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ORIGINAL ARTICLE

Soil pollution evaluation and health risk assessment of heavy metals around Douroud cement factory, Iran

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Abstract
Industrial activates have contaminated the soils around the industries to some pollutants such as heavy metals. Nowadays, among the different industries, cement factories are of major environmental pollutant sources. Therefore, the main objective of this study was to evaluate the soil pollution to heavy metals around Douroud cement factory in terms of geo-accumulation index, pollution index, and integrated pollution index. Also, a health-risk assessment was carried out. Sampling was performed at intervals of 500 m, 1250 m, and 2000 m from the factory site. Soil samplings were taken from the depths of 0–10 cm and 10–20 cm from the top surface. The health-risk assessment regarding soil around the factory was assessed based on the USEPA procedure. The study results showed that the average concentrations of chromium, nickel, copper, lead and zinc in the soil around the cement factory were 115.77 mg/kg, 139.07 mg/kg, 80.47 mg/kg, 56.27 mg/kg, and 135.73 mg/kg, respectively. Also, the results showed that the concentration of the heavy metals in the top soil was significantly higher than subsurface sampling layers. Furthermore, the findings showed that the concentrations of all evaluated heavy metals were higher than the USEPA standard. The pollution index values in the soil around the cement factory were Cu > Pb > Zn > Ni > Cr. Based on this study, the daily intake rate of all the elements by oral ingestion route was higher than the inhalation and dermal contact routes. The hazard quotient values of all metals in all studied sampling points were < 1.

Keywords Health-risk assessment · Soil pollution · Cement factory · Doroud · Iran · Heavy metals

List of symbols

I_{geo}	Geo-accumulation index
B_n	The geochemical background concentration of the metal
C_n	The measured concentration of the metal in sediment
PI	The pollution index,
C	The concentration of each heavy metal (mg/kg)
B	The background value (mg/kg)
IPI	The mean values for all the PIs of all studied metals
RI	Computed as the sum of all 6 risk factors for heavy metals in soils,
E_i	The monomial potential ecological risk factor for individual factors
f_i	The metal pollution factor
T_i	The metal toxic factor
C_i	The concentration of metal in the street dust
C_b	The reference value of a given metal
C_n	The concentration of each heavy metal in samples (mg/kg)
B_n	The background concentration (mg/kg)
AD_{ing}	The average daily intake of heavy metals ingested from soil (mg/kg-day)
AD_{inh}	The average daily intake of heavy metals inhaled from soil (mg/kg-day)
AD_{der}	The exposure dose via dermal contact from soil (mg/kg-day)
ABS	Absorption Factor
AF	Adherence Factor (mg/cm^2)
AT	Averaging time (day)
BW	Body weight (kg)
CF	Conversion factor (kg/mg)
ED	Exposure duration (year)
EF	Exposure frequency (day/year)
PEF	Particle emission factor (m^3/kg)
SA	Exposed skin surface area (cm^2)

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IR_{ing}	Ingestion rate (mg/day)
IR_{inh}	Inhalation rate (mg/day)
HQ	Hazard quotient
HQ_{ing}	Hazard quotient through inhalation pathway
HQ_{inh}	Hazard quotient through dermal contact pathway
HQ_{total}	Hazard quotient through all pathway
RfD	The corresponding reference doses
RfD_{inh}	The corresponding reference dose through inhalation pathway
RfD_{der}	The corresponding reference dose through dermal contact pathway
SF	The slope factor of the contaminant
SF_{inh}	The slope factor of the contaminant through inhalation pathway
HI	Hazard index
ICP-OES	Inductively coupled plasma-optical emission spectrometry
USEPA	United States Environmental Protection Agency

