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RESEARCH ARTICLE

Human health risk assessment of potentially toxic heavy metals in the atmospheric dust of city of Hamedan, west of Iran

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Abstract

The atmospheric dust is an important route of human exposure to kinds of pollutants particularly toxic heavy metals. The current study was carried out to assess the ecological and health risk assessment of Co, Cr, and Mn in the atmospheric dust of city of Hamedan, Iran. In so doing, a total of 54 samples of atmospheric dust were collected from the three regions of the study area in 2014. After acid digestion of samples in the laboratory, the Co, Cr, and Mn contents were determined using inductively coupled plasma-optical emission spectrometer (ICP-OES). The results showed that the average contents (mg kg^{-1}) of Co, Cr, and Mn in the analyzed samples were 0.23, 0.89, and 8.10, respectively. The results of human health risk assessment showed that ingestion of dust particles is the main exposure route to heavy metals in the dust for the local residents. Also, the upper limit of the 95% confidence interval of hazard indices for non-carcinogenic risks of all analyzed metals in the atmospheric dust was within the safe level (= 1) for both children and adults. The carcinogenic risk levels of Co and Cr were all lower than the acceptable range for local citizens. Based on the results, it can be suggested that special attention be paid to toxic heavy metals that long-term exposure to which via atmospheric dust can have adverse effects on the city resident health.

Keywords Health risk assessment · Toxic heavy metals · Atmospheric dust · Non-carcinogen

Introduction

Heavy metal refers to the metallic chemical element that has a relatively high density which usually makes it toxic for living organisms even at low contents. Natural and human factors, such as storm runoff, soil erosion, industrial activities, smelting and quarrying activities, metal plating, agriculture, mining, and fossil-fuel combustion can discharge high amounts of heavy metals into the surface and groundwater, soil, air and ultimately the biosphere (Sobhanardakani et al. 2015; Philip et al. 2017). In this regard, some factors, including industrial discharges, exhaust fumes, oil lubricants, corrosion of building materials, automobile parts, and also atmospheric deposition can cause accumulation of heavy metals on urban surfaces especially street dust. Therefore, people living along highways, areas with high traffic volume, automobile repair shops, and production industries, are usually at high risk of heavy metals poisoning such as lung diseases, oxidative damage to DNA, oxidative stress, acute inflammatory reaction through inhalation, ingestion, and dermal absorption of airborne particulate matter containing heavy metals (Alhassan et al. 2012; Philip et al. 2017). Therefore, concerns about the quality of dust and atmospheric depositions are growing around the globe (Dick et al. 2003; Valavanidis et al. 2006; Al-Momani et al. 2008; Shi et al. 2008; Sobhanardakani and Saedi 2015; Shokri Ragheb and Sobhanardakani 2016).

Emissions to the atmosphere in the form of particles and gases from natural and anthropogenic sources can return to the land and sea through atmospheric depositional processes by dry and wet precipitation (Zheng et al. 2005). In this regard, particle size and also the surface properties of the substrate on which metals are deposited are the main factors that affect the dispersion and distribution of environmentally sensitive elements (Wong et al. 2006).

Cobalt is an essential nutrient which is beneficial to humans because it is an integral part of vitamin B12, is a vital element for proper thyroid functioning and plays important roles in regulating blood pressure. However, the exposure to high amounts of Co can cause adverse effects on human health

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(Fallah et al. 2011; Hosseini et al. 2013; Sobhanardakani and Jamshidi 2015).

Chromium as an essential mineral is widely distributed in human tissues even in extremely low and variable concentrations. Trivalent chromium can help in the consumption of proteins and lipids, and also in the metabolism of carbohydrate (Hosseini et al. 2013; Stancheva et al. 2014), whereas, Cr(VI) compounds are known as toxic carcinogens that pose risks to human health (Kabata-Pendias 2010).

Like Co and Cr, manganese is also known as an essential element,. Toxicity of Mn has been reported as a result occupational and dietary overexposure and can affect the central nervous system, although cardiac, liver, lung, reproductive and fetal toxicity have also been noted. Also, neurotoxicity of this element can cause a progressive disorder of the extra-pyramidal system which is similar to Parkinson's disease (Crossgrove and Zheng 2004; ÓNeal and Zheng 2015). However, there is no evidence that manganese can cause cancer in humans (Shokri Ragheb and Sobhanardakani 2016).

