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Assessment of Heavy Metal Pollution and Human Health Risks Assessment in Soils Around an Industrial Zone in Neyshabur, Iran

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Abstract
Heavy metal pollution of soils in industrial zones continues to attract attention because of its potential human health risks. The present research is an attempt to assess the pollution status of heavy metals including As, Cd, Cr, Ni, and Pb using various indices like contamination factor (CF), pollution index (I_{POLL}), and geo-accumulation index (I_{geo}). In total, 60 surface soil samples were collected from four area (north, south, east, and west) in Khayyam industrial zone from depths of 10–20 cm. The results indicated that average metal concentration ranges (in mg/kg) observed in study soils were 8.84, 1.9, 37.66, 15.77, and 57.33 for As, Cd, Cr, Ni, and Pb, respectively. The concentrations of heavy metals As, Cr, Ni, and Pb with the exception of Cd in soils of southern areas of the industrial zone were higher. Cd concentration vary negligibly in sampling sites of north, south, east, and west. Based on the CF, I_{POLL}, and I_{geo} indices, the pollution of soil in regard to concentration of heavy metals was in the following order: Cd > As > Pb > Ni > Zn. Industrial activities have therefore resulted in elevated concentrations of so in the soil environments in the Khayyam industrial zone. Based on the results of human health risk assessments, the soil metals pose negligible carcinogenic and non-carcinogenic risks to the adults and children living in this area. The need for the monitoring of the soil around the industrial zone, especially for Cd and As, is needed to reduce potential environmental issues.

Keywords Soil contamination · Heavy metals · Pollution indices · Khayyam industrial zone

Introduction

There has been a great universal concern over the last 3 decades about attributing polluted environmental effects to the people health [1–3]. The World Health Organization (WHO) reports that about one fourth of the human diseases are due to the exposures of environmental pollutants [4]. Soil pollution is expressed as a phenomenon defined as the deterioration of structural and biological characteristics by the soil layers due to various human activities and natural processes, such as industrial activities, wind, deforestation, and chemical application [5]. Soil is generally regarded as the ultimate sink for heavy metals released into the environment [6]. Soil pollution of areas covered by industries is one of the greatest environmental issues whose importance is underestimated in many countries. Soil pollution is posing major issues to the environment, organisms, and humans. Iran being one of the economy-growing countries in Middle East is facing many problems to control the increasing trend of land pollution. Human activities undoubtedly create many environmental issues, which considerably affect the surrounding soil and local groundwater [7]. For example, soil of highly urbanized industrial areas and municipalities are vulnerable to a degradation processes caused by human activities. One of the major environmental effects of industry is the continuing change in the chemical quality of ecosystems situated around pollution sources. Heavy metals due to non-biodegradability and long resistance properties are among the critical contaminants in environment. Heavy metals in soil can be adsorbed by plants and enter into food chain. They also may contaminate surface and

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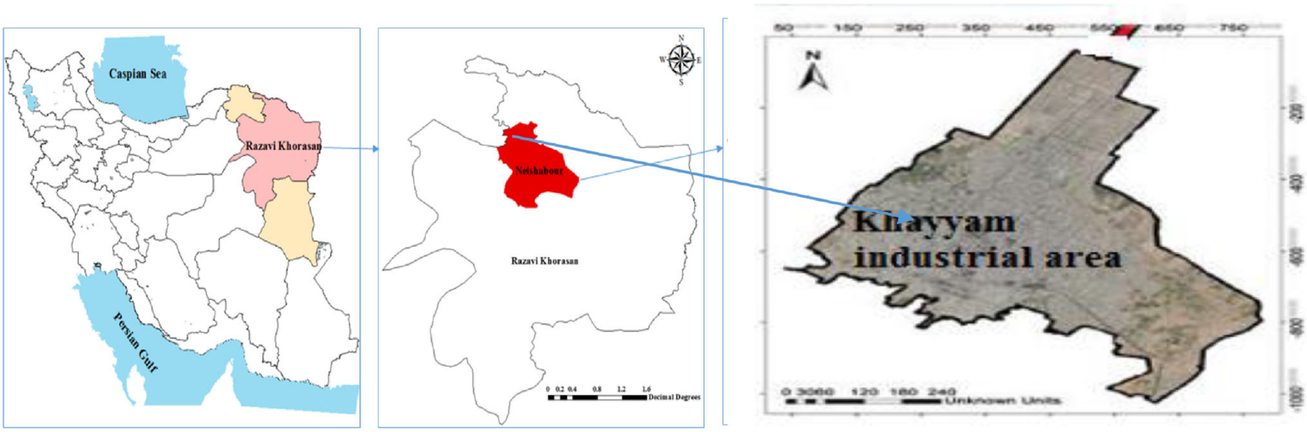

Fig. 1 The geographical location of study area in Khayyam industrial area in Neyshabur County, Iran

groundwater resources [8, 9]. Continuous release of trace elements from man-made sources result in the considerable changes in the bio-geochemical cycle of those elements [10]. Metals also can combine with organic and inorganic matters in soils and increase the toxicity of the soils [11]. Previous works reported that exposure to high concentrations of heavy metals in soils can result in numerous health problems. For example, long-term exposure to As can result in dermal lesions, skin cancer, peripheral neuropathy, and peripheral vascular problems, while long-term ingestion of Cd can have detrimental effects such as prostatic proliferative lesions, bone fractures, kidney problem, hypertension lung cancer, and pulmonary adenocarcinomas. Intake of high concentrations of Pb can damage the skeletal, circulatory, nervous, enzymatic, endocrine, and immune systems in human body [12]. Therefore, human health risk as a result of exposing soil to heavy metals should not be ignored. Investigations on the heavy metal level in soil are mostly emphasized on heavily developed regions like industrial areas and city accumulations, as well as on the regions of constant and linear emitters including industrial plants, waste landfills, and roads. Many investigations have revealed the heavy metal contamination in the soils of industrial regions [13–15]. Numerous numerical approaches have been utilized in literature to assess the quality of soil [16]. So it is of great importance to select a valid and applicable method to assess soil quality and develop a clear understanding of soil contamination for decision-making and spatial planning. Pollution indices are powerful tools for the process, analysis, and transport of raw environmental data to decision-makers, managers, health professional, and the public [17, 18]. In the present study, an assessment method for surface soils using soil heavy metal contamination caused by industrial activities is developed based on contamination factor (CF), pollution index (I_{POLL}), and geo-accumulation index (I_{geo}).

