference element concentration. The reference element in the determination of the EF is an element, with a purely geological origin. According to the presented classification, $EF < 2$, $2 \leq EF < 5$, $5 \leq EF < 20$, $20 \leq EF < 40$, and $40 \leq EF$ show low, moderate, high, very high, and extremely high pollution, respectively (20):

Equation 4
$$EF = \frac{\left(\frac{C_x}{C_{ref}}\right)_{\text{Sample}}}{\left(\frac{C_x}{C_{ref}}\right)_{\text{Background}}}$$

Geoaccumulation Index

The I_{geo} can determine the degree of soil pollution (Equation 5). In this equation, I_{geo} is the geoaccumulation index; C_n is the concentration of heavy metal in the soil; B_n is the concentration of the ground (i.e., the average of shale). According to the Müller classification, there are seven classes of contamination, including $I_{geo} < 0$ (nonpollution), 1-0 (nonpollution to moderate pollution), 2-1 (moderate pollution), 3-2 (moderate to strong pollution), 4-3 (strong pollution), 5-4 (strong to extreme pollution), and $5 < I_{geo}$ (extreme pollution) (21).

Equation 5
$$I_{geo} = \log_2 (C_n / 1.5 * B_n)$$

Ecological Risk

In equations 6 and 7, CF is the contamination factor; Er the ecological risk of each studied element; RI represents the ecological risk of the total elements. Tr values, which are called the indicators of the toxicity of heavy metals, are 30, 5, 5, 2, and 1 for Cd, Cu, Pb, Cr, and Zn, respectively. The ecological risk for each element is classified into five hazard levels of low ($Er < 40$), moderate ($40 \leq Er < 80$), considerable ($80 \leq Er < 160$), high ($160 \leq Er < 320$), and very high ($Er \geq 320$). To analyze the potential of ecological risk (RI), four categories were considered for ecological risk, including low ($RI < 150$), moderate ($150 \leq RI < 300$), considerable ($300 \leq RI < 600$), and very high ($600 \leq RI$) (18).

Equation 6
$$Er = Tr \times CF$$

Equation 7
$$RI = \sum Er$$

Health Risk Assessment

Heavy metal health risk assessment was performed based on the health risk assessment method provided by the US Environmental Protection Agency (EPA). This assessment is considered in two parts of carcinogenic and noncarcinogenic risks and risks of human

exposure to metals from all three pathways of ingestion, respiration, and dermal contact. An average daily dose of metal through each pathway was calculated using equations 8 to 10 as follows (22):

Equation 8
$$ADD_{ing} = \frac{C \times IngR \times CF \times EF \times ED}{BW \times AT}$$

Equation 9
$$ADD_{inh} = \frac{C \times InhR \times EF \times ED}{PEF \times BW \times AT}$$

Equation 10
$$ADD_{dermal} = \frac{C \times SA \times CF \times AF \times ABF \times EF \times ED}{BW \times AT}$$

where ADD_{ing} , ADD_{inh} , and ADD_{dermal} are the average daily doses of metals (mg/kg-day) through ingestion, respiration, and dermal contact, respectively; C is the concentration of metals in soil (mg/kg); $IngR$ and $InhR$ are ingestion rate and soil respiration rate (mg/day and m³/day), respectively; EF is the exposure frequency of metal (day/year); ED is exposure duration of metals (year); BW is bodyweight of the individual exposed to metals (kg); AT is the average time for exposure to each metal (day); EF is a factor of emission of metals from soil to air (m³/kg); SA is the skin surface area exposed to metals (cm²); AF is an adhesion factor of soil to the skin (mg/cm²-day); ABF is the dermal absorption factor (without units). The noncarcinogenic hazard of all the pathways of ingestion, respiration, and dermal contact for children and adults was determined using the ratio of total daily absorption of heavy metals in each pathway to the reference value of the toxicity of that metal according to Equation 11 as follows (22):