As similar studies in terms of the human health risk assessment of heavy metals in the atmospheric dust have not previously been conducted in the study area, the current study was conducted for the first time to analyze human health risks caused by heavy metals (Co, Cr, and Mn) in an atmospheric dust in regions with different traffic intensity in the city of Hamedan in 2014.

Materials and methods

Study area

The city of Hamedan as the capital of Hamedan Province is one of the biggest cities in the western part of Iran, located in the northern part of Mount Alvand at an altitude of 1850 m above sea level and lies between longitudes 48° 31′ E, and between latitudes 34° 48′ N with an urban area about of 56 km^2 and a population of 581,925. It has a favorable climate, with four distinct seasons. Hamedan has cold winters and there is usually rainfall in the winter and spring. The annual average temperature and annual average precipitation of this city are 11.3 °C, and 317.7 mm, respectively (Shokri Ragheb and Sobhanardakani 2016).

Reagents

Standard stock solutions of analyzing metal ions at the content of 1000 ppm were used to prepare working solutions after appropriate dilution. Standard solutions were of analytical grade (Merck, Darmstadt, Germany). Distilled deionized water was used in all dilution procedures.

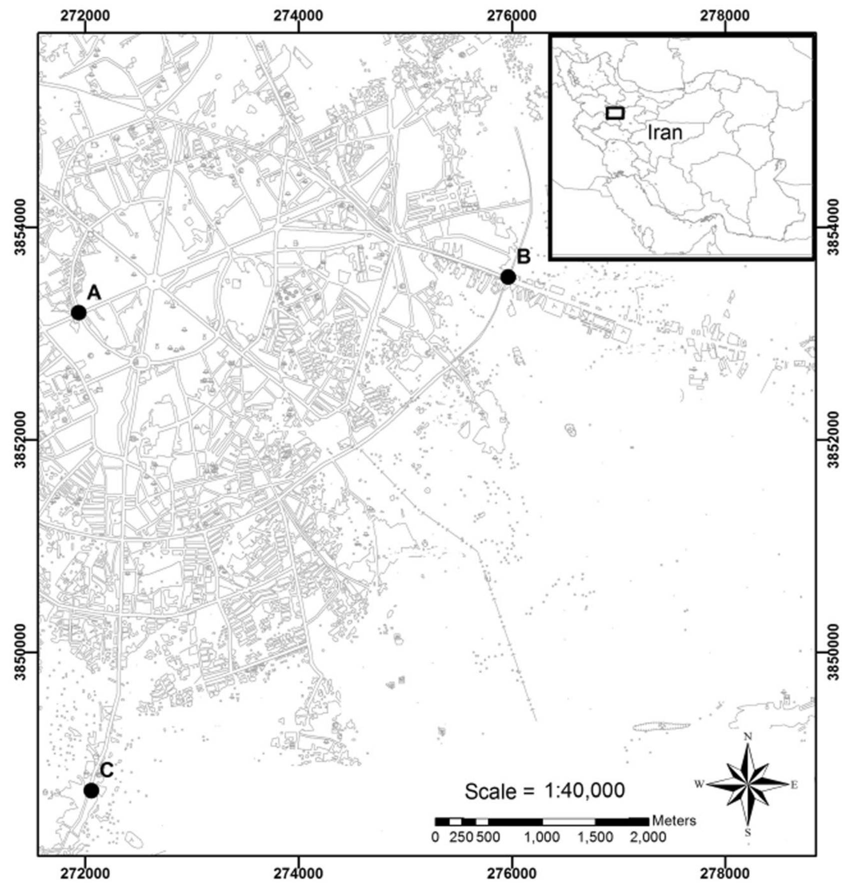
Sampling and sample analysis

In this study, totally 36 atmospheric dry deposition samples were collected on five-day intervals from mid-September to mid-October, 2014. Samples were collected from residential areas of three regions of the Hamedan with high (A), moderate (B), and low/light (C) traffic intensity (Fig. 1) by placing high-density polyethylene bucket with a 30 cm diameter on an elevated tripod stand (1 m) above the ground surface to minimize contamination from resuspended particles generated by natural wind and traffic-induced. For samples digestion, 1.0 g of each sieved sample was transferred into a digestion vessel and 10 ml of HNO_3 was added, mixed thoroughly and covered with a watch glass. Then, the samples were heated to 90 °C and refluxed at this temperature for 15 min after which they were allowed to cool for 10 min at 20 °C. Thereafter, 5 ml of concentrated nitric acid was added to each sample, which was covered and refluxed again at 90 °C for 30 min. Then, the solutions were allowed to evaporate without boiling to approximately 5 ml each and cooled again for 10 min at room temperature. This was followed by the addition