There is no published literature on heavy metal pollution of the soils around the Khayyam industrial zone in Neyshabur; therefore, the main aim of this research was to determine the concentrations of heavy metals including Pb, As, Cd, Cr, and Ni in soils lying around Khayyam industrial area in Neyshabur, to evaluate the soil pollution status and to assess the risk of these elements to the people residing in these areas. This article provides the estimation of heavy metal soil pollution by computing various pollution indices, and this study also contains helpful reference for rational planning and scientific management of industrial activities for pollution control in relation to human health risk.

Table 1 Classes of CF

CF	Category
CF < 1	Low contamination
1 ≥ CF ≥ 3	Moderate contamination
3 ≥ CF ≥ 6	Considerable
CF ≥ 6	Very high

Materials and Methods

Overview of Study Area

The Khayyam industrial zone is situated in Neyshabur City in the east of Iran, in Razavi Khorasan Province. It is an example of an area occupied by industries and exposed to numerous pollutants such as heavy metal contamination. Neyshabur has

Table 2 I_{geo} classes with respect to soil quality

Class	Value	Soil quality
0	< 0	Practically uncontaminated
1	0–1	Uncontaminated to moderately uncontaminated
2	1–2	Moderately contaminated
3	2–3	Moderately to heavily contaminated
4	3–4	Heavily contaminated
5	4–5	Heavily to extremely contaminated
6	> 5	Extremely contaminated

Table 3 Exposure factors used in this study

Factor	Definition	Unit	Value		Reference
C	Heavy metal concentration in soil	mg/kg			This study
IngR	Ingestion rate of soil	mg/day	200	100	[21]
EF	Exposure frequency	Days/year	350	350	[28]
ED	Exposure duration	Years	6	24	[21]
BW	Body weight of exposed individual	kg	15	55.9	[28]
AT	Average time	Days	365 × ED	365 × ED	[20]
InhR	Inhalation rate of soil	m^3/kg	7.6	20	[29]
PEF	Particle emission factor	m^3/kg	1.36×10^9	1.36×10^9	[21]
SA	Exposed skin surface area	cm^2	1600	4350	[28]
AF	Skin adherence factor	Mg/cm day	0.2	0.7	[30]
ABF	Dermal absorption factor	Unitless	0.001	0.001	[31]

451,780 persons and is the second most populous city in Razavi Khorasan Province. Neyshabur is influenced by the local steppe climate. In Neyshabur, there is little rainfall throughout the year. Its climate is classified as BSk by the Köppen-Geiger system. Its average yearly temperature is 12.2 °C with an average annual precipitation of 228 mm. This cross-sectional descriptive research is conducted in Khayyam industrial zone of Neyshabur in 2017. The industrial zone is located in the 20th kilometer of Neyshabur-Mashhad road and is one of the largest industrial zones in Razavi Korasan. It covers an area of 246 ha and has 144 active industries [19]. The main industries developed in this area include petrochemical, tire manufacture, plastics industry, metallurgy, and food industry. The geographical location of the study area is shown in Fig. 1.

Sampling and Analysis

All the samples were taken from local soil, which is not the subject of any form of protection. The study area was firstly divided into four areas (North, South, East, and West). In each area, 5 sites were selected. From each site, 4 soil samples were taken. The samples of each field were mixed to obtain a representative composite sample, weighting up to 1 kg. In total, 20 samples were taken from surface soil (0–20 cm) in the Khayyam industrial zone around Neyshabur City in January 2019. The sampling sites were randomly distributed to cover the entire study area. In the beginning, the collected soil samples were air-dried, crushed using a mortar, and sieved through a sieve with the mesh size of 2 mm to remove large debris, stones, sand, and pebbles, and then, they were kept in plastic bags for further analysis. Then, 1 g of a dried uniformly mixed soil was weighed. After that, 5 ml concentrated HNO_3 (65%), 15 ml HCl (37%), and 2 ml H_2O_2 were added to each soil sample, and the suspension was kept in room temperature for 24 h. The suspension was heated on a heater at 105 °C for 2 h for a complete digestion. The concentrations of Pb, As, Cd, Cr, and Ni in the different soil samples were determined with a Varian AA240 Atomic Absorption Spectrometer after acid digestion. All samples were analyzed in duplicate, and the average values were read as the concentration value for each metal.

Soil Pollution Index Methods

Pollution assessment indices are tools employed to assess the presence and intensity of anthropogenic contaminants in soils. In order to evaluate the pattern of metal contamination in the soil of study area, useful pollution indices such as the contamination factor (CF), pollution index (I_{POLL}), and geo-accumulation index (I_{geo}) were employed to compute heavy metal concentration in soils.

