RESEARCH ARTICLE

CrossMark

Concentration, contamination level, source identification of selective trace elements in Shiraz atmospheric dust sediments (Fars Province, SW Iran)

Amir Karimian Torghabeh[1] · Ashkan Jahandari[2] · Roya Jamasb[2]

Abstract

Geogenic dust is one of the most important environmental hazards in Iran. This study investigated the concentration, contamination level, potential sources, and ecological risk and human health assessment of Shiraz atmospheric dust, the largest city in southern Iran. Contents of atmospheric dust sediments geochemistry were determined by inductively coupled plasma-optical emission spectrometry (ICP-OES). The mean concentrations of the elements in atmospheric dust are Zn (106.6 mg/kg), Cr (98.4 mg/kg), Ni (68.1 mg/kg), Cu (40.5 mg/kg), Pb (30.6 mg/kg), As (4.5 mg/kg), and Cd (0.28 mg/kg). Except As and Cd, levels of all other elements in dust sediments samples were higher than corresponding background world soils. In comparison with the concentrations of studied heavy metals in Shiraz urban street dust, the concentrations of heavy metals in Shiraz atmospheric dust were substantially at low levels. Based on Enrichment Factor (EF) and Geo-accumulation index (Igeo), Shiraz atmospheric dust is moderately to minimally polluted by selected heavy metals. The values of risk index (RI) for seven heavy metals in all dust samples were 146.2 and 130.8, which were lower than 150, indicating that ecological risks posed by studied elements in atmospheric dust were moderate. Human health risk assessment (non-carcinogenic) suggested that of the three exposure pathways, ingestion of atmospheric dust was the major pathway exposure to heavy metals in dust, followed by skin contact. The hazard index (HI) values for all studied heavy metals decreased in the following order: Cr > Pb > Ni > Cu > Zn > Cd for both children and adults. Cr and Ni contribute most to health risk posed by atmospheric dust exposure for both children and adults, and Cd, Zn, and Cu have smaller contributions. The result of cancer risk assessment suggested that Cr, Ni, and Cd were all below the safe level. Principal component analysis (PCA) indicated that grouped Cd, Ni, and Zn and grouped Cr, Cu, and Pb could be controlled by two different types of anthropogenic source. Whereas, As and Zn were controlled by both human and geogenic sources.

Keywords Atmospheric dust · Heavy metals · Health risk assessment · Shiraz

---

• This is the first report about human health risk assessment of heavy metals in atmospheric dust.
• Levels of heavy metals in atmospheric dust samples were not comparable with urban street dust.
• Exposure to Cr in atmospheric dust that contributes most to health risk poses high cancer risk for Shiraz inhabitants.

✉ Amir Karimian Torghabeh
amirkarimian@shirazu.ac.ir

[1] Department of Earth Sciences, Faculty of Sciences, Shiraz University, Shiraz, Iran

[2] Department of Geology, Shahid Bahonar University of Kerman, Kerman, Iran

Introduction

Dust storms are trouble geogenic hazard phenomena in the Middle East. It has significant adverse effects on the human health, industries, agricultures, and transportation activities. On the other hand, with the increase of dust storm occurrence, the heavily packed structures in urban areas cause atmospheric dust deposits, leading to increased exposure of citizens to atmospheric dust. Also, atmospheric dust can easily adsorb air pollutants such as heavy metals which are released by various sources and carry them over long distances.

Sedimentology studies have a major role in the different aspect of sciences such as basin analysis and petroleum systems and also a major role in dust studies (Karimian Torghabeh et al. 2014, 2015; Karimian Torghabeh and

Pimentel 2016; Karimian Torghabeh et al. 2018). Atmospheric dust sediments as a primary source, sink, and carrier multimedia air pollutants play an essential role in atmospheric environmental quality and also provide a useful indicator for characterizing urban regions. Heavy metals, one of the most important pollutants in the urban areas, are regarded as hazardous contaminant because they could cause potentially chronic problems to urban inhabitants. Citizens are mainly exposed to heavy metals in dust via three routes, direct breathing, ingestion, and dermal contact absorption (Li et al. 2016; Shi et al. 2011). Among different age groups, children have major exposure to dust due to their hand-to-mouth habit. VanWijnen et al. (1990) and Calabrese et al. (1997) have pointed out that maximum average of deliberately ingested soil in children can reach 1800 g each month, where one-third of the ingested metals such as lead are bioavailable (Evans et al. 1992). Contamination of the atmospheric dust by heavy metals occurs as the result of numerous human activities. Atmospheric dust consists of different minerals, organic components, microfossils, anthropogenic particles, and heavy metals that may originate from geochemical process and range of human activities including mining, oil and gas industries, and transportation systems. Nevertheless, in urban area plants, traffic emission, car bodies, municipal wastes, and deterioration of the building and pavements are the principal sources of heavy metal pollution (Filippelli et al. 2012). For example, Cd, Pb, and Zn mainly originated from road traffic emission (Budai and Clement 2018), while Cr and Ni have been sourced by fuels combustion and vehicular emissions (Men et al. 2018). The source of Zn and Cd in atmospheric dust is believed to be from worn vehicle tires and the corrosion of galvanized automobile bodies (Kamani et al. 2015; Karimian Torghabeh et al. 2018). Additionally, As in atmospheric dust can originate from industrial activities, automotive emissions, and fossil fuel combustion, while Cu is mainly traced to car lubricants (Alloway 2013). It has been showed that adverse health effect of heavy metals in atmospheric dust includes respiratory tract disorders, cardiovascular diseases, nervous system interruptions, and increased risk of cancer (Wei et al. 2015).

Enrichment of atmospheric dust by heavy metals posed a risk to human societies and is of a notable subject to many scholars, so we need to further review in order to formulate regulatory and corrective actions to reduce the effects of atmospheric dust. Research on the heavy metal contamination level, distribution, toxicity, and source identification in atmospheric dust generally has not been carried out in the southern cities of Iran. However, most studies focused mainly on the urban street dust of the cities (Alsbou and Al-Khashman 2018; Pan et al. 2017; Kamani et al. 2017; Shabbaj et al. 2017). For example, Keshavarzi et al. (2015) have attempted to determine and evaluate the potential health risk of heavy metals in Shiraz urban street dust (receptors which are 1.6~2.0-m high). Heavy metal pollution in atmospheric dust has seldom been studied. Studies on the pollution character of atmospheric dust in urban areas laid much emphasis on the contamination level and sources of heavy metals, while the literature on the ecological and human risk assessment was rare.

Shiraz is one of the southern cities of Iran which is affected by dust storm. The region is the largest populated city in southern Iran where the impact of rapid population growth. Heavy metal contents in the atmospheric dust of the Shiraz area, their contamination levels, pollution sources, and ecological and health risk assessment have not been investigated. Due to the high occurrence of dusty days in Shiraz, characterizing the heavy metal pollution in atmospheric dust is essential to aid carrying out of suitable management approaches. So, the objectives of this work were as follows: (i) to determine total concentration of As, Cd, Cr, Cu, Ni, Pb, and Zn in atmospheric dust from Shiraz region, (ii) to assess the degree of contamination of heavy metals in atmospheric dust using contamination indices, (iii) to evaluate the ecological risks of heavy metals based on ecological risk (RI), (iv) to assess population health risk due to heavy metal exposure to atmospheric dust based on hazard indexes (HIs) and cancer risk, and (v) to identify the potential source of heavy metals by multivariate analysis.