of 2 ml of deionized water and 3 ml of H_2O_2 (30%) to each. The vessels were covered and heated just enough to warm the solutions for the peroxide reaction to start. This process was continued until effervescence subsided and the solutions were cooled (Zheng et al. 2005; Al-Momani et al. 2008; Shokri Ragheb and Sobhanardakani 2016). Finally, the elements content were analyzed using inductively coupled plasma-optical emission spectrometry (710-ES, Varian, Australia) at wavelengths 228.615 nm for Co, 267.716 nm for Cr, and 257.610 nm for Mn. The accuracy of the analytical methods, limits of detection (LOD) and limits of quantification (LOQ) were all determined based on the method described by Al-Momani et al. (2008) and Lu et al. (Lu et al. 2010). The results showed good accuracy, with recovery rates for analyzed elements between 97.1 and 100.2 for dust samples. Limits of detection and LOQ values are presented in Table 1.

Health risk assessment model

In this study, the model developed by the U.S. EPA was used to evaluate the human exposure to heavy metals in atmospheric dry deposition samples in Hamedan. The assumptions of this model are as follows: (1) Human beings are exposed to atmospheric dry deposition through ingestion (D_{ing}), inhalation via the nose and mouth (D_{inh}) and also dermal absorption of metals in dust particles adhered to exposed skin (D_{dermal}), (2) particle emission factors and intake rates approximate those developed in the soil, (3) relevant exposure parameters of adults and children in the study area are similar to those of reference populations, (4) the total non-carcinogenic risk for Co, Cr, and Mn, and the overall carcinogenic risk for Co, and Cr can be calculated by summing the individual risks obtained

Fig. 1 Map of the sampling stations



from the ingestion, inhalation and dermal exposure pathways (Ferreira-Baptista and de Miguel 2005; Li et al. 2014).

The exposure dose contacted via each of the three pathways is calculated based on Eqs. 1 to 3 (Xu et al. 2015):

$$D_{\text{ing}} = C \times \frac{\text{IngR} \times \text{EF} \times \text{ED}}{\text{BW} \times \text{AT}} \times 10^{-6}, \tag{1}$$

Table 1 Heavy metal analysis of atmospheric dust (mg kg^{-1})

Sampling station	Metal concentration		
	Co	Cr	Mn
A	0.29 ± 0.04a	1.01 ± 0.01a	8.82 ± 0.11a
B	0.21 ± 0.04b	1.02 ± 0.17a	8.24 ± 0.09b
C	0.19 ± 0.03b	0.65 ± 0.05b	7.23 ± 0.03c
Min.	0.17	0.61	7.19
Max.	0.34	1.21	8.95
Mean	0.23	0.89	8.10
S.D.	0.06	0.20	0.70
LOD	0.06	0.08	0.05
LOQ	0.19	0.23	0.16

