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ORIGINAL PAPER

Analysis, sources and health risk assessment of trace elements in street dust collected from the city of Hamedan, west of Iran

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Abstract

In the current study, concentrations of some trace elements (Al, As, Cd, Cr, Cu, Pb, Ni and Zn) in street dust samples collected from commercial, residential and industrial regions in the city of Hamedan, Iran, were studied to analyze the possible dust contamination rates and also to assess their potential risk to human health. Total 378 street dust samples were obtained from 18 sampling sites during April to October 2019. After samples preparation, the concentrations of the elements in the street dust specimens were measured via ICP-OES. The dust pollution rate and the human health risks (HI) associated with those elements were evaluated through enrichment factor (EF), geo-accumulation index (I-geo), contamination/pollution index (CPI), integrated pollution index (IPI), pollution load index (PLI) and hazard quotient (HQ). Based on the results obtained, the mean concentrations of the analyzed elements (mg/kg) in dust specimens were 11,058 for Al, 2.31 for As, 0.225 for Cd, 41.3 for Cr, 48.8 for Cu, 65.2 for Pb, 79.2 for Ni and 211 for Zn. About 66% of the street dust specimens appeared to be severely polluted with Zn, while the mean CPI value of Al indicated that 95% of dust samples were slightly contaminated by this metal. The results of the sources identification of the elements showed that Al had lithogenic sources, whereas others resulted from predominantly anthropogenic activities. The PLI values of the analyzed samples with an average value of 1.00 revealed that 22%, 77% and 1% of street dust specimens were low, moderately and highly contaminated, respectively. The results of HI revealed that ingestion is the main exposure pathway to the elements for both children and adults. Also, the values of 95% UCL of HI for non-carcinogenic risks of children and adults all were within the safe limit (= 1) for the local residents. Moreover, the 95% UCL values of carcinogenic risks (CR) indicated that the CR values of As, Cd, Cr, Pb and Ni are lower than the allowable range (10^{-6}–10^{-4}), and therefore, these elements in the urban street dust cannot pose carcinogenesis to the local residents. The results of principal component analyses (PCA) and hierarchical cluster analysis (HCA) of the analyzed elements suggested that anthropogenic activities are the most important sources of As, Cd, Cr, Cu, Pb, Ni and Zn pollution, whereas natural geochemical processes (crustal soil) are the most important sources of Al. Finally, based on the findings, it was recommended that special attention be paid to the determination of the concentrations of other trace elements and particularly persistent organic pollutants (POPs) in the urban street dusts of the study area for assessing their potential ecological and health risks.

Keywords Anthropogenic activities · Carcinogenic risk · Dust contamination · Exposure pathways · Source identification

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Introduction

Nowadays, trace elements are known as useful indicators of soil contamination. These metals may be accumulated in surface soil through atmospheric deposition processes and pose a potential threat to public health and local ecosystems because they constitute toxic pollutants if they exist in elevated amounts in an area (Cook et al. 2005; Tokalıog and Kartal 2006; Melaku et al. 2008; El-Gammal et al. 2011; Li et al. 2013).

Factors such as flushing of street runoff, transport by wind and also cleanup make the residence time of street dust shorter than soils and sediments (Charlesworth et al. 2003; Zhang et al. 2013). Although like soil and sediment, dust also, originates primarily from the earth's crust, it can be considered as the major source of pollutants can pose great risks to human health. Street or road dust originates from natural (soil minerals) and anthropogenic sources such as road construction, vehicle emission, industrial discharges, waste incineration or atmospheric depositions and is generally composed of car exhaust, wind transported particles and airborne particles (Adachi and Tainosho 2005; Tokalıog and Kartal 2006; Sobhanardakani 2019). It should be noted that abrasion of automobile parts, corrosion of building materials and atmospheric deposition can lead to accumulation of trace elements on the street (road) dust. Therefore, residents in the vicinity of production industries, regions with high traffic intensity, highways and vehicle repair shops are usually at poisoning risks associated with such trace elements (Alhassan et al. 2012; Philip et al. 2017; Sobhanardakani 2018a).

Specific characteristics of trace elements including long biological half-lives, indestructibility, persistency and non-biodegradability, biomagnifications capability and bioaccumulation potential in living organism tissues, can lead to severe adverse health effects and environmental risks. Hence, the environmental pollution by these elements is a worldwide concern (Rezaei Raja et al. 2016; Giri et al. 2017; Sobhanardakani 2019).

Concerning the importance of the studied elements, it should be noted that aluminum is easily found at quantifiable rates in various tissues and biological fluids (Glynn 1999). Kidney and liver dysfunctions, osteomalacia, fatigue, dementia dialectica, anemia, neurodegenerative disorders, dental caries, Parkinson and Alzheimer diseases are the main adverse effects of exposure to Al (Storey and Masters 1995; López et al. 2002; Rezaei Raja et al. 2016).

Arsenic, as a metalloid, is a human carcinogen even at low levels of exposure (Sobhanardakani et al. 2018). Anorexia, fever, hair loss, muscle spasms, goiter, herpes, kidney and liver damage decreased production of WBCs and RBCs and also nausea and vomiting are the main adverse effects of exposure to this element (Tasleem Jan et al. 2015; Sobhanardakani 2018b).

Cadmium, Cr (VI) and Pb are very toxic elements which are widely distributed in the environment through anthropogenic activities (Zhu et al. 2011; Chen et al. 2014; Hosseini et al. 2015; Sobhanardakani 2018a). Exposure to Cd leads to fragile bones, kidney disease, lung damage, anemia, hypertension, cardiovascular disease, arthritis, hypoglycemia, diabetes, osteoporosis, and specially cancer (Ju et al. 2012; Liao et al. 2015), whereas nose ulcers, wheezing, asthma and shortness of breath are some of the symptoms that are associated with inhaling high levels of Cr (VI) (Hosseini et al. 2013, Sobhanardakani 2017, Sabzevari and Sobhanardakani 2018). Besides, damage to the central nervous system and kidneys in adults, and enzymatic, skeletal, endocrine and immune system damage and delays in cognitive development in children are the main consequences of exposure to Pb (Liu et al. 2010; Mohammadi et al. 2018).

Copper has a vital role in biological systems and is important for nerve conduction, synthesis of red blood cells, healthy hormone secretion, growth of connective tissues and biological transfer of electrons (Saracoglu et al. 2009; Ghafari and Sobhanardakani 2017; Sobhanardakani 2017). Allergies, anorexia, adrenal hyperactivity, hair loss, depression, hyperactivity, strokes, kidney and liver dysfunctions and also cancer are known as the important adverse effects of exposure to critical doses of this element (Ackah et al. 2014).

Although deficiency of nickel as an essential micronutrient for living organisms can cause nervous system damage, neurasthenia, inflammation, teratogenic, mutagenic, heart disorders and lung cancer (Das et al. 2008; Qu et al. 2013; Al-Khashman, 2014; Sobhanardakani 2018c), exposure to high amounts of this element has been associated with health conditions such as genotoxicity hematotoxicity, teratogenicity, immunotoxicity and carcinogenicity (Cameron et al. 2011; Mohammadi et al. 2018; Akar et al. 2019; Sobhanardakani 2019).

Zinc as a vital structural and functional element for the normal growth and development of human body serves an important role in biological systems particularly in the mediation of redox reactions. However, it has been shown that exposure to high levels of this element can interfere with some of the vital human physiological processes (Mohammadi et al. 2018; Sabet Aghlidi et al. 2020).

The review of literature shows that many studies have so far been carried out on street dust contamination focusing on the analysis of the trace elements (Salim Akhter and Madany 1993; De Miguel et al. 1997; Charlesworth et al. 2003; Ordonez et al. 2003; Yeung et al. 2003; Al-Khashman 2004; Sezgin et al. 2004; Ferreira-Baptista and De Miguel, 2005; Tokalıog and Kartal 2006; Rashed 2008; Christoforidis and Stamatis 2009; Lu et al. 2010; El-Gammal et al. 2011;

Alhassan et al. 2012; Li et al. 2013; Zhang et al. 2013; Harb et al. 2015; Xu et a. 2015; Suryawanshi et al. 2016; Philip et al. 2017; Dytłow and Górka-Kostrubiec 2021). However, few such studies have been conducted in the Iranian setting (see for example, Saeedi et al. 2012; Salmanzadeh et al. 2015; Soltani et al., 2015; Kamani et al. 2015, 2017, 2018; Heidari Sareban and Saeb 2018; Sadeghdoust et al. 2020).

Currently, due to rapid development of manufacturing industries and building activities, population growth and traffic density, Hamedan is facing severe environmental issues notably dust pollution. As similar studies in terms of analysis, source identification and human health risk assessment of trace elements in the street dust had not previously been conducted in the city of Hamedan, the current study was carried out for the first time (1) to determine the concentrations of some trace elements (Al, As, Cd, Cr, Cu, Pb, Ni and Zn) in the street dusts collected from commercial, residential and industrial regions of the city of Hamedan in 2019; (2) to identify the possible sources of these elements in the collected samples using principal component analyses (PCA) and hierarchical cluster analysis (HCA); (3) to assess the human health risks associated with the analyzed elements and (4) to measure the dust contamination rates using enrichment factor (EF), geo-accumulation index (I-geo), contamination/pollution index (CPI), integrated pollution index (IPI) and pollution load index (PLI).

