

Ecological and human health risk assessment of toxic metals in street dusts and surface soils in Ahvaz, Iran

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Abstract This study aimed to examine the concentrations and environmental health risk of the potentially toxic metals including Pb, Zn, Cu, Cd, Cr, and As in street dusts and surface soils of Ahvaz, the capital of Khuzestan province, located in the southwest of Iran. To this end, a total of 81 street dusts and 96 surface soils were collected from Ahvaz urban areas. Toxic metals were measured by inductively coupled plasma-mass spectrometry and evaluated using enrichment factors, potential ecological risk index and human health risk assessment. Lead in street dusts and Pb and Cu in surface soil showed the highest enrichment factor. The results revealed that there are two major sources of toxic metals in Ahvaz, including industrial activities and road traffic emissions and also resuspension of soil and dust particles. Cu, Pb, Zn, and Cr in Ahvaz soil and dust particles are strongly influenced by anthropogenic activity, mainly industrial and traffic emissions, while As and Co originate

from resuspension of soil natural parent particles. The potential ecological risk index (RI) values for dust samples indicated that 58.02% of all samples showed low potential ecological risk. Moreover, 33% and 9% of samples showed moderate and considerable ecological risk, respectively. In addition, the RI values for soil samples indicated that 57% and 40% of all samples had low and moderate ecological risk, respectively, and 3% had a high ecological risk. The hazard index (HI) values of studied potentially toxic metals showed that there is no non-carcinogenic risk for children and adults. Furthermore, the HI value for children was 2–7 times upper than those for adults, which confirm that children show more potential health risks for exposition to these potential toxic metals. Cancer risks of the studied potential toxic elements for both adults and children decreased in the following order $Cr_{dust} > Cr_{soil} > Cd_{dust} > Cd_{soil} > As_{dust} > As_{soil} > Pb_{dust} > Pb_{soil}$. The carcinogenic risk values of Cd, As, and Pb for adults and children was lower than 1×10^{-6} , suggesting carcinogenic risk of potentially toxic metals in the street dust and surface soil could be neglected. On the other hand, the carcinogenic risk value of Cr was greater than 1×10^{-6} for both adults and children revealing that the carcinogenic risks of Cr essentially need more consideration for environmental management control.

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Introduction

Potentially heavy/toxic metals including lead (Pb), copper (Cu), zinc (Zn), cadmium (Cd) and chromium (Cr) in general contain elements that have a density higher than 5 g/cm^3 (Hu and Cheng 2013). Potentially toxic metals are considered to be the main source of contamination in the urban areas. Displaced surface soil and regional dust storm deposition are the major origins of street dust and subsequently of metals therein (Al-Khashman 2004; Batjargal et al. 2010; Nazarpour et al. 2017). Dermal and hand-to-mouth contact can represent a direct exposure to contaminated dust particle with potentially toxic metals, especially uptake by children exposure in school grounds, parks, and city side road (Ghanavati and Nazarpour 2016; Watt et al. 1993). There are two major sources of potentially toxic metals in street dust, natural, and anthropogenic sources; the first one mainly results from resuspension of parent and weathered materials (Oves et al. 2012; Zarasvandi et al. 2011b). The major anthropogenic sources of potentially toxic metals in urban environment include vehicular traffic, industrial activities, fossil fuel combustion, and residential population density (Lu et al. 2014; Nazarpour et al. 2016).

Many studies have reported the human health risk of potentially toxic metals in both soil and dust particles in the urban environment (Smith et al. 2006). Human can be subjected to dust and soil containing potentially toxic metals from various pathways such as ingestion, inhalation, and skin exposure from active situations, such as wind, industrial, traffic, and other human activities (Al-Awadhi and AlShuaibi 2013; Birch and McCready 2009; Hwang et al. 2016). As a result, children living in the industrial cities like Ahvaz certainly undergo high-level health risks because of the polluted urban soils and street dusts. There are some studies which have indicated the harmful impacts of potentially toxic metals on human health (Wei et al. 2015). For instance, long ingestion of some potentially toxic metals like Cd from dust particles or suspended soil can cause lung cancer, respiratory problems, bone fissures, and hypertension (Chen et al. 2015; Wei et al. 2015; Wu et al. 2015).

Environmental factors, including enrichment factor (EF) and modified pollution indices, can be used for the assessment of potentially toxic metals pollution, separating different potentially toxic metals sources,

parent materials and anthropogenic, in soil and dust (Cai et al. 2011). These methods could not consider the hazardous toxicities of metal elements to the environment and human health. To evaluate the possible environmental and human health risks by toxic metals in soil and dust, the potential ecological risk index (PERI) has been extensively applied (Abdallah 2011; Caeiro et al. 2005; Chen et al. 2012; Medici et al. 2011). In recent studies, the US EPA's health risk models have been effectively applied to examine potentially toxic metal exposure from the urban soil and dust (Hu et al. 2012; USEPA 2001). In developing countries such as Iran, anthropogenic issues related to toxic metals contamination of surface soil and street dust is more needed because of uncontrolled release of pollutants and the absence of environmental pollution management, poor emission standards, vehicles emission, and industrial and power plants. There are few studies which have reported human health risk and ecological risk associated with toxic metals in surface soil and dust in some cities such as Tehran (Saeedi et al. 2012), Isfahan (Soltani et al. 2015), and Shiraz (Keshavarzi et al. 2015). Ahvaz is one of the main cities in Iran, which contains the super-giant oil files with active oil well drilling activities by National Iranian Drilling Company (NIDC), steel companies such as Khuzestan Steel Company (KSC), Iran National Industrial Group (INIG), Khuzestan Oxin Steel Company (KOSC), Zergan power plant, Carbon Black Company (BC) and small industrial towns, which are located in the border of city which have made Ahvaz as one of the most important industrial centers of Iran. Incidentally, there is no comprehensive study covering the entire Ahvaz and investigating the human health risk and ecological risk index on toxic metals in both surface soil and street dust. Therefore, the objectives of the present study are to:

- determine the concentration of potentially toxic metals in the street surface soils and street dust of Ahvaz and compare the concentrations with other cities in the world; moreover, the anthropogenic and geo-genic sources of highly concentrated potentially toxic metals in the Ahvaz street dust and surface soil samples are assessed;
- assess potentially toxic metals pollution in the street dust and surface soil using potential ecological risk index;

- assess human health risk of potentially toxic metals in children and adults via the three main exposure pathways including inhalation, ingestion, and dermal contact.

Materials and methods

Study area

Ahvaz is the capital of Khuzestan province, in the southwest of Iran, located on Ahvaz oil field (one of the most important Iranian super-giant oil fields) with more than 450 oil wells. Also, this region is one of the largest industrial regions in Iran where impact of rapid population growth and industrialization on limited natural sources and agricultural lands is progressively high and as a result, much of areas may have become contaminated (Nazarpour et al. 2017; Zarasvandi et al. 2011a).

The soil of the study areas was classified as sandy loam, sandy loam to loam, and loam to clay loam (Ghanavati and Nazarpour 2016). The pH of soils in the study area ranges from 8.10 to 8.24, which suggest sub-alkaline condition for soil samples (Zarasvandi et al. 2011a). The climate of study area which is almost near Persian Gulf is arid and sultry and almost cold and rainy in winter. Average temperature in the study area is 32 °C in January, 38 °C in April, and 49 °C in July. The rainy season normally extends from late December to almost end of March with an average annual rainfall of 213 mm/year. The altitude datum in industrial town is about 25 m above the sea level.