The letters (a, b, and c) represent the significant difference between the mean content of metals in dust samples based on the results of onE−way ANOVA and Duncan's multiple range test ($p = 0.05$)

where D_{ing} indicates dose contacted via ingestion of atmospheric dry deposition particles (mg kg^{-1} day^{-1}); C is the exposure point concentration (mg kg^{-1}) of the heavy metal; IngR represents the ingestion rate (200 mg day^{-1} and 100 mg day^{-1} for children and adults, respectively); EF, ED, BW, and AT shows the exposure frequency (180 days year^{-1}), exposure time (6 years and 24 years for children and adults, respectively), average body weight (15.0 kg and 70 kg for children and adults, respectively) and average time (ED × 365 days for non-carcinogens and 26,280 (72 × 365) days for carcinogens), respectively (Ferreira-Baptista and de Miguel 2005; Zheng et al. 2010; Luo et al. 2012; Sobhanardakani 2017).

$$D_{\text{inh}} = C \times \frac{\text{InhR} \times \text{EF} \times \text{ED}}{\text{PEF} \times \text{BW} \times \text{AT}}, \tag{2}$$

in this equation, D_{inh} indicates dose contacted via inhalation of atmospheric dry deposition particles (mg kg^{-1} day^{-1}); InhR and PEF show the inhalation rate (7.6 m^3 day^{-1} for children and 20 m^3 day^{-1} for adults) and particle emission factor (1.36 × 10^9 m^3 kg^{-1}), respectively (Li et al. 2013; Xu et al. 2015).

$$D_{\text{dermal}} = C \times \frac{\text{SA} \times \text{SL} \times \text{ABS} \times \text{EF} \times \text{ED}}{\text{BW} \times \text{AT}} \times 10^{-6}, \tag{3}$$

where D_{dermal} represent the dose absorbed via dermal contact with street atmospheric dry deposition particles (mg kg^{-1} day^{-1}); SA, SL, and ABS indicate exposed skin area, (2800 cm^2 and 5700 cm^2 for children and adults respectively), skin adherence factor (0.2 mg cm^{2-1} day^{-1} and 0.07 mg cm^{2-1} day^{-1} for children and adults, respectively) and dermal absorption factor (0.001) for Co, Cr, and Mn (Ferreira-Baptista and de Miguel 2005; Man et al. 2010; Zheng et al. 2010).

The cancer risk through inhalation exposure route of Co and Cr was computed in accordance with Eq. 4:

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

where LADD represents the lifetime average daily dose (mg kg^{-1} day^{-1}) (Xu et al. 2015).

Risk characterization

After the exposure dose values contacted via each of the three pathways (D_{ing}, D_{inh}, and D_{dermal}) were measured, the potential non-carcinogenic and carcinogenic risks for individual metals were calculated using Eqs. 5 to 7, respectively:

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

$$\mathrm{HI} = \sum \mathrm{HQi}, \quad (6)$$

where HQ represents the non-cancer toxic risk, D and RfD indicate the average daily dose and a specific reference dose (Tables 2, 3), respectively (Man et al. 2010).

The hazard index (HI) is equal to the sum of HQs and is used to estimate the health risk of different exposure pathways. Here, $\mathrm{HI} \leq 1$ indicates no adverse health effects and $\mathrm{HI} > 1$ shows possible adverse health effects (Kong et al. 2011).

$$\mathrm{CR} = D \times \mathrm{SF}, \quad (7)$$

where CR and SF indicate the carcinogenic risk and the slope factor (Table 3), respectively (Zheng et al. 2010).

Statistical analysis

To analyze the obtained data first Kolmogorov-Smirnov (K-S) test was run to check the normality of the data. Then the homogeneity of the variance was tested running ANOVA with a DMS post hoc and Duncan multiple range test. Besides, the mean levels of heavy metals in the atmospheric dry deposition were compared with maximum permissible concentrations (MPC) using a one sample t test. Finally, to study the correlation between the metals in the different samples, Pearson's correlation was run.