Material and methods

Study area

The city of Hamedan as a metropolitan city in the west of Iran with area of 56 km^2 and 554,406 residents is located at an altitude of about 1850 m above sea level. This city lies between longitudes 48° 31' E, and between latitudes 34° 48' N. The annual average precipitation and also annual average temperature of the study area are estimated as 317.7 mm and 11.3 °C, respectively (Sobhanardakani 2018a,d).

Sample collection and analysis

In the present study, totally 378 street dust samples were obtained from 18 sampling sites (Fig. 1) during mid-April to mid-October 2019 through scraping the sidewalk with a spatula. Sampling sites were selected considering some criteria such as traffic density; population activity from roads and streets at different land use areas including commercial/business districts (BD), residential areas (RA) and industrial estates (IE). The dust specimens were then dried at room temperature (25 °C) for one week, were grinded by a mortar and were sieved through a 0.900 mm sieve. For samples digestion, 1.00 g of each dust specimen was transferred into a digestion vessel and then 10.0 ml of nitric acid was added. In the next step, the specimens were heated to 90.0 °C, and were then let to cool at 20.0 °C and were refluxed for 15 min. Next, 5.00 ml of 68% nitric acid (HNO_3) was added to each specimen and was refluxed again at 90.0 °C for half-hour. This process was followed by the addition of ddH_2O (2.00 ml) and 3.00 ml of hydrogen peroxide (H_2O_2) to each specimen. After the peroxide reaction started, the process was allowed to continue until effervescence subsided and the solutions were cooled (Zheng et al. 2005; Sobhanardakani 2018a). At the end, the concentrations of the elements were determined using ICP-OES (710-ES, Varian, Australia) at following wavelengths (nm): 308.215 for Al, 188.980 for As, 226.502 for Cd, 267.716 for Cr, 324.754 for Cu, 220.353 for Pb, 231.604 for Ni and 206.200 for Zn. Also, the quality control (QC) and quality assurance (QA) were both run through the method described by Lu et al. (2010) using SRM (SQC-001, Sigma-Aldrich, Spain). As the results showed, good accuracy in recovery rates (%) was achieved between 98.2 and 101.5 for Al, 96.4 to 100.8 for As, 97.4 to 101.2 for Cd, 95.9 to 100.3 for Cr, 97.1 to 102.6 for Cu, 95.8 to 101.7 for Pb, 94.8 to 100.3 for Ni and 96.2 to 103.5 for Zn. The values of limits of detection (LOD) and limits of quantification (LOQ) are presented in Table 2.

Human health risk assessment

To assess the human exposure to trace elements in street dusts via the three exposure routes including oral or ingestion (D_{ing}), inhalation (D_{inh}) and also dermal contact (D_{dermal}), the model established by the USEPA was used, in which the exposure rates are calculated based on Eqs. 1 to 3 (USEPA 1989; Li et al. 2014; Sobhanardakani 2019):

$$Ding = C \times \frac{IngR \times EF \times ED}{BW \times AT} \times 10^{-6}, \quad (1)$$

where D_{ing} stands for the dose contacted via ingestion of dust in mg/kg/day; C indicates the exposure point concentration of the element in mg/kg; IngR is the ingestion rate; EF, ED, BW and AT represent the exposure frequency, exposure time, average body weight and average time, respectively. In this study, IngR was considered 200 mg/day for children and 100 mg/day for adults; EF was considered 180 days per year; ED was considered 6 years for children and 24 years for adults; BW was considered 15.0 kg for children and 70.0 kg for adults; and AT was considered ED × 365 days for non-carcinogens and 26,280 (72.0 × 365) days for carcinogens (USEPA 1996).

$$Dinh = C \times \frac{InhR \times EF \times ED}{PEF \times BW \times AT}, \quad (2)$$

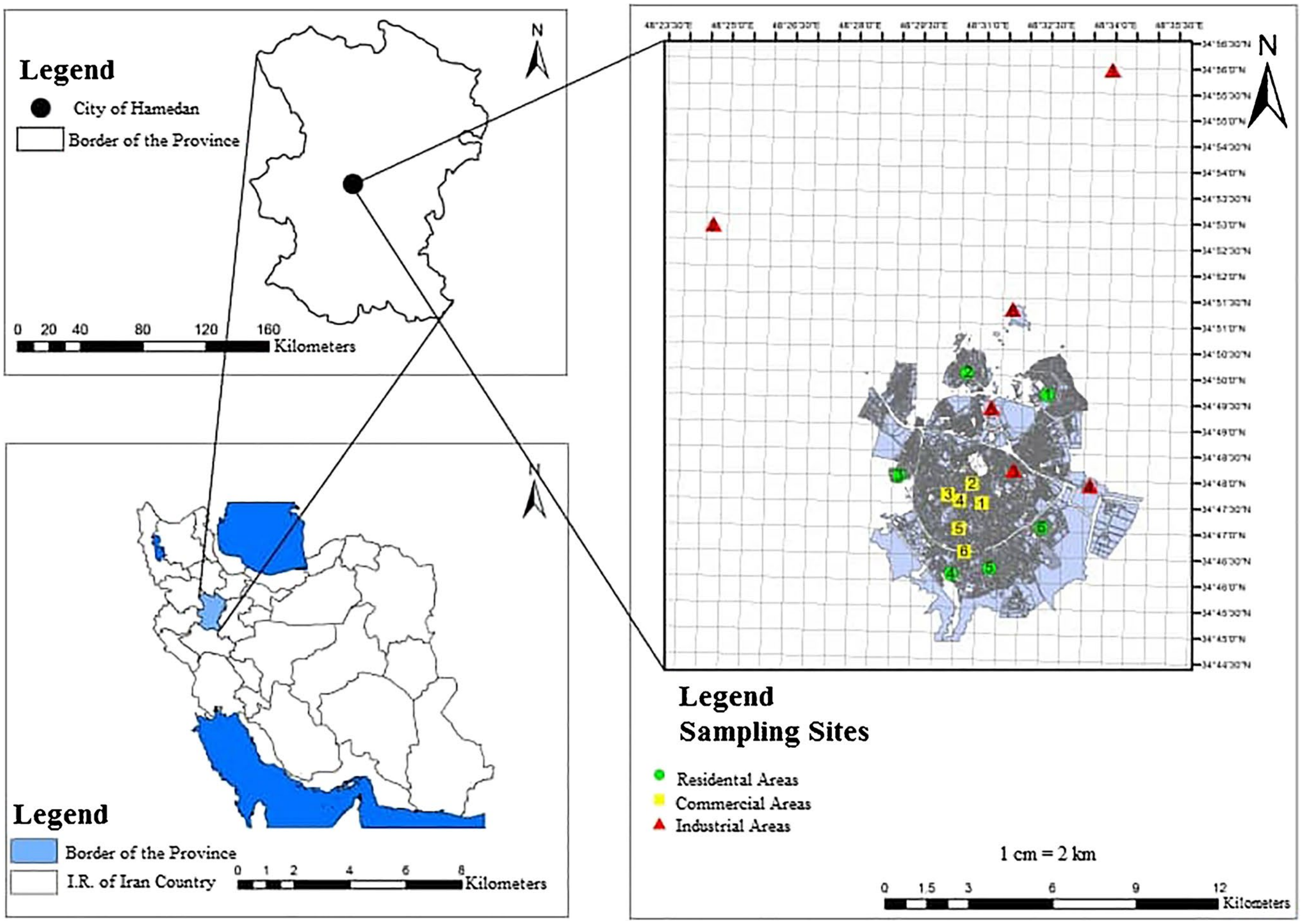


Fig. 1 Sampling sites of urban street dust in city of Hamedan

where D_{inh} (mg/kg/day) represents the dose contacted via inhalation of street dust; *InhR* and *PEF* show the inhalation rate and particle emission factor, respectively. In this study, *InhR* was considered 7.60 m^3/day for children and 20.0 m^3/day for adults and *PEF* was considered 1.36×10^9 m^3/kg (USEPA 1996; Xu et al. 2015).

$$Ddermal = C \times \frac{SA \times SL \times ABS \times EF \times ED}{BW \times AT} \times 10^{-6}, \quad (3)$$

where D_{dermal} (mg/kg/day) shows the dose absorbed through dermal (skin) contact with street dust; *SA*, *SL* and *ABS* stand for the exposed skin area, the skin adherence factor and the dermal absorption factor for the studied elements. In the present study, *SA* was considered 2800 cm^2 for children and 5700 cm^2 for adults, *SL* was considered 0.200 mg cm^2/day for children and 0.070 mg cm^2/day for adults and *ABS* was considered 0.001 for the studied elements (Zheng et al. 2010a; Sobhanardakani 2019).