Equation 11
$$HQ_i = \sum \frac{ADD_i}{RfD_i}$$

where HQ is the noncarcinogenic hazard quotient of metals in each pathway; ADD_i is the average daily dose of metal in each pathway of exposure to metal (mg/kg-day). If HQ is less than 1, it is not incompatible with human health. Moreover, if HQ is higher than 1, it has adverse effects on human health. The values of

cumulative noncarcinogenic hazard index of total metals for both groups of adults and children were obtained according to Equation 12 as follows (22):

Equation 12
$$HI = \sum HQ_i$$

The carcinogenic assessment of each of the three pathways for these metals was performed using Equation 13 as follows (22):

Equation 13
$$RI = \sum ADD_i \times SF_i$$

where RI is the carcinogenic risk; ADD_i is the value of average daily metal uptake in each of the metal exposure pathways (mg/kg-day); SF_i is the cancer risk factor per unit of metal exposure (mg/kg/day).

Statistical Analysis

Analyzing the data, drawing tables, calculating the equations of pollution indices, and assessing health hazards were performed using SPSS software (version 16.0) and Excel software (version 2007).

Results

The accumulation amount of the heavy metals in the surface soils of Ahvaz was obtained as Cu > Pb > Cr > Zn > As > Cd. Statistical results showed an abnormal distribution in this regard. The amplitude of the coefficient of variation corresponding to the samples of the study area demonstrated high changes in this parameter (the coefficient of variation > 20%). In addition, the skewness coefficient of the studied metals was higher than 0, indicating the skew distribution to the right (Table 2).

The average CF and heavy metal PI in the surface soils of Ahvaz were obtained as Cd > Pb > Cu > As > Zn > Cr. The CF for Pb, Cd, and Cu showed that 55.27%, 72.37%, and 34.21% of the soil samples had severe

pollution, respectively. The Zn, Cr, and As soil samples were reported with moderate (38.6%), low (59.65%), and high (41.23%) pollution, respectively (Table 3).

The average PI of the heavy metals showed that the surface soils of Ahvaz were polluted with heavy metals. The PI for Pb demonstrated that 46.49% of the soil samples had low pollution. Zn, Cr, Cd, and As had no pollution in 55.7%, 55.7%, 89.47%, and 87.28% of the soil samples, respectively. Regarding Cu, 70.61% of the soil samples had moderate pollution (Table 3).

The average NIPI of the heavy metals of surface soils of Ahvaz was calculated at 1.8 (Table 4). The obtained values of the EF were reported as Zn > Pb > Cu > Cd > As > Cr. The

EF of Pb, Cu, Cd, and As showed that 52%, 84%, 100%, and 96% of the soil samples were highly polluted. Moreover, the EF of Cr demonstrated that 96% of the soil samples were moderately polluted. In addition, the EF of Zn indicated that 48% of soil samples were severely polluted (Table 5).

The average Igeo in the form of Cd > Cr > Cu > As > Zn > Pb was obtained indicating that 26.32% and 21.49% of the soil samples were strongly polluted with Pb and Cd, respectively. In addition, 35.96%, 41.67%, and 23.68% of the soil samples were moderately polluted with Zn, As, and Cu, respectively. Moreover, 75.88% of the soil samples were not polluted with Cr (Table 6). The risk index of heavy metals in the surface soils of Ahvaz was 157.42

Table 2) Average concentration (mg/kg) of heavy metals in surface soils of Ahvaz, Iran

Element	Mean±standard deviation	Minimum (mg kg-1)	Maximum (mg kg-1)	Coefficient of variation (%)	Variance	Skewness
Lead	181±167	9.36	793.3	108	28215	1.25
Zinc	89±58	13	297	96	3394	1
Copper	185±167	8	1060	90	27822	1.7
Arsenic	9±5	0.5	270	76	24	1.2
Chromium	102±75	6	384	73	5580	1.1
Cadmium	6±8	0.01	59.4	134	57	3.5