Contamination Factor

The estimation of soil contamination can also be performed using contamination factor (CF). CF enables the estimation of soil contamination, taking into account the concentrations of heavy metal from the soil. The contamination factor was computed using the formula proposed by Hakanson (1980):

$$CF = \frac{C_n}{C_b} \quad (1)$$

where C_n is the concentration of metals from the sampling sites and C_b is the pre-industrial concentration of individual metal (Table 1).

Pollution Index

To estimate the intensity of metal contamination in the soils around the Khayyam industrial area, the pollution index was computed using:

$$I_{POLL} = log_2(C_n/B_n) \quad (2)$$

Table 4 ABS, SF, and Rfd values used in this study [14, 25, 32, 33]

Metal	ABS	SF inh	RfD ing	RfD inh	RfD derm
As	1		3.000E-4	3.00E-04	1.23E-04
Cd	0.025	6.3	1.00E-03	1.00E-03	1.00E-05
Cr	0.013	42	3.00E-03	2.86E-05	6.00E-05
Ni	1	0.84	2.00E-02	2.00E-02	5.40E-03
Pb	1	0.42	3.50E-03	3.25E-03	5.25E-04

where C_n is the total metal concentration in soils and B_n is the lithogenous portion of metal. The interpretation of the obtained results is the same as the I_{geo}.

Geo-accumulation Index

The (I_{geo}) provides the estimation of contamination by considering the measured heavy metal concentrations and the background concentrations in the soils. It is computed by the following equation:

$$I_{geo} = \log_2\left[\frac{C_n}{1.5B_n}\right] \quad (3)$$

In the above equation, C_n is the measured metal concentration, and B_n is background concentrations of that metal obtained from the control site. A value of 1.5 is used to minimize the effect variations in the background concentrations which may be due to geological structure differences. I_{geo} classes are summarized in Table 2.

Table 6 The results of CF, I_{POLL}, and I_{geo} for all sampling stations

Index	As	Cd	Cr	Ni	Pb
CF	4.91	9.45	0.37	0.71	1.12
I_{POLL}	0.66	0.98	− 0.46	− 0.17	0.04
I_{geo}	1.00	− 0.59	3.35	3.45	2.16

Health Risk Assessment

Health risk estimation of populations for the soils around was estimated through oral, dermal, and contact pathways. In this study, the health risk methods of the United States Environmental Protection Agency (US EPA) was applied for risk assessment [20, 21]. Local residents were categorized into children and adults. The chronic daily intake (ADD) in milligrams per kilogram per day values of heavy metals (As, Cr, Ni, and Pb) through oral, dermal, and inhalation pathways can be computed using the following equations [2, 22–24]:

$$ADDing = C \times \frac{IngR \times EF \times ED}{BW \times AT} \times 10^{-6} \quad (4)$$

$$ADDinh = C \times \frac{InhR \times EF \times ED}{PEF \times BW \times AT} \quad (5)$$

Table 5 The average concentrations of heavy metals in samples collected from soils in the Khayyam industrial zone (mg/kg)

Zone		Unit	As	Cd	Cr	Ni	Pb
West	Min	mg/kg	7.426	1.50	24.37	40.55	13.55
	Max	mg/kg	10.27	1.96	28.38	43.46	19.29
	Mean	mg/kg	8.57	1.74	26.84	42.36	16.47
East	Min	mg/kg	7.90	1.53	23.90	35.07	12.52
	Max	mg/kg	12.11	2.18	39.50	59.55	17.98
	Mean	mg/kg	9.19	1.81	31.73	47.17	14.12
South	Min	mg/kg	6.31	1.81	33.18	52.38	12.00
	Max	mg/kg	25.24	2.30	102.60	160.31	18.31
	Mean	mg/kg	12.06	1.98	52.14	81.33	15.73
North	Min	mg/kg	7.86	1.74	29.88	42.24	15.55
	Max	mg/kg	10.45	2.27	45.01	67.23	17.54
	Mean	mg/kg	8.78	1.99	39.07	57.41	16.48
Total	Min	mg/kg	6.31	1.50	23.90	35.07	12.00
	Max	mg/kg	25.2	2.30	102.60	160.31	19.29
	Mean	mg/kg	8.37	1.92	34.19	52.89	15.58
Standard and background values	Dutch guideline	mg/kg	55	12	380	210	530
	G.L.C. guidelines	mg/kg	30	–	100	20	200
	US EPA	mg/kg	5	0.06	100	40	10
	Earth crust	mg/kg	1.8	0.3	90	80	12
	Shale	mg/kg	–	0.3	90	68	20

Table 7 Results of ADD and HQ values for children and adults in the study area

Group	Metal	ADDing	ADDinh	ADDderm	HQing	HQinh	HQderm
Children	AS	1.07014E-04	2.99009E-09	2.99638E-07	3.56712E-02	9.96696E-06	2.436E-03
	Cd	2.45479E-05	6.85898E-10	6.87342E-08	2.4548E-02	6.85898E-07	6.873E-03
	Cr	4.37132E-04	1.2214E-08	1.22397E-06	1.45711E02	4.270603E-04	2.04E-02
	Ni	6.76219E-04	1.88944E-08	1.89341E-06	3.3811E-02	9.17202E-07	3.51E-03
	Pb	1.99196E-04	5.56578E-09	5.5775E-07	5.691E-03	1.58119E-06	1.062E-03
Adults	AS	1.14658E-05	1.68614E-09	4.57484E-08	3.8219E-02	5.62047E-06	3.72E-04
	Cd	2.63014E-06	3.86785E-10	1.04942E-08	2.63E-03	3.86785E-07	1.049E-03
	Cr	4.68356E-05	6.88759E-09	1.86874E-07	1.5612E-02	2.40825E-04	3.115E-03
	Ni	7.24521E-05	1.06547E-08	2.89084E-07	3.623E--03	5.17219E-07	5.35E-05
	Pb	2.13425E-05	3.1386E-09	8.51564E-08	6.1E-04	8.91647E-07	1.62E-04

$$\text{ADDdermal} = C \times \frac{SA \times AF \times ABF \times EF \times ED}{BW \times AT} 10^{-6} \quad (6)$$

where IngR and InhR are the ingestion and inhalation rates, respectively; EF and ED represent exposure frequency (365 days/year) and exposure duration (6 and 30 years, respectively); SA is exposed skin area; ABF is absorption factor; BW is body weight; and AT is average timing.