Table 2 Daily exposure dose of metals in particles of atmospheric dry deposition to children and adults via three routes (mg kg^{-1} day^{-1})

Metal		Co	Cr	Mn
Children				
	Minimum	1.12E−06	4.01E−06	4.73E−05
D_{ing}	Maximum	2.24E−06	7.96E−06	5.88E−05
	95% UCL	1.44E−06	5.56E−06	5.06E−05
	Minimum	3.12E−11	1.12E−10	1.32E−09
D_{inh}	Maximum	6.25E−11	2.22E−10	1.64E−09
	95% UCL	4.01E−11	1.55E−10	1.41E−09
	Minimum	3.13E−09	1.12E−08	1.32E−07
D_{dermal}	Maximum	6.26E−09	2.23E−08	1.65E−07
	95% UCL	4.02E−09	1.56E−08	1.42E−07
	Minimum	1.12E−06	4.02E−06	4.74E−05
Total	Maximum	2.25E−06	7.98E−06	5.90E−05
	95% UCL	1.44E−06	5.58E−06	5.07E−05
Adults				
	Minimum	1.20E−07	7.05E−08	5.07E−06
D_{ing}	Maximum	2.40E−07	8.52E−07	6.31E−06
	95% UCL	1.54E−07	5.96E−07	5.42E−06
	Minimum	1.76E−11	6.32E−11	7.45E−10
D_{inh}	Maximum	3.52E−11	1.25E−10	9.27E−10
	95% UCL	2.26E−11	8.76E−11	7.97E−10
	Minimum	4.78E−10	1.71E−09	2.20E−08
D_{dermal}	Maximum	9.56E−10	3.40E−09	2.52E−08
	95% UCL	6.14E−10	2.38E−09	2.16E−08
	Minimum	1.20E−07	7.23E−08	5.09E−06
Total	Maximum	2.41E−07	8.56E−07	6.34E−06
	95% UCL	1.55E−07	5.98E−07	5.44E−06
LADD				
	Minimum	8.47E−12	3.04E−11	
	Maximum	1.69E−11	6.03E−11	
	95% UCL	1.09E−11	4.21E−11	

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

Results and discussion

The mean content of heavy metals in the atmospheric dust is presented in Table 1. As the data in Table 1 shows among the analyzed atmospheric dust samples, Co was detected in amounts ranging from 0.17 to 0.34 mg kg^{-1}, Cr from 0.61 to 1.21 mg kg^{-1}, and Mn from 7.19 to 8.95 mg kg^{-1}.

Table 3 Reference dose (RfD) and slope factor (SF) of heavy metals (Li et al. 2013; Xu et al. 2015)

Metal	Co	Cr	Mn
RfD_{ing}	2.00E−02	3.00E−03	4.60E−02
RfD_{inh}	5.71E−06	2.86E−05	1.43E−05
RfD_{dermal}	1.60E−02	6.00E−05	1.84E−03
Inhal. SF	9.80E+00	4.20E+01	

The results of the K-S test for element contents in dust samples showed that the data for all analyzed metals were normality distributed ($p > 0.01$). The results of the Independent One-Sample t test comparing the heavy metal contents in the atmospheric dry deposition samples with the MPC (30.0 mg kg^{-1} for Co, 100.0 mg kg^{-1} for Cr, and 1500.0 mg kg^{-1} for Mn) established by WHO (Chen et al. 2005) showed that the mean contents of analyzed metals in all samples were lower than those in the MPC. Also, based on the results of Pearson's test, although a meaningful relationships was not found between contents of Co and Cr ($r = 0.620$, $p = 0.075$), positive relationships were observed between contents of Co and Mn ($r = 0.735$, $p = 0.024$) and also between contents of Cr and Mn ($r = 0.857$, $p = 0.003$). Here, when the Co and Cr contents increased, the Mn content increased too.

The results of health risk assessment of metals in the particles of atmospheric dust from Hamedan for both children and adults are presented in Table 2. Based on the results, the maximum exposure doses for children and adults were 5.90E−05 and 6.34E−06 mg kg^{-1} day^{-1}, both for Mn. In the case of children, the daily doses of all metals by ingestion were about 1.5 to 2 times higher than those obtained by the inhalation and dermal contact. While in the case of adults, the daily doses of all metals by ingestion were about 1.5 times higher than by the other two pathways. In terms of total exposure amounts, Co and Cr were showed the same magnitudes (E−07 mg kg^{-1} day^{-1}), which was lower than that of Mn (E−06 mg kg^{-1} day^{-1}). On the whole, children are exposed to more metals in atmospheric dust than adults by each of the three pathways. For carcinogenic metals, the maximum values dose of LADD (mg kg^{-1} day^{-1}) for both Co and Cr was E−11.