Sampling and treatments

In July 2014, eighty-one streets dusts samples and ninety-six surface soil samples were collected from the Ahvaz city (Fig. 1). Samples were selected in the driest month of the year to prevent rain-washing away street dusts. The meteorological conditions were steady throughout the sampling, with no rainfall during 1 month earlier of sample collection. About 300–500 gs of a composite street dust and surface soil samples (0–5 cm) were collected. The collected samples were sieved through a 63 µmm mesh, air-dried and stored in polyethylene bags, labeled following procedures of Tanner et al. (2008), and then

transferred to the laboratory. The sampling sites are marked as shown in Fig. 1. Geographical coordination of samples locations was recorded at each sample point with a handheld GPS device.

To assess the binding of heavy metals to the main fractions in soils, digestion methods were performed and described as the following process. Five grams of collected samples from the street dusts and soil samples were mixed in highly purified nitric-hydrofluoric per chloric acids (5 mL HNO₃–4 mL HF–2HClO₄) to decompose the samples for measuring the concentrations of potentially toxic metals, based on GB/T 17441-1997 and GB/T 17238-1997; USEPA (1997) (Chen et al. 2015; Soltani et al. 2015). Sulfur-hydrochloric-nitric-hydrofluoric acid methods were used for determining Cr according to GB/T 17137-1997 (USEPA 1997). Toxic metals were measured by inductively coupled plasma-mass spectrometry (ICP-MS; Perkin-Elmer Elan 6100 DRCplus). The quality assurance (QA) and quality control (QC) were assessed by measuring blank and standard reference material NIST 2710 which provided an accuracy of 100 ± 5% (*n* = 15) (Nazarpour et al. 2018), while the precision of duplicate samples was 4–6%. Standard reference material (SRM) 2710 was simultaneously applied to 15% of the dust collected from the streets samples to ensure the data quality of samples.

Enrichment factor

In general, the enrichment factor (EF) is a useful method to delineate metal sources, which originate from parent materials or human/anthropogenic sources (Lu et al. 2014). For calculation of EF for every element, normalization with a reference metal element should be considered. General form of EF equation is presented in Eq. (1).

$$EF = \frac{\left(\frac{C_i}{C_{ref}}\right)_{\text{sample}}}{\left(\frac{C_i}{C_{ref}}\right)_{\text{background}}} \quad (1)$$

where C_i is the value of the *i*th toxic metal (mg/kg); C_{ref} is the value of target metal in the reference environment. Elements such as Sr, Mn, Ti, Al, and Fe were usually chosen as references (Lu and Bai 2010; Yuen et al. 2012). According to Zhang and Liu (2002), EF values $0.05 \leq EF \leq 1.5$ show that the metal has a

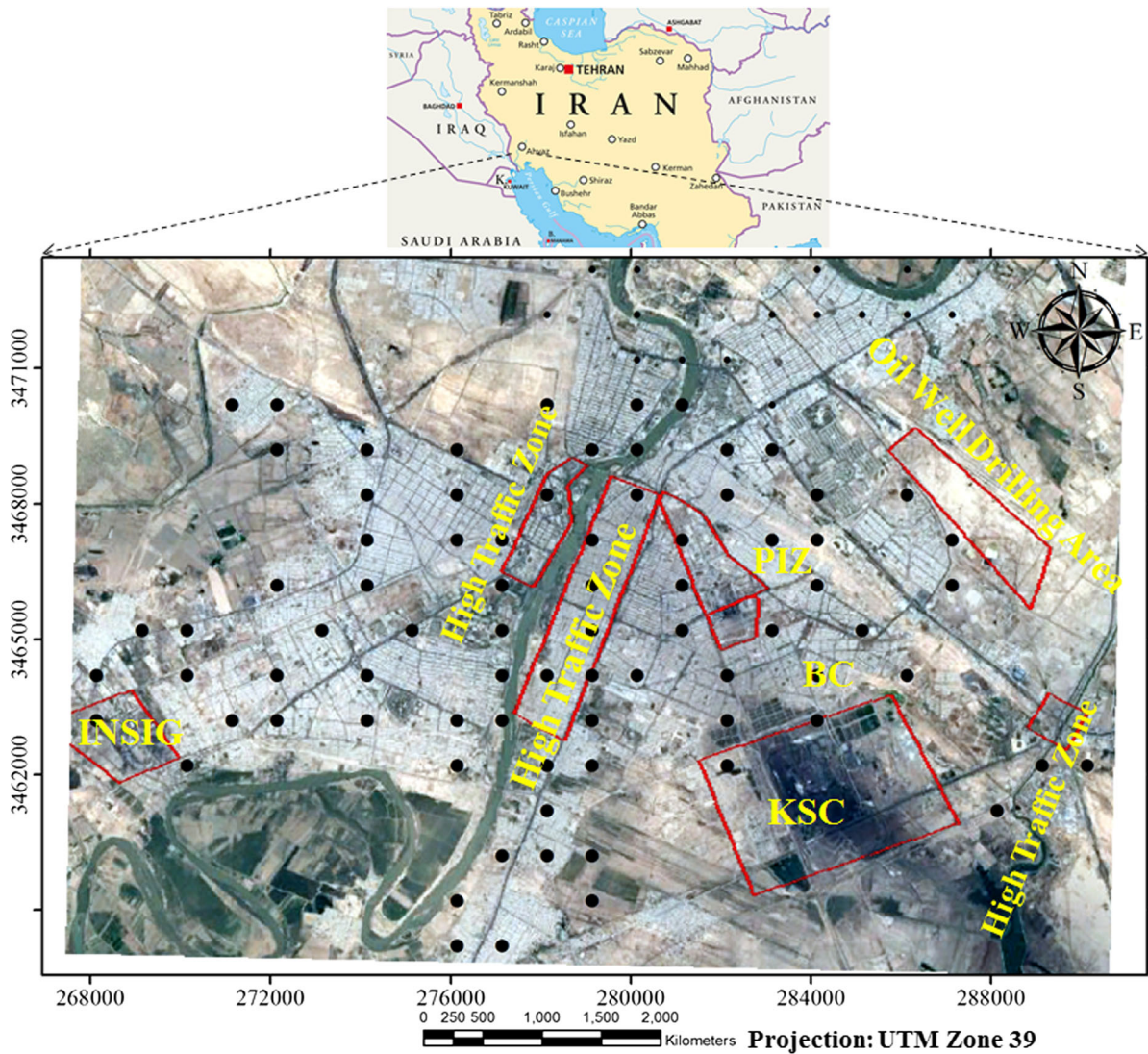


Fig. 1 Location of soil and street dust samples sites in the Ahvaz city

natural source, while values higher than 1.5 would indicate anthropogenic source of toxic metals. Degree of contamination can be categorized in five classes (Namaghi et al. 2011): (1) $EF < 2$ (low); (2) $2 \leq EF \leq 5$ (moderate); (3) $5 \leq EF \leq 20$ (significant); (4) $20 \leq EF \leq 40$ (very high), and (5) $EF > 40$ (extremely high).