The parameters used for the calculation of ADD values of heavy metals through oral, dermal, and contact pathways are given in Table 3.

In this study, the non-carcinogenic (HQ and HI) and carcinogenic (RI) risks are calculated [25]. HQ is expressed as the ratio of ADD to reference dose (Rfd) (mg/kg day) of each metal for each pathway [20]. An HQ value lower than 1 indicates no adverse health effects, while HQ more than 1 indicates that detrimental health effects are likely to occur [26]. The hazard index (HI) is equal to the sum of all expected non-carcinogenic risks (HQs) through oral, dermal, and inhalation pathways and is employed to compute the total potential non-carcinogenic risks of different contaminants through 3 exposure routes mentioned above. An HI below 1 shows that there is no significant risk of non-carcinogenic effects. If HI is above 1, then a non-carcinogenic effect is likely to occur. HI and RI values were determined using following equations [27]:

$$\text{HI} = \sum \text{HQi} = \sum \frac{\text{ADIi}}{\text{RFDi}} \quad (7)$$

$$\text{Risk (RI)} = \sum \text{ADIi} \times \text{SFi} \quad (8)$$

where SF is the corresponding slope factor in milligrams per kilogram per day. The SF value is a toxicity value that numerically shows the relationship between received dose and response. A $RI < 10^{-6}$, $RI > 10^{-4}$, and $10^{-6} > RI > 10^{-4}$ indicates low, high, and acceptable cancer risk by the US EPA, respectively [2, 25] (Table 4).

Results

Heavy Metal Concentrations in the Studied Soil Samples

Soil plays an important role in ecological stability but its quality with regard to the contents of heavy metals may

Table 8 Results of HI and RI values for children and adults in the study area

	Metal	HI	Interpretation	RI	Interpretation
Children	As	0.359158	Negligible risk		
	Cd	0.031422	Negligible risk	4.32116E-09	Negligible cancer risk
	Cr	0.166537	Negligible risk	5.12988E-07	Negligible cancer risk
	Ni	0.034163	Negligible risk	1.58713E-08	Negligible cancer risk
	Pb	0.006755	Negligible risk	2.33763E-09	Negligible cancer risk
Adults	As	0.038597	Negligible risk		
	Cd	0.00368	Negligible risk	2.43674E-09	Negligible cancer risk
	Cr	0.018967	Negligible risk	2.89279E-07	Negligible cancer risk
	Ni	0.003677	Negligible risk	8.94996E-09	Negligible cancer risk
	Pb	0.000773	Negligible risk	1.31821E-09	Negligible cancer risk

Table 9 Comparison of heavy metal concentrations measured in this study with those reported in other studies in mg/kg

Country	Measurement technique	Pb	Ni	Cr	Cd	As	Reference
China	P-AES	45.1	33.5	69.9	0.27	–	[38]
Nigeria	ICP-MS	19.32	20.09	76.44	–	–	[39]
India	AAS	43.46	2.78	1.7	0.2	–	[40]
China	ICP-AE	70.10	–	65.10	0.54	17.56	[33]
Iran	AAS	8.37	52.89	34.19	1.92	8.37	Present study

be compromised by many anthropogenic activities. The concentrations of heavy metals in soils of the Khayyam industrial zone near Neyshabur, Iran, are given in Table 5. The results showed that the concentrations of heavy metals including As, Cr, Ni, and Pb except Cd were high in the south of the industrial area. But the values of Cd did not vary.

Pollution Assessment of Heavy Metals in Soil of Study Area

The results of calculated contamination factor (CF), pollution index (I_{POLL}), and geo-accumulation index (I_{geo}) for heavy metal concentration in soil are given in Table 6.

MVSP software was applied to investigate the relationships among heavy metals. Figure 5 shows the relationships between heavy metals in the soil of the study area.

Health Risks of Local Inhabitants by Contaminated Soils

There is a growing public concern about the potential accumulation of heavy metals in soil, owing to rapid industrial development in many areas of world. The results of ADD, HQ, HI, and RI values for children and adults in the study area are given in Tables 7 and 8.

Discussion

The results of heavy metal concentrations in the study area are given in Table 1. The mean values of As, Cd, Cr, Ni, and Pb were 8.37, 1.92, 34.19, 52.89, and 15.58 mg/kg, respectively. The highest concentration of As, Cr, and Ni was observed in the south. For Pb, the lowest amount was measured in the east because there was no transport road in the east. The concentration of Pb did not vary significantly in other areas. To evaluate the status of soil pollution with heavy metals due to human activities, the concentrations should be compared with the soil composition of the geology and background levels of metals in unaffected areas by human activities [32, 34]. Because the geology and soil composition of earth vary in different regions and areas. There is no a separate standard for evaluation of the degree of soil contamination in Iran; therefore, the standards of other countries were used. In this study, the concentrations of heavy metals As, Cd, and Pb were higher than their mean concentrations in earth crust [35]. But As and Pb were above the US EPA standards. The mean values of heavy metal concentrations in this work are compared with the results obtained in other areas of Iran. The results showed that the concentrations of metals in the Khayyam industrial area were higher than those other related studies in Iran. The concentrations of Cd, Cr, Ni, and As are higher than those reported in Kerman and Qaemshahr [36, 37]. But concentrations of Cr, Pb, and As in Qaemshahr and Shahroud were higher than in the present study [37]. The high