The results of the hazard quotient (HQ) values of different exposure pathways, hazard index, and cancer risk of the analyzed heavy metals in the particles of atmospheric dust from Hamedan are presented in Table 4. Based on the results for non-carcinogenic effect, ingestion of dust particles is the main route of exposure to heavy metals in dust compared to inhalation and especially dermal adsorption. However, dermal exposure to the particles for Co, Cr, and Mn is almost negligible compared with the other exposure pathways. Also, there are some differences between the 95% UCL values of HIs for all the analyzed metals in the particle samples in both children and adults, i.e., for children and adults the 95% UCL values of HIs decrease in the order Cr > Mn > Co. That is, they all were far below the safe level (= 1) indicating that there would be little non-carcinogenic health risk to local inhabitants, including children and adults due to the existence Co, Cr, and Mn in the particles of atmospheric dust. On the other hand, the HQ values of ingestion, inhalation and dermal exposure routes and HI values of all analyzed heavy metals for children are higher than those for adults. Therefore, children in comparison with adults may have more potential non-cancer risk due to the exposure to airborne dust.

Table 4 The hazard quotient (non-carcinogenic risks) and carcinogenic risk of each heavy metal and exposure pathway in particles of atmospheric dry deposition from city of Hamedan

Metal		Co	Cr	Mn
Children				
	Minimum	5.60E−05	1.34E−03	1.03E−03
HQ_{ing}	Maximum	1.12E−04	2.65E−03	1.28E−03
	95% UCL	7.20E−05	1.85E−03	1.10E−03
	Minimum	5.46E−06	3.92E−06	9.23E−05
HQ_{inh}	Maximum	1.09E−05	7.76E−06	1.15E−04
	95% UCL	7.02E−06	5.42E−06	9.86E−05
	Minimum	1.96E−07	1.87E−04	7.17E−05
HQ_{dermal}	Maximum	3.91E−07	3.72E−04	8.97E−05
	95% UCL	2.51E−07	2.60E−04	7.72E−05
	Minimum	6.17E−05	1.53E−03	1.19E−03
HI	Maximum	1.23E−04	3.03E−03	1.48E−03
	95% UCL	7.93E−05	2.12E−03	1.28E−03
Carcinogenic risk				
	Minimum	3.06E−10	4.70E−09	
	Maximum	6.12E−10	9.32E−09	
	95% UCL	3.93E−10	6.51E−09	
Adults				
	Minimum	6.00E−06	2.35E−05	1.10E−04
HQ_{ing}	Maximum	1.20E−05	2.84E−04	1.37E−04
	95% UCL	7.70E−06	1.99E−04	1.18E−04
	Minimum	3.08E−06	2.21E−06	5.21E−05
HQ_{inh}	Maximum	6.16E−06	4.37E−06	6.48E−05
	95% UCL	3.96E−06	3.06E−06	5.57E−05
	Minimum	2.99E−08	2.85E−05	1.20E−05
HQ_{dermal}	Maximum	5.97E−08	5.67E−05	1.37E−05
	95% UCL	3.84E−08	3.97E−05	1.17E−05
	Minimum	9.11E−06	2.86E−05	1.74E−04
HI	Maximum	1.82E−05	3.45E−04	2.15E−04
	95% UCL	1.17E−05	2.42E−04	1.85E−04
Carcinogenic risk				
	Minimum	1.72E−10	2.65E−09	
	Maximum	3.45E−10	5.25E−09	
	95% UCL	2.21E−10	3.68E−09	

It has been proved that, the local natural environment, including topography and climate, and also human activities, such as waste disposal, industrial production, fossil-fuel combustion, exhaust fumes, as well as population size and development stage of the area are the main factors that influence the metal content in the atmospheric dust and resuspended particles of street dust (Charlesworth et al. 2003; Shi et al. 2008; Zhao et al. 2014). Consequently, the diversity in the content of heavy metals in the atmospheric dust may be related to their sources, their intensity, and also anthropogenic activities (Shi et al. 2008; Xu et al. 2015).