The carcinogenic risk via inhalation exposure route of As, Cd, Cr, Pb and Ni was calculated based on Eq. 4:

$$LADD = \frac{C \times EF}{PEF \times AT} \times \left[\frac{InhRchild \times EDchild}{BWchild} + \frac{InhRadult \times EDadult}{BWadult}\right], \quad (4)$$

in this equation, *LADD* (mg/kg/day) is considered as the lifetime average daily dose (USEPA 2001).

Risk characterization

In the present study, the potential non-carcinogenic (*HQ*) and carcinogenic risks (*CR*) for each element were computed based on Eqs. 5 to 7, respectively:

$$HQ = \frac{D}{RfD}, \quad (5)$$

$$HI = \sum HQi, \quad (6)$$

, where *D* and *RfD* stand for the average daily dose and a specific reference dose, respectively, as presented in Table 1 (Sobhanardakani 2019).

Table 1 Reference dose (RfD) and slope factor (SF) of studied elements (Ferreira-Baptista and de Miguel 2005; Xu et al. 2015; Iwegbue et al. 2017; Sobhanardakani 2018c)

Element	Al	As	Cd	Cr	Cu	Pb	Ni	Zn
RfD_{ing}	10.0×10^{-1}	3.00×10^{-4}	1.00×10^{-3}	3.00×10^{-3}	4.00×10^{-2}	3.50×10^{-3}	2.00×10^{-2}	3.00×10^{-1}
RfD_{inh}	1.43×10^{-3}	43.0×10^{-1}	1.00×10^{-3}	2.86×10^{-5}	4.02×10^{-2}	3.52×10^{-3}	2.06×10^{-2}	3.00×10^{-1}
RfD_{dermal}	1.00×10^{-1}	1.23×10^{-4}	1.00×10^{-5}	6.00×10^{-5}	1.20×10^{-2}	5.25×10^{-4}	5.40×10^{-3}	6.00×10^{-2}
Inhal. CSF		151×10^{-1}	63.0×10^{-1}	5.00×10^{-3}		8.50×10^{-3}	8.40×10^{-1}	

The hazard index (HI) is used to estimate the health risks through above-mentioned exposure routes and is determined by calculating the sum of hazard quotients. When HI ≤ 1.00, no adverse effects are expected to occurs via exposure to dust, while HI > 1.00 represents possible health effects (Zhang et al. 2013).

$$CR = Dinh \times SF, \quad (7)$$

in this equation, *CR* represents the carcinogenic risk and *SF* indicates the slope factor as mentioned in Table 1 (Sobhanardakani 2019).

Assessment of dust contamination

Enrichment factors (EF)

Enrichment factors (EFs) are used to diagnose the origin of elements in dusts including anthropogenic influences and natural background concentrations (Han et al. 2006). In this regard, EF > 10.0 indicates the anthropogenic origins of elements, while EF < 10.0 shows their crustal source (Li et al. 2013; Latif et al. 2014). In this work, based on the reasons described by Benhaddya and Hadjel (2014), enrichment factor values were computed with respect to Al as the reference element in accordance with Eq. 8 (Benhaddya and Hadjel 2014):

$$EF = \left(\frac{Cn}{Cref}\right) streetdust / \left(\frac{Bn}{Bref}\right) background, \quad (8)$$

where (Cn/Cref) sample is the concentration ratio of a studied element in the street dust specimens and (Bn/Bref) baseline represents the concentration ratio of Al in the background topsoil (Sutherland 2000).

Seven contamination classifications have been recognized on the basis of the EF values as follows (Wedepohl 1995; Tytła and Kostecki 2019):

EF < 1.00	No enrichment (NE)
1.00 ≤ EF < 3.00	Minor enrichment (ME)
3.00 ≤ EF < 5.00	Moderate enrichment (MDE)
5.00 ≤ EF < 10.0	Moderately severe enrichment (MSE)
10.0 ≤ EF < 25.0	Severe enrichment (SE)
25.0 ≤ EF < 50.0	Very severe enrichment (VSE)
EF > 50.0	Extremely severe enrichment (ESE)

Pollution indices

In this work, the contamination level of the studied elements and consequently the general contamination class of dust specimen were assessed using pollution indices including contamination/pollution index (CPI), integrated pollution index (IPI) and pollution load index (PLI) (Chen et al. 2005; Lu et al. 2014):

These indices were computed in accordance with Eqs. 9 to 11:

$$CPI = \frac{\text{Concentrationofelementindustsample}}{\text{Referencevalue}}, \quad (9)$$

A CPI > 1.00 and a CPI < 1.00 are associated with the pollution range the contamination range, respectively.

$$IPI = mean(CPIi), \quad (10)$$

$$PLI = \left(CPI_1 \times CPI_2 \times CPI_3 \times \cdots \times CPI_n\right)^{1/n}, \quad (11)$$

, where "*n*" refers to the number of the analyzed elements.

Also, the degree of contamination index (DC) was computed to assess the additive and synergistic effects of elements on human health (Eq. 12) (Hakanson 1980; Sun et al. 2010; Wang et al. 2013; Hu et al. 2014; Mirzaei et al. 2014; Shang et al. 2015):

$DC = \sum_1^n CPI$, (12).

CPI < 0.100	Very slight contamination (VSC)
0.100–0.250	Slight contamination (SLC)
0.260–0.500	Moderate contamination (MC)
0.510–0.750	Severe contamination (SC)
0.760–1.00	Very severe contamination (VSC)
1.10–2.00	Slight pollution (SLP)

2.10–4.00	Moderate pollution (MP)
4.10–8.00	Severe pollution (SP)
8.10–16.0	Very severe pollution (VSP)
CPI > 16.0	Excessive pollution (EXP)

IPI < 1.00	Low	PLI < 1.00	Unpolluted (UP)
1.00 < IPI < 2.00	Middle	1.00 ≤ PLI < 2.00	Moderately polluted (MP)
IPI > 2.00	High	2.00 ≤ PLI < 3.00	Strongly polluted (SP)
		PLI ≥ 3.00	Extremely polluted (EP)

DC < 6.00	Low degree of contamination (LDC)
6.00 < DC ≤ 12.0	Moderate degree of contamination (MDC)
12.0 < DC ≤ 24.0	Considerable degree of contamination (CDC)

Geo-accumulation index (I-geo)

In this work, I-geo was computed for the evaluation and classification of dust contamination levels based on Eq. 13 (Gonzáles-Macías et al. 2006; Sabet Aghlidi et al. 2020):

$$\mathrm{I-geo} = \log2\frac{Cn}{1.5Bn} \quad (13)$$

In this equation, C_n and B_n refer to the concentrations of the tested elements in the dust samples and the reference value of each analyzed element, respectively. In Eq. 13, the constant (1.50) was used to minimize the effect of possible changes in the geochemical reference values (Mohammadi Roozbahani et al., 2015). The classification of I-geo is shown in below (Muller 1969; Loska et al. 2004; Benhaddya and Hadjel 2014);

I-geo ≤ 0.000	Unpolluted (UP)
0.000 < I-geo ≤ 1.00	Unpolluted to moderately polluted (UPMP)
1.00 < I-geo ≤ 2.00	Moderately polluted (MP)
2.00 < I-geo ≤ 3.00	Moderately to strongly polluted (MSP)
3.00 < I-geo ≤ 4.00	Strongly polluted (SP)
4.00 < I-geo ≤ 5.00	Strongly to very strongly polluted (SVSP)
I-geo > 5.00	Very strongly polluted (VSP)

Statistical analysis

The normality of the obtained data and the homogeneity of the variance were examined using Kolmogorov–Smirnov (K–S) test and ANOVA, respectively. Moreover, the correlation between the element concentrations of the street dust specimens was checked by Pearson's correlation coefficient (PCC). To compare the different sampling sites in terms of concentrations of the elements in dust samples, independent samples t test was run. All statistical analyses were done using SPSS version 19.0 (SPSS Inc., Chicago, IL, USA) statistical package.

Multivariate analysis and contamination source identification

In the present study, principal component analysis (PCA) was performed to find out the contamination sources. Moreover, PCA and hierarchical cluster analysis (HCA) were conducted to distinguish the different groups of the analyzed elements from different sources.