Introduction

In recent years, the environmental pollution by heavy metals has increased. Rapid industrial development, especially in developing countries, has caused serious soils contamination around the industries (Fakhri et al. 2018). Generally, heavy metals may release to the environment through industrial activities, fertilizers, pesticides, solid waste disposal, irrigation with effluents, sludge application, and automobile exhausts (Qasemi et al. 2018a, b; Kamani et al. 2017; Princewill and Adanma 2011; Afsharnia et al. 2018). Cement factories are one of the most common sources of pollutants including heavy metals. Actually, cement factories mainly contribute to environmental pollution by heavy metals through the emission of cement dusts and various gasses (Adejoh 2016; Maina et al. 2013; Rezaeian and Moghadam 2016). According to the studies, cement dust is a major source of released heavy metals and one of the most important sources of surrounding soil pollution in different countries, especially developing countries (Addo et al. 2012; Mandal and Voutchkov 2011). The most common metals in cement dust are Al, Be, Cr, Cu, Mn, Ni, Zn, As, Cd, Pb, and Hg (Adejoh 2016). Based on the findings of Khashman and Shawabkeh, the concentrations of Pb, Zn, and Cd were significantly higher in soils around the cement factory (Al-Khashman and Shawabkeh 2006). The results of Semhi et al. study also showed that the concentrations of heavy metals in the radius of 500–2000 m around a cement factory were higher (Hong-gui et al. 2012; Semhi et al. 2010). High accumulation of heavy metals in agricultural soils around a cement factory may result in increase of heavy metal uptake through food crops consumption and a great concern of potential health risk to human (Adejoh 2016). Pollution index methods for heavy metals have been widely used to evaluate the soil health quality (Zhong et al. 2010). The main objective of this study was to evaluate the soil pollution to heavy metals around a cement factory with geo-accumulation index (I_{geo}), pollution index (PI), and integrated pollution index (IPI) and to assess the related health risk.

Materials and methods

Study area

Doroud cement factory is located in southwest of Iran at Lorestan province (33°29′N; 49°4′E). Actually, the factory is located in the city centre and adjacent to residential areas. Figure 1 shows the location of the factory. The factory has three main units, which were established in 1959, 1969, and 1989, respectively. Also, the nominal capacity of cement production in these units is 400 ton/day, 1000 ton/day and 2500 ton/day, respectively. These units work in a dry method and can produce type I, type II, and type IV cement (Farhadi et al. 2017; Nourmoradi et al. 2016).

Sample collection and preparation

All soil samples were taken around the cement factory at the direction of the dominant winds. Based on other studies, sampling was performed at intervals of 500 m, 1250 m, and 2000 m from the main factory site (Addo et al. 2012). Soil samplings were taken from depths of 0 to 10 cm and 10 to 20 cm from the soil surface. Before measuring the concentration of heavy metals, the samples were digested using an acidic solution (HCl: HNO_3, in a 1:3 volume ratio) (Okoro et al. 2017) and prepared (Princewill and Adanma 2011). For digestion, 1 g of each soil sample was added to 10 ml nitric acid and 3 ml chloric acid and then heated until boiling. After that, the soil solution was prepared by processing the residue with 4 ml of hot HCl (5 Molar). The digested was filtered into 50 ml volumetric flask and diluted with double-distilled water. A triplicate digestion of each soil sample was carried out. A blank (digest without the soil sample) was also used to remove the errors relating to possible materials and method. Finally, the concentrations of heavy metals in the solution were quantified using an ICP-OES (Instrument Model: Varian VISTA-MPX) (Kamani et al. 2017).

Indices to assess soil enrichment with heavy metals in the study area

Generally, to assess the status the soils, there are several indices. Table 1 shows the most important indices for