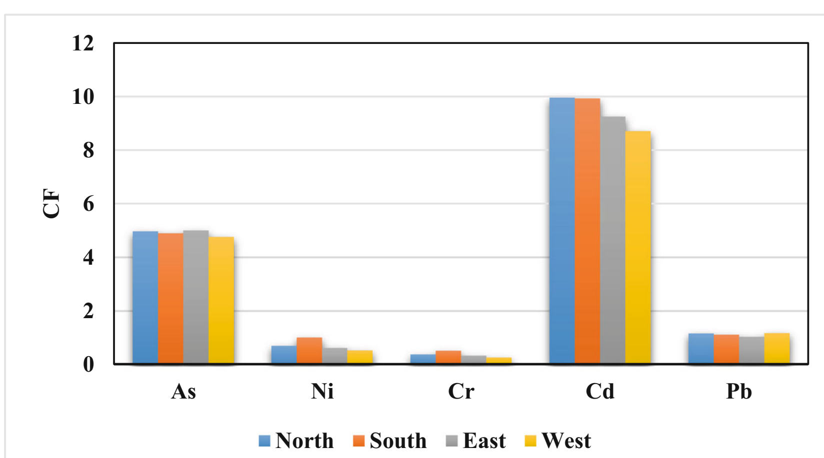

Fig. 2 The graph of mean values CF in the study area

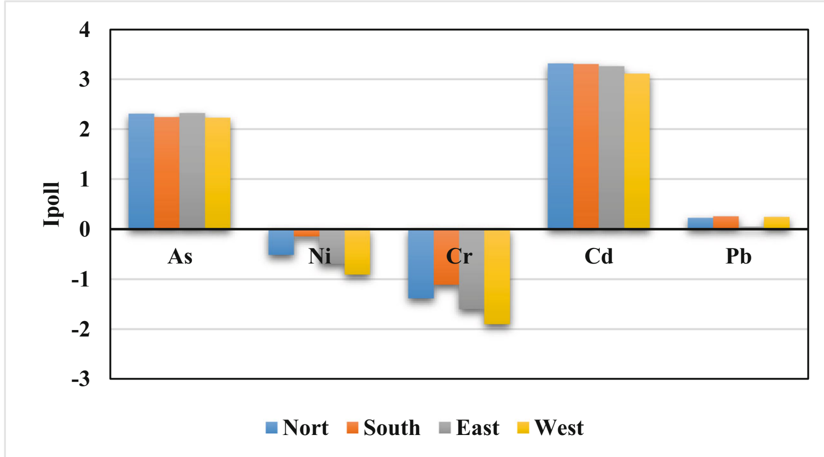

Fig. 3 The graph of mean values of I_{POLL} in the study area

concentrations of metals in this study are due to long-term industrial activities in the area. Some studies in other countries are summarized in Table 9.

For the evaluation of soil contamination to heavy metals, CF, I_{POLL}, and I_{geo} indices were employed. Based in the Fig. 2, the CF values were considerable for As, high for Cd, moderate for Pb, and low for Cd and Ni. The soils were moderately contaminated for As and moderately-to-heavily contaminated for Cd considering the I_{geo}. This index was in practically uncontaminated category for other metals (Figs. 3 and 4).

According to the I_{POLL}, the Cd and As contamination was heavy. For As, it was in moderately-to-heavily contaminated category. The index indicated unpolluted-to-moderately unpolluted region for Pb (Fig. 3). According to the study of relations between heavy metals, the dendrogram (Fig. 5) showed no relations between Cr and Ni and other studied metals. However, Cr and Ni showed a positive relation indicating these metals have a similar resource. Moreover, the positive relation was observed for Cd, As, and Pb. Furthermore, according to the outcomes of human health risk valuations, the soil metals pose insignificant carcinogenic and non-carcinogenic risks to the adults and children living in this region. The higher levels of the risks were observed in the children. It is likely that the differences of the physiology, developmental stages, and behavior of children contributed to these higher assessed exposure values. There are different routes that a chemical can enter the human body from the environment; specifically, it may be ingested, inhaled, and absorbed via the skin. In our study, the importance of the three different exposure pathways for the metals decreased in the following order: ingestion > skin contact > inhalation. These results are consistent with the results of previous works [31, 41, 42].

Nwankwoala et al. studied contamination indices and heavy metal concentrations in soils of Okpoko, Southeastern Nigeria. PLI and I_{geo} showed that the soils are heavily polluted from the activities at the fuel filling and service stations in the area [43]. Kabir et al. investigated the status of trace metal pollution in soils affected by industrial activities. The results of their study indicated that soils were polluted most significantly by metals such as Pb, Zn, Cu, and Cd. In most cases, metal concentrations in the sampled areas were found to exceed the standard levels regulated by many nations. The I_{geo} calculated to evaluate the enhancement of metal levels in soil