Materials and methods

Study area

Shiraz as a capital of Fars province is the largest and most densely populated city in south of Iran (Fig. 1a). Shiraz has an area of 240 km^2 and a population of above 1,500,000, making it the sixth most populated city in Iran. The city is bounded to the west and the east by the Derak and Babakohi mountains, respectively. The Shiraz experiences moderate climate with an annual average precipitation of 1.9 mm year^{-1} and the highest annual average precipitation is 185.2 mm year^{-1}. Figure 1b shows the dominant wind direction (rose plot) in the studied area and shows that western and southwestern winds are the most frequent winds in the Shiraz area. The high occurrence of dust events, rapid urbanization, and industrial development in Shiraz leads to a decrease in air quality. The local sources of air pollution in Shiraz are traffic and transportation systems and many kinds of industries, such as petrochemical, cement, and electrical plants. However, since Shiraz is a syncline valley city (NW–SE elongated), it is faced with land use restrictions to the development of urban streets; so this city due to tight streets is congested by a heavy traffic which has become the most important cause of air pollution in the study area (Jahandari 2015). Shiraz also is an essential transpiration junction, which connects the northern and central parts of Iran to the southern regains of the Persian Gulf. Also, it is an important center of medical, economy, and education in southern Iran.
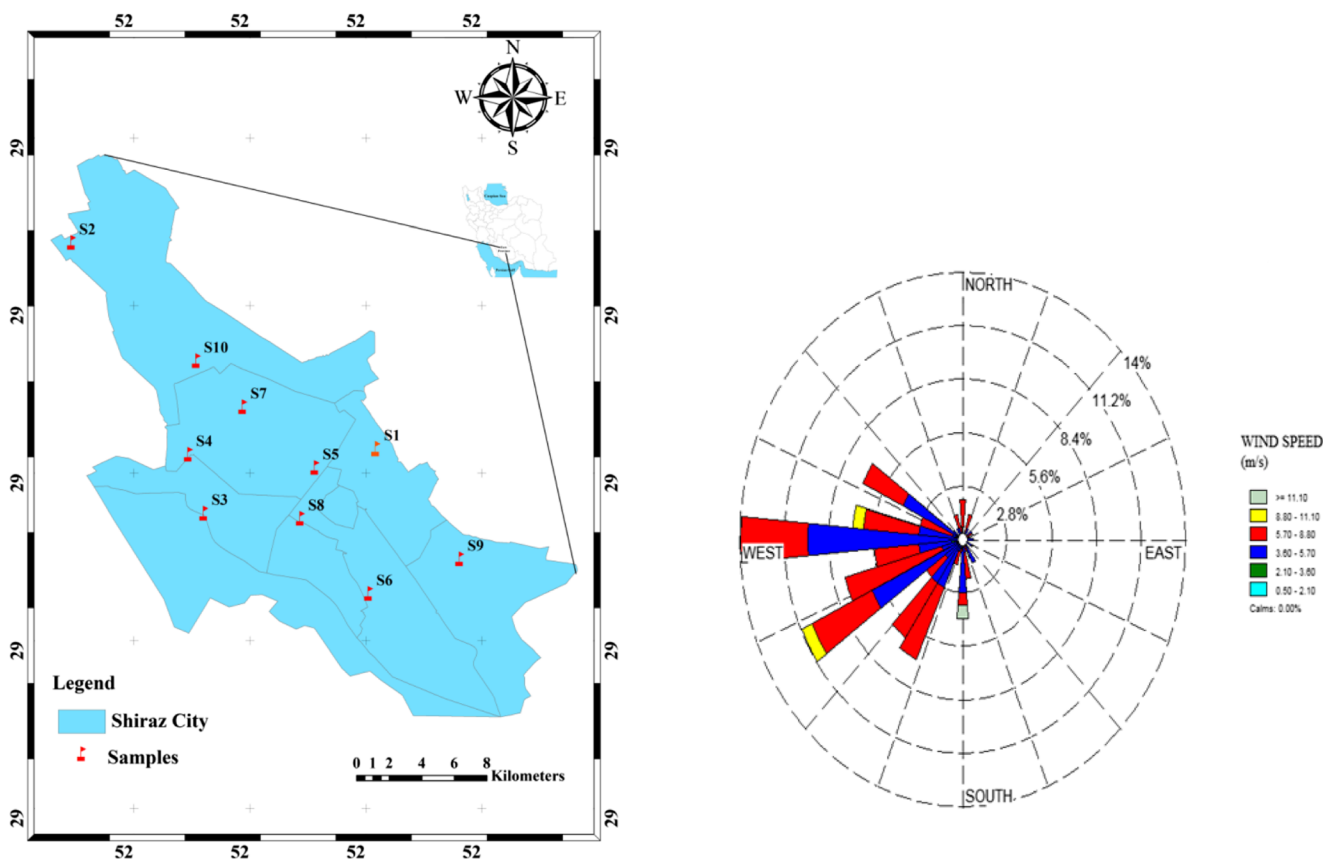
Fig. 1 Location map of the study area and sampling sites in the Shiraz city (**a**); wind rose plot in the studied area (**b**)

Atmospheric dust sampling and chemical analysis

For atmospheric dust, 10 sites in different parts of the study area were selected (Fig. 1). Similar to the method procedures employed by Menéndez et al. (2007), Hojati et al. (2012), and Norouzi et al. (2015, 2017), the collectors were made of glass trays with a surface area 1 m² which is covered with polyethylene net 2-mm mesh, in order to produce a rough surface to trap and immobilize the deposited atmospheric dust on a glass tray. The collectors were installed at above 3–5 m from the ground level on flat-roofed buildings. The fixed collector in this altitude reduces any kind of vandalism in the sampling sites. It also eliminates the effects of low altitude wind which contains local dust such as urban street dust. All collector trays were washed with distilled water following sampling. Atmospheric dust have been stored in a polyethylene microtube, labeled, and transported to the lab for subsequent processing. Dust samples were analyzed by inductively coupled plasma-optical emission spectrometry (ICP-OES) at ZarAzma Mineral Studies Company, Iran (accredited according to ISO 17025 Standard by Iranian National Standards Organization (ISRI) No.IAS/20992), following Aqua Regia Digestion. The quality assurance (QA)/quality control (QC) included the duplicate analyses, certified materials, and

analysis of blanks. To evaluate the quality of chemical analysis, certified reference materials (CRMs) such as GEOSTATS and OREAS were used. The relative standard deviation (RSD) for studied heavy metals was less than 10% (1.8% for As, 9% for Cd, 3.8% for Co, 1.4% for Cr, 5.1% for Cu, 1.6% for Mo, 3% for Ni, 8.3% for Pb, 4.6% for Sr, and 0.69% for Zn).

Pollution assessment

Enrichment Factor

Contamination ranks of heavy metals in atmospheric dust were assessed using contamination indices including Enrichment Factor (EF) and Geo-accumulation index (Igeo). The Enrichment Factor has been widely used to study the degree of pollution and the source of heavy metals in atmospheric dust (Doabi et al. 2017). The formula to calculate the EF value is expressed as:

$$EF = \frac{(C_x/C_r)\text{Sample}}{(C_x/C_r)\text{background}} \qquad (1)$$

where C_x refers to the concentration of target elements and C_r is the concentration of the reference element in the samples

and UCC (upper continental crust), respectively. In the present study, aluminum (Al) due to high frequency and lack of anthropogenic source was employed as the reference material. According to Jadoon et al. (2018), EF value of 1 can be considered geogenic origin for heavy metal in the atmospheric dust, whereas ratios greater than 1.5 denote non-crustal source. The rank of heavy metal pollution of EF is shown in Table 1 (Sutherland 2000).

Geo-accumulation index (Igeo)

An Igeo (developed by Müller 1969) approach was widely utilized to assess metal pollution. In this study, Igeo was used to evaluate degree heavy metal pollution in collected dust. Igeo is expressed as follows:

$$\text{Igeo} = \log 2 \left(\frac{Cn}{1.5 \times Bn} \right) \tag{2}$$

where Cn is the measured concentration of heavy metals and Bn is the geochemical background value of each element, and UCC is used as the background content for the purposes of this study and coefficient 1.5 is the background matrix correction factor due to lithospheric effects (Muller, 1969). The Geo-accumulation index for the investigated heavy metal is classified in Table 1.

Potential ecological risk index (PER)

Potential ecological risk index (proposed by Hakanson (1980)) is also introduced to assess the contamination degree of heavy metals in the atmospheric dust. This index provides probability assessment of adverse ecological effects caused by exposure by to one or more pollutants (Li et al. 2015a). Potential ecological risk index (RI) was calculated according to Eqs. (3)–(5):

$$C_i^f = \frac{Ci}{B} \tag{3}$$

$$E_i^f = \sum_{i=1}^{n} \left(T_i^f \times C_i^f \right) \tag{4}$$

$$RI = \sum_{i=1}^{n} E_f^{\ i} \tag{5}$$

where C_i^f is a contamination factor for considered metal in the dust sample; B is a reference value for heavy metals (UCC); E_i^f is the potential ecological risk factor for each heavy metal; T_i^f is the metal toxic factor of an individual element, which is determined for Zn = Ni = 1, Cr = 2, Pb = Cu = 5, Cd = 30, and As = 10. Table 1 provides the criteria for potential ecological risk factor and potential ecological risk of heavy metals (Hakanson 1980).