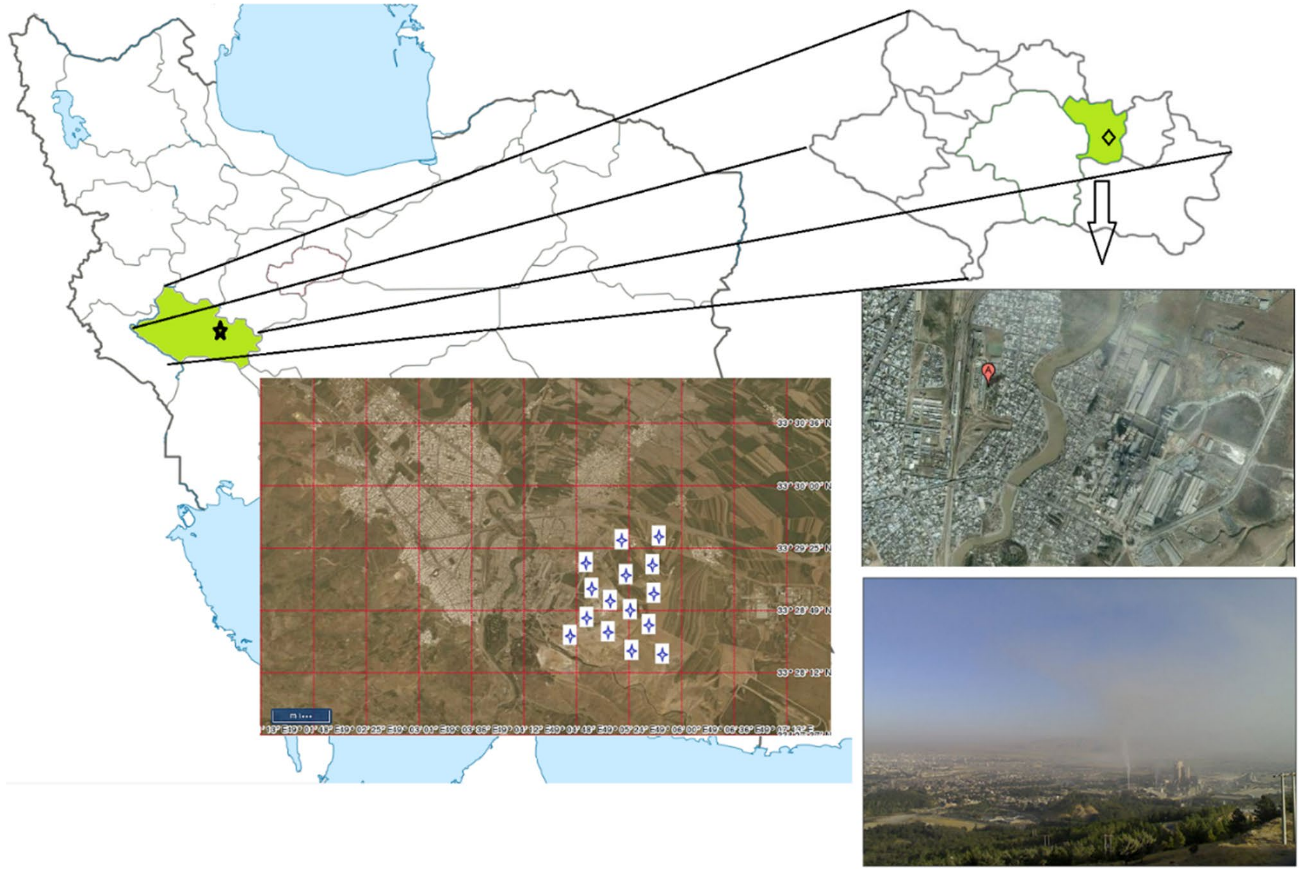

Fig. 1 Location of Doroud cement factory

describing the soil contamination to heavy metals. There are two common ways to monitor a soil in terms of enrichment: I_{geo} and EF (Kamani et al. 2017; Qingjie et al. 2008). I_{geo} was developed by Müller indicating the degree of soil contamination. Muller has considered six classes for I_{geo} (Muller 1969) as shown in Table 1. There are two important indices describing the quality of the soil environment including PI and IPI (Malkoc et al. 2010). In this work, these indices were applied to assess the degree of metal pollution around the cement factory. Both these indicators have four degrees of pollution (Table 1).

Health-risk assessment

The health-risk assessment of heavy metals in the soil is a multi-step process and categorized into carcinogenic and non-carcinogenic effects (Qasemi et al. 2018a, b; Ghaderpoori et al. 2018a, b; Jafari et al. 2017). In both the carcinogenicity and non-carcinogenicity risk assessments, all three routes of human exposure to heavy metals (i.e. oral ingestion, inhalation, and dermal absorption) are considered. In this work, the health-risk assessment of the heavy metal in the soil was evaluated based on the USEPA method (Keramati et al. 2018; Karim 2011; Ravankhah et al. 2016). The equations used to calculate the health-risk assessment are shown in Table 1. The input variables and their values for calculating the health-risk assessment through oral ingestion, inhalation, and dermal absorption are also presented in Tables 2 and 3, respectively.