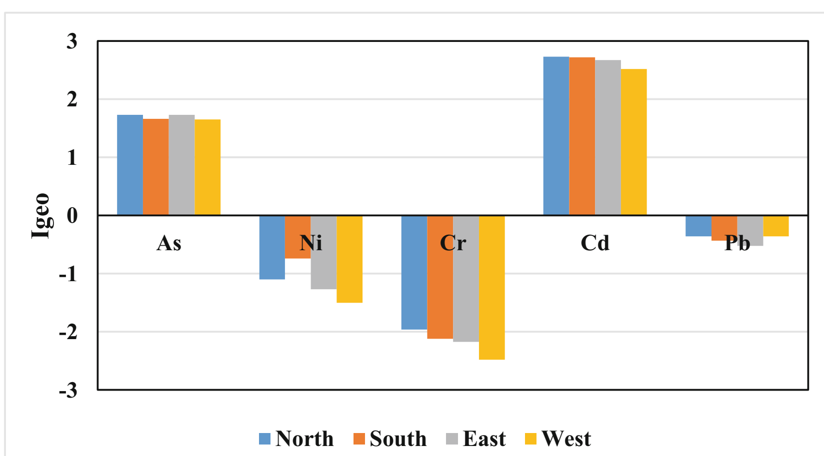

Fig. 4 The graph of mean values of I_{geo} in the study area

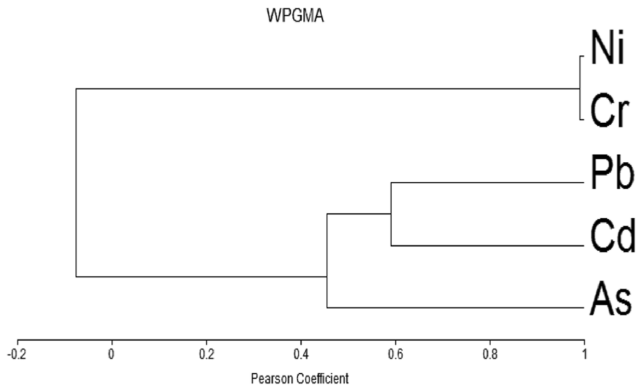

Fig. 5 Dendrogram of cluster analysis among heavy metals in soil

revealed that the level of metal contamination in most investigation fields was important, particularly for Pb and Cd [44]. Parizanganeh et al. assessed heavy metal (Pb, Zn, and Cd) pollution in surficial soils surrounding zinc industrial complex in Zanjan, Iran. The major sources for the heavy metal contamination in studied area were most possibly emissions from zinc factory. Pb, Zn, and Cd concentrations up to 63, 3066, 18.5 mg/kg were determined in most sampling areas [45]. Mohamed et al. used pollution indices for evaluation of heavy metals in soil close to phosphate fertilizer plant, Assiut in Egypt. Results of soil analysis indicated that the area has been considerably affected by the heavy metals as follows: Cd, Cu, Pb, and Zn, and their average concentrations were 0.3, 57.0, 94.7, and 80.7 mg/kg, respectively. The heavy metal concentrations were higher than the levels in soil background (0.013 mg/kg for Cd, 9.62 mg/kg for Cu, 5.17 mg/kg for Pb, and 11.56 mg/kg for Zn) obtained from an unaffected area far from industrial activities and also were above the international standards for soil pollution suggested by the WHO. The estimated results of contamination indices (I_{geo}, EF, and I_{POLL}) showed that the studied area lies under the class of high pollution. Generally, the study area was highly affected by emissions from the fertilizer plant [46]. Sun et al. investigated the levels, sources, and spatial distribution of heavy metals (Zn, Pb, Cd, Hg, and Cu) in soils from a typical coal industrial city of Tangshan, China. The concentrations of metals were below the guideline values. However, accumulation of Zn, Pb, Cd, Hg, and Cu in the surface soils, and Zn, Cu, Cd, and Hg in the sub-surface soils, was observed compared with their background values. The I_{geo} and CF reported that most of collected soil samples were slightly-to-moderately polluted by some metals such as Hg and Cd. Industrial activities, wastewater irrigation and use of agrochemicals, and vehicle emission were the possible man-made sources of heavy metals [47]. Wu et al. assessed the heavy metal (Cr, Cu, Zn, As, Cd, Ni, and Pb (pollution and human health risks in urban soils around an electronics manufacturing facility in China. The total concentrations of the 7 metals (∑metals) was in the range of 3738.86–5173.25 mg/kg, and the concentrations were highest in the commercial area followed (in decreasing order) by the roadside, farmland, and residential areas. The HI values for children and adults were in the following order: Cr > As > Pb > Cd > Cu > Ni > Zn. The carcinogenic risks of two metals, namely, Cr and As, for children and adults were above 10^{-4}, and children were exposed to higher health risks [42].

Conclusions

Soil heavy metal pollution has become a serious problem to human health and environment in many regions of the world. Industries are one of the anthropogenic activities that have contributed to increased concentrations of many heavy metals which eventually find their way into surrounding environments and soil. In this research, heavy metal concentrations in soils of the Khayyam industrial zone were measured and heavy metal soil pollution indices and also health risk assessment were investigated. The CF values were considerable for As, high for Cd, moderate for Pb, and low for Cd and Ni. The soils were moderately contaminated for As and moderately-to-heavily contaminated for Cd considering the I_{geo}. According to the I_{POLL}, the Cd and As were heavy. For As, it was in moderately-to-heavily contaminated category. The index showed uncontaminated-to-moderately uncontaminated area for Pb. In this study, the concentrations of heavy metals As, Cd, and Pb were higher than their mean concentrations in the earth crust and As and Pb were above the US EPA standards, implying the accumulation of these elements in soils. These results indicated that industrial activities probably have a considerable effect on the heavy metal accumulation and distribution in soils in the study zone, calling for the attention and actions of the prevention and minimization of heavy metal contamination in soils of the Khayyam industrial zone. In addition, based on the results of human health risk assessments, the soil metals pose negligible carcinogenic and non-carcinogenic risks to the adults and children living in the study area. This study presents useful information regarding soil heavy metal contamination in an industrial area for the identification of the major contamination sources and also provides the risk assessment of heavy metal contamination to the inhabitants.