Natural and anthropogenic sources, such as weathering of soil and rocks, erosion, sea water spray, volcanoes, forest fires, continental, and marine biogenic emissions and also traffic are known as the main sources of cobalt in the atmospheric dust/street dust (Nriagu 1989). Based on the results of this study, Co contents in atmospheric dust samples were found in average amounts of 0.23 ± 0.06 mg kg^{-1}. On the other hand, the highest mean level of this element found in the station with heavy traffic volume (0.29 ± 0.04 mg kg^{-1}) would result from the corrosion of metallic parts of vehicles and the wear of the brake lining (Arditsoglou and Samara 2005; Al-Khashman 2007). Literature reviews showed the average content of cobalt in dust samples collected from Bushehr, Iran to be 11.70 mg kg^{-1} (Naderizadeh et al. 2016). Table 5 shows a comparison of metal content in the atmospheric dry deposition/street dust from Hamedan with some other cities reported in the literature.

Chromium is used in many alloys especially stainless steel. Grinding, welding, and also polishing of stainless steel, as well as waste incineration and the burning of fossils fuels, can lead to the discharge of Cr into the environment (Alhassan et al. 2012). Human tissues can accumulate considerable quantities of this element before pathological changes result. Chromium and its compounds can cause cancers of the nasal cavity, para nasal sinus, and lungs. Cancers of the stomach and larynx can also be related to the exposure to Cr (Shi et al. 2008; Kabata-Pendias 2010). As can be seen in Table 1, the Cr content in atmospheric dust samples from Hamedan was found in the range of 0.61–1.21 mg kg^{-1} with an average of 0.89 ± 0.20 mg kg^{-1}. Also, the highest mean level of Cr was found in areas with moderate traffic intensity (1.02 ± 0.17 mg kg^{-1}). While the lowest contents of Cr was found in areas with light traffic volume (0.65 ± 0.05 mg kg^{-1}). Therefore, it can be concluded that the content of Cr decreases with the traffic volume. It is believed that the chromium in dust may be associated with the chrome plating of some motor vehicle parts and also corrosion of vehicular parts (Al-Shayep and Seaward 2001; Lu et al. 2009). Also, natural and anthropogenic sources, such as geogenic and tannery and dying industries, are also known as the sources of Cr in the environment (Imperato et al. 2003; Ahmed and Ishiga 2006). In general, the mean value of Cr from this work was lower than those measured in other cities of the world like Baotou with an average of 247.8 mg kg^{-1} (Xu et al. 2015), Xian with an average of 52.61 mg kg^{-1} (Han et al. 2008), Luanda with an average of

Table 5 Comparison of heavy metal contents (mg kg^{-1}) in atmospheric dust/street dusts reported from the literature to those measured in this study

Location	Metal			Source of data
	Co	Cr	Mn	
Iran (Hamedan)	0.23	0.89	8.10	This study
Spain (Madrid)	3.00	–	362.00	(de Miguel et al. 1997)
Norway (Oslo)	19.00	–	833.00	(de Miguel et al. 1997)
U.K. (Lancaster)	–	10–91	–	(Harrison 1979)
Hawaii (Honolulu)	46.00	–	–	(Sutherland et al. 2000)
Canada (Ottawa)	2.31–12.59	14.7–71.7	145.1–618.3	(Rasmussen et al. 2001)
Spain (Aviles)	–	42.0	–	(Ordónez et al. 2003)
Turkey (Tokat)	–	41.0	415.0	(Tūzen 2003)
Kosovo	10.77	–	–	(Arditsoglou and Samara 2005)
Turkey (Yozgat)	23.27	33.00	–	(Divrikli et al. 2003)
Angola (Luanda)	2.90	–	258.00	(Ferreira-Baptista and de Miguel 2005)
Turkey (Kayseri)	19.66	27.91	–	(Kartal et al. 2006)
Turkey (Kayseri)	16.50	29.00	–	(Tokalioğlu and Kartal 2006)
China (Xian)	–	–	687.00	(Yongming et al. 2006)
Jordan (Aqaba)	14.85	–	–	(Al-Khashman 2007)
Jordan (Amman)	0.00015	–	–	(Al-Momani et al. 2008)
Spain (Barcelona)	–	104.07	–	(Pérez et al. 2008)
Greece (Kavala)	–	196.00	–	(Christoforidis and Stamatis 2009)
China (Hangzhou)	51.29	51.29	–	(Zhang and Wang 2009)
China (Baoji)	15.90	–	–	(Lu et al. 2010)
China (Nanjing)	10.11	–	–	(Li et al. 2013)
China (Shanghai)	–	145.00	–	(Zhang et al. 2013)
China (Xining)	50.00	–	–	(Zhao et al. 2014)
China (Baotou)	56.20	–	566.30	(Xu et al. 2015)