Health risk assessment model on human

Exposure evaluation via ingestion, dermal contact, and inhalation The models used in our study to calculate the exposure risk of children and adults to toxicant heavy metals in atmospheric dust are based on those developed by US Environmental Protection Agency (USEPA 1996, 2001) and Dutch National Institute of Public Health Agency (Van den Berg 1994). According to published corresponding literatures (Li et al. 2016, 2015a, b; Huang et al. 2016), residential adult and children exposure to heavy metals in atmospheric dust is through the following three main pathways: direct ingestion of dust (Ding), inhalation of re-suspended dust particles through mouth and nose (Dinh), and dermal absorption of heavy elements in dust particles that adhered to exposed skin (Dder). The corresponding dose received through each of the three exposure paths was calculated using Eqs. (6), (7), and (8) respectively for non-carcinogenic risk (USEPA 1996, 2001). For carcinogens, the lifetime average daily dose (LADDinh) for Cd and Cr inhalation exposure pathway was used in the assessment of cancer risk by Eq. (9) (USEPA 1996, 2001). Values of the variables for the estimation of the health risk assessment model on human are presented in Table 2.

$$\text{Ding} = \frac{C \times \text{ingR} \times \text{EF} \times \text{ED}}{\text{BW} \times \text{AT}} \times 10^{-6} \tag{6}$$

$$\text{Dinh} = \frac{C \times \text{inhR} \times \text{EF} \times \text{ED}}{\text{PEF} \times \text{BW} \times \text{AT}} \tag{7}$$

Table 1 Grades of Enrichment Factor, index of geo-accumulation, and modified degree of contamination

EF value	Contamination level (class)	I_{geo}	Sediment quality	E_i^r	Grads	RI	Potential ecological hazard
EF < 1	No enrichment (0)	$I_{geo} \leq 0$	No pollution	$E_i^r < 40$	Low	RI < 150	Low
EF < 2	Deficiency to minimal enrichment (1)	$0 < I_{geo} \leq 1$	Low pollution	$40 \leq E_i^r < 80$	Moderate	$150 \leq RI < 300$	Moderate
EF = 2–5	Moderate enrichment (2)	$1 < I_{geo} \leq 2$	Moderate pollution	$80 \leq E_i^r < 160$	High	$300 \leq RI < 600$	High
EF = 5–20	Significant enrichment (3)	$2 < I_{geo} \leq 3$	Median pollution	$160 \leq E_i^r < 320$	Serious	$RI \geq 600$	Very high
EF = 20–40	Very high enrichment (4)	$3 < I_{geo} \leq 4$	Heavy pollution	$E_i^r \geq 230$	Severe	RI	
EF > 40	Extremely high enrichment (5)	$4 < I_{geo} \leq 5$	Serious pollution				
		$5 > I_{geo}$	Extreme pollution				

$$Dder = \frac{C \times SL \times SA \times ABS \times EF \times ED}{BW \times AT} \times 10^{-6} \quad (8)$$

$$LADDinh = \frac{C \times EF}{AT \times PE} \times \left(\frac{inhR \times EDchild}{BWchild} + \frac{inhR \times EDadult}{BWadult} \right) \quad (9)$$

Risk characterization In order to determine the human health risk from heavy metals, after the exposure dose at three exposure pathways is calculated, a hazard quotient (HQ) and also hazard index (HI) that represents a magnitude of deleterious effects of total exposure routes are calculated as follows Eq. (10):

$$HI = HQ_{ing} + HQ_{inh} + HQ_{der}$$
$$= \left[(D_{ing}/R_f D_{ing}) + (D_{inh}/R_f D_{inh}) + (D_{der}/R_f D_{der}) \right] \quad (10)$$

where HI is Hazardous index based on non-cancer toxic risk, HQ_{ing}, HQ_{inh}, and HQ_{der} are hazard quotient for each exposure routs to certain heavy metals, and $R_f D$ (mg kg^{-1} day^{-1}) is the specific reference dose for each heavy metal and for exposure pathway (Table 3). Baseline RfD values represented of maximum permissible risk on human population daily exposure during a lifetime (Jiang et al. 2017). Except Cd and Cr, there is no data for inhalation-specific toxicity ($R_f D_{inh}$) for studied heavy metals (Cu, Pb, Ni, and Zn). So, for other heavy metals, we substitute oral reference dose ($R_f D_{ing}$) as an inhalation reference dose based on this hypothesis that after inhalation, the absorption of the particle-bound toxicants will result in similar health effects when the particles had been ingested (Li et al. 2016; Ferreira-Baptista and De Miguel 2005; Van den Berg 1994). HI is calculated by the sum of $HQ_{ing,inh,der}$ and is used to denote the total potential non-carcinogenic risks of different heavy metals via three exposure pathways described previously. HI < 1 indicates

that there are no adverse health effects, and if HI values > 1, it indicates that possible non-carcinogenic health effects exist (USEPA 2001).

In the case of carcinogenic risks, the exposure doses at three exposure route were multiplied by the corresponding cancer slop factor (SF) ((kg·day)/mg) (Table 3) to present an estimate of cancer risk (Li et al. 2015a, b, 2016) Eq. (11):

$$CancerRisk(CR) = LADD \times SF \quad (11)$$

The international acceptable precautionary risk level for regulatory purposes is 1E−06 (Li et al. 2016). The $R_f D$ and SF values for studied elements are presented in Table 3.

Results

Heavy metal concentration in atmospheric dust sediments

The average concentrations and basic statistic parameters of seven heavy metal measurement in atmospheric dust, as well as concentration values of these elements in atmospheric dust from different cities and world soils, are presented in Table 4. The total heavy metal contents in atmospheric dust increase in the order of Cd < As < Pb < Cu < Ni < Cr < Zn. The mean concentrations of As, Cd, Cr, Ni, Pb, Cu, and Zn were approximately 3, 2, 2.8, 3.4, 1.5, 1.6, 1.7, and 1.5 times higher than their corresponding UCC values, respectively. The average concentrations of Cr, Cu, Ni, Pb, and Zn in Shiraz atmospheric dust are higher than those in world soils. The atmospheric dust in Shiraz has higher average Cr content compared with Shiraz urban street dust, whereas As, Cd, Cu, Pb, and Zn contents in atmospheric dust are lower than those of the urban street dust

Table 2 Values of the variables for the estimation of health risk assessment model on human

Variable	Definition	Value		References
		Children	Adult	
C	Heavy metal concentrations	mg/kg		This study
IngR	Ingestion rate	100 mg day^{-1}	200 mg day^{-1}	USEPA (2001)
InhR	Inhalation rate	7.6 m^3 day^{-1}	20 m^3 day^{-1}	Van den Berg (1994)
EF	Exposure frequency	350 day year^{-1}		Li et al. (2016)
ED	Exposure duration	6 year	24 years	USEPA (2001)
SL	Skin adherence factor	0.2 mg m^{-2}d^{-1}	0.7 mg m^{-2}d^{-1}	USEPA (2001)
SA	Exposed skin area	2800 cm^2	5700 cm^2	USEPA (2001)
ABS	Dermal absorption factor	0.001		USEPA (2001)
PEF	Particle emission factor	1.36 × 10^9 m^{3}kg^{-1}		USEPA (2001)
AT (non-carcinogenic)	Averaging contact time	ED × 365 day		Zheng et al. (2010)
AT (carcinogenic)	Averaging contact time	25,550 day		Zheng et al. (2010)
BW	Average body weight	15 kg	70 kg	USEPA (2001)

Table 3 The RfD$_{ing, inh, and der}$ and SF of heavy metals

	Cd	Cr	Cu	Pb	Ni	Zn	Reference
R$_f$D$_{ing}$	1.00E−03	3.00E−03	4.00E−02	3.50E−03	2.00E−02	3.00E−01	Luo et al. (2012)
R$_f$D$_{der}$	2.50E−05	6.00E−05	1.20E−02	5.25E−04	5.40E−03	6.00E−02	Ferreira-Baptista and De Miguel (2005)
R$_f$D$_{inh}$	5.71E−05	2.86E−05	–	–	–	–	Ferreira-Baptista and De Miguel (2005)
SF	6.30E+00	4.20E+01	–	–	8.40E−01	–	Ferreira-Baptista and De Miguel (2005)

(Fig. 2). This observation indicated that urban street dust (Keshavarzi et al. 2015) compared to atmospheric dust was more enriched to heavy metals. So, it can be explained that Shiraz road dust compared to Shiraz atmospheric dust was greatly affected by urban pollution sources. Heavy metal concentrations in Shiraz atmospheric dust are compared with data reported for other cities (Table 4). Chromium and Ni concentrations in Shiraz atmospheric dust are substantially higher for all mentioned cities, except for Kermanshah. The mean concentrations of As, Cd, Cu, and Pb in atmospheric dust sampled in Shiraz are lower than those sampled in Isfahan, Riyadh, Kermanshah, and Beijing. The mean concentration of Zn in atmospheric dust samples of Shiraz is significantly lower than that for the other sampled cities. It can, therefore, be concluded that by increasing the sampling time, atmospheric dust was highly affected by various anthropogenic pollutant sources in the urban area (Table 4).