Table 3) Results of contamination factor and pollution index

Element	Surface contamination of samples (PI)				Surface contamination of samples (CF)				
	Mean	Nonpollution n (%)	Low pollution n (%)	Moderate pollution n (%)	High pollution n (%)	Low pollution n (%)	Moderate pollution n (%)	High pollution n (%)	Severe pollution n (%)
Lead	10.65	51 (22.23)	105 (46.49)	60 (26.32)	11 (4.82)	18 (7.89)	42 (18.42)	42 (18.42)	125 (55.27)
Zinc	3.16	126 (55.7)	92 (40.35)	9 (3.95)	0	32 (14.03)	87 (38.6)	84 (36.84)	24 (10.52)
Copper	5.61	22 (9.65)	21 (9.21)	160 (70.61)	24 (10.53)	24 (10.53)	72 (31.58)	54 (23.68)	77 (34.21)
Arsenic	4.27	198 (87.28)	28 (12.28)	1 (0.44)	0	12 (5.26)	68 (29.82)	93 (41.23)	54 (23.68)
Chromium	1.04	126 (55.7)	74 (32.46)	22 (9.65)	5 (2.19)	135 (59.65)	87 (38.16)	5 (2.19)	0
Cadmium	28.13	203 (89.47)	21 (9.21)	3 (1.32)	0	17 (7.46)	35 (15.35)	11 (4.82)	164 (72.37)

PI: Pollution index

CF: Contamination factor

Table 4) Results of Nemro Integrated Pollution Index of heavy metals in surface soils of Ahvaz, Iran

NIPI			Surface contamination of samples				
Minimum	Maximum	Mean	Nonpollution n (%)	Warning line of pollution n (%)	Low pollution n (%)	Moderate pollution n (%)	High pollution n (%)
0.35	3.9	1.8	10 (4.39)	15 (6.58)	124 (54.82)	71 (31.14)	7 (3.07)

NIPI: Nemro Integrated Pollution Index

(Table 7), which was at the average level.

The highest and the lowest daily doses of heavy metals were 0.00310469 and 9.08956e⁻¹⁰ mg/kg-day related to Pb in adults through ingestion and Cd in adults through respiration, respectively (Table 8). The highest risk indices were reported for Cr and As with the values of 0.42958686 and 0.382283105 in children

through ingestion, respectively. In addition, the lowest risk index was reported as 4.76866e⁻⁸ related to Zn in adults through respiration (Table 9). The highest and lowest values of carcinogenic risk index were related to Cr in children with a value of 4.01121e⁻⁵ and Pb in adults with a value of 9.58801e⁻⁹, respectively. In case of the noncarcinogenic index, the

Table 5) Results of enrichment factor of heavy metals in surface soils of Ahvaz, Iran

Element	Mean	Surface contamination of samples				
		Low pollution n (%)	Moderate pollution n (%)	High pollution n (%)	Very high pollution n (%)	Extremely high pollution n (%)
Lead	24.49	0	0	13 (52)	8 (32)	4 (16)
Zinc	46.84	0	0	1 (4)	12 (48)	12 (48)
Copper	15.2	0	0	21 (84)	2 (8)	2 (8)
Arsenic	7.18	0	1 (4)	24 (96)	0	0
Chromium	3.21	0	24 (96)	1 (4)	0	0
Cadmium	12.96	0	0	25 (100)	0	0

Table 6) Geoaccumulation index values of heavy metal in surface soils of Ahvaz, Iran

Element	Mean	Surface contamination of samples						
		Nonpollution n (%)	Nonpollution to moderate pollution n (%)	Moderate pollution n (%)	Moderate to strong pollution n (%)	Strong pollution n (%)	Strong to extreme pollution n (%)	Extreme pollution n (%)
Lead	-1.21	32 (14.03)	31 (13.6)	39 (17.1)	42 (18.42)	60 (26.32)	24 (10.53)	0
Zinc	-1.81	41 (27.19)	61 (26.75)	82 (35.96)	23 (10.1)	0	0	0
Copper	-2.57	43 (18.86)	53 (23.25)	54 (23.68)	53 (23.25)	23 (10.1)	2 (0.88)	0
Arsenic	-2.21	27 (11.84)	53 (23.25)	95 (41.67)	52 (22.8)	1 (0.44)	0	0
Chromium	-4.61	173 (75.88)	50 (21.93)	5 (2.19)	0	0	0	0
Cadmium	-4.91	36 (15.79)	19 (8.33)	9 (3.95)	34 (14.91)	49 (21.49)	37 (16.23)	44 (19.3)