Results and discussion

Table 2 illustrates the descriptive statistics for the concentrations of the analyzed elements in the dust specimens of the study area. As shown in Table 2, the Kolmogorov–Smirnov test confirmed that all the obtained data about the analyzed elements are normally distributed. Based on the results, the concentrations of the elements (mg/kg) varied between 1234 and 19,300 for Al, 0.150 and 6.20 for As, 0.030 and 0.940 for Cd, 6.00 and 87.4 for Cr, 10.4 and 164 for Cu, 22.0 and 159 for Pb, 55.0 and 107 for Ni and 85.2 and 426 for Zn. The average concentrations for the elements were 11,058, 2.31, 0.225, 41.3, 48.8, 65.2, 79.2 and 211 mg/kg, respectively. The descending order of the median values for the total concentrations of the analyzed elements (Al > Zn > Ni > Pb > Cu > Cr > As > Cd) could be taken to indicated distinct changes in the rates of elements among the dust specimens as well as the diversity in the levels of elements due to their origins and the intensity and the manner of anthropogenic activities (Xu et al. 2015). Besides, the high amounts of Zn in dust samples compared to other analyzed elements (except Al) may have been related to the tire dust produced by the cars speeding up on mostly worn-out and rough pavement surfaces beside corrosion of vehicular parts, exhaust emissions and also industrial activities in the study area. This elevated concentration of zinc might also have been the result of the population density in the study area and could have commercial and domestic roots. These findings are in line with those of the other researchers (see, for example, Chon et al. 1995; De Miguel et al. 1997; Kim et al. 1998; Sutherland et al. 2000; Rasmussen et al. 2001; Banerjee 2003; Charlesworth et al. 2003; Ordonez et al. 2003; Robertson et al. 2003; Yeung et al. 2003; Duzgoren-Aydin et al. 2006; Han et al. 2006, 2008; Christoforidis and Stamatis 2009; Lu et al. 2010; Zheng et al. 2010a; Duong and Lee 2011; El-Gammal et al. 2011; Li et al. 2013; Zhang et al. 2013; Xu et al. 2015;

Table 2 Descriptive statistics and LOD and LOQ values for the concentrations of the selected elements in the street dust samples of the commercial, residential and industrial regions of the study area

Study area	Element (mg/kg)	Min	Max	Median	Mean	SD	K-Sp	CV (%)	Reference values*	LOD (mg/kg)	LOQ (mg/kg)
Commercial (n = 126)	Al	5380	15,100	10,987	11,011	2033	0.727	19.0	82,300	0.084	0.260
	As	0.150	4.20	2.10	2.10	0.990	0.453	47.0	2.00	0.061	0.200
	Cd	0.030	0.800	0.155	0.198	0.157	1.371	79.0	0.230	0.073	0.240
	Cr	6.00	84.9	44.8	43.1	20.5	0.733	48.0	20.8	0.068	0.190
	Cu	10.4	86.1	41.8	42.9	17.0	0.485	40.0	28.3	0.087	0.280
	Pb	23.1	159	72.6	73.5	28.1	0.356	38.0	34.2	0.049	0.150
	Ni	63.8	95.3	81.7	81.9	6.80	0.633	83.0	45.7	0.062	0.200
	Zn	85.2	312	186	183	56.3	0.858	31.0	40.2	0.077	0.260
Residential (n = 126)	Al	1234	16,200	10,240	10,204	2342	0.953	23.0	82,300	0.079	0.250
	As	0.150	3.60	1.60	1.70	0.927	0.562	54.0	2.00	0.070	0.210
	Cd	0.050	0.370	0.165	0.183	0.077	0.746	42.0	0.230	0.068	0.200
	Cr	18.4	72.8	30.4	33.6	13.6	1.104	41.0	20.8	0.059	0.180
	Cu	10.6	68.7	40.3	39.9	15.9	0.888	40.0	28.3	0.056	0.180
	Pb	22.0	99.2	44.2	50.3	18.4	1.062	37.0	34.2	0.051	0.150
	Ni	55.0	90.3	75.7	73.8	8.24	0.771	11.0	45.7	0.073	0.240
	Zn	88.3	365	183	178	66.3	0.693	37.0	40.2	0.066	0.190
Industrial (n = 126)	Al	4610	19,300	11,950	11,959	2810	0.626	23.0	82,300	0.082	0.250
	As	1.10	6.20	3.00	3.12	1.11	0.671	36.0	2.00	0.064	0.200
	Cd	0.090	0.940	0.245	0.295	0.179	0.902	61.0	0.230	0.066	0.200
	Cr	21.6	87.4	44.0	47.1	16.6	0.669	35.0	20.8	0.060	0.180
	Cu	21.5	164	59.9	63.4	23.1	1.222	36.0	28.3	0.075	0.230
	Pb	28.4	134	67.6	71.8	23.9	0.576	33.0	34.2	0.059	0.180
	Ni	58.3	107	81.8	81.9	11.2	0.382	14.0	45.7	0.068	0.210
	Zn	184	426	260	271	70	0.911	26.0	40.2	0.052	0.160
Total (n = 378)	Al	1234	19,300	10,832	11,058	2503	0.978	23.0	82,300	0.076	0.230
	As	0.15	6.20	2.30	2.31	1.17	0.629	51.0	2.00	0.069	0.210
	Cd	0.030	0.940	0.190	0.225	0.152	1.886	68.0	0.230	0.065	0.190
	Cr	6.00	87.4	39.5	41.3	17.9	0.925	43.0	20.8	0.057	0.170
	Cu	10.4	164	46.0	48.8	21.5	0.996	44.0	28.3	0.073	0.220
	Pb	22.0	159	64.3	65.2	25.9	0.800	40.0	34.2	0.060	0.180
	Ni	55.0	107	79.3	79.2	9.65	0.784	12.0	45.7	0.059	0.180
	Zn	85.2	426	202	211	77.1	1.524	37.0	40.2	0.061	0.190

* Turekian and Wedepohl (1961); Azimzadeh and Khademi (2013); Mazloomi et al. (2017); Amouei et al. (2018);Sabet Aghlidi et al. (2020)

Kamani et al. 2015, 2017) who attributed the high amounts of Zn in the street dust to tire abrasion, lubricants, corrosion of vehicular parts, brake abrasion, industrial activities, exhaust emissions and also the population density. The results of other similar studies conducted in cities of Tehran, Eslamshahr and Isfahan, Iran, documented the descending order of the mean concentrations of the analyzed elements as Zn > Cu > Pb > Ni > Cr > Cd; Zn > Cu > Pb > Cd > Ni > Cr and Zn > Pb > Cu > Ni > As > Cd (Soltani et al., 2015; Kamani et al. 2017, 2018). On the other hand, Saeedi et al. (2012), reported that the minimum and maximum mean concentrations of the analyzed elements in the street dusts of the city of Tehran were found to be related to Cd and Zn with 10.7 mg/kg and 873 mg/kg, respectively.

In the current study, the total concentrations of all the tested elements except Pb in different sites decreased in the order of IA > CA > RA, while for Pb was: CA > IA > RA. Similarly, Kamani et al. (2015) argued that the higher concentrations of Pb in the street dust of the commercial regions of the city of Zahedan, east of Iran, as compared to Pb rates in the residential and industrial areas could be due to vehicle emissions, historical long-term use of leaded fuels and ongoing emissions from tire wear, bearing wear and lubricating oils.

Table 3 Daily exposure dose of the analyzed elements in street dust samples for children and adults through ingestion, inhalation and dermal contact pathways (mg/kg/day)