Pollution assessment

Enrichment Factor analysis

Since atmospheric dust, unlike urban street dust, has no local origin, in this study, heavy metal concentration in UCC was used as reference values for calculating Enrichment Factor.

Figure 3 shows the result of EF. The EF values are the following (present in increasing order): Zn with 2.2 to 1.6 (average 1.7), Pb with 3.3 to 1.4 (average 1.8), Cu with 2.02 to 1.83 (average 1.93), Cr with 4.1 to 3.4 (average 3.3), Cd with 3.9 to 3.1 (average 3.4), As with 4.8 to 2.6 (average 3.59), and Ni with 4.3 to 3.9 (average 4.02). The EF values of arsenic, Ni, and Cr are significantly higher than those of other heavy metals. Jadoon et al. (2018) suggested that these heavy metals, As, Cd, Cr, and Ni with mean EF values of higher than 1.5, are anthropogenic sources. However, Pb and Zn with mean EF values close to 1.5 are considered mainly from geogenic sources. Based on Table 2, the ranking of average EF values of heavy metals is as follows: Ni (moderate enrichment) > As (moderate enrichment) > Cd (moderate enrichment) > Cr (moderate enrichment) > Cu (minimal enrichment) > Pb (minimal enrichment) > Zn (minimal enrichment). The average EF values of all collected dust exceeding 2.5 indicate moderate pollution levels in Shiraz atmospheric dust.

Geo-accumulation index analysis (IGeo)

The heavy metal IGeo in Shiraz atmospheric dust is shown in Fig. 4. The IGeo values are the following (presented in decreasing order): Ni > As > Cd > Cr > Cu > Pb > Zn. Negative values of IGeo were determined for Zn at sites 2, 4, 5, 6, 7, 9,

Table 4 Statistical parameters and comparison of heavy metal concentrations (mg/kg) in Shiraz atmospheric dust, UCC, world soils, and other selected cities

|	As	Cd	Cr	Cu	Ni	Pb	Zn	Al	Sampling time	Reference
Mean	4.5	0.28	98.4	40.5	68.1	30.6	106.6	67,277	May 2018	This study
S.D.	0.9	0.01	7.5	0.97	1.4	9.6	8.1	1824.4	–	–
Min	3.2	0.25	93	40	67	23	101	64,864	–	–
Max	5.9	0.31	118	43	70	57	103	70,217	–	–
UCC	1.5	0.098	35	25	20	20	71	80,400	–	Taylor and McLennan (1995)
World soils	4.7	1.1	42	14	18	25	63	–	–	Alloway (2010)
Shiraz urban dust	6.58	0.5	67.16	136.4	77.25	115.71	403.6	–	August 2013	Keshavarzi et al. (2015)
Isfahan (Iran)	50.60	0.98	37.2	67	53.4	96.3	400.3	–	June 2012 to May 2013	Norouzi et al. (2017)
Riyadh (Saudi Arabia)	–	0.9	88.9	77.7	57.2	22.2	206.3	–	February 2013	Modaihsh and Mahjou (2013)
Beijing (China)	–	–	72.1	98	37.6	119	408	–	March 2008 to February 2009	Tang and Han (2017)
Kermanshah (Iran)	–	–	119	110	238	–	490	–	March to September 2013	Doabi et al. (2017)
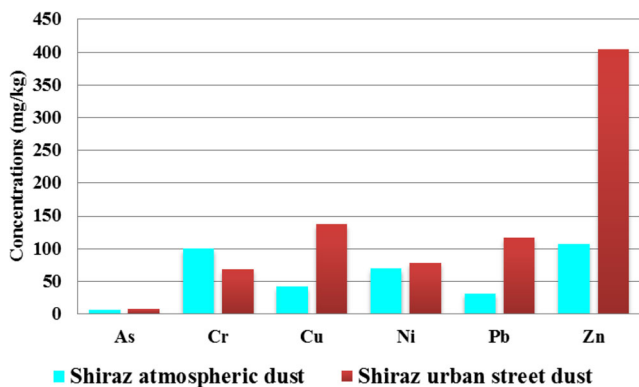
Fig. 2 Comparison of heavy metal concentration in atmospheric dust and urban street dust from Shiraz city

and 10 and for Pb in all sites except sites 1, 4, and 5 suggesting that these sites were not polluted by these metals. On the other hand, Keshavarzi et al. (2015) reported that Shiraz urban dust were heavily polluted by some heavy metals, particularly Pb and Zn. This difference indicates that the atmospheric dust transported to Shiraz are seriously influenced by local pollution sources, such as traffic emissions or fossil fuel combustion. The total IGeo value ranking for Ni, As, Cd, and Cr was median pollution, while total IGeo values class for remaining heavy metals were no pollution to low pollution.

Potential ecological risk assessment of heavy metals in Shiraz atmospheric dust

The potential ecological risk assessment result of investigated heavy metals in Shiraz atmospheric dust is shown in Fig. 5. The mean ecological risk (E_r^i) of heavy metals showed an increasing order of Zn < Ni < Cr < Pb < Cu < As < Cd. The result shows that risk for metals polluted was predominantly attributed to Cd and As. The E_r^i value contribution of Cd, As, and Cu to the potential hazard index of these heavy metals was 61, 21, and 6%, respectively. For other heavy metals, the average E_r^i was found
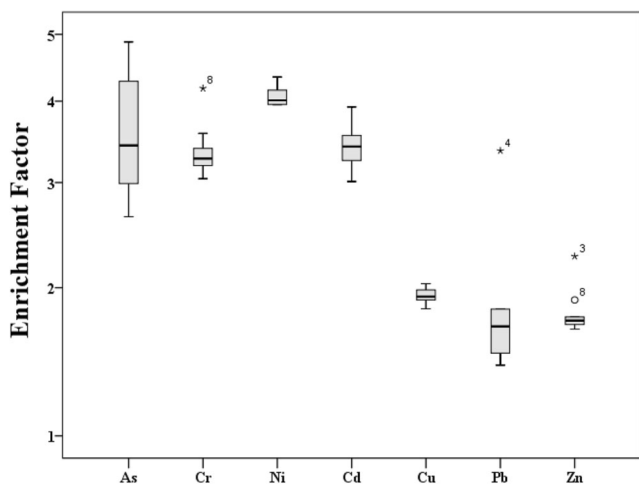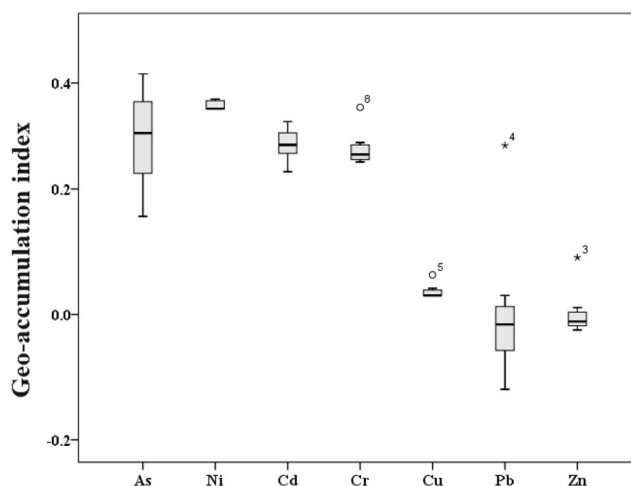

Fig. 4 Box plot of Geo-accumulation index

to be only 12%. According to Table 1, ecological risk indices of As, Cr, Cu, Ni, Pb, and Zn were lower than 40, which indicates a low potential ecological risk of these elements in the Shiraz atmospheric dust. Among the seven studied elements, the average E_r^i of Cd exceeds 40, reflecting moderate potential ecological risk of cadmium in atmospheric dust sampled. The mean RI values are 142.97 which suggested that ecological risks posed by studied elements in atmospheric dust were moderate. Compared to the results presented by Keshavarzi et al. (2015), the potential ecological risks of heavy metals in Shiraz urban street dust are far more than Shiraz atmospheric dust. This situation warns that the atmospheric dust deposited over Shiraz by adsorbing heavy metals from various urban pollutant sources provides a very high ecologic risk for Shiraz citizens.