Statistical analysis

Data obtained in this study were evaluated using statistical analyses to determine the distribution of data obtained from One-Sample Kolmogorov–Smirnov test. Determination of the relationship between heavy metals concentration and distance from the source of contamination was performed using Analysis of variance (ANOVA).

Results and discussion

The results of measuring the concentration of heavy metals based on the distance from the source and the sampling depths are shown in Table 4. The results showed that the average concentrations of chromium, nickel, copper, lead

Table 1 Formulas used in this study (Rezaei et al. 2018; Ghaderpoori et al. 2018a, b; Chen et al. 2005; Hosseini et al. 2016; Ravankhah et al. 2016; Wan et al. 2016)

Indices	Formula	Contamination level
Geo-accumulation index (Igeo)	$I_{geo} = \log_2(\frac{C_n}{1.5B_n})$	≤ 0, uncontaminated 0 < I ≤ 1, uncontaminated to moderately contaminated 1 < I ≤ 2, moderately contaminated 2 < I ≤ 3, moderately to heavily contaminated 3 < I ≤ 4, heavily contaminated 4 < I ≤ 5, heavily to extremely contaminated I > 5, extremely contaminated
PI	$\mathrm{PI} = \frac{C_n}{B_n}$	PI < 1, low 1 ≤ PI < 3, moderate 3 ≤ PI < 6, considerable PI ≥ 6, very high
IPI	IPI is the mean value for all PIs of all studied metals	IPI ≤ 1, low 1 < IPI ≤ 2, moderate 2 < IPI ≤ 5, high IPI > 5, extreme
Exposure dose (through ingestion)	$\mathrm{AD_{ing}} = \frac{C \times \mathrm{IR_{ing}} \times F \times \mathrm{EF} \times \mathrm{ED} \times \mathrm{CF}}{\mathrm{BW} \times \mathrm{AT}}$	
Exposure dose (through inhalation)	$\mathrm{AD_{ing}} = \frac{C \times \mathrm{IR_{ing}} \times F \times \mathrm{EF} \times \mathrm{ED}}{\mathrm{PEF} \times \mathrm{BW} \times \mathrm{AT}}$	
Exposure dose (through dermal adsorption)	$\mathrm{AD_{ing}} = \frac{C \times \mathrm{CF} \times \mathrm{SA} \times \mathrm{AF} \times \mathrm{ABS} \times F \times \mathrm{EF} \times \mathrm{ED}}{\mathrm{BW} \times \mathrm{AT}}$	
Hazard quotient	$HQ = \frac{AD}{RfD}$	
Hazard index	$\mathrm{HI} = \sum_{i=1}^{i} \mathrm{HO}i$	

Table 2 Parameters applied in exposure assessment model (Wan et al. 2016)

Parameter	Carcinogenic effects	Non-carcinogenic effects
ABS	0.01	0.01
AF	0.07	0.07
AT	25,550	14,600
BW	70	70
CF	0.000001	0.000001
ED	50	40
EF	250	250
F	0.0694	0.0694
PEF	1,360,000,000	1,360,000,000
SA	4350	4350
$\mathrm{IR_{ing}}$	100	100
$\mathrm{IR_{inh}}$	20	20