Element		Al	As	Cd	Cr	Cu	Pb	Ni	Zn
Children									
	Min	8.11×10^{-3}	9.86×10^{-7}	1.97×10^{-7}	3.94×10^{-5}	6.84×10^{-5}	1.45×10^{-4}	3.62×10^{-4}	5.60×10^{-4}
D_{ing}	Max	1.27×10^{-1}	4.08×10^{-5}	6.18×10^{-6}	5.75×10^{-4}	1.08×10^{-3}	1.04×10^{-3}	7.04×10^{-4}	2.80×10^{-3}
	95% UCL	6.91×10^{-2}	1.44×10^{-5}	1.41×10^{-6}	2.58×10^{-4}	3.05×10^{-4}	4.07×10^{-4}	4.95×10^{-4}	1.32×10^{-3}
	Min	2.27×10^{-7}	2.76×10^{-11}	5.51×10^{-12}	1.10×10^{-9}	1.91×10^{-9}	4.04×10^{-9}	1.01×10^{-8}	1.56×10^{-8}
D_{inh}	Max	3.55×10^{-6}	1.14×10^{-9}	1.73×10^{-10}	1.61×10^{-8}	3.01×10^{-8}	2.92×10^{-8}	1.97×10^{-8}	7.83×10^{-8}
	95% UCL	1.93×10^{-6}	4.03×10^{-10}	3.93×10^{-11}	7.21×10^{-9}	8.52×10^{-9}	1.14×10^{-8}	1.38×10^{-8}	3.68×10^{-8}
	Min	2.27×10^{-5}	2.76×10^{-9}	5.52×10^{-10}	1.10×10^{-7}	1.91×10^{-7}	4.04×10^{-7}	1.01×10^{-6}	1.57×10^{-6}
D_{dermal}	Max	3.55×10^{-4}	1.14×10^{-7}	1.73×10^{-8}	1.61×10^{-6}	3.01×10^{-6}	2.92×10^{-6}	1.97×10^{-6}	7.83×10^{-6}
	95% UCL	1.93×10^{-4}	4.03×10^{-8}	3.93×10^{-9}	7.21×10^{-7}	8.52×10^{-7}	1.14×10^{-6}	1.38×10^{-6}	3.68×10^{-6}
	Min	8.13×10^{-3}	9.89×10^{-7}	1.97×10^{-7}	3.95×10^{-5}	6.86×10^{-5}	1.45×10^{-4}	3.63×10^{-4}	5.62×10^{-4}
Total	Max	1.27×10^{-1}	4.09×10^{-5}	6.20×10^{-6}	5.77×10^{-4}	1.08×10^{-3}	1.04×10^{-3}	7.06×10^{-4}	2.81×10^{-3}
	95% UCL	6.93×10^{-2}	1.44×10^{-5}	1.41×10^{-6}	2.59×10^{-4}	3.06×10^{-4}	4.08×10^{-4}	4.96×10^{-4}	1.32×10^{-3}
Adults									
	Min	8.69×10^{-4}	1.06×10^{-7}	2.11×10^{-8}	4.23×10^{-6}	7.33×10^{-6}	1.55×10^{-5}	3.87×10^{-5}	6.00×10^{-5}
D_{ing}	Max	1.36×10^{-2}	4.37×10^{-6}	6.62×10^{-7}	6.16×10^{-5}	1.16×10^{-4}	1.12×10^{-4}	7.54×10^{-5}	3.00×10^{-4}
	95% UCL	7.40×10^{-3}	1.55×10^{-6}	1.51×10^{-7}	2.76×10^{-5}	3.27×10^{-5}	4.36×10^{-5}	5.30×10^{-5}	1.41×10^{-4}
	Min	1.28×10^{-7}	1.55×10^{-11}	3.11×10^{-12}	6.22×10^{-10}	1.08×10^{-9}	2.28×10^{-9}	5.70×10^{-9}	8.83×10^{-9}
D_{inh}	Max	2.00×10^{-6}	6.42×10^{-10}	9.74×10^{-11}	9.05×10^{-9}	1.70×10^{-8}	1.65×10^{-8}	1.11×10^{-8}	4.41×10^{-8}
	95% UCL	1.09×10^{-6}	2.27×10^{-10}	2.21×10^{-11}	4.06×10^{-9}	4.80×10^{-9}	6.42×10^{-9}	7.80×10^{-9}	2.08×10^{-8}
	Min	3.47×10^{-6}	4.22×10^{-10}	8.43×10^{-11}	1.69×10^{-8}	2.92×10^{-8}	6.18×10^{-8}	1.55×10^{-7}	2.39×10^{-7}
D_{dermal}	Max	5.42×10^{-5}	1.74×10^{-8}	2.64×10^{-9}	2.46×10^{-7}	4.61×10^{-7}	4.47×10^{-7}	3.01×10^{-7}	1.20×10^{-6}
	95% UCL	2.95×10^{-5}	6.17×10^{-9}	6.00×10^{-10}	1.10×10^{-7}	1.30×10^{-7}	1.74×10^{-7}	2.11×10^{-7}	5.63×10^{-7}
	Min	8.73×10^{-4}	$1.06E \times 10^{-7}$	2.12×10^{-8}	4.23×10^{-6}	7.36×10^{-6}	1.56×10^{-5}	3.89×10^{-5}	6.02×10^{-5}
Total	Max	1.37×10^{-2}	4.39×10^{-6}	6.65×10^{-7}	6.19×10^{-5}	1.16×10^{-4}	1.12×10^{-4}	7.57×10^{-5}	3.01×10^{-4}
	95% UCL	7.43×10^{-3}	1.56×10^{-6}	1.52×10^{-7}	2.77×10^{-5}	3.28×10^{-5}	4.38×10^{-5}	5.32×10^{-5}	1.42×10^{-4}
LADD									
	Min		7.48×10^{-12}	1.49×10^{-12}	2.99×10^{-10}		1.10×10^{-9}	2.74×10^{-9}	
	Max		3.09×10^{-10}	4.68×10^{-11}	4.36×10^{-9}		7.92×10^{-9}	5.33×10^{-9}	
	95% UCL		1.09×10^{-10}	1.06×10^{-11}	1.96×10^{-9}		3.09×10^{-9}	3.75×10^{-9}	

95% UCL: Upper limit of the 95% confidence interval for the mean

As shown in Table 3, the maximum exposure doses to studied elements in the street dusts of the study area with 1.27×10^{-1} and 1.37×10^{-2} mg/kg/day, both belonged to Al. Based on the results of daily exposure dose analyses, it was found that in both children and adults, the daily doses of the analyzed elements through ingestion of street dust are higher than those obtained by the other routes. Moreover, children seem to be exposed to higher amounts of elements in street dust than adults are through each of the major routes. For carcinogen agents, the maximum dose values of LADD for chromium, lead and nickel were 1×10^{-9} mg/kg/day, while for arsenic and cadmium, they were 1×10^{-10} and 1×10^{-11} mg/kg/day.

The hazard quotient (HQ) values for the three exposure pathways, and HI and CR of the tested elements in the street dusts of the study area are shown in Table 4. As indicated, for non-carcinogenic effect, the ingestion of the street dust particles appears to have been the main pathway of exposure to the elements, followed by skin contact and inhalation. It should be noted that since the studied elements were digested with nitric acid, therefore, these element concentrations may have led to an overestimation of the health risk estimates (Praveena et al. 2015; Zheng et al. 2020).

Li et al. (2013) noted that except for Al, ingestion was the main pathway of exposure to elements of urban street dust particles and thus, compared with skin contact, they posed a higher health risk to both children and adults. Therefore, inhalation of street dust posed an almost negligible risk compared with the other exposure routes. These findings, they argued, could be attributed to more frequent hand-to-mouth habits of children, and also to the daily outdoor activities (i.e., wiping sweat and food consumption

Table 4 The hazard quotients (HQ) and carcinogenic risks (CR) of the analyzed elements trough the three exposure routes in the street dust of the city of Hamedan