Human health assessment exposure to atmospheric dust

The result of evaluating non-carcinogenic risk of heavy metals in atmospheric dust is presented in Table 5. The ingestion of
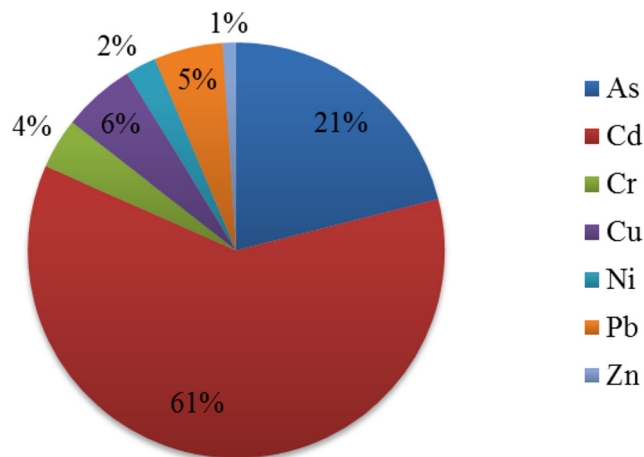

Fig. 3 Box plots of Enrichment Factor

Fig. 5 Contribution of studied heavy metals to potential ecological risk indices in Shiraz atmospheric dust

Table 5 Daily dose and hazard indices of heavy metals in atmospheric dust for both children and adults

Elements		D_{ing}	D_{der}	D_{inh}	HQ_{ing}	HQ_{der}	HQ_{inh}	HI
Children								
Cd	Min	3.19635E−06	8.94977E−09	8.93097E−11	3.20E−03	3.58E−04	1.56E−06	3.56E−03
	Max	3.96347E−06	1.10977E−08	1.10744E−10	3.96E−03	4.44E−04	1.94E−06	4.41E−03
	Mean	3.57991E−06	1.00237E−08	1.00027E−10	3.58E−03	4.01E−04	1.75E−06	3.98E−03
Cr	Min	1.51E−03	4.22429E−06	3.11666E−10	5.03E−01	7.04E−02	1.08974E−05	5.73E−01
	Max	1.19E−03	3.32932E−06	1.93594E−10	3.96E−01	5.55E−02	6.76902E−06	4.52E−01
	Mean	1.29E−03	2.54714E−12	2.16728E−10	4.19E−01	4.25E−08	7.57792E−06	4.19E−01
Cu	Min	5.11E−04	1.43196E−06	1.42896E−08	1.28E−02	1.19E−04	3.57E−07	1.29E−02
	Max	5.50E−04	1.53936E−06	1.53613E−08	1.37E−02	1.28E−04	3.84E−07	1.38E−02
	Mean	5.18E−04	1.44986E−06	1.44682E−08	1.29E−02	1.21E−04	3.62E−07	1.30E−02
Ni	Min	8.57E−04	2.39854E−06	2.3935E−08	4.28E−02	4.44E−04	1.20E−06	4.32E−02
	Max	8.95E−04	2.50594E−06	2.50067E−08	4.47E−02	4.64E−04	1.25E−06	4.52E−02
	Mean	8.71E−04	2.43792E−06	2.4328E−08	4.35E−02	4.51E−04	1.22E−06	4.40E−02
Pb	Min	2.94E−04	8.23379E−07	8.21649E−09	8.40E−02	1.57E−03	2.35E−06	8.56E−02
	Max	7.29E−04	2.04055E−06	2.03626E−08	2.08E−01	3.89E−03	5.82E−06	2.12E−01
	Mean	3.91E−04	1.09545E−06	1.09315E−08	1.12E−01	2.09E−03	3.12E−06	1.14E−01
Zn	Min	1.36E−03	3.81618E−06	3.80817E−08	1.28E−02	6.36E−05	1.27E−07	1.29E−02
	Max	1.32E−03	3.68731E−06	3.67956E−08	1.37E−02	6.15E−05	1.23E−07	1.38E−02
	Mean	1.29E−03	3.61571E−06	3.60811E−08	1.29E−02	6.03E−05	1.20E−07	1.30E−02
Adult								
Cd	Min	3.42466E−07	1.36644E−09	1.91378E−11	3.42E−04	5.47E−05	3.35E−07	3.97E−04
	Max	4.24658E−07	1.69438E−09	2.37309E−11	4.25E−04	6.78E−05	4.16E−07	4.93E−04
	Mean	3.83562E−07	1.53041E−09	2.14343E−11	3.84E−04	6.12E−05	3.75E−07	4.46E−04
Cr	Min	1.62E−03	6.44959E−07	9.03304E−09	5.39E−02	1.07E−02	3.16E−03	6.78E−02
	Max	1.27E−03	5.08315E−07	7.11926E−09	4.25E−02	8.47E−03	2.49E−03	5.35E−02
	Mean	1.35E−04	5.3783E−07	7.53263E−09	4.49E−02	8.96E−03	2.63E−04	5.41E−02
Cu	Min	5.47945E−05	2.1863E−07	3.06205E−09	1.37E−03	1.82192E−05	7.66E−08	1.39E−03
	Max	5.89041E−05	2.35027E−07	3.2917E−09	1.47E−03	1.95856E−05	8.23E−08	1.49E−03
	Mean	5.54795E−05	2.21363E−07	3.10032E−09	1.39E−03	1.84469E−05	7.75E−08	1.41E−03
Ni	Min	9.17808E−05	3.66205E−07	5.12893E−09	4.59E−03	6.78158E−05	2.56E−07	4.66E−03
	Max	9.58904E−05	3.82603E−07	5.35858E−09	4.79E−03	7.08524E−05	2.68E−07	4.86E−03
	Mean	9.32877E−05	3.72218E−07	5.21313E−09	4.66E−03	6.89292E−05	2.61E−07	4.73E−03
Pb	Min	3.15068E−05	1.25712E−07	1.76068E−09	9.00E−03	2.39E−04	5.03E−07	9.24E−03
	Max	7.80822E−05	3.11548E−07	4.36342E−09	2.23E−02	5.93E−04	1.25E−06	2.29E−02
	Mean	4.19178E−05	1.67252E−07	2.34247E−09	1.20E−02	3.19E−04	6.69E−07	1.23E−02
Zn	Min	1.46E−04	5.82649E−07	8.16035E−09	4.87E−04	9.71E−06	2.72E−08	4.97E−04
	Max	1.41E−04	5.62973E−07	7.88477E−09	4.70E−04	9.38E−06	2.63E−08	4.79E−04
	Mean	1.38E−04	5.52041E−07	7.73167E−09	4.61E−04	9.20E−06	2.58E−08	4.70E−04

atmospheric dust had a higher risk contribution to health risks for both children and adult, followed by skin contact. On the other hand, non-carcinogenic risk of inhalation (HQ_{inh}) exposure to heavy metals in atmospheric dust is significantly lower than other two exposure routes. Therefore, inhalation of atmospheric dust particles is negligible compared with ingestion and dermal pathways. These results ($HQ_{ing} > HQ_{der} > HQ_{inh}$) were consistent with some previous studies by Jiang et al. (2017), Ferreira-Baptista and De Miguel (2005), and Li

et al. (2016). Additionally, non-carcinogenic risks of HQ_{ing} and HQ_{der} exposure values for children were 9.46 and 4.58 times higher than those for adults, respectively.