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Compliance with Ethical Standards

Conflict of Interest The authors declare that they have no conflict of interest.

References

1. Saleh HN, Panahande M, Yousefi M, Asghari FB, Conti GO, Talaee E, Mohammadi AA (2019) Carcinogenic and non-carcinogenic risk assessment of heavy metals in groundwater wells in Neyshabur Plain, Iran. Biol Trace Elem Res 190(1):251–261
2. Qasemi M, Shams M, Sajjadi SA, Farhang M, Erfanpoor S, Yousefi M, Zarei A, Afsharnia M (2019) Cadmium in groundwater consumed in the rural areas of Gonabad and Bajestan, Iran: occurrence and health risk assessment. Biol Trace Element Res 1-10 https://doi.org/10.1007/s12011-019-1660-7
3. Mohammadi AA, Yousefi M, Soltani J, Ahangar AG, Javan S (2018) Using the combined model of gamma test and neuro-fuzzy system for modeling and estimating lead bonds in reservoir sediments. Environ Sci Pollut Res 25(30):30315–30324
4. Basma G, Alhogbi AFA (2017) Soil pollution: a case study on the determination of toxic elements in soil in Jeddah City. Saudi Arabia Can Center Sci Educ 9(2):37–44
5. Esmaeilzadeh M, Jaafari J, Mohammadi AA, Panahandeh M, Javid A, Javan S (2019) Investigation of the extent of contamination of heavy metals in agricultural soil using statistical analyses and contamination indices. Human Ecol Risk Assess: An International Journal 25(5):1125–1136
6. Qingjie G, Jun D, Yunchuan X, Qingfei W, Liqiang Y (2008) Calculating pollution indices by heavy metals in ecological geochemistry assessment and a case study in parks of Beijing. J China Univ Geosci 19(3):230–241
7. Miri M, Akbari E, Amrane A, Jafari SJ, Eslami H, Hoseinzadeh E, Zarrabi M, Salimi J, Sayyad-Arbabi M, Taghavi M (2017) Health risk assessment of heavy metal intake due to fish consumption in the Sistan region, Iran. Environ Monit Assess 189(11):583
8. Varol M (2011) Assessment of heavy metal contamination in sediments of the Tigris River (Turkey) using pollution indices and multivariate statistical techniques. J Hazard Mater 195:355–364
9. Diagomanolin V, Farhang M, Ghazi-Khansari M, Jafarzadeh N (2004) Heavy metals (Ni, Cr, Cu) in the karoon waterway river, Iran. Toxicol Lett 151(1):63–67
10. Shadborestan A, Khaksar E, Shokrzadeh M, Taghavi M (2013) Cadmium, lead and chromium contents in rice (champa) produced in the Mobarakeh county in 2009. J Mazandaran Univ Med Sci 22(2):122–127
11. Imperato M, Adamo P, Naimo D, Arienzo M, Stanzione D, Violante P (2003) Spatial distribution of heavy metals in urban soils of Naples city (Italy). Environ Pollut 124(2):247–256
12. Zhou H, Guo X (2015) Soil heavy metal pollution evaluation around mine area with traditional and ecological assessment methods. J Geosci Environ Protect 3(10):28–33
13. Szolnoki Z, Farsang A, Puskás I (2013) Cumulative impacts of human activities on urban garden soils: origin and accumulation of metals. Environ Pollut 177:106–115
14. Karim Z, Qureshi BA, Mumtaz M, Qureshi S (2014) Heavy metal content in urban soils as an indicator of anthropogenic and natural influences on landscape of Karachi—a multivariate spatio-temporal analysis. Ecol Indic 42:20–31
15. Mahmoudabadi E, Sarmadian F, Moghaddam RN (2015) Spatial distribution of soil heavy metals in different land uses of an industrial area of Tehran (Iran). Int J Environ Sci Technol 12(10):3283–3298
16. Cheng J-l, Zhou S, Zhu Y-w (2007) Assessment and mapping of environmental quality in agricultural soils of Zhejiang Province, China. J Environ Sci 19(1):50–54
17. Caeiro S, Costa MH, Ramos T, Fernandes F, Silveira N, Coimbra A, Medeiros G, Painho M (2005) Assessing heavy metal contamination in Sado Estuary sediment: an index analysis approach. Ecol Indic 5(2):151–169
18. Qasemi M, Farhang M, Biglari H, Afsharnia M, Ojrati A, Khani F, Samiee M, Zarei A (2018) Health risk assessments due to nitrate levels in drinking water in villages of Azadshahr, northeastern Iran. Environ Earth Sci 77(23):782
19. Alidadi H, Mohammadi AA, Najafpoor AA, Dehghan A, Zamand S, Taghavimanesh V (2019) Survey of wastes management status of Khayyam industrial estate in Neyshabur City (Northeastern Iran) in 2017. MethodsX 6:482–491
20. US EPA UEPA (1989) Risk assessment guidance for Superfund. Human Health Evaluation Manual Part A. Office of Health and Environmental Assessment, Washington, DC. .
21. US EPA (2001) Baseline human health risk assessment.VasquezBoulevardandI-70 superfund site Denver, Denver (Co).
22. Jafari A, Ghaderpoori M, Kamarehi B, Abdipour H (2019) Soil pollution evaluation and health risk assessment of heavy metals around Douroud cement factory, Iran. Environ Earth Sci 78(8):250
23. Jamal A, Delavar MA, Naderi A, Nourieh N, Medi B, Mahvi AH (2019) Distribution and health risk assessment of heavy metals in soil surrounding a lead and zinc smelting plant in Zanjan, Iran. Human Ecol Risk Assess: An International Journal 25(4):1018–1033
24. Djahed B, Taghavi M, Farzadkia M, Norzaee S, Miri M (2018) Stochastic exposure and health risk assessment of rice contamination to the heavy metals in the market of Iranshahr, Iran. Food Chem Toxicol 115:405–412
25. Wei X, Gao B, Wang P, Zhou H, Lu J (2015) Pollution characteristics and health risk assessment of heavy metals in street dusts from different functional areas in Beijing, China. Ecotoxicol Environ Saf 112:186–192
26. Qasemi M, Afsharnia M, Farhang M, Bakhshizadeh A, Allahdadi M, Zarei A (2018) Health risk assessment of nitrate exposure in groundwater of rural areas of Gonabad and Bajestan, Iran. Environ Earth Sci 77(15):551
27. Omidi F, Dehghani F, Fallahzadeh RA, Miri M, Taghavi M, Eynipour A (2019) Probabilistic risk assessment of occupational exposure to volatile organic compounds in the rendering plant of a poultry slaughterhouse. Ecotoxicol Environ Saf 176:132–136
28. Environmental site assessment guideline (2009) DB11/T656-2009. (In Chinese).
29. Huma-Khan N, Nafees M, Bashir A (2016) Study of heavy metals in soil and wheat crop and their transfer to food chain. Sarhad Journal of Agriculture 32(2):70–79
30. US EPA (1993) Reference dose (RfD): description and use in health risk assessments. Background Document1 A. Integratedriskinformationsystem (IRIS).
31. Chabukdhara M, Nema AK (2013) Heavy metals assessment in urban soil around industrial clusters in Ghaziabad, India: probabilistic health risk approach. Ecotoxicol Environ Saf 87:57–64
32. Afshari A, Khademi H, Delavar M (2015) Heavy metals contamination assessment in soils of different land uses in central district of Zanjan province using contamination factor. Water Soil Sci (Agricultural Sciences) 25(4/2):41–52
33. Li X, Liu L, Wang Y, Luo G, Chen X, Yang X, Hall MH, Guo R, Wang H, Cui J (2013) Heavy metal contamination of urban soil in an old industrial city (Shenyang) in Northeast China. Geoderma 192:50–58
34. Blaser P, Zimmermann S, Luster J, Shotyk W (2000) Critical examination of trace element enrichments and depletions in soils: As, Cr, Cu, Ni, Pb, and Zn in Swiss forest soils. Sci Total Environ 249(1-3):257–280
35. Taylor S (1964) Abundance of chemical elements in the continental crust: a new table. Geochim Cosmochim Acta 28(8):1273–1285
36. Sistani N, Moeinaddini M, Khorasani N, Hamidian A, Ali-Taleshi M, Azimi Yancheshmeh R (2017) Heavy metal pollution in soils