Element		Al	As	Cd	Cr	Cu	Pb	Ni	Zn
Children									
	Min	8.11×10^{-3}	3.29×10^{-3}	1.97×10^{-4}	1.31×10^{-2}	1.71×10^{-3}	4.14×10^{-2}	1.81×10^{-2}	1.87×10^{-3}
HQ_{ing}	Max	1.27×10^{-1}	1.36×10^{-1}	6.18×10^{-3}	1.92×10^{-1}	2.70×10^{-2}	2.97×10^{-1}	3.52×10^{-2}	9.33×10^{-3}
	95% UCL	6.91×10^{-2}	4.80×10^{-2}	1.41×10^{-3}	8.60×10^{-2}	7.62×10^{-3}	1.16×10^{-1}	2.48×10^{-2}	4.40×10^{-3}
	Min	1.59×10^{-4}	6.42×10^{-12}	5.51×10^{-9}	3.85×10^{-5}	4.77×10^{-8}	1.15×10^{-6}	4.90×10^{-7}	5.20×10^{-8}
HQ_{inh}	Max	2.48×10^{-3}	2.65×10^{-10}	1.73×10^{-7}	5.63×10^{-4}	7.52×10^{-7}	8.29×10^{-6}	9.56×10^{-7}	2.61×10^{-7}
	95% UCL	1.35×10^{-3}	9.37×10^{-11}	3.93×10^{-8}	2.52×10^{-4}	2.13×10^{-7}	3.24×10^{-6}	6.70×10^{-7}	1.23×10^{-7}
	Min	2.27×10^{-4}	2.24×10^{-5}	5.52×10^{-5}	1.83×10^{-3}	1.59×10^{-5}	7.70×10^{-4}	1.87×10^{-4}	2.62×10^{-5}
HQ_{dermal}	Max	3.55×10^{-3}	9.27×10^{-4}	1.73×10^{-3}	2.68×10^{-2}	2.51×10^{-4}	5.56×10^{-3}	3.65×10^{-4}	1.31×10^{-5}
	95% UCL	1.93×10^{-3}	3.28×10^{-4}	3.93×10^{-4}	1.20×10^{-2}	7.10×10^{-5}	2.17×10^{-3}	2.55×10^{-4}	6.13×10^{-5}
	Min	8.50×10^{-3}	3.31×10^{-3}	2.52×10^{-4}	1.50×10^{-2}	1.73×10^{-3}	4.14×10^{-2}	1.83×10^{-2}	1.90×10^{-3}
HI	Max	1.33×10^{-1}	1.37×10^{-1}	7.91×10^{-3}	2.19×10^{-1}	2.73×10^{-2}	3.03×10^{-1}	3.56×10^{-2}	9.34×10^{-3}
	95% UCL	7.24×10^{-2}	4.83×10^{-2}	1.80×10^{-3}	9.82×10^{-2}	7.69×10^{-3}	1.18×10^{-1}	2.51×10^{-2}	4.46×10^{-3}
Carcinogenic risk									
	Min		4.17×10^{-10}	3.47×10^{-11}	5.50×10^{-12}		3.43×10^{-11}	8.48×10^{-9}	
	Max		1.72×10^{-8}	1.09×10^{-9}	8.05×10^{-11}		2.48×10^{-10}	1.65×10^{-8}	
	95% UCL		6.08×10^{-9}	2.48×10^{-10}	3.61×10^{-11}		9.69×10^{-11}	1.16×10^{-8}	
Adults									
	Min	8.69×10^{-4}	3.53×10^{-4}	2.11×10^{-5}	2.07×10^{-7}	1.83×10^{-4}	4.43×10^{-3}	1.93×10^{-3}	2.00×10^{-4}
HQ_{ing}	Max	1.36×10^{-2}	1.46×10^{-2}	6.62×10^{-4}	3.02×10^{-6}	2.90×10^{-3}	3.20×10^{-2}	3.77×10^{-3}	1.00×10^{-3}
	95% UCL	7.40×10^{-3}	5.17×10^{-3}	1.51×10^{-4}	1.35×10^{-6}	8.17×10^{-4}	1.25×10^{-2}	2.65×10^{-3}	4.70×10^{-4}
	Min	8.95×10^{-5}	3.60×10^{-12}	3.11×10^{-9}	2.17×10^{-5}	2.70×10^{-8}	6.48×10^{-7}	2.77×10^{-7}	2.94×10^{-8}
HQ_{inh}	Max	1.40×10^{-3}	1.49×10^{-10}	9.74×10^{-8}	3.16×10^{-4}	4.25×10^{-7}	4.69×10^{-6}	5.39×10^{-7}	1.47×10^{-7}
	95% UCL	7.62×10^{-4}	5.28×10^{-11}	2.21×10^{-8}	1.42×10^{-4}	1.20×10^{-7}	1.82×10^{-6}	3.79×10^{-7}	6.93×10^{-8}
	Min	3.47×10^{-5}	3.43×10^{-6}	8.43×10^{-6}	2.82×10^{-4}	2.43×10^{-6}	1.18×10^{-4}	2.87×10^{-5}	3.98×10^{-6}
HQ_{dermal}	Max	5.42×10^{-4}	1.41×10^{-4}	2.64×10^{-4}	4.10×10^{-3}	3.84×10^{-5}	8.51×10^{-4}	5.57×10^{-5}	2.00×10^{-5}
	95% UCL	2.95×10^{-4}	5.02×10^{-5}	6.00×10^{-5}	1.83×10^{-3}	1.08×10^{-5}	3.31×10^{-4}	3.91×10^{-5}	9.38×10^{-6}
	Min	9.93×10^{-4}	3.56×10^{-4}	2.95×10^{-5}	3.04×10^{-4}	1.85×10^{-4}	4.55×10^{-3}	1.96×10^{-3}	2.04×10^{-4}
HI	Max	1.55×10^{-2}	1.47×10^{-2}	9.26×10^{-4}	4.42×10^{-3}	2.94×10^{-3}	3.28×10^{-2}	3.83×10^{-3}	1.02×10^{-3}
	95% UCL	8.46×10^{-3}	5.22×10^{-3}	2.11×10^{-4}	1.97×10^{-3}	8.28×10^{-4}	1.28×10^{-2}	2.69×10^{-3}	4.79×10^{-4}
Carcinogenic risk									
	Min		2.34×10^{-10}	1.96×10^{11}	3.11×10^{-12}		1.94×10^{-11}	4.79×10^{-9}	
	Max		9.70×10^{-9}	6.14×10^{-10}	4.53×10^{-11}		1.40×10^{-10}	9.32×10^{-9}	
	95% UCL		3.43×10^{-9}	1.39×10^{-10}	2.03×10^{-11}		5.46×10^{-11}	6.55×10^{-9}	

outside) of adults, and would lend support to the possibility of the ingestion of trace elements of street dust (Li et al. 2013; Sobhanardakani 2018a,b). Xu et al. (2015) found that in the case of children and adults, exposure to resuspended particles of street dust through ingestion route was 2–5 times higher than it was through the other routes (Xu et al. 2015). Such findings agreed with the results of other studies (Ferreira-Baptista and de Miguel 2005; Zheng et al. 2010a,b; Zhang et al. 2013; Lu et al. 2014). Meanwhile, in the target population differences were observed between the 95% UCL values of the HI for all the studied trace elements in the street dust samples.

In the present study, values of hazard index (HI) decreased in the order of Pb > Cr > Al > As > Ni > Cu > Zn > Cd for children and Pb > Al > As > Ni > Cr > Cu > Zn > Cd, for adults and all values were far below the safe limit (= 1) suggested by USEPA. These findings suggest that non-carcinogenic health risk to local residents could be considered as negligibly small. In this regard, Healy et al. (2008) and Sabzevari and Sobhanardakani (2018) found that lead in the urban environments is the main source of blood Pb for children as they ingest the household or street contaminated dust more (Healy et al. 2008; Sabzevari and Sobhanardakani 2018), and consequently, this exposure of children to the contaminated dust poses more potential health risks to them than it does to adults. In general, it can be noted that the HQs of all the exposure routes and also HIs of all the tested elements are higher for children than they are for adults. Hence, children may face more potential non-cancer health risks via exposure to street dust. Overall, concerning the HI values (Table 4), it can be argued that Pb with 1.18×10^{-1} for children and 1.28×10^{-2} for adults and Cd with 1.80×10^{-3} for children and 2.11×10^{-4} for adults poses the highest and lowest risk on the target population, respectively. Similarly, Li et al. (2013) reported that in comparison with other trace elements, Pb had the highest risk value (1.25×10^{-1} for children and 1.36×10^{-2} for adults) in urban street dust from Nanjing, China (Li et al. 2013). Sadeghdoust et al. (2020) also confirmed that for all the analyzed elements (As, Cd, Cr, Cu, Pb, Ni and Zn) in street dusts of the city of Dezful, south of Iran, the HI values were higher for children than they were for adults, and therefore, the risk of exposure to these elements could be higher for children. Moreover, the highest HQ in children and adults could be attributed to Pb ingestion.

As listed in Table 4, the CR of the analyzed elements for the local inhabitants due to street dust exposure in the study areas decreased in the order of Ni > As > Cd > Pb > Cr. Based on the results obtained, the CR levels of As, Cd, Cr, Pb and Ni were found to be lower than the allowable range (10^{-6}–10^{-4}), indicating that these elements in the urban street dust cannot pose carcinogenesis to the local residents. In another study, Sadeghdoust et al. (2020) reported that the CR levels of As, Cd, Cr, Pb and Ni in street dust of city of Dezful, Southwest of Iran were within the allowable range. Besides, Li et al. (2013) reported that the CR levels of Cd, Cr and Ni in urban street dust of city of Nanjing, China, were within the allowable range. Also, the obtained results are similar to the findings of Ferreira-Baptista and de Miguel (2005) who concluded that the CR levels of As, Cd, Cr and Ni in urban street dust collected from city of Luanda, Angola, were within the allowable range.

As illustrated in Table 5, the mean values of EF varied from 7.28 to 39.1; therefore, the quality of the street dust specimens in the city of Hamedan could be classified as ranging from moderately severe to very severe enrichment. Based on the EF values, it could be admitted that, except for Al, the other analyzed elements could be considered to originate mainly from anthropogenic sources (Dai et al. 2013; Nowrouzi and Pourkhabbaz 2014), although, according to Liu et al. (2003) and Li et al. (2013) the EF mean values of lower than 10.0 for As and Cd might imply that these elements could have originated from background soil materials (Liu et al. 2003; Li et al. 2013).

On the other hand, the mean values of CPI varied from 0.134 to 5.25, and therefore, based on the results obtained, the street dust specimens quality in the city of Hamedan could be classified as falling between slightly contaminated to severely polluted. However, the DC value of 14.9 indicated that the quality of the analyzed street dust specimens could be described as considerably contaminated. Besides, in agreement with the CPI results, the mean values of the I-geo showed that the street dust specimens in the city of Hamedan could be classified as unpolluted to moderately polluted. Also, the results presented in Table 5 showed a high accumulation of Zn in the specimens, as observed by its respective maximum value of I-geo (1.81). In contrast, the I-geo value of Al (-3.48), As (-0.377) and Cd (-0.617), suggested that the street dusts of the city are not polluted by these elements.