The hazard index (HI) values for all studied heavy metals increased in the following orders: Cd < Zn < Cu < Ni < Pb < Cr for children and Cd < Zn < Cu < Ni < Pb < Cr for adults. Chromium, Pb, and Ni mainly by more than 90% noncancerous risk contribute mostly to health risk posed by atmospheric dust exposure for both children and adults, and Cd, Zn, and Cu

have smaller contributions. The non-carcinogenic risk for children due to heavy metals from atmospheric dust exposure was higher than that for adults by 8.25 orders of magnitude. The HI values of Cd, Cr, Cu, Ni, Pb, and Zn were 8.9, 7.7, 9.24, 9.29, 9.26, and 9.27 times higher than those for adults. So, it is obvious that children were at higher potential health risks compared with adults. As HI values for all heavy metals are lower than safe level (1) (Ferreira-Baptista and De Miguel 2005), there is low potential health risk from atmospheric dust in Shiraz area. At the same time, HI value of Cr for children is 7.74 times higher than the adult. Since HI value of Cr (0.41–0.05) is below to safe level, it should be considered that this element is a cumulative and human carcinogen, so that inhaling Cr can increase the risk of lung cancer (USEPA 2001). Therefore, exposure to chromium via atmospheric dust should not be considered trivial. This situation can also be deliberated for lead, especially in children, with the difference that Pb generally affects the central nervous system and may manifest neurological disorders (Selinus and Alloway 2013).

Among the carcinogenic heavy metals, only the cancer risks of Cd, Cr, and Ni were analyzed (based on inhalation exposure) (Table 2). Result exhibits that the potential risk of cancer increased in the order Cd < Ni < Cr. Cr had the highest cancer risk level (4.11995E−07), followed by Ni (1.97687E−16), whereas Cd had the lowest level (1.76E−10). The cancer risk level of Cd, Ni and, Cr was lower than 1.00E−06 (internationally acceptable range), suggesting negligible carcinogenic risk (Table 6).

Source identification

Principal component analysis (PCA) was applied to assist in the identification of probable sources of heavy metals in atmospheric dust by applying varimax normalization rotation (Aminiyan et al. 2018). Table 7 displays the factor loadings as well as eigenvalue, percentile of variance, and cumulative percentages of the total loadings. Three-dimensional space plot of the PCA loadings is shown in Fig. 6, and the

relationships between the studied heavy metals are readily observed. According to Table 7, three factors were obtained, accounting for 77.73% of the total variance. Factor 1 is dominated by Cd and Ni accounting for 38.44% of the total variance. The concentrations of Cd and Ni in atmospheric dust samples are higher than corresponding UCC values. Also, the EF values of these two elements were significantly higher than those of the other elements. These observations show that Cd and Ni probably originated from a similar anthropogenic source. Previous studies (Al-Khashman 2013; Zhang et al. 2013; Aminiyan et al. 2018; Kabata-Pendias and Mukherjee 2007; Wei et al. 2009) have reported that vehicle emissions, diesel fuel, and fossil fuel combustion are known as the primary anthropogenic source for Cd and Ni atmospheric pollution.

Factor 2, dominated by As and Zn, explains 23.006% of the total variance. The mean concentration of As in dust samples is lower than corresponding background soil values. On the other hand, EF value for As indicates that this element has an anthropogenic source, while Zn had a natural origin. As a result, this factor source may be explained by the contributions of primarily mixed geogenic and anthropogenic origin. Several researches (Kabata-Pendias and Mukherjee 2007; Yongming et al. 2006; Duan and Tan 2013; Wong et al. 2003; Sharma et al. 2008) have pointed out that the industrial and agricultural activities, coal combustion, and automotive emissions are major source of As and Zn in dust. In the studied area, there are many industrial activities including petrochemical, cement and asphalt plants, sand mining, coal-fired power plants, and electrical industries (Jahandari 2015; Keshavarzi et al. 2015). Hence, the mentioned cases are suggested as a possible source of As in Shiraz atmospheric dust samples. Factor 3 explained 15.58% of the total variance and load on Cr, Cu, and Pb. This group of elements has been introduced as traffic-related elements which are mainly linked to traffic

Table 6 Daily dose and cancer risk of heavy metals in atmospheric dust for children

Element		LADD	CR
Cd	Min	2.49223E−11	1.57E−10
	Max	3.09036E−11	1.95E−10
	Mean	2.7913E−11	1.76E−10
Cr	Min	1.17633E−08	4.94E−07
	Max	9.27109E−09	3.89E−07
	Mean	9.80942E−09	4.12E−07
Ni	Min	6.67918E−09	5.61E−09
	Max	1.95086E−16	1.64E−16
	Mean	2.35341E−16	1.98E−16

Table 7 Rotated component matrix for data of Shiraz atmospheric dust

Element	Component			Communities
	1	2	3	
As	0.211	*0.890*	0.109	0.849
Cd	*0.921*	−0.098	−0.212	0.902
Cr	0.140	−0.689	*0.660*	0.930
Cu	−0.350	0.238	*0.368*	0.316
Ni	*0.810*	0.164	−0.160	0.709
Pb	−0.787	0.37	*0.960*	0.749
Zn	0.617	*0.360*	0.672	0.961
Eigenvalue cumulative % of	38.44	23.006	15.925	
Variation	38.44	61.450	77.735	
Cumulative				
Percent				

Fig. 6 Factor analysis results in the 3-D space plot of loading of the first three factors
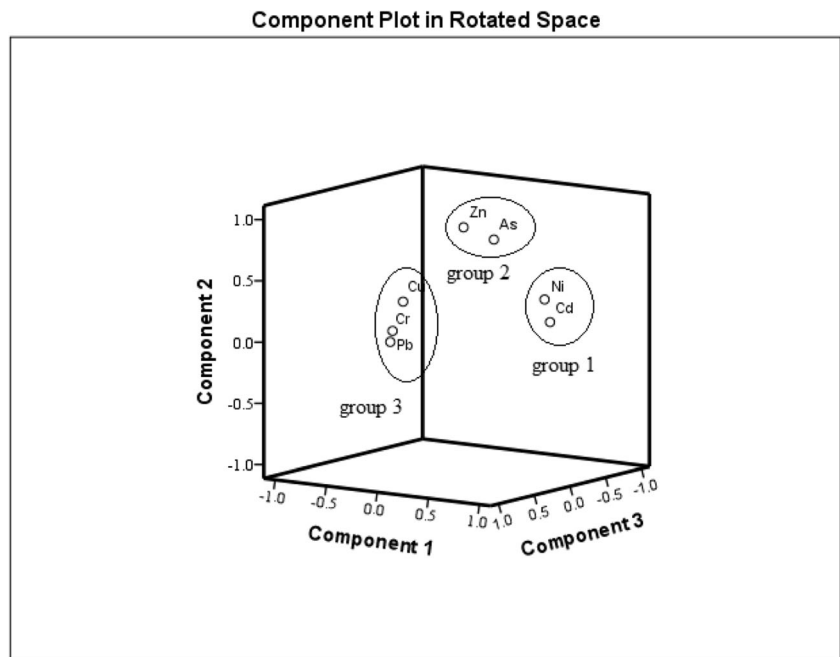
activities in the dust pollution (Kabata-Pendias and Mukherjee 2007; Djingova et al. 2003; Smichowski et al. 2007; Wrobel et al. 2000; Rauch et al. 2000). Also, Keshavarzi et al. (2015) reported that traffic-related materials, such as brake dust, tires tread, and fossil fuel being combusted, are a major source of these elements in the Shiraz urban street dust.

Conclusions

The major results of the current study were as follows:

1. Concentrations of all studied heavy metals (As, Cd, Cr, Cu, Ni, Pb, and Zn) in Shiraz atmospheric dust are higher than their UCC values, while the mean concentrations of Cr, Cu, Ni, Pb, and Zn in Shiraz atmospheric dust are higher than those in world soils. In comparison with the concentrations of studied heavy metals in Shiraz urban street dust, the concentrations of heavy metals in atmospheric dust were significantly lower, which indicated that in the studied area, substantial increase emission of the heavy metals occurs from regional pollutant sources.