Table 7) Risk index values of heavy metals in surface soils of Ahvaz, Iran

Mean ecological risk						
Lead	Zinc	Copper	Arsenic	Chromium	Cadmium	
53.25	3.16	28.05	42.7	2.08	843.9	
Ecological risk (Risk index)			Surface contamination of samples			
Mean	Maximum	Minimum	Low n (%)	Moderate n (%)	Considerable n (%)	Very high n (%)
157.42	740.79	21.73	141 (62.28)	67 (29.39)	11 (4.82)	8 (3.51)

Table 8) Daily doses (mg/kg-day) of heavy metals among adults and children in surface soils of Ahvaz, Iran

Element	Ingestion		Respiration		Dermal contact	
	Adults	Children	Adults	Children	Adults	Children
Lead	0.00310469	0.002314027	2.92206e-08	6.49119e-08	9.45377e-06	3.70244e-06
Zinc	0.000152001	0.001132913	1.4306e-08	3.17799e-08	4.62843e-06	1.81266e-06
Copper	0.000317571	0.002366959	2.9889e-08	6.63967e-08	9.67002e-06	3.78713e-06
Arsenic	1.53871e-05	0.000114685	1.44819e-09	3.21708e-09	4.68536e-07	1.83496e-06
Chromium	0.000174267	0.001298868	1.64016e-08	3.64351e-08	5.30642e-06	2.07819e-06
Cadmium	9.65766e-06	7.19817e-05	9.08956e-10	2.01919e-09	2.94076e-07	1.15171e-07



Table 9) Hazard quotients of heavy metals among adults and children in surface soils of Ahvaz, Iran

Element	Ingestion		Respiration		Dermal contact	
	Adults	Children	Adults	Children	Adults	Children
Lead	0.088705369	0.0661150685	8.3013e-06	1.84409e-05	0.01800719	0.007052274
Zinc	0.00050667	0.003776377	4.76866e-08	1.05933e-07	7.71404e-05	3.0211e-05
Copper	0.007939263	0.059173973	7.43507e-07	1.65166e-06	0.000805835	0.000315595
Arsenic	0.05129022	0.382283105	4.67159e-06	1.03777e-05	0.003809237	0.001491837
Chromium	0.05808889	0.43295586	0.000573481	0.001273956	0.088440335	0.034636469
Cadmium	0.009657657	0.071981735	9.08956e-07	2.01919e-06	0.029407565	0.011517078

Table 10) Noncarcinogenic hazard index and carcinogenic risk index of heavy metals among adults and children in surface soils of Ahvaz, Iran

Element	Noncarcinogenic hazard index		Carcinogenic risk index	
	Adults	Children	Adults	Children
Lead	0.10672086	0.6682216	9.58801e-09	7.14626e-08
Zinc	0.000583858	0.003806694	-	-
Copper	0.008745842	0.059491219	-	-
Arsenic	0.055104128	0.383785319	1.6971e-08	1.26491e-07
Chromium	0.147102706	0.468866285	5.38176e-06	4.011121e-05
Cadmium	0.039066131	0.083500832	4.47377e-08	3.33445e-07

highest and lowest levels were 0.6682216 for Pb in children and 0.000583858 for Z in adults, respectively (Table 10).

Discussion

The average amounts of Pb, Zn, Cu, Cr, Cd, and As in the surface soils of Ahvaz were higher than the background values probably indicating the impact of activities, such as oil, gas, and steel industries, and light and heavy traffic in the study area. The levels of As, Cr, and Cd in the surface soils of Ahvaz were higher than the standard values of Iran soil; however, the levels of Pb, Zn, and Cu were lower. The average levels of As, Pb, Cr, Cu, and Cd in the surface soils of Ahvaz were higher than the global average values (i.e., 6, 35, 70, 30, and 0.35 mg/kg, respectively); nevertheless, the amount of Zn was equal to the world average value (i.e., 90 mg/kg) (23). Other studies carried out on the heavy metals in the surface soils of Aran and Bidgol, Isfahan, Iran, (6) and soils adjacent to Kerman Steel Industry in Kerman, Iran, (24) have confirmed the effects of industrial pollution on surface soils,

which is consistent with the results of the present study.