Potential ecological risk (PER)

Potential Ecological Risk (PER) assessment of toxic metals was first presented by Hakanson (1980). While there is no published work evaluating the PER index

for soil and street dust simultaneously, a number of researchers have applied the PER to assess the ecological risks of toxic metals in the urban soils (Szolnoki et al. 2013). The PER was estimated as follows:

$$C_j^i = C_j^i / C_n^i \quad (2)$$

$$E_j^i = T_r^i \times C_s^i \quad (3)$$

$$RI = \sum_i^n E_r^i \quad (4)$$

where

RI: is the total amount of potential ecological risk for all toxic metals

E_r^i : is the potential ecological risk of toxic metals

T_r^i : is the toxicity coefficient response factor of every toxic metal

C_s^i : is the measured values of toxic metals

C_n^i : is the background value

Toxicity coefficient response factors for Pb, Zn, Cu, Cr, Cd, and As are 5, 1, 5, 2, 30, and 10, respectively (Wang et al. 2014). Table 3 indicates the classifying standards of PER of toxic metals.

Ecological risk values can be characterized in the following order: $E_r_i < 40$, low potential ecological risk; $40 \leq E_r_i < 80$, moderate potential ecological risk; $80 \leq E_r_i \leq 160$, considerable potential ecological risk; $160 \leq E_r_i \leq 320$, high potential ecological risk; and $E_r_i > 320$, very high ecological risk (Wu et al. 2015; Zhao et al. 2014). Risk index values can be categorized as follows: $RI < 150$, low ecological risk; $150 \leq RI < 300$, moderate ecological risk; $300 \leq RI < 600$, considerable ecological risk; and $RI > 600$, very high ecological risk.

Background (reference) data

Geochemical baseline maps are not yet available in Iran though work has been initiated under Global Geochemical Baselines. In this study, the background levels of toxic metals in soil and dust samples were evaluated by using statistical methods (Soltani et al. 2015; Teng et al. 2010). In environmental geochemical studies, the mean ± 2 standard deviation is usually applied to distinct thresholds of about 2.5% of upper (or lower) extreme values and act as the threshold for more examination of bulky data sets (Hawkes and Webb 1963). This technique requires that the variable follow normal distribution. Outlier data from high-contaminated areas can influence the results. Thereby, the mean ± 2 standard deviation cannot provide an applicable threshold estimation. Therefore, noticeable outliers are frequently separated from the raw data or log-transformed data performed earlier the computation. Yet, the outcomes are not reliable, as the data once log transformed do not follow normal distribution.

The median $\pm 2MAD$ ($MAD = \text{median}_i (|X_i - \text{median}_j(X_j)|)$) as a method of exploratory data analysis (EDA) have been extensively applied to estimate the background values (Esmaeili et al. 2014; Nazarpour et al. 2016; Soltani et al. 2015). The EDA can affect the non-normality limitation by generating potentially explainable data pattern (Tukey 1977). In this study, we applied this technique to delineate the background value determination in the study area. The median + 2MAD (upper limit) in background soil and street dust samples is presented in Table 1.

Health risk evaluation

Human health risk evaluation is the method to estimate the possible harmful health impacts in children and adults, which are subject to environmental chemical components (Council 1983). In this method, the hazard quotient (HQ) and cancer risk (CR) were applied to determine non-carcinogenic and carcinogenic risks of individual toxic metals, respectively (Jiang et al. 2017b). Humans are exposed to dust and surface soil throughout three main exposure including ingestion (D_{ing}), inhalation (D_{inh}), and dermal absorption (D_{dermal}). These factors can be calculated based on the exposure factors handbook (USEPA 1996). The average daily dose (ADD) taken by every exposure pathways is evaluated by Eqs. (5)–(7) for daily intake (Staff 2001; USEPA 1996).

$$ADD_{ing} = \frac{C \times IngR \times CF \times EF \times ED}{BW \times AT} \tag{5}$$

$$ADD_{inh} = \frac{C \times InhR \times EF \times ED}{PEF \times BW \times AT} \tag{6}$$

$$ADD_{dermal} = \frac{C \times SA \times CF \times AF \times ABF \times EF \times ED}{BW \times AT} \tag{7}$$

Based on the USEPA (1997), IngR and InhR are the ingestion and inhalation rates. Ingestion exposure rate of soil and dust is 200 m³/day and 100 m³/day for adults, respectively. Inhalation exposure rate for children and adults is 7.6 m³/day and 20 m³/day, respectively (Van den Berg 1994). C is the mean value (mg/kg) of each toxic metal. EF and ED are exposure frequency and exposure duration, respectively. The EF value is 350 day/year for children and adults (EPA 2001); ED value is 30 years for adults and 6 years for

Table 1 Statistical summaries of metal concentrations in street dusts and surface soils from Ahvaz (mg/kg)

Element	Surface soil (<i>n</i> = 96)					Street dust (<i>n</i> = 81)					
	Min–Max	Mean ± SD	Skewness	World-soil average	Median + MAD	Min–Max	Mean ± SD	Skewness	Background	Upper crust content ^a	Median + MAD
Pb	8–510	189.14 ± 147.54	0.67	25	37.76	11–793	202.14 ± 173.19	1.22	14	17	24.1
Zn	6–213	93.56 ± 53.17	0.42	62	114.5	16–296	104.24 ± 58.57	0.95	28	67	132.1
Cu	9–483	187.06 ± 133.76	0.64	14	33.9	19–641	207.60 ± 149.91	0.98	33	28	43
Cd	0.006–19	5.58 ± 5.28	0.97	1.1	0.43	0.01–56	6.80 ± 7.87	3.36	2	0.09	0.62
Cr	6–249	107.42 ± 67.32	0.45	42	95.4	11.60–306	115.84 ± 68.88	0.57	98	92	115.1
AS	0.36 – 14.01	6.91 ± 3.52	0.06	4.7	12.8	0.68–21.20	9.33 ± 5.26	0.31	3.1	4.8	17.1

^aRudnick and Gao (2003a, b)

children (EPA 2001); CF is the conversion factor (1×10^{-6} kg/mg) for both children and adults; SA is the surface area of the skin which is in contact with dust; SA value is 2800 cm² and 3300 cm² for children and adults, respectively (EPA 2001). AF is the skin adherence factor, and AF factor is 0.2 mg/cm²/h for children and 0.7 mg/cm²/h for adults (EPA 2001). ABF is the dermal absorption factor (0.001). Particle emission factor (PEF) is 1.36×10^9 m³/kg (EPA 2001). BW factor is the mean of body weight for children (15 kg) and adults (70 kg), and AT is the averaging time (for non-carcinogens, AT = 365 × ED days; for carcinogens, AT = 70 × 365 = 25,550 days).

According to non-cancer risk of individual toxic metals and a specific reference dose (RfD), the hazard quotient (HQ) was calculated (Man et al. 2010). Specific reference dose (mg/kg day) was an estimation of the highest acceptable risk to a population through a life. The hazard index (HI) is the addition of HQs and was applied to assess three main exposure pathways individually. HI values < 1 indicate that there are no obvious adverse health effects of toxic metals for residential population, whereas, if HI > 1 exceeds one, it indicates that hostile health effects can occur (Man et al. 2010).

$$HQ_i = \sum \frac{ADD_i}{RfD_i} \quad (8)$$

$$HI = \sum HQ_i \quad (9)$$

In general, carcinogenic risk is considered as possibility of cancer during life because of contact to carcinogenic hazards (Li et al. 2014; Nazarpour et al. 2018). The following equation was used to calculate carcinogenic risks of toxic metals during a lifetime (USEPA 1996):

$$CR = \sum ADD_i \times SF_i \quad (10)$$

Carcinogenic slope factor was defined as (SF) (per mg/kg/day), which transfers the assessed daily intake of a contaminant during lifetime of exposure to the incremental risk of an individual developing cancer (USEPA 1996). Risks higher than 1×10^{-4} are considered as unacceptable, risks values < 1×10^{-6} are not regarded as significant, and values between 1×10^{-4} and 1×10^{-6} are considered as a standard range (Chen et al. 2012).