25.65 mg kg^{-1} (Ferreira-Baptista and de Miguel 2005) and Madrid with an average of 61.0 mg kg^{-1} (de Miguel et al. 1997). A comparison of our findings with other studies is shown in Table 5.

It has been shown that the main source of Manganese in the atmospheric dust samples is related to the geological materials (lithogenic source), traffic, and also tire wear (Akhter and Madany 1993; Divrikli et al. 2003). Based on the results, the highest Mn content with an average of 8.82 ± 0.11 mg kg^{-1} has been found to be at the heavy traffic intensity sampling station. In the literature, Mn contents in dust samples collected from Yozgat (Turkey) was detected in amounts ranging from 778.0 to 910.0 mg kg^{-1} for areas with heavy traffic intensity, ranging from 472.0 to 655.0 mg kg^{-1} for areas with moderate traffic intensity, and ranging from 433.0 to 627.0 mg kg^{-1} for area with light traffic intensity (Divrikli et al. 2003). Also, Alhassan et al. (2012) reported that the Mn levels in street dust samples collected from five major roads within the trunk of Kano metropolis (Nigeria) was detected in amounts ranging from 3.88 to 6.80 mg kg^{-1}. A comparison of the Mn contents in the atmospheric dust samples in the study area and other selected regions are presented in Table 5.

Based on the results of this study, the risk for Cr was the highest for ingestion contact pathway, followed by Mn, and Co. On the other hand, as for the three exposure routes, obviously, ingestion was the dominant way for both children and adults. In this regard, Shi et al. (2011) reported that Cr was the trace element of greatest concern in the Shanghai urban dust regarding potential health risk. Also, previous studies have indicated that for non-cancer effect, ingestion of dust particles is the main pathway of exposure to toxic heavy metals in dust that leads to a higher risk (Ferreira-Baptista and de Miguel 2005; Zheng et al. 2010; Lu et al. 2014; Xu et al. 2015). The rates of cancer risk associated with exposure to Co and Cr in atmospheric dust were all below the receivable range or threshold values (10^{-6}–10^{-4}) indicating no carcinogenic risk from these elements for children and adults similar to other studies (Li et al. 2013). Therefore, it can be concluded that exposure to toxic metals in atmospheric dust per se would not cause serious health hazards in the study area. However, the calculated risk of both non-cancer and cancer due to exposure to toxic heavy metals from atmospheric and road dust was under a high degree of uncertainty (Shi et al. 2011).

Conclusion

This study was carried out to analyze the heavy metal concentrations and also human health risk factors in atmospheric dust of Hamedan, Iran. Based on the results, the atmospheric dry deposition element contents increase in the following descending order: Co > Cr > Mn. Also, the mean contents of Co, Cr, and Mn in the all dust samples were lower than those in the MPC. The maximum levels of CR in children with 6.12E−10 for Co and 9.32E−09 for Cr and in adults with 3.45E−10 for Co and 5.25E−09 for Cr were all lower than the acceptable range. Also, the results of HQ showed that ingestion is the main exposure pathway of local residents especially children to heavy metals in dust. On the other hand, the 95%UCL of hazard indices for non-carcinogenic risks of Co, Cr and Mn in the dust samples were within the safe level for both children and adults, although, children may have more potential non-cancer risk than adults do. Therefore, it is recommended that special attention be given to toxic heavy metals content of atmospheric dust that city residents especially children have long-term exposure to.

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