The average CF of Cd, Pb, and Cu indicated that the surface soils were severely polluted with these metals. Zn, Cr, and As had moderate, low, and high pollution, respectively. The urban environment has undergone many changes by humans to provide habitats suitable for human living conditions. Some distinctive features of such environments are the dense population and relatively high levels of change resulting from industrial activities (25). In fact, the soils of urban areas are significantly damaged due to intense human activities and may even be transported from other areas (26).

The PI of Pb, Zn, Cu, Cr, Cd, and As showed that the surface soils of Ahvaz were highly polluted, because the PI of all the studied metals was higher than 1, indicating the frequency of contamination in comparison to that of the noncontaminated site (27). The EF demonstrated that Pb, Zn, Cu, Cr, Cd, and As in the surface soils of Ahvaz were affected by human activities. The heavy metals in the soil, such as Pb, Zn, Cu, and Cd, can originate from automobile components, tire friction, grease and lubricants, industrial exhaust (i.e., smoke),

and furnaces (15).

The results of a study conducted on heavy metal pollution of road dust at Vellore, India, using EF and CF were calculated for 10 trace elements, namely Cu, Co, Cr, Ga, Mn, Ni, Pb, Rb, Sr, and Zn. Ga and Zn were reported with the highest EF and CF values (28). The average NIPI indicated low levels of metal contamination. The most important advantage of the NIPI, compared to other indices, is the determination of the pollution risk of all metals studied in the region using this index (29).

The results of the Igeo showed that Pb, Cd, As, Zn, and Cu have entered the surface soils of Ahvaz as a result of human activities and had no natural or geological origin. The CF and Igeo of the studied metals in the surface soils around Ahvaz Industrial Town No. 2 confirmed the highest amount of contamination related to Pb (30), which is in line with the findings of the present study for these two indices regarding Pb. The results of the Igeo in the agricultural soils of Kamfiruz, Fars, Iran, showed that the soil was not contaminated with Cr, Cu, Ni, Pb, and Zn; however, it was moderately contaminated with Cd and As (31). Knowledge of the concentration of heavy metals in the soil helps to discover the source of contamination in the study area (24).

According to the calculations, the highest and lowest ecological risk values were related to Cd and Cr, respectively. Other studies performed on the surface soils of Abadan, Ahvaz, Kerman, Isfahan, Birjand, Qazvin, Rasht, and Aran and Bidgol, Iran, (5, 6, 32, 10, 24, 33, 34) considered the industrial activities, traffic, and urban transportation the factors increasing heavy metal pollution in the soil. The average concentrations of Cr, Zn, Ni, Pb, Cu, and V in the soil of Ahvaz parks have been reported as 167.26, 131.92, 78.75, 51.83, 28.71, and 12.49 mg/Kg, respectively. The average concentrations of all heavy metals, except Cu and V, are several times higher than the background values. According to the

average EF and PI in the study area, Ni, Zn, and Pb highly polluted the area. In addition, the highest average Igeo is related to Ni, Zn, and Pb. The contamination sources of the studied metals are anthropogenic activities, such as traffic and fossil fuels (35). The results of the aforementioned study confirmed the contamination associated with the heavy metals of the surface soils of Ahvaz.

The results of a study carried out on the heavy metal pollution of Urabi fields in El Obour, Egypt, using CFs, degree of pollution, PLI, environmental risk index, and Igeo showed that the soil samples were not contaminated with Cr, Cu, and Pb; however, they were significantly contaminated with Cd and highly contaminated with As (14). According to the results of the present study, the daily doses of Pb, Zn, Cu, As, Cr, and Cd were obtained in children through ingestion and adults through respiration and dermal contact. In addition, the highest risk index for Cr and As was obtained through ingestion in children, and the lowest risk index for Zn was obtained through respiration in adults.