Results and discussion

Toxic metals concentration

Table 3 represents the statistical concentration data for toxic metal in street dust and surface soil of Ahvaz vs the upper continental crust (UCC) (Dehghani et al. 2017; Kabata-Pendias 2010; Rudnick and Gao 2003a; Soltani et al. 2015) and background values of world soils (Rudnick and Gao 2003b). The concentration value (mg/kg) of toxic metals in surface soil samples ranged as follows: Pb 8–510 (average: 189.1), Zn 6–213 (average: 93.56), Cu 9–483 (average: 187.06), Cd 0.006–19 (average: 5.58), Cr 6–249 (average: 107.42), and As 0.36–14.01 (average: 6.91) mg/k.

The concentration of studied metals in street dust samples indicated the following ranges: Pb 11–793 (average: 202.14), Zn 16–296 (average: 104.24), Cu 19–641 (average: 207.60), Cd 0.01–56 (average: 6.80), Cr 11.60–306 (average: 115.84), and As 0.68–21.20 (average: 9.33) mg/k. Based on Yuen et al. (2012), metals with natural source indicate low coefficient of variations (CV) compared to those affected by anthropogenic sources. The normality of the soil and dust samples was tested by using Kolmogorov–Smirnov test. The results indicate that all variables are non-normally distributed (significant level > 0.05) except for As (significant level > 0.05). The ranges of CV in studied samples indicate high variability (CV $> 20\%$), indicating that the concentration differences of studied metals in all soil and dust samples are appreciable and that the effects of anthropogenic activities on the concentrations of these metals are striking. Distributions of studied toxic metals indicate right skewedness pattern (Table 1), suggesting that the distribution of toxic metals in studied samples is not random and affected by some anthropogenic sources. High concentrations (above background values) coupled with a high coefficient of variation indicate anthropogenic inputs for toxic metals in Ahvaz soil and street dust samples.

The mean values of Pb, Cu, Cr, As, Cd, and Zn in street dust and surface soil samples were higher than their corresponding upper UCC and background values of world soils. The upper limit of statistical methods (median + 2MAD) of the study area was compared to the median soil worldwide (Rudnick and Gao 2003a) and mean upper continental crust (Kabata-Pendias 2010; Soltani et al. 2015). The background

values of studied toxic metals were higher than both references (with the exception of Cd of values of world soils). These results imply that the anthropogenic sources such as vehicle exhaust, fuel combustion, industrial activity, construction, and deposition of aerosols are the main source of the studied toxic metals in the surface soil and street dust in the study area.

In developing countries like Iran, there is not yet official reference toxic metals values, and specifically such values do not exist in the study area. The mean contents of contaminants in street dust and soils are commonly compared in areas of different urban environments. Mean values of toxic metal in the Ahvaz street dusts samples were compared to other cities in the world (Table 2). The source of toxic metal values in street dusts which is significant among the cities is anthropogenic. Generally, the concentration of toxic metals in urban soil and street dust particles varies significantly among metropolises depending on the traffic density and industrial activities, technologies employed, as well as local weather conditions (Dehghani et al. 2017; Soltani et al. 2015). The average value of Pb in Ahvaz street dusts (present work) is greater than average concentration in Shiraz and Beijing, and lower than Tehran, Ottawa, Calcutta, Amman, and London (Table 2). The average values of Zn in street dusts of Ahvaz are lower than other metropolitan cities. Copper concentration is higher than Shiraz, Ottawa, Calcutta, London, and Beijing and lower than Amman and Tehran. The average value of Cd is higher than other cities except Tehran. The average value of As in Ahvaz is greater than Ottawa and Shiraz and lower than Calcutta. The average value of Cr in Ahvaz is higher than other metropolitan cities (Table 2).

Concentration of toxic metals in soil samples of Ahvaz city indicates that all of metals except Cu and Cd were lower than the Chinese soil quality guidelines. Indeed, the percentages of the sample which exceed China guideline include 40% for Pb, 64% for Zn, 13% for Cu, and 85% for Cd (Table 3). The average values of studied metals showed that Pb (70% of samples), Cu (66% of samples), and Cr (52% of samples) were greater than the Canadian soil quality guidelines (Gaudet et al. 1995). In addition, average values of Cu, Cd, and Cr were higher than the suggested values in the Dutch soil quality guideline (VROM, 2000). Generally, concentration of toxic metals in urban soil and street dust particles

Table 2 A comparison of toxic metals values (mg/kg) in street dusts of Ahvaz and other cities

City	As	Cd	Cr	Cu	Pb	Zn	References
Tehran (Iran)	–	10.7	33.5	225.3	257.4	873.2	Saeedi et al. (2012)
Shiraz (Iran)	6.6	0.5	67.2	136.3	115.7	403.5	Keshavarzi et al. (2015)
London (England)	–	3.5	126.7	155.0	1030	680.0	
Ottawa (Canada)	1.3	0.37	43.3	65.84	433	112.5	
Calcutta (India)	23	3.13	54	44	536	149	Chatterjee and Banerjee (1999)
Amman (Jordan)	–	1.1	18.3	249.6	976.0	401.0	Jiries (2003)
Beijing (China)	13.4	1.1	126	123	103	394	Tanner et al. (2008)
Ahvaz (Iran)	6.91	5.58	107.4	187.0	189.1	93.56	This study

Table 3 Concentration of toxic metal values (mg/kg) in the Ahvaz soils ($n = 96$) and related guideline values

	Pb	Zn	Cu	Cr	Cd
Ahvaz average value	189.1	93.56	187	107.4	5.58
Chinese soil quality guidelines	200	250	100	200	0.3
Canadian soil quality guidelines	87	360	91	87	22
Dutch soil guidelines (target value)	100	140	36	100	0.8
Dutch soil guidelines (intervention value)	380	720	190	380	12
% Sample which exceeded China guideline	40	0	64	13	85
% Sample which exceeded Canadian guideline	70	0	66	52	0
% Sample which exceeded Dutch target value	65	25	88	49	78
% Sample which exceeded Dutch intervention value	13	0	41	0	14

significantly depends on the traffic density and industrial activities, weather conditions, and wind patterns (Soltani et al. 2015).

Enrichment factor (EF)

As mentioned earlier, there are no official metal environmental reference values in Iran. Since this is the first scientific report of Ahvaz dust and surface soil contamination, in this paper, the mean value of metal values in UCC was applied as background concentration for EF calculation as reported in previous studies (Kartal et al. 2006; Reimann and de Caritat 2005). The EFs of toxic metals in dust and surface soil have been calculated to discriminate anthropogenic from natural sources.

Table 4 represents the percentage of each class of EF evaluation of toxic metals in dust and surface soils. The results indicate that the average of EF values for studied metals in dust decreases as follows: $Pb > Cu > Zn > As > Cd > Cr$. The average values of

EF for Pb, Cu, Zn, As, Cd, and Cr in Ahvaz street dust samples are > 1.5 , suggesting their anthropogenic sources in the study area (Zhang and Liu 2002). The results of EF for soil samples indicated that the average values of EF decrease as follows: $Cu > Pb > As > Cd > Cr > Zn$. The Cr and Zn mean showed moderate enrichment, and the Cu and As showed significant enrichment. In addition, Pb and Cu with the highest EF mean showed very high enrichment. This finding suggested that the dust and soil samples were significantly affected by human activities.