and zinc in the top soil around the cement factory were 115.77, 139.07, 80.47, 56.27, and 135.73 mg/kg, respectively. In this study, the highest concentration was related to nickel. Also, the results showed that the concentration of heavy metals in the soil top layer, 0–10 cm, was significantly higher than that of the depth of 10–20 cm, ($P_{\mathrm{value}} < 0.05$). The findings of Olowoyo et al. showed that the concentration of heavy metals measured at depth of 0–15 cm is higher than that of depth of 15–30 cm (Olowoyo et al. 2015). Also, the Khashman et al. results showed that the concentration of heavy metals, especially zinc metal, was higher at the yaer of 0–19 cm, in the soils around a cement factory (Kashem et al. 2007). The results of Okoro et al. showed that in the soil around a cement factory in Ewekoro, the order of mean concentrations of the heavy metals content in the three soil samples was Fe > Zn > Mn > Cr > Cu > Pb (Okoro et al. 2017). Based on the results of these studies, it can be said that the existence of industries such as the cement plant can significantly increase the concentration of heavy metals in the surrounding soil. Similar results were reported by Mandal et al. and Princewill et al. (Mandal and Voutchkov 2011; Princewill and Adanma 2011). The findings of Addo et al. indicated that the concentration of most heavy metals was above the background and critical limits for soil and vegetation, respectively (Addo et al. 2012). To understand the complexity of the distribution of heavy metals in the

Table 3 The reference RfD and SF of heavy metals (Wan et al. 2016)

	RfD_{ing} (mg kg^{-1} day^{-1})	RfD_{inh} (mg kg^{-1} day^{-1})	RfD_{der} (mg kg^{-1} day^{-1})	SF_{inh} (kg day mg^{-1})
Cr	3.00E–03	2.86E–05	6.00E–05	4.10E+01
Ni	2.00E–02	2.06E–02	5.40E–03	8.40E–01
Cu	4.00E–02	4.02E–02	1.20E–02	
Pb	3.50E–03	3.52E–03	5.25E–04	
Zn	3.00E–01	3.00E–01	6.00E–02	

Table 4 The concentration of heavy metals based on the distance from the source and the sampling depth

Sample	Distance (m)	Depth (cm)	Pb	Ni	Cr	Zn	Cu
1	500	10–20	59	60	95	75	11
2	500	10–20	27	79	113	74	64
3	500	10–20	27	79	188	67	56
4	500	10–20	39	69	201	86	56
5	500	0–10	116	97	180	138	233
6	500	0–10	86	48	77	128	48
7	500	0–10	111	42	65	70	122
8	500	0–10	133	41	70	402	49
9	500	10–20	43	64	89	70	67
10	500	10–20	77	80	175	90	93
11	1250	10–20	82	121	127	293	2584
12	1250	10–20	34	90	97	241	180
13	1250	10–20	12	79	107	67	23
14	1250	10–20	12	70	73	51	19
15	1250	10–20	26	65	100	157	23
16	1250	0–10	22	62	95	113	20
17	1250	10–20	23	89	112	70	25
18	1250	10–20	19	92	124	68	25
19	1250	10–20	17	92	126	74	26
20	1250	10–20	20	90	122	77	26
21	2000	0–10	208	86	92	766	126
22	2000	10–20	41	117	125	91	10
23	2000	10–20	25	85	102	85	17
24	2000	10–20	21	100	114	86	37
25	2000	10–20	24	105	139	80	41
26	2000	10–20	17	94	123	86	35
27	2000	10–20	19	61	97	70	16
28	2000	10–20	24	101	126	74	25
29	2000	10–20	16	95	125	83	29
30	2000	10–20	308	61	94	240	86

soil around the cement factory, mathematical models of geo-accumulation index, pollution index, and integrated pollution index were applied (Addo et al. 2012). The results of the various calculated indices are shown in Table 5. The results of the geo-accumulation index are shown in Table 5A. The I_{geo} mean values for Cr, Cu, Ni, Pb, and Zn in the soil around the cement factory were −0.31, 0.1, 0.14, 0.54, and 0.06, respectively. The lowest and highest average values of I_{geo} were calculated for Cr and Pb, respectively. According to Table 1, I_{geo} classification for Cu, Ni, Pb, and Zn was as uncontaminated to moderately contaminate. I_{geo} classification for Cr was uncontaminated. The findings of this study showed that I_{geo} classification for the soil samples varies from metal-to-metal and site-to-site. These changes were also reported in Okoro et al. (Okoro et al. 2017). In the present work, to further assess the contamination levels of the heavy metals, the pollution index and the integrated pollution index were also used. The results of the calculated PI

Table 5 Assessment of pollution levels of heavy metals based on different indices