2. The calculated results of Enrichment Factor and Geo-accumulation index of heavy metals revealed the order of Ni > As > Cd > Cr > Cu > Pb > Zn. The analysis of EF value results determined moderate enrichment for Ni, As, Cd, and Cr, and minimal enrichment for Cu, Pb, and Zn. The analysis of IGeo values also showed a median pollution for Ni, As, Cd, and Ni, while Cu, Pb, and Zn were evaluated to have no pollution to low pollution.

3. According to the ecological risk assessment, eco-risks related with As, Cr, Cu, Ni, Pb, and Zn are generally low,

whereas the eco-risk associated with Cd is high. Also, the RI values with mean 142.97 are indicating that ecological risks posed by studied elements in Shiraz atmospheric dust were moderate.

4. The main exposure route of heavy metals to both adults and children is ingestion, followed by skin contact. Non-carcinogenic risk of HQ_{ing} and HQ_{der} exposure values for children, as compared with adults, is 9.46 and 4.58 times higher. So, children are at higher risk of heavy metals in atmospheric dust. The hazard index values for investigated elements decreased in the following orders: Cr > Pb > Ni > Cu > Zn > Cd for both children and adults. HIs for exposure to heavy metals in atmospheric dust for adults and children in Shiraz city are lower than the safe level (1), showing that there is a low potential health risk due to atmospheric dust. Moreover, some heavy metals such as Cr and Pb which have cumulative poison characteristics to the human body for long times can have adverse effects on citizens, especially in children.

5. Based on PCA analysis and Enrichment Factor, four main sources of heavy metals in atmospheric dust of Shiraz were identified. Ni and Cd were probably originated from vehicle emissions, diesel, and fossil fuel combustion; Cr, Cu, and Pb traffic activities emission; Zn has a natural source; As has a mixed geogenic and anthropogenic source.

6. Collation results of geochemical indices as well as ecological and human health risk assessment caused by heavy metals in atmospheric dust with urban street dust suggest that comparing heavy metal status in atmospheric dust versus urban street dust provides a useful and low-cost indicator to the evaluation of discharging and pollution of heavy metals in urban environments.

Publisher's Note Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

References

Al-Khashman OA (2013) Assessment of heavy metals contamination in deposited street dusts in different urbanized areas in the city of Ma'an, Jordan. Environ Earth Sci 70(6):2603–2612. https://doi.org/10.1007/s12665-013-2310-6

Alloway B (2010) Heavy metals in soils: trace metals and metalloids in soils and their bioavailability, 3rd edn. Springer Publications, Berlin, p 614

Alloway BJ (2013) Sources of heavy metals and metalloids in soils. In: Heavy metals in soils. Springer, Dordrecht, pp 11–50. https://doi.org/10.1007/978-94-007-4470-7_2

Alsbou EME, Al-Khashman OA (2018) Heavy metal concentrations in roadside soil and street dust from Petra region, Jordan. Environ Monit Assess 190(1):48. https://doi.org/10.1007/s10661-017-6409-1

Aminiyan MM, Baalousha M, Mousavi R, Aminiyan FM, Hosseini H, Heydariyan A (2018) The ecological risk, source identification, and pollution assessment of heavy metals in road dust: a case study in Rafsanjan, SE Iran. Environ Sci Pollut Res 25(14):13382–13395. https://doi.org/10.1007/s11356-017-8539-y

Budai P, Clement A (2018) Spatial distribution patterns of four traffic-emitted heavy metals in urban road dust and the resuspension of brake-emitted particles: findings of a field study. Transp Res Part D: Transp Environ 62:179–185. https://doi.org/10.1016/j.trd.2018.02.014

Calabrese EJ, Stanek E, James RC, Roberts SM (1997) Soil ingestion: a concern for acute toxicity in children. Environ Health Perspect 105(12):1354–1358. https://doi.org/10.1289/ehp.971051354

Djingova R, Kovacheva P, Wagner G, Markert B (2003) Distribution of platinum group elements and other traffic related elements among different plants along some highways in Germany. Sci Total Environ 308(1–3):235–246. https://doi.org/10.1016/S0048-9697(02)00677-0

Doabi SA, Afyuni M, Karami M (2017) Multivariate statistical analysis of heavy metals contamination in atmospheric dust of Kermanshah province, western Iran, during the spring and summer 2013. J Geochem Explor 180:61–70. https://doi.org/10.1016/j.gexplo.2017.06.007

Duan J, Tan J (2013) Atmospheric heavy metals and arsenic in China: situation, sources and control policies. Atmos Environ 74:93–101. https://doi.org/10.1016/j.atmosenv.2013.03.031

Evans E, Ma M, Kingston L, Leharne S, Chowdhry B (1992) The speciation pattern of lead in street dusts and soils in the vicinity of two London schools. Environ Int 18(2):153–162. https://doi.org/10.1016/0160-4120(92)90003-M

Ferreira-Baptista L, De Miguel E (2005) Geochemistry and risk assessment of street dust in Luanda, Angola: a tropical urban environment. Atmos Environ 39(25):4501–4512. https://doi.org/10.1016/j.atmosenv.2005.03.026

Filippelli GM, Morrison D, Cicchella D (2012) Urban geochemistry and human health. Elements 8(6):439–444. https://doi.org/10.2113/gselements.8.6.439

Hakanson L (1980) An ecological risk index for aquatic pollution control. A sedimentological approach. Water Res 14(8):975–1001

Hojati S, Khademi H, Cano AF, Landi A (2012) Characteristics of dust deposited along a transect between central Iran and the Zagros Mountains. Catena 88(1):27–36. https://doi.org/10.1016/j.catena.2011.09.002

Huang J, Li F, Zeng G, Liu W, Huang X, Xiao Z, He Y (2016) Integrating hierarchical bioavailability and population distribution into potential eco-risk assessment of heavy metals in road dust: a case study in Xiandao District, Changsha city, China. Sci Total Environ 541:969–976. https://doi.org/10.1016/j.scitotenv.2015.09.139

Jadoon WA, Khpalwak W, Chidya RCG, Abdel-Dayem SMMA, Takeda K, Makhdoom MA, Sakugawa H (2018) Evaluation of Levels, Sources and Health Hazards of Road-Dust Associated Toxic Metals in Jalalabad and Kabul Cities, Afghanistan. Arch Environ Contam Toxicol 74(1):32–45. https://doi.org/10.1007/s00244-017-0475-9

Jahandari A (2015) An investigation on urban geological conditions and hazards of Shiraz City, using GIS techniques (M. Sc. Thesis, Shahid Bahonar University of Kerman, Iran) (In Persian)

Jiang Y, Shi L, Guang AL, Mu Z, Zhan H, Wu Y (2017) Contamination levels and human health risk assessment of toxic heavy metals in street dust in an industrial city in Northwest China. Environ Geochem Health 40:1–14. https://doi.org/10.1007/s10653-017-0028-1

Kabata-Pendias A, Mukherjee AB (2007) Trace elements from soil to human. Springer Science & Business Media, Berlin

Kamani H, Ashrafi SD, Isazadeh S, Jaafari J, Hoseini M, Mostafapour FK, Bazrafshan E, Nazmara SH, Mahvi AH (2015) Heavy metal contamination in street dusts with various land uses in Zahedan, Iran. Bull Environ Contam Toxicol 94(3):382–386. https://doi.org/10.1007/s00128-014-1453-9

Kamani H, Mahvi AH, Seyedsalehi M, Jaafari J, Hoseini M, Safari GH, Ashrafi SD (2017) Contamination and ecological risk assessment of heavy metals in street dust of Tehran, Iran. Int J Environ Sci Technol 14(12):2675–2682. https://doi.org/10.5812/jhealthscope.39703

Karimian Torghabeh A, Pimentel N (2016) Paleogeography and sequence stratigraphy in Dariyan Carbonate Reservoir, NE Shiraz. Open Journal of Geology 6:1423

Karimian Torghabeh A, Rezaee R, Moussavi-Harami R et al (2014) Electrofacies in gas shale from well log data via cluster analysis: a case study of the Perth Basin, Western Australia. Open Geosciences 6:393–402

Karimian Torghabeh A, Rezaee R, Moussavi-Harami R, Pimentel N (2015) Using electrofacies cluster analysis to evaluate shale-gas potential: Carynginia Formation, Perth Basin, Western Australia. International Journal of Oil Gas and Coal Technology 10:250–271