Spatial analysis pattern of toxic metals

The spatial distribution with 20-percent intervals of toxic metal concentration was mapped using ArcGIS to evaluate the possible sources of potentially toxic metals and to recognize hot spot areas, which have high potential of toxic metals (Wang et al. 2015). Street dusts and surface soils concentration patterns of the studied toxic metals in the Ahvaz city are shown in

Table 4 Enrichment factors (EFs) from potentially toxic metals in street dusts and surface soils of Ahvaz

	Metals	EF			Number of sample (%)				
		Min	Max	Average	Minimal enrichment	Moderate enrichment	Significant enrichment	Very high enrichment	Extremely high enrichment
Dust	Pb	2.67	164.78	43.76	0	6 (7.41%)	19 (23.45%)	24 (29.62%)	32 (39.51%)
	Zn	1.35	33.80	11.57	2 (2.46%)	10 (12.34%)	59 (72.86%)	10 (12.34%)	0
	Cu	1.47	89.75	19.37	2 (2.46%)	6 (7.41%)	40 (49.38%)	26 (32.10%)	7 (8.65%)
	Cr	0.34	8.96	3.69	22 (27.16%)	36 (44.44%)	23 (28.39%)	0	0
	Cd	0.01	50.62	6.83	22 (27.16%)	19 (23.45%)	37 (45.67%)	3 (3.72%)	0
	As	0.63	42.17	9.84	5 (6.17%)	16 (19.75%)	55 (67.90%)	3 (3.70%)	2 (2.47%)
Surface soil	Pb	0.90	90.81	27.34	2 (2.08%)	14 (14.58%)	29 (30.20%)	28 (29.60%)	23 (23.55%)
	Zn	0.31	12.42	3.76	24 (25%)	49 (51.04%)	24 (23.96%)	0	0
	Cu	1.41	145.85	27.99	3 (3.12%)	7 (7.29%)	35 (36.45%)	24 (25%)	27 (28.14%)
	Cr	0.36	14.77	4.95	22 (22.91%)	34 (35.41%)	40 (41.68%)	0	0
	Cd	0.01	25.65	5.75	30 (31.25%)	24 (25%)	40 (41.67%)	2(2.08%)	0
	As	0.46	30.43	11.01	4 (4.16%)	18 (18.75%)	64 (66.66%)	10 (10.43%)	0

Figs. 2 and 3. Lead, Zn, Cu, Cr, Cd, and As show similar spatial distribution patterns. High values of toxic metals concentrations are associated with areas in the vicinity of the center of the city characterized by shopping centers, road junctions and main roads with high amounts of traffic volume, and high dense population districts. The industrial zones are high-tech industrial areas of Ahvaz, with toxic traffic density passing its main road. Pipe Industrial Zone (PIZ), Carbon Black Company (CB), steel smelting industry such as Khuzestan Steel Company (KSC), Iran National Steel Industrial Group (INSIG), oil-based drilling activity by National Iranian Drilling Company (NIDC), oil well drilling area, are the main sources of toxic metals in Ahvaz city. Generally, the spatial patterns of hot spots of the toxic metals show that there are two main kinds of hot spots in Ahvaz: (1) continuous hot spots in the center of the city, which emerged in the high dense residential zones; and (2) areas that are located near the city entrance with high traffic volume and industrial enterprises.

Potential ecological risk (PER)

In the present study, potential ecological risks of toxic elements were assessed according to Hakanson technique (Hakanson 1980). Statistical parameters of ecological risk factors including *Er* and *RI* of every toxic metal in dust and surface soil samples are

presented in Tables 5 and 6. According to the analysis, the trend of *Er* in dusts samples were: Pb > Cu > As > Cd > Zn > Cr. Average value of *Er* of Cu, As, Cd, Zn, and Cr was < 40 suggested low risk for studied metals, thus indicating low potential ecological risk. In contrast, Pb had considerable *Er* average value (115.5) than those of the other five toxic metals.

The trend of *Er* for toxic metals in surface soils was as follows: Pb > Cu > As > Cd > Cr > Zn. The results of average value of *Er* indicated moderate risk for As, Cd, and Cr considerable for Pb, Zn, and Cu. In addition, the potential ecological risk value of Pb and Cu was greater than the other toxic metals.

The *RI* values were evaluated to assess the risk of multi-metals in dusts and surface soils. In general, *RI* describes sensitivity of environment to the potentially toxic metals and overall pollution. In dusts, the *RI* indicates that values for 58.02% of street dust samples were at low risk, 33.33% and 7% were at moderate to considerable risk, respectively. In addition, results of *RI* values of soil samples show that the 57.29% of soil samples were at low risk, 39.58% and 3.13% were at considerable moderate risk, respectively. The ecological risk index, accounting for the contamination of Pb, Zn, Cu, Cd, As, and Cr suggest that Ahvaz city is suffering from considerable contamination from surface soil and street dust.

The spatial distribution patterns of ecological risk index values (*RI*) in the Ahvaz surface soil and street

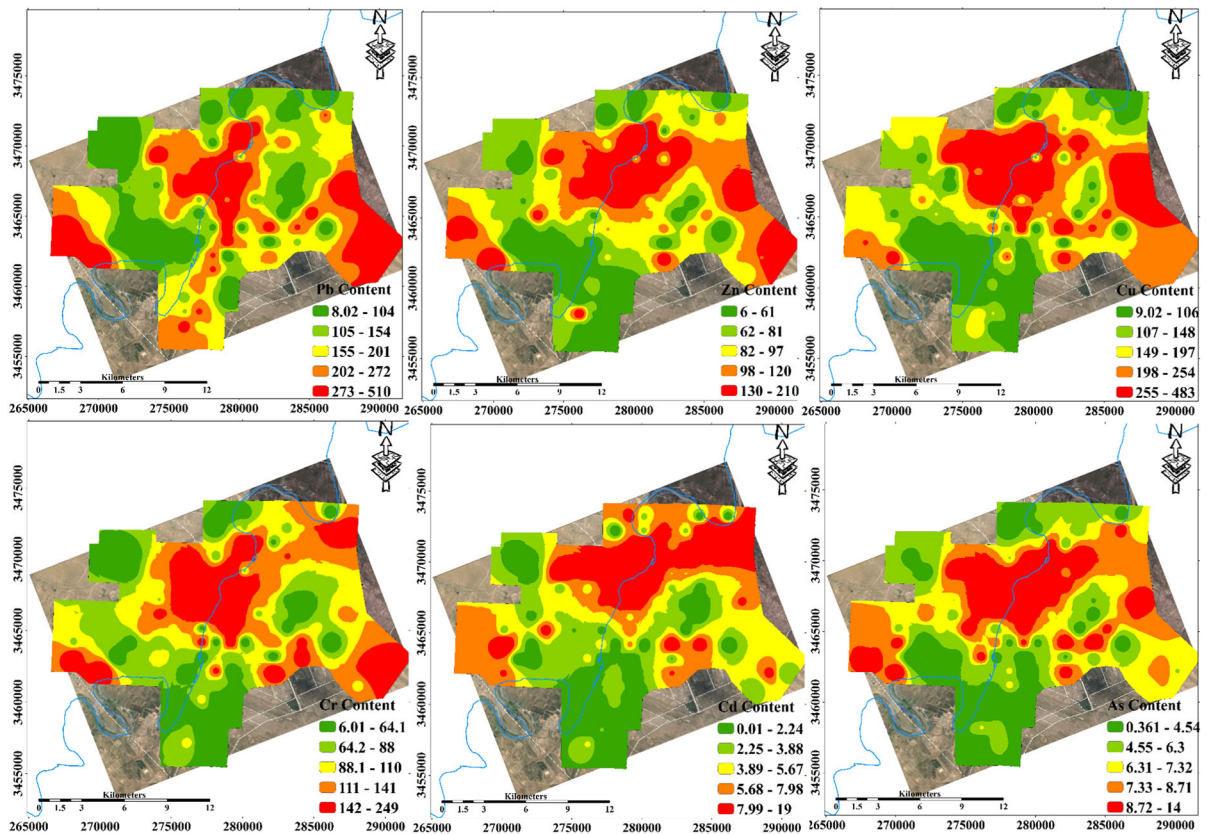


Fig. 2 Spatial distribution of toxic metals in surface soil samples in the Ahvaz city