The mean CPI values of Zn with 5.25 implied that from the 378 street dust samples, 249 (66%) and 26 (7%) samples are severely and very severely polluted by Zn, respectively, while the mean CPI value of Al (0.134) indicated that from the 378 street dust samples, 19 (5%) and 359 (95%) samples are very slightly and slightly contaminated by Al, respectively. The mean CPI value of As with 1.16 showed that from the 378 street dust samples, 26 (7%), 68 (18%), 41 (11%), 193 (51%) and 23 (6%) samples could be classified as moderately contaminated, severely contaminated, very severely contaminated, slightly polluted and moderately polluted, respectively, whereas the mean CPI value of Cd (0.978) meant that from the 378 street dust samples, 57 (15%), 98 (26%), 68 (18%), 76 (20%) and 23 (6%) samples could be classified as moderately contaminated to moderately polluted, respectively. Besides, the mean CPI value of Cr with 1.99 showed that from the 378 street dust samples, 23 (6%), 140 (37%) and 151 (40%) samples could be classified as being very severely contaminated to moderately polluted, respectively. Also, the mean CPI value of Cu with 1.72 implied that from the 378 street dust samples, 53 (14%), 181 (48%) and 106 (28%) samples could be classified as very severely contaminated to moderately polluted, respectively. Furthermore, the mean CPI value of Pb of 1.91 showed that from the 378 street dust samples, 34 (9%), 170 (45%) and 151 (40%) samples could be classified as very severely contaminated to moderately polluted by this element, respectively. At the end, based on the mean CPI value of Ni with 1.73, it could be argued that from the 378 street dust samples, 340 (90%) and 34 (9%) samples are slightly and moderate polluted, respectively.

Based on the results presented in Table 6, the mean IPI value of all the street dust samples (1.86) implied that the sampling stations 6, 234 and 138 could be regarded as low, middle and high IPI, respectively. This meant that, 62% of the specimens could be classified as moderately contaminated dust. Moreover, the mean PLI value of all the studied street dust specimens (1.00) implied that 77% of the samples could be considered as moderately polluted dust.

Table 5 EF, CPI, DC and I-geo values for the elements in the street dust samples of the study area

Station	Element	EF value	Dust quality	CPI value	Dust quality	DC value	Dust quality	I-geo value	Dust quality
BD	Al	1.00	-	0.134	SLC	14.13	CDC	-3.49	UP
	As	7.85	MSE	1.05	VSC			-0.515	UP
	Cd	6.43	MSE	0.861	VSC			-0.801	UP
	Cr	15.5	SE	2.07	MP			0.466	UPMP
	Cu	11.3	SE	1.52	SLP			0.016	UPMP
	Pb	16.1	SE	2.15	MP			0.519	UPMP
	Ni	13.4	SE	1.79	SLP			0.257	UPMP
	Zn	34.0	VSE	4.55	SP			1.60	MP
RA	Al	1.00	-	0.124	SLC	12.31	CDC	-3.59	UP
	As	6.86	MSE	0.850	VSC			-0.818	UP
	Cd	6.42	MSE	0.796	VSC			-0.916	UP
	Cr	13.0	SE	1.62	SLP			0.107	UPMP
	Cu	11.4	SE	1.41	SLP			-0.089	UP
	Pb	11.9	SE	1.47	SLP			-0.029	UP
	Ni	13.0	SE	1.61	SLP			0.107	UPMP
	Zn	35.7	VSE	4.43	SP			1.56	MP
IE	Al	1.00	-	0.150	SLC	18.12	CDC	-3.37	UP
	As	10.7	SE	1.56	SLP			0.057	UPMP
	Cd	8.83	MSE	1.28	SLP			-0.226	UP
	Cr	15.6	SE	2.26	MP			0.594	UPMP
	Cu	15.4	SE	2.24	MP			0.575	UPMP
	Pb	14.5	SE	2.10	MP			0.485	UPMP
	Ni	12.3	SE	1.79	SLP			0.257	UPMP
	Zn	46.4	VSE	6.74	SP			2.17	MSP
Total	Al	1.00	-	0.134	SLC	14.87	CDC	-3.48	UP
	As	8.60	MSE	1.16	SLP			-0.377	UP
	Cd	7.28	MSE	0.978	VSC			-0.617	UP
	Cr	14.8	SE	1.99	SLP			0.405	UPMP
	Cu	12.8	SE	1.72	SLP			0.200	UPMP
	Pb	14.2	SE	1.91	SLP			0.346	UPMP
	Ni	12.9	SE	1.73	SLP			0.208	UPMP
	Zn	39.1	VSE	5.25	SP			1.81	MP

Table 6 IPI and PLI values of the analyzed elements in the street dusts of the study area

IPI			Number of samples			PLI			Number of samples			
Min	Max	Mean	Low	Middle	High	Min	Max	Mean	Low	Moderate	High	Extremely high
0.610	4.38	1.86	6	234	138	0.24	2.00	1.00	84	291	3	0

As presented in Table 7, the results of Pearson's coefficient matrix for the eight analyzed elements of the street dust specimens showed positive correlations between As and Cd ($r_{\text{As-Cd}} = 0.303$), between As and Cu ($r_{\text{As-Cu}} = 0.507$), between As and Pb ($r_{\text{As-Pb}} = 0.386$), between As and Zn ($r_{\text{As-Zn}} = 0.469$), between Cd and Cr ($r_{\text{Cd-Cr}} = 0.265$), between Cd and Cu ($r_{\text{Cd-Cu}} = 0.514$), between Cd and Pb ($r_{\text{Cd-Pb}} = 0.349$), between Cd and Zn ($r_{\text{Cd-Zn}} = 0.343$), between Cr and Cu ($r_{\text{Cr-Cu}} = 0.305$), between Cr and Pb ($r_{\text{Cd-Pb}} = 0.592$), between Cu and Pb ($r_{\text{Cu-Pb}} = 0.349$), between Cu and Ni ($r_{\text{Cu-Ni}} = 0.258$) and between Cu and Zn ($r_{\text{Cu-Zn}} = 0.482$) at a significance level of $p < 0.010$ and also between As and Ni ($r_{\text{As-Ni}} = 0.209$) and between Pb and Zn ($r_{\text{Pb-Zn}} = 0.219$) at a significance level of $p < 0.050$. These findings may point to a common source of these elements.

Based on the results of the independent samples t test, a significant difference ($p < 0.010$) was found between residential and industrial areas in mean levels of Al, Cr, Pb and Ni, while a significant difference ($p < 0.010$) was observed between commercial and industrial areas and also between

Table 7 The correlation matrix between the elements in the street dust samples

Element	Al	As	Cd	Cr	Cu	Pb	Ni	Zn
Al	1							
As	0.013	1						
Cd	0.044	0.303**	1					
Cr	0.155	0.146	0.265**	1				
Cu	0.087	0.507**	0.514**	0.305**	1			
Pb	-0.015	0.386**	0.349**	0.592**	0.349**	1		
Ni	0.056	0.209*	0.046	-0.024	0.258**	-0.128	1	
Zn	0.038	0.469**	0.343**	0.126	0.482**	0.219*	0.122	1

* $p < 0.05$ (2-tailed)

** $p < 0.01$ (2-tailed)

residential and industrial areas in mean levels of As, Cd, Cu and Zn. Moreover, a significant difference ($p < 0.010$) was found in mean levels of Cr, Pb and Ni between commercial and residential areas.

In this work, PCA was used for the element source identification of street dust (Table 8). Based on the results of loading plots of the components (Fig. 2), the tested element concentrations were grouped into PC1, PC2 and PC3 with 30.7%, 21.4% and 13.5% of all the data variation, respectively, which accounted for 66% of the cumulative variance. The PC1 showed significant positive loadings for Cu (0.806), As (0.707), Cd (0.677), Pb (0.670) and Zn (0.651), whereas it represented moderate and low positive loadings for Cr (0.554) and Ni (0.203), respectively. Therefore, as compared with the reference values, the higher average levels of these elements could suggest that they might have originated from an anthropogenic source. The PC2 showing strong loadings with Ni while, the PC3, suggests that Al has unequivocally isolated from other analyzed elements and due to its lower mean concentrations than the background value could be originated from the crustal soil sources (lithogenic origin).