	A					B					IPI
	Geo-accumulation index (Igeo)					Pollution index (PI)					
	Cr	Cu	Ni	Pb	Zn		Cr	Cu	Ni	Pb	Zn	
Mean	−0.31	0.10	0.14	0.54	0.06	Mean	1.26	4.97	1.71	3.31	2.03	2.21
Max	0.54	5.94	0.78	3.59	2.93	Max	2.18	92.29	2.57	18.12	11.43	17.57
Min	−1.09	−2.07	−0.78	−1.09	−0.98	Min	0.71	0.36	0.87	0.71	0.76	0.74

Table 6 The results of the ANOVA test

	Sum of squares	*df*	Mean square	*P*	Sig.
Pb					
Between Groups	5.089	2	2.545	4.278	0.05
Within groups	16.059	27	0.595		
Total	21.148	29			
Cr					
Between groups	0.027	2	0.014	0.165	0.05
Within groups	2.230	27	0.083		
Total	2.257	29			
Ni					
Between groups	0.636	2	0.318	5.492	0.05
Within groups	1.564	27	0.058		
Total	2.200	29			
Zn					
Between groups	0.099	2	0.049	0.121	0.05
Within groups	11.046	27	0.409		
Total	11.145	29			
Cu					
Between groups	2.246	2	1.123	0.928	0.05
Within groups	32.684	27	1.211		
Total	34.930	29			

and IPI in the soil around the cement factory are illustrated in Table 5B. The PI mean values for of Cr, Cu, Ni, Pb, and Zn were 1.26, 4.97, 1.71 to 3.31, and 2.03, respectively. The lowest and highest mean values of PI were for Cr and Cu, respectively. According to Table 1, PI classifications for Cr, Cu, Ni, Pb, and Zn were moderate, considerable, moderate, considerable, and moderate, respectively.

The results of One-Sample Kolmogorov–Smirnov test showed that the concentration of heavy metals measured around the cement factory has a normal distribution ($P_{value} > 0.05$), so that the parametric tests were used for its analysis. Table 6 presents the results of the ANOVA test. Based on Table 6, there is a significant relationship between the concentrations of Pb, Cr, Ni, Zn, and Cu with distance from the source of pollution (cement factory).

Health-risk assessment relating to soil metals was conducted in two parts of non-carcinogenicity and carcinogenicity effects. The daily intakes of heavy metals in ingestion, inhalation, and dental contact pathways are shown in Table 7. The concentration of heavy metals in one region depends on various factors. Industry type is one of the most important soil contamination factors in a region and the degree of contamination varies based on industry

Table 7 The daily intake of heavy metals in ingestion, inhalation, and dental contact pathways

Elements	Mean	Min	Max	AD_{ing}			AD_{inh}		
				Mean	Min	Max	Mean	Min	Max
Cr	115.7667	65	201	7.86E−06	4.41E−06	1.36E−05	1.16E−09	6.49E−10	2.01E−09
Cu	139.0667	10	2584	9.44E−06	6.79E−07	0.000175	1.39E−09	9.99E−11	2.58E−08
Ni	80.46667	41	121	5.46E−06	2.78E−06	8.22E−06	8.04E−10	4.09E−10	1.21E−09
Pb	56.26667	12	308	3.82E−06	8.15E−07	2.09E−05	5.62E−10	1.2E−10	3.08E−09
Zn	135.7333	51	766	9.22E−06	3.46E−06	5.2E−05	1.36E−09	5.09E−10	7.65E−09
	AD_{inh}			AD_{der}			AD_{total}		
	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max
Cr	8.26E−10	4.64E−10	1.43E−09	2.39E−07	1.34E−07	4.16E−07	8.1E−06	4.55E−06	1.41E−05
Cu	9.92E−10	7.13E−11	1.84E−08	2.88E−07	2.07E−08	5.34E−06	9.73E−06	7E−07	0.000181
Ni	5.74E−10	2.92E−10	8.63E−10	1.66E−07	8.48E−08	2.5E−07	5.63E−06	2.87E−06	8.47E−06
Pb	4.01E−10	8.56E−11	2.2E−09	1.16E−07	2.48E−08	6.37E−07	3.94E−06	8.4E−07	2.16E−05
Zn	9.68E−10	3.64E−10	5.46E−09	2.81E−07	1.05E−07	1.58E−06	9.5E−06	3.57E−06	5.36E−05