dusts indicate that samples with significant risk exist in areas with very high population density and near areas including the old urban area, city center, areas with high traffic density, close to local industrial towns, construction companies, chemical industry, oil well drilling activity, large industries such as Khuzestan Steel Company (KSC), Iran National Industrial Group (INIG), Khuzestan Oxin Steel Company (KOSC), Zergan power plant, and Carbon Black Company (BC) (Fig. 4). Low- and medium-risk areas are those developed in recent decades where traffic and low population densities and industry are still low.

Health risk assessment

Human health risk assessment of studied toxic metals in the street dust and surface soil samples through the three main exposure pathways including ingestion, dermal exposure, and inhalation was performed for children and adults (Table 7) (EPA 2001; USEPA 1997). The results showed that the soil and dust

exposure pathways of toxic metals for both children and adults decreased as follows: ingestion > dermal contact > inhalation. Lead, As, Cu, and Zn showed the same order of HQ in children, while HQs of Cd and Cr were higher than other pathways in adults due to dermal contact of soil and specially dust particles, suggesting that ingestion of soil and dust appears to be the important exposure pathway to harm human health (Ferreira-Baptista and De Miguel 2005; Zheng et al. 2010).

Earlier works similarly indicated that ingestion is the main exposure pathway to dust and soil particles for children and adults (Cheng et al. 2018; Huang et al. 2014; Wang et al. 2014) that could be explained by easily suspended of toxic metals via dust and soil exposure to residents which is likely to be more dependent on hand-to-mouth contact (particularly by young children) than on dermal contact and inhalation.

For non-carcinogenic toxic metals, the HI value in the street dust and surface soil decreased as follows: Pb > Cr > As > Cd > Cu > Zn for children, and

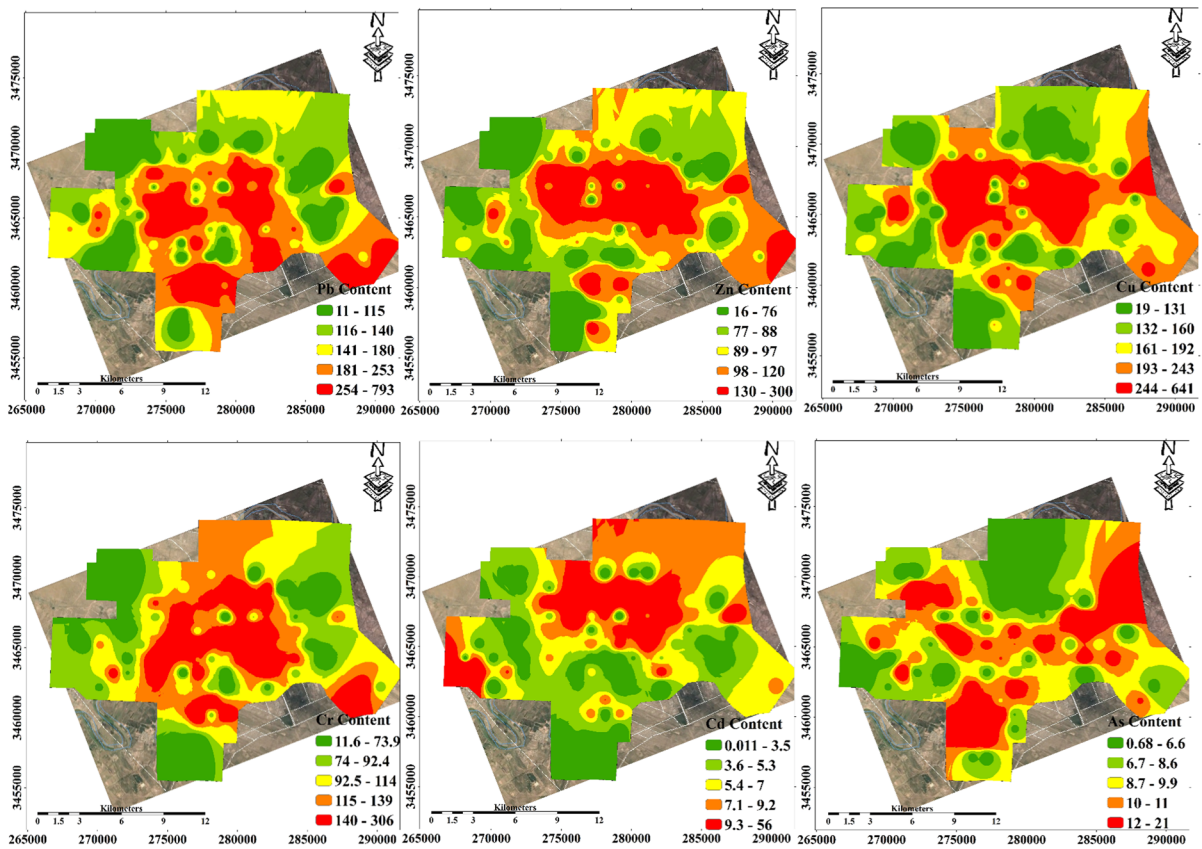


Fig. 3 Spatial distribution of toxic metals in street dust samples in the Ahvaz city

Table 5 Statistical analysis of potential ecological risk factor (*Er*) of studied potentially toxic metals

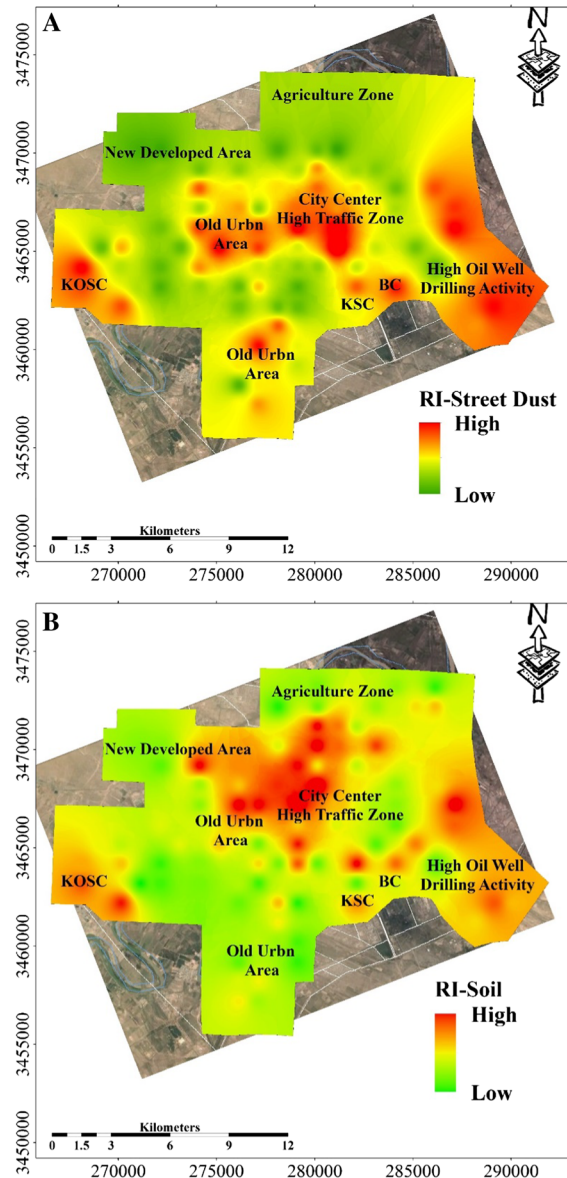
Element	Er			Er		
	Street dust			Surface soil		
	Min	Max	Average	Min	Max	Average
Pb	3.93	283.21	72.19	1.86	118.60	43.98
Zn	0.57	10.57	3.72	0.08	2.72	1.19
Cu	2.88	97.12	31.45	2.06	110.78	42.90
Cd	0.02	93.33	11.33	0.01	31.67	9.30
Cr	0.24	6.24	2.36	0.18	7.29	3.15
AS	2.19	68.39	30.09	1.80	70.05	34.53