As shown in Fig. 3, HCA analyses yielded two different clusters (CI and CII), where CI contained As, Cd, Cr, Cu, Pb, Ni and Zn and CII contained only Al, which probably originated from a different source. Therefore, PCA and HCA analyses suggested that the tested elements could be classified as group 1 (G1) which included As, Cd, Cr, Cu, Pb, Ni and Zn and group 2 (G2) which included Al. Hence, it could be argued that except for Al that originated from crustal soil

Table 8 Total variance and the component models of the studied elements based on the PCA and Varimax methods

Component	Initial eigenvalues			Extraction sums of squared loadings			Rotation sums of squared loadings		
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	2.84	35.5	35.5	2.84	35.5	35.5	2.46	30.7	30.7
2	1.35	16.9	52.4	1.35	16.9	52.4	1.71	21.3	52.0
3	1.05	13.2	65.6	1.05	13.2	65.5	1.08	13.5	65.6
4	0.822	10.3	75.8						
5	0.711	8.88	84.7						
6	0.531	6.63	91.3						
7	0.395	4.93	96.3						
8	0.297	3.72	100						

Elements	Component matrix			Rotated component matrix		
	PC1	PC2	PC3	PC1	PC2	PC3
Al	0.120	-0.034	**0.917**	-0.040	0.089	0.920
As	**0.707**	0.278	-0.162	0.768	0.104	-0.056
Cd	**0.677**	-0.031	-0.066	0.578	0.359	0.014
Cr	0.554	-0.593	0.251	0.155	0.789	0.275
Cu	**0.806**	0.224	0.035	0.800	0.201	0.147
Pb	**0.670**	-0.552	-0.123	0.327	0.809	-0.079
Ni	0.203	**0.677**	0.286	0.464	-0.491	0.354
Zn	**0.651**	0.322	-0.144	0.738	0.038	-0.042

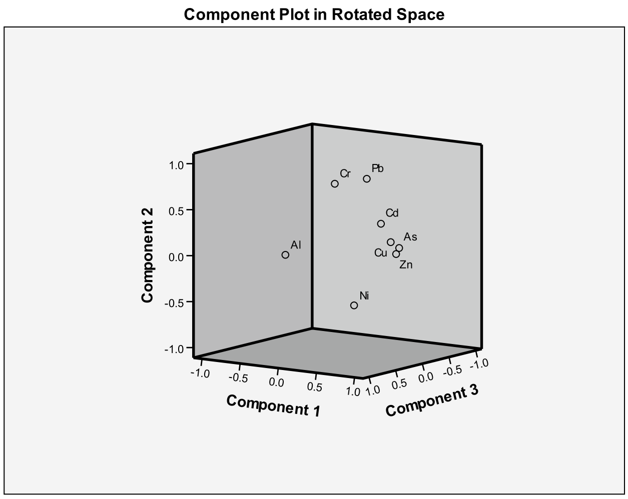


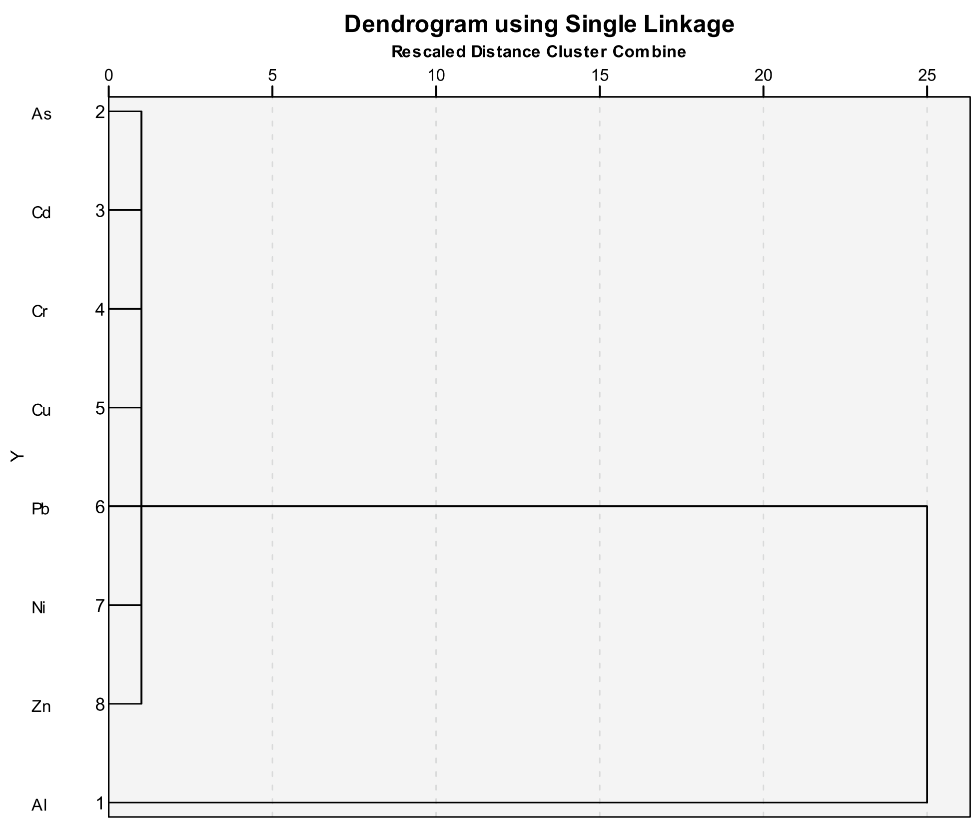
Fig. 2 Loading plot of the analyzed elements in the space described by three principal component (PC1, PC2 and PC3)

(geogenic) sources, other elements might be associated with anthropogenic sources in the study area.

The median values of As and Cd, compared with the reference values as described by other researchers (Turekian and Wedepohl 1961; Azimzadeh and Khademi 2013), indicated that the elements in the street dust samples of the study area may have been affected by extrinsic factors less; however, since the Cd and As with 68% and 51% of the coefficient of variation (CV%), respectively, had the greatest variation among the street dust specimens, it could be admitted that these elements would have the greatest probability of being affected by human activities as external factors (Chen et al. 2008; Cai et al. 2015; Yehia Mady and Shein 2017; Sabet Aghlidi et al. 2020). Also, the results showed that Ni with a CV value of 12% has a weak variation and its concentration might be constant in all sampling sites. In other words, the lower CV% of Ni and Al in comparison with the other elements may suggest that their distribution in street dust samples of the study area is relatively homogenous. Similarly, Ferreira-Baptista and de Miguel (2005) maintained that the greatest variation of Pb (68%), Zn (56%) and Cd (43%) among the street dust specimens of Luanda, Angola, may have been related to the effects of the external factors (Ferreira-Baptista and de Miguel 2005). Similarly, the findings of Lu et al. (2010) showed that the greatest variation of Pb (72%), Ni (61%) and Zn (45%) among the street dust specimens of Baoji, China, would be related to the external factors also (Lu et al. 2010).

The obtained values of CPI, IPI and PLI implied that based on the site category, the quality of the street dusts of the study area could be described as moderately polluted through activities with anthropogenic origin including exhaust fumes, industrial discharges, oil lubricants, corrosion of automobile parts, tire abrasion and brake dust (Sobhanardakani 2018a,c). On the other hand, street dusts of the study area could be affected by trace elements contamination arising from human activities.

Fig. 3 Dendrogram from nearest neighbor of the CA of the trace elements in the street dusts of the city of Hamedan



As the results of Pearson's correlation coefficient showed that Al has weak or inverse correlations with the other elements; this, coupled with a mean level much lower than the corresponding background value (82,300 mg/kg), could suggest that possibly Al possibly originates from lithogenic sources. Furthermore, the significant correlations between other elements coupled with a higher average concentration than the background values indicated that these elements could have originated from a different pollution source.

The results of element source identification indicated that PCA results were consistent with EF, CPI, IPI, PLI, I-geo and correlations matrices. This means that Al concentration in the street dust specimens of city of Hamedan may have been originated from lithogenic sources, while the contamination of the street dust by other elements may have been the result of human interventions. The results of HCA also agreed well with those of the PCA and confirmed them.

Conclusions

In this study, the street dust contamination of the city of Hamedan, Iran, with trace elements was assessed for the first time. The findings showed that the median values of Cu, Pb, Ni and Zn are higher than the background concentrations reported for Iran. Also, both anthropogenic and natural factors have their own respective loadings on the element concentrations in the street dust specimens. The mean EF values follow a descending order of Zn > Cr > Pb > Ni > Cu > As > Cd. The values of I-geo indicated that compared with the other elements, Zn with the highest average index value of 1.81 is significantly accumulated in the dust samples, and that 66% (249) of the street dust are severely polluted by this element. The mean CPI value of Al implied that 95% (359) of street dust samples are slightly contaminated by this element. The IPI values showed that 37% (140) of the studied dust specimens have high contamination. Besides, the PLI values indicated moderate levels (77%) of street dust contamination. The results of PCA and HCA of the analyzed elements suggested that anthropogenic resources including traffic emissions, increases in the number of old vehicles in the transportation fleet of Hamedan, industrial discharges, tire abrasion, corrosion of vehicular parts, oil lubricants and also urban green space management are the most important sources of As, Cd, Cr, Cu, Pb, Ni and Zn pollution, whereas natural geochemical processes (crustal soil) are the most important sources of Al in the dust samples. In summary, the results of the daily exposure dose of elements imply that, for both children and adults, the daily doses of all the elements through the ingestion of street dust are higher than those obtained via other routes. Moreover, compared to children, the non-carcinogenic health risks for adults due to exposure to trace elements in street dusts are lower. Finally, special attention for the determination of concentrations of other trace elements and particularly persistent organic pollutants (POPs) such as PCBs and PAHs in the urban street dust for assessing their ecological and health risk is recommended.

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Data availability Due to the nature of this research, participants of this study did not agree for their data to be shared publicly, so supporting data are not available.

Declarations

Ethical approval and consent to participate This article does not contain any studies with animals and human subjects. The authors confirm that all the research meets ethical guidelines and adheres to the legal requirements of the study country.

Consent for publication The authors declare that this manuscript does not contain any individual person's data and material in any form.

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

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