activity. From environmental point, cement factory is one of the most important industries that can adversely affect the environment and human health (Darivasi et al. 2016). The rate and degree of contamination to heavy metals may also change significantly by the distance from the main factory site. Olowoyo et al. showed a significant difference in the concentrations of heavy metals in different directions (Olowoyo et al. 2015). The results of present study showed that the dominant wind direction has the highest concentration of heavy metals in the soil top. According to the USEPA standard, the background concentrations of Cr, Cu, Ni, Pb, and Zn are 100, 30, 40, 888, and 50 mg/kg, respectively. Comparing the results of this study with USEPA standard, it was revealed that the concentrations of all the measured metals were higher. Therefore, health-risk assessment studies should be considered. The results of Darivasi et al. showed that the concentration of heavy metals in soil around Neka cement factory was higher than the standard values (Darivasi et al. 2016). As the distance from the factory increased, the concentration of heavy metals was significantly reduced. Therefore, the highest concentration is always observed around the factory. The daily intakes of heavy metals via ingestion, inhalation, and dental contact pathways are shown in Table 7. In ingestion pathway, the highest and lowest daily intakes of metals were found for Zn (9.44×10^{-6} mg/kg) and Pb (3.82×10^{-6} mg/kg). In oral inhalation pathway, for non-carcinogenicity, the highest and lowest daily intakes of metals were found for Cu (1.39×10^{-9} mg/kg) and Pb (5.62×10^{-10} mg/kg). In inhalation pathway, for carcinogenicity, the highest and lowest daily intakes of metals were for Cu (9.92×10^{-10} mg/kg) and Pb (4.01×10^{-10} mg/kg). In the dermal contact pathway, the highest and lowest daily intakes of metals were found for Zn (2.88×10^{-7} mg/kg) and Pb (1.16×10^{-7} mg/kg). Based on the results, the daily intake rate of all the elements in the oral ingestion route was greater than the inhalation and dermal contact. The mean of daily intake rates of metals for all the three pathways for Cr, Cu, Ni, Pb, and Zn was 8.1×10^{-6}, 9.73×10^{-7}, 5.63×10^{-6}, 3.94×10^{-6}, and 9.5×10^{-6}, respectively. To evaluate the non-carcinogenic health effects of heavy metals, HQ was determined. If HQ is greater than 1, it reflects harmful health effects on human health (Karim 2011). The HQ values of heavy metals by oral ingestion, inhalation, and dental contact pathways are shown in Table 8. Based on the results (Table 8), the HQ value of all metals in all studied sampling points was less than 1. In the ingestion pathway, the highest and lowest daily intakes of metals were found for Cr (2.62×10^{-3} mg/kg) and Zn (3.07×10^{-5} mg/kg). In the inhalation pathway, the highest and lowest daily intakes of metals were found on Cr (4.04×10^{-5} mg/kg) and Zn (4.52×10^{-9} mg/kg). In the dermal contact pathway, the highest and lowest daily intake of metals was found for Cr (3.99×10^{-3} mg/kg) and Zn (4.68×10^{-6} mg/kg). Based on the results, the HQ values of all the elements in the ingestion route were greater than the inhalation and dermal contact. The mean of HQ values of metals for the total of three pathways for Cr, Cu, Ni, Pb, and Zn was 6.65×10^{-6}, 2.6×10^{-4}, 3.04×10^{-4}, 1.31×10^{-3}, and 3.54×10^{-5}, respectively. The results of the non-carcinogenicity health-risk assessment, HI, for the total three pathways for each individual metal are shown in Table 8. Some heavy metals, in addition to non-carcinogenic effects, can also have carcinogenic effects such as Cd, As, Cr, Ni, and Co (Kamunda et al. 2016). The HI index is used to calculate the

Table 8 The HQ values of heavy metals in ingestion, inhalation, and dental contact pathways