Cr > Pb > As > Cd > Cu > Zn for adults (Table 7), indicating a greater risk for children vs adults. The results can be attributed to particular behavior model of the children, such as frequent pica behavior and hand or finger sucking (Li et al. 2015; Wei et al. 2015).

The HQ of Pb, Cr, As, and Cd for both soil and dust samples accounted for 40%, 29%, 21%, and 5% of the whole HI value, respectively. Additionally, the total percentage of Cu and Zn for the total HI value is lower than 5%. The HI values of the studied metals for children were 2.12–6.90 times greater than those for adults. The results also confirm that children are exposed to health risk from potentially toxic metals at higher level vs adults. The HI value for every metal was < 1, showing no non-carcinogenic risk for studied potentially toxic metals. Comparing HI values for both children and adults revealed that children have further potential of non-carcinogenic risk from toxic metals in the urban environment than adults. According to the results, cancer risks of the studied metals for both adults and children decreased as the following order: Cr_{dust} > Cr_{soil} > Cd_{dust} > Cd_{soil} > As_{dust} > As_{soil} > Pb_{dust} > Pb_{soil}.

Table 6 Potential ecological risk indices for street dust and soil samples

	RI			Number of sample	Number of sample			
	Min	Max	Mean		Low risk	Moderate risk	Considerable risk	High risk
Street dust	26.68	429.90	151.14	81	47 (58.02%)	27 (33.33%)	7 (8.64%)	0
Surface soil	15.66	1207.40	435.65	96	55 (57.29%)	38 (39.58%)	2 (3.13%)	0

**Fig. 4** Spatial distribution of RI of street dust (a) and surface soil (b) samples in the Ahvaz city

In addition, the RI value for Cd, As, and Pb were lower than 1×10^{-6} , suggesting that the carcinogenic risk of studied potentially toxic metals in the street dust and surface soil could be neglected. On the other hand, the carcinogenic risk of Cr was greater than 1×10^{-6} , indicating that the carcinogenic risk of Cr is at critical situation and needs more attention.

Toxic metal source identification

Inter-element relationships between elements provide useful information about the sources and pathways of toxic metals. Spearman's correlation coefficients of toxic metals in Ahvaz street dusts and surface soils are presented in Table 8. One group of toxic metals in street dusts Pb, Zn, Cu, Cr, and Cd show a very significant correlation with each other at $p < 0.01$. The strong positive correlation shows that the specifications and origins of emission for these toxic metals came from common anthropogenic sources. Arsenic show weak correlations with the other metals, suggesting they were derived from different sources. In surface soils, group of toxic metals including Pb, Zn, Cu, and Cr show a very significant correlation with each other at $p < 0.01$. The strong positive correlation shows that the specifications and origins of emission for these toxic metals came from common anthropogenic sources. Arsenic and Cd show weak correlations with the other metals, indicating they were derived from different sources.

However, Spearman's correlation coefficients are still not convincing, and so other multivariate statistical analyses were applied to further investigate the relationships among these toxic metals and their sources. We computed that the Bartlett's test of sphericity was significant at $p < 0.001$ and the analysis of Kaiser–Meyer–Olkin Index was 0.569, which corroborated that the toxic metal contents were appropriate for (PCA). The result of principle component analysis (PCA) with varimax rotation was used

Table 7 Health risk factors from toxic metal in street dusts and surface soils of Ahvaz

(mg/kg	Pb	Zn	Cu	Cd	Cr	As
C(95% UCL)	10.58	751.91	9.75	0.39	15.74	1.44
R_fD_{ing} (mg/kg day)	3.00E – 03	3.00E – 01	4.00E – 02	1.00E – 03	3.00E – 03	3.00E – 04
R_fD_{inh} (mg/kg day)	3.52E – 03	3.00E – 01	4.02E – 02	1.00E – 03	2.86E – 05	3.1E – 04
R_fD_{derm} (mg/kg day)	5.25E – 04	6.00E – 02	1.20E – 02	1.00E – 05	6.00E – 05	1.23E – 04
SF_{inh} (mg/kg day) ⁻¹	–	–	–	6.30E + 00	4.20E + 01	1.51E + 01
Dust						
Children						
HQing	7.38E – 01	4.44E – 03	6.63E – 02	8.69E – 02	4.93E – 01	3.97E – 01
HQinh	2.05E – 05	1.24E – 07	1.85E – 06	2.43E – 06	1.45E – 03	1.07E – 05
HQderm	7.87E – 03	3.55E – 05	3.53E – 04	1.39E – 02	3.94E – 02	1.55E – 03
HI = $\sum HQ_i$	7.46E – 01	4.47E – 03	6.67E – 02	1.00E – 01	5.34E – 01	3.99E – 01
Cancer risk	7.88E – 08	–	–	4.02E – 07	4.57E – 05	1.31E – 07
Adults						
HQing	9.90E – 02	5.95E – 04	8.90E – 03	1.16E – 02	6.62E – 02	5.33E – 02
HQinh	9.27E – 06	5.60E – 08	8.33E – 07	1.09E – 06	6.53E – 04	4.85E – 06
HQderm	2.01E – 02	9.07E – 05	9.03E – 04	3.55E – 02	1.00E – 01	3.96E – 03
HI = $\sum HQ_i$	1.19E – 01	6.86E – 04	9.80E – 03	4.71E – 02	1.67E – 01	5.73E – 02
Cancer risk	1.07E – 08	–	–	5.40E – 08	6.13E – 06	1.76E – 08
Surface soil						
Children						
HQing	6.90E – 01	3.98E – 03	5.97E – 02	7.13E – 02	4.57E – 01	2.94E – 01
HQinh	1.92E – 05	1.11E – 07	1.66E – 06	2.00E – 06	1.34E – 03	7.99E – 06
HQderm	7.36E – 03	3.18E – 05	3.18E – 04	1.14E – 02	3.66E – 02	1.14E – 03
HI = $\sum HQ_i$	6.98E – 01	4.01E – 03	6.01E – 02	8.27E – 02	4.95E – 01	2.95E – 01
Cancer risk	7.46E – 08	–	–	3.30E – 07	4.24E – 05	9.74E – 08
Adults						
HQing	9.26E – 02	5.34E – 04	8.02E – 03	9.57E – 03	6.14E – 02	3.95E – 02
HQinh	8.67E – 06	5.03E – 08	7.51E – 07	9.00E – 07	6.06E – 04	3.59E – 06
HQderm	1.88E – 02	8.14E – 05	8.14E – 04	2.91E – 02	9.35E – 02	2.93E – 03
HI = $\sum HQ_i$	1.11E – 01	6.16E – 04	8.83E – 03	3.87E – 02	1.55E – 01	4.24E – 02
Cancer risk	1.00E – 08	–	–	4.43E – 08	5.69E – 06	1.30E – 08