In a study conducted on the surface soils of Arak, Iran, it was reported that the daily dose of Pb through ingestion is higher for children than adults (36), which can be considered a possible reason for more children's contact with soil (37, 38). This finding is in line with the results of the present study. Ravankhah et al. (2016) also reported that the daily doses of Cd, Ni, Zn, and Cu in the soil of Aran and Bidgol through dermal contact and respiration were higher than that of Pb. In addition, carcinogenic and noncarcinogenic risks are higher in children than adults (6), which is consistent with the results of the current study.

The metal carcinogenic risk index demonstrated that the highest and lowest values of this index are observed for Cr in children and Pb in adults, respectively. The highest and lowest noncarcinogenic indices were reported for Pb in children and Zn in adults,

respectively. According to the amounts of heavy metals in the soil, the risk indices of Pb, Zn, Cu, As, Cr, and Cd were less than 1. Based on the standard of the US EPA, if the daily metal uptake is greater than the reference value of metal toxicity in each pathway, the risk of noncarcinogenic metals in each pathway will be higher than the permitted limit which has adverse effects on human health (39, 40). The reference daily intakes of Cd, Pb, Zn, and Cu are reported as 0.001, 0.3, 0.02, and 0.04 mg/kg/day, respectively (41, 42). It should be noted that in the present study, the total daily intakes of Cr, Cu, Zn, As, Pb, and Cd in humans are less than the acceptable daily intakes provided by the US EPA.

Heavy metal risk assessment in the surface soils of Bojnourd, Iran, showed that the daily exposure of children to Cu, Zn, Pb, and Cd through soil ingestion in the sampling stations resulted in the maximum daily intakes of 6.64×10^{-4} , 19.6×10^{-4} , 1.03×10^{-4} , and 4.45×10^{-6} for Cu, Zn, Pb, and Cd, respectively (5). The heavy metal health risk assessment of agricultural soils in Tangail industrial areas of Bangladesh demonstrated that the total risk index for each heavy metal in the areas was reported as less than 1, and their carcinogenic risk values were less than 10^{-6} (43). A study carried out on soil contamination by Cd, Cr, Cu, Mn, Ni, Pb, and Zn in Ijebu-Ode, Nigeria, reported the carcinogenic risk of Cu, Mn, Pb, and Zn in children and Mn, Pb, and Zn in adults as higher than the acceptable limits (13).

According to a formal risk assessment of human health using the US EPA framework, it was indicated that Pb in Kolkata, India, and Cr in Bengaluru, India, were mostly concerned among Cr, Ni, Cu, Zn, and Pb. Nevertheless, children's exposure to Pb in Kolkata was the only significant risk combination (i.e., hazard index). Contamination through ingestion dominating the risk pathways was significantly greater than that reported for dermal and inhalation routes (44).

Conclusion

The amounts of Cu, Cr, and Cd in the surface soils of Ahvaz were higher than those reported for other cities in the world. The amount of Zn in the surface soils of Ahvaz was lower, compared to those of other cities in Iran and around the world. The amounts of As, Cr, and Cd in the surface soils of Ahvaz were higher than the standard values of Iranian soil; however, the amounts of Pb, Zn, and Cu were lower. The CF, PI, and Igeo calculated in the present study showed the amounts of heavy metals in the surface soils of Ahvaz as $Cr < Zn < As < Cu < Pb < Cd$, respectively. Based on the NIPI and ecological risk, more than 50% of the surface soils of Ahvaz were reported with low pollution.

According to the obtained results, it is suggested to carry out further studies to obtain the sources of production and dispersion patterns of heavy metals in different components of the environment, especially on individuals who are directly affected. It is also recommended to perform studies on the pollution of heavy metals in other cities and alongside industrial towns and using various physical and chemical methods for the elimination of heavy metal pollution in the soil. Recently, phytoremediation has been used as a new method for the removal of soil pollution.

Footnotes

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Conflict of Interest

The authors declare that there is no conflict of interest concerning the publication of the study.

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