Karimian Torghabeh A, Pimentel N, Jahandari A, Wang G (2018) Mineralogy, composition and heavy metals' concentration, distribution and source identification of surface sediments from the saline Maharlou Lake (Fars Province, Iran). Environ Earth Sci 77(19):700. https://doi.org/10.1007/s12665-018-7877-5

Keshavarzi B, Tazarvi Z, Rajabzadeh MA, Najmeddin A (2015) Chemical speciation, human health risk assessment and pollution level of selected heavy metals in urban street dust of Shiraz, Iran. Atmos Environ 119:1–10. https://doi.org/10.1016/j.atmosenv.2015.08.001

Li F, Huang J, Zeng G, Huang X, Liu W, Wu H, Yuan Y, He X, Lai M (2015a) Spatial distribution and health risk assessment of toxic metals associated with receptor population density in street dust: a case study of Xiandao District, Changsha, Middle China. Environ Sci Pollut Res 22(9):6732–6742. https://doi.org/10.1007/s11356-014-3753-3

Li K, Liang T, Wang L, Yang Z (2015b) Contamination and health risk assessment of heavy metals in road dust in Bayan Obo Mining Region in Inner Mongolia, North China. J Geogr Sci 25(12):1439–1451. https://doi.org/10.1007/s11442-015-1244-1

Li F, Zhang J, Huang J, Huang D, Yang J, Song Y, Zeng G (2016) Heavy metals in road dust from Xiandao District, Changsha City, China: characteristics, health risk assessment, and integrated source

identification. Environ Sci Pollut Res 23(13):13100–13113. https://doi.org/10.1007/s11356-016-6458-y

Luo XS, Ding J, Xu B, Wang YJ, Li HB, Yu S (2012) Incorporating bioaccessibility into human health risk assessments of heavy metals in urban park soils. Sci Total Environ 424:88–96. https://doi.org/10.1016/j.scitotenv.2012.02.053

Men C, Liu R, Xu F, Wang Q, Guo L, Shen Z (2018) Pollution characteristics, risk assessment, and source apportionment of heavy metals in road dust in Beijing, China. Sci Total Environ 612:138–147. https://doi.org/10.1016/j.scitotenv.2017.08.123

Menéndez I, Diaz-Hernandez JL, Mangas J, Alonso I, Sánchez-Soto PJ (2007) Airborne dust accumulation and soil development in the North-East sector of Gran Canaria (Canary Islands, Spain). J Arid Environ 71(1):57–81. https://doi.org/10.1016/j.jaridenv.2007.03.011

Modaihsh AS, Mahjou MO (2013) Falling dust characteristics in Riyadh city, Saudi Arabia during winter months. APCBEE Proc 5:50–58. https://doi.org/10.1016/j.apcbee.2013.05.010

Muller G (1969) Index of geoaccumulation in sediments of the Rhine River, Geol J 2:108–118

Norouzi S, Khademi H, Cano AF, Acosta JA (2015) Using plane tree leaves for biomonitoring of dust borne heavy metals: a case study from Isfahan, Central Iran. Ecol Indic 57:64–73. https://doi.org/10.1016/j.ecolind.2015.04.011

Norouzi S, Khademi H, Ayoubi S, Cano AF, Acosta JA (2017) Seasonal and spatial variations in dust deposition rate and concentrations of dust-borne heavy metals, a case study from Isfahan, central Iran. Atmos Pollut Res 8(4):686–699. https://doi.org/10.1016/j.apr.2016.12.015

Pan H, Lu X, Lei K (2017) A comprehensive analysis of heavy metals in urban road dust of Xi'an, China: contamination, source apportionment and spatial distribution. Sci Total Environ 609:1361–1369. https://doi.org/10.1016/j.scitotenv.2017.08.004

Rauch S, Morrison GM, Motelica-Heino M, Donard OF, Muris M (2000) Elemental association and fingerprinting of traffic-related metals in road sediments. Environ Sci Technol 34(15):3119–3123 https://pubs.acs.org/doi/abs/10.1021/es000001r

Selinus O, Alloway BJ (2013) In: Centeno JA, Finkelman RB, Fuge R, Lindh U, Smedley P (eds) Essentials of medical geology. Springer, New York, p 820

Shabbaj II, Alghamdi MA, Shamy M, Hassan SK, Alsharif MM, Khoder MI (2017) Risk assessment and implication of human exposure to road dust heavy metals in Jeddah, Saudi Arabia. Int J Environ Res Public Health 15(1):36. https://doi.org/10.3390/ijerph15010036

Sharma RK, Agrawal M, Marshall FM (2008) Atmospheric deposition of heavy metals (Cu, Zn, Cd and Pb) in Varanasi city, India. Environ Monit Assess 142(1–3):269–278. https://doi.org/10.1007/s10661-007-9924-7

Shi G, Chen Z, Bi C, Wang L, Teng J, Li Y, Xu S (2011) A comparative study of health risk of potentially toxic metals in urban and suburban road dust in the most populated city of China. Atmos Environ 45(3):764–771. https://doi.org/10.1016/j.atmosenv.2010.08.039

Smichowski P, Gómez D, Frazzoli C, Caroli S (2007) Traffic related elements in airborne particulate matter. Appl Spectrosc Rev 43(1):23–49. https://doi.org/10.1080/05704920701645886

Sutherland RA (2000) Bed sediment-associated trace metals in an urban stream, Oahu, Hawaii. Environ Geol 39(6):611–627. https://doi.org/10.1007/s002540050473

Tang Y, Han G (2017) Characteristics of major elements and heavy metals in atmospheric dust in Beijing, China. J Geochem Explor 176:114–119. https://doi.org/10.1016/j.gexplo.2015.12.002

Taylor SR, McLennan SM (1995) The geochemical evolution of the continental crust. Rev Geophys 33(2):241–265. https://doi.org/10.1029/95RG00262

USEPA (1996) Soil screening guidance: technical background document. EPA/540/R–95/128. Office of soild waste and emergency response. U.S. Environmental Protection Agency, Washington DC

USEPA (2001) Supplemental guidance for developing soil screening levels for superfund sites. OSWER 9355.4–24. U.S. Environmental Protection Agency, Washington DC

Van den Berg R (1994) Human exposure to soil contamination: a qualitative and quantitative analysis towards proposals for human toxicological intervention values (partly revised edition). RIVM Rapport 725201011, Bilthoven, p 104

VanWijnen JH, Clausing P, Brunekreef B (1990) Estimated soil ingestion by children. Environ Res 51(2):147–162. https://doi.org/10.1016/S0013-9351(05)80085-4

Wei B, Jiang F, Li X, Mu S (2009) Spatial distribution and contamination assessment of heavy metals in urban road dusts from Urumqi, NW China. Microchem J 93(2):147–152. https://doi.org/10.1016/j.microc.2009.06.001

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. https://doi.org/10.1007/s10661-015-4763-4

Wong CSC, Li XD, Zhang G, Qi SH, Peng XZ (2003) Atmospheric deposition of heavy metals in the Pearl River Delta, China. Atmos Environ 37:767–776. https://doi.org/10.1016/S1352-2310(02)00929-9

Wrobel A, Rokita E, Maenhaut W (2000) Transport of traffic-related aerosols in urban areas. Sci Total Environ 257(2–3):199–211. https://doi.org/10.1016/S0048-9697(00)00519-2

Yongming H, Peixuan D, Junji C, Posmentier ES (2006) Multivariate analysis of heavy metal contamination in urban dusts of Xi'an, Central China. Sci Total Environ 355(1–3):176–186. https://doi.org/10.1016/j.scitotenv.2005.02.026

Zhang J, Deng H, Wang D, Chen Z, Xu S (2013) Toxic heavy metal contamination and risk assessment of street dust in small towns of Shanghai suburban area, China. Environ Sci Pollut Res 20(1):323–332. https://doi.org/10.1007/s11356-012-0908-y

Zheng N, Liu J, Wang Q, Liang Z (2010) Health risk assessment of heavy metal exposure to street dust in the zinc smelting district, Northeast of China. Sci Total Environ 408(4):726–733. https://doi.org/10.1016/j.scitotenv.2009.10.075