Elements	HQ_{ing}			HQ_{inh}		
	Mean	Min	Max	Mean	Min	Max
Cr	2.62E−03	1.47E−03	4.55E−03	4.04E−05	2.27E−05	7.02E−05
Cu	2.36E−04	1.70E−05	4.39E−03	3.45E−08	2.48E−09	6.42E−07
Ni	2.73E−04	1.39E−04	4.11E−04	3.90E−08	1.99E−08	5.87E−08
Pb	1.09E−03	2.33E−04	5.98E−03	1.60E−07	3.40E−08	8.74E−07
Zn	3.07E−05	1.15E−05	1.73E−04	4.52E−09	1.70E−09	2.55E−08
HI	4.25E−03	1.87E−03	1.55E−02	4.07E−05	2.28E−05	7.18E−05
	HQ_{der}			HQ_{total}		
	Mean	Min	Max	Mean	Min	Max
Cr	3.99E−03	2.24E−03	6.93E−03	6.65E−03	3.73E−03	1.15E−02
Cu	2.40E−05	1.72E−06	4.45E−04	2.60E−04	1.87E−05	4.83E−03
Ni	3.08E−05	1.57E−05	4.63E−05	3.04E−04	1.55E−04	4.57E−04
Pb	2.22E−04	4.73E−05	1.21E−03	1.31E−03	2.80E−04	7.19E−03
Zn	4.68E−06	1.76E−06	2.64E−05	3.54E−05	1.33E−05	2.00E−04
HI	4.27E−03	2.31E−03	8.66E−03	8.56E−03	4.20E−03	2.42E−02

carcinogenic effects of heavy metals (Table 1). The HI value ranges for chromium and nickel were 1.9×10^{-8}–5.88×10^{-8} and 6.65×10^{-6}–2.6×10^{-4}, respectively. According to the results of this study, the carcinogenic risk of chromium and nickel was less than 1×10^{-6}. The findings of Chabukdhara et al. study showed that in an industrial soil sample, the highest HI value was related to chromium, nickel, lead and cadmium (Chabukdhara and Nema 2013). The risk of carcinogenicity of the heavy metals was less than the recommended limit set by the USEPA. The results of the health-risk assessment of heavy metals in the surface soil of the study area reflect the fact that the risk of carcinogenicity of these metals provides serious doubts about the health of children and adults. Despite the fact that less attention has been paid to the entry of heavy elements through inhalation, oral ingestion, and dermal contact, these routes can be very important and have high potential risk (Ravankhah et al. 2016). In short, in this research the health-risk assessment of heavy metals in the soil top around the cement factory was carried out by the proposed method of the US Environmental Protection Agency. This method generally identifies the potential health risks and the high risk of health that does not imply a health hazard and, if there is spatial data on health hazards at large scale, it may be possible to check their compliance with the health risks assessment.

Conclusion

In this study, the health-risk assessment of heavy metals in the soils around the Doroud cement factory was studied. Both carcinogenic and non-carcinogenic effects were investigated. All calculations were performed based on the proposed method of the US Environmental Protection Agency. All samplings were performed at intervals of 500 m, 1250 m, and 2000 m. Soil samplings were taken from depths of 0–10 cm and 10–20 cm. To assess the condition of the soil, there were several indices such as geo-accumulation index, pollution index, and integrated pollution index. The study results showed that the concentration of heavy metals in the soil top was significantly higher than that of the lower depths of soil. The results also showed that the dominant wind direction affected the high concentration of heavy metals in the soil top around the plant. Comparison of heavy metal concentrations measured in this study with US EPA standard showed that concentrations of all metals were higher than the standard. Based on the results, the HQ values of all the elements intakes via ingestion route were greater than the inhalation and dermal contact pathways. The mean of HQ values through all three pathways for Cr, Cu, Ni, Pb, and Zn was 6.65×10^{-6}, 2.6×10^{-4}, 3.04×10^{-4}, 1.31×10^{-3}, and 3.54×10^{-5}, respectively. According to the results of this study, the carcinogenic risk of chromium and nickel was less than 1×10^{-6}.

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