to the toxic metals concentration. In street dusts, two principal components (PC) accounted for 75% of the total variance. The first component (PC1) explains 57% of total variance, including Pb, Zn, Cu, Cr, and Cd, which indicated independent behavior and unique anthropogenic source (Fig. 5). Meanwhile, high EF and CV implied that these metals were originated from anthropogenic sources. The second component (PC2) accounts for 18% of total variance showing positive loadings for As. In soils sample, three principal components (PC) accounting for 81% of the total variance are presented in Fig. 6. The first principal component (PC1) explains 49% of the total variance dominated by Pb, Zn, Cu, and Cr indicating

independent behavior and unique anthropogenic source. The second component (PC2) which accounts for 17% of total variance is characterized by Cd. In the loading plot (Fig. 3), a third (PC3) explains 15% of total variance which is primarily dominated by As.

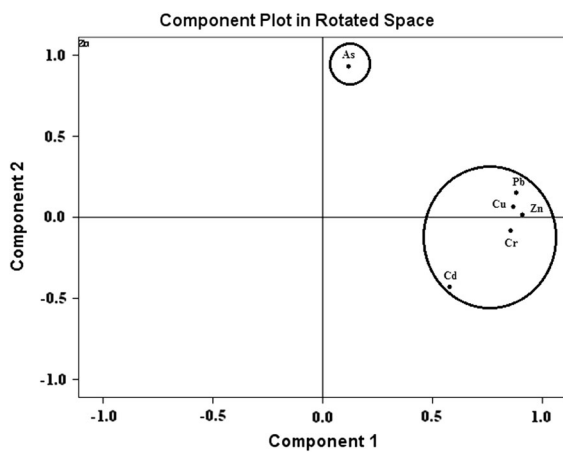
Factor 1 mainly suggests anthropogenic sources released from traffic emission, as reported in earlier studies (Alloway 2013; Shi et al. 2008; Soltani et al. 2015). Traffic-related pollutants are mainly vehicle exhaust and other particles from tire and brake lining erosion (Pacyna et al. 2007). As previously reported, the major source of Pb is the fuel combustion of leaded gasoline (Cheng and Hu 2010; Zhang et al. 2017). Motor lubricating oil leakage, street paint, mechanical

Table 8 Correlation matrix for toxic metal concentrations in street dusts and surface soils from Ahvaz

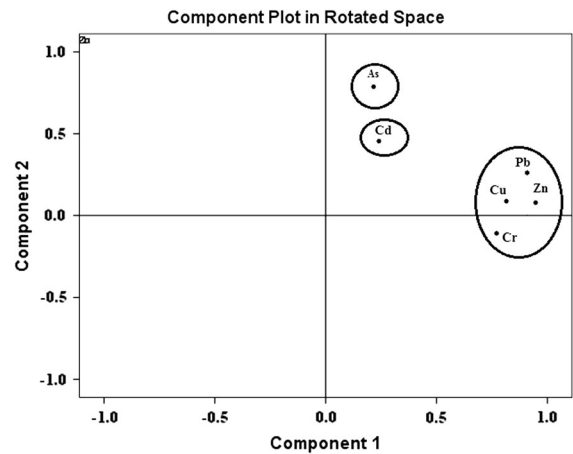
Element	Surface soil (<i>n</i> = 96)						Street dust (<i>n</i> = 81)					
	Pb	Zn	Cu	Cr	Cd	As	Pb	Zn	Cu	Cr	Cd	As
Pb	1.000						1.000					
Zn	0.759**	1.000					0.796**	1.000				
Cu	0.750**	0.818**	1.000				0.723**	0.797**	1.000			
Cd	0.056	0.060	0.070	1.000			0.747**	0.729**	0.693**	1.000		
Cr	0.652**	0.689**	0.715**	0.750**	1.000		0.615**	0.626**	0.624**	0.701**	1.000	
AS	0.015	0.083	0.023	0.060	0.191	1.000	0.061	0.053	0.083	− 0.014	− 0.020	1.000

*Correlation is significant at the 0.05 level (2-tailed)

**Correlation is significant at the 0.01 level (2-tailed)

**Fig. 5** Matrix of principal component analysis loadings for toxic metal concentrations in street dusts from Ahvaz

abrasion, car parts wearing-out, corrosion, and physical abrasion of vehicles can also be considered as the sources of Zn on urban soil and street dust (Abbasi et al. 2017; Civardi et al. 2016; Dehghani et al. 2017). Cu is generally used in brakes to control heat transfer (Huang et al. 2009). Other industrial activities in Ahvaz city such as steel-related companies, Carbon Black Company, oil well drilling activities, drilling pits around the Ahvaz city also significantly contribute to the concentration of toxic metals. The concentration of As may also potentially be related to traffic and coal combustion sources in urban environment (Dai et al. 2012; Huang et al. 2009; Ozaki et al. 2004). Cr and Cd can be related to steel companies, mainly oil well drilling mud pits, and resuspension of soil-derived particles (Karbassi et al. 2015; Sarma et al. 2016). Finally, related toxic metals in PC1 for both soil and

**Fig. 6** Matrix of principal component analysis loadings for toxic metal concentrations in surface soil from Ahvaz

dust samples are possibly originated from common sources including industrial activities, residential area, and traffic emission (Jiang et al. 2017a; Wang et al. 2015).

Conclusion and remarks

The concentration values, enrichment factors, ecological, and human health risk of the potentially toxic metals (Pb, Zn, Cu, Cd, Cr, and As) in street dusts of Ahvaz were examined in this paper. The average values of analyzed potentially toxic metals in street dust and surface soil were greater than their corresponding average of UCC and other reference soils, demonstrating that this pollution may be related to

anthropogenic sources. Lead in street dusts and Cd and Cu in surface soil showed the highest EF values. This finding suggests that the dust and soil in this study area are significantly affected by human activities. The results of PCA and Pearson's correlation coefficient confirmed that the main sources of toxic metals are industrial activities and road traffic emissions and also resuspension of soil and dust particles. Cu, Pb, Zn, and Cr in Ahvaz soil and dust particles are strongly influenced by industrial and traffic emissions, while As and Co originate from resuspension of soil natural parent particles. It was found that the mean potential ecological risk Er values in dusts for Cu, As, Cd, Zn, and Cr have low PER. In contrast, moderate-to-high PER average values are indicated by Pb (72.19). The average PER values in surface soil are low for As, Cd, Cr, and Zn. In contrast, Pb and Cu have moderate Er.

Human health risk assessment of studied metals in the street dust and surface soil samples indicates the following order of exposure pathways for studied potentially toxic metals: ingestion > dermal contact > inhalation. The non-carcinogenic HQs of potentially toxic metals in Ahvaz street dust and surface soil samples were higher for children vs adults. The value of HI for each metal was < 1 (close enough), which suggests no non-carcinogenic risk for both target populations. The Cr carcinogenic risk calculation is > than 1×10^{-6} for children and adults. The present study will be helpful and valuable for inhabitants (especially for children) and for authorities to take the proper action to better protect the health of Ahvaz citizens.

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