nearby Kerman steel industry: metal richness and degree of contamination assessment. Iran J Health Environ 10(1):75–86
37. Soleimannejad Z, Abdolzadeh A, Sadeghipour HR (2016) Heavy metal concentrations in industrial area soils and landfill site, Ghaemshahar, Iran. J Mazandaran Univ Med Sci 26(136):196–201
38. Qing X, Yutong Z, Shenggao L (2015) Assessment of heavy metal pollution and human health risk in urban soils of steel industrial city (Anshan), Liaoning, Northeast China. Ecotoxicol Environ Saf 120: 377–385
39. Kolo MT, Khandaker MU, Amin YM, Abdullah WHB, Bradley DA, Alzimami KS (2018) Assessment of health risk due to the exposure of heavy metals in soil around mega coal-fired cement factory in Nigeria. Results in Physics 11:755–762
40. Harikumar P, Jisha T (2010) Distribution pattern of trace metal pollutants in the sediments of an urban wetland in the southwest coast of India. Int J Eng Sci Technol 2(5):840–850
41. Lin Y, Fang F, Wang F, Xu M (2015) Pollution distribution and health risk assessment of heavy metals in indoor dust in Anhui rural, China. Environ Monit Assess 187(9):565
42. Wu W, Wu P, Yang F, Sun D-L, Zhang D-X, Zhou Y-K (2018) Assessment of heavy metal pollution and human health risks in urban soils around an electronics manufacturing facility. Sci Total Environ 630:53–61
43. Nwankwoala H, Ememu A (2018) Contamination indices and heavy metal concentrations in soils in Okpoko and Environs, Southeastern Nigeria. J Environ Sci Public Health 2(2):77–95
44. Kabir E, Ray S, Kim K-H, Yoon H-O, Jeon E-C, Kim YS, Cho Y-S, Yun S-T, Brown RJ (2012) Current status of trace metal pollution in soils affected by industrial activities. Sci World J 2012:1–18. https://doi.org/10.1100/2012/916705
45. Parizanganeh A, Hajisoltani P, Zamani A (2010) Assessment of heavy metal pollution in surficial soils surrounding Zinc Industrial Complex in Zanjan-Iran. Procedia Environ Sci 2:162–166
46. Mohamed TA, Mohamed MAK, Rabeiy R, Ghandour MA (2014) Application of pollution indices for evaluation of heavy metals in soil close to phosphate fertilizer plant, Assiut, Egypt. Assiut Univ Bull Environ Res 17(1):45–55
47. Lu Sun DG, Liu K, Meng H, Zheng Y, Yuan F, Zhu G (2018) Levels, sources, and spatial distribution of heavy metals in soils from a typical coal industrial city of Tangshan, China. Catena 175:101–109