International Journal of Biometeorology (2018) 62:1075–1083
https://doi.org/10.1007/s00484-018-1510-x

ORIGINAL PAPER

Health risk assessment on human exposed to heavy metals in the ambient air PM_{10} in Ahvaz, southwest Iran

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Received: 22 December 2017 / Revised: 17 January 2018 / Accepted: 30 January 2018 / Published online: 20 February 2018

Abstract

Heavy metals (HM) are one of the main components of urban air pollution. Today, megacities and industrial regions in southwest of Iran are frequently suffering from severe haze episodes, which essentially caused by PM_{10}-bound heavy metals. The purpose of this study was to evaluate the health risk assessment on human exposed to heavy metals (Cr, Ni, Pb, and Zn) in the ambient air PM_{10} in Ahvaz, southwest Iran. In this study, we estimated healthy people from the following scenarios: (S3) residential site; (S2) high-traffic site; (S1) industrial site in Ahvaz metropolitan during autumn and winter. In the current study, high-volume air samplers equipped with quartz fiber filters were used to sampling and measurements of heavy metal concentration. Inductively coupled plasma optical emission spectroscopy (ICP-OES) was utilized for detection of heavy metal concentration (ng m^{-3}). Also, an estimate of the amount of health risk assessment (hazard index) of Cr, Ni, Pb, and Zn of heavy metal exposure to participants was used. Result of this study showed that the residential and industrial areas had the lowest and the highest level of heavy metal. Based on the result of this study, average levels of heavy metal in industrial, high-traffic, and residential areas in autumn and winter were 31.48, 30.89, and 23.21 μg m^{-3} and 42.60, 37.70, and 40.07 μg m^{-3}, respectively. Based on the result of this study, the highest and the lowest concentration of heavy metal had in the industrial and residential areas. Zn and Pb were the most abundant elements among the studied PM_{10}-bound heavy metals, followed by Cr and Ni. The carcinogenic risks of Cr, Pb, and the integral HQ of metals in PM_{10} for children and adults via inhalation and dermal exposures exceeded 1×10^{-4} in three areas. Also, based on the result of this study, the values of hazard index (HI) of HM exposure in different areas were significantly higher than standard. The health risks attributed to HM should be further investigated from the perspective of the public health in metropolitans. The result of this study showed increasing exposure concentrations to heavy metal in the studied scenarios have a significant potential for generating different health endpoints, while environmental health management in ambient air can cause disorders in citizenship and causing more spiritual and material costs.

Keywords Heavy metals · Health risk assessment · Human · Ambient air · Iran

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Introduction

Indoor and outdoor air pollution is a heterogeneous mixture of gases, vapors, and particles (Dobaradaran et al. 2016; Neisi et al. 2016; Soleimani et al. 2013; Marzouni et al. 2017). In recent years in developing countries, one of the most public health and crucial environmental concerns is air pollution, especially source of several toxic chemical contaminants including heavy metals (Dobaradaran et al. 2016; Neisi et al. 2016; Soleimani et al. 2013; Delfino et al. 2009; Elder et al. 2015; Fiala et al. 2001; Pruneda-Álvarez et al. 2016a; Chen et al. 2016; Liu et al. 2016; Goudarzi et al. 2017; Khaniabadi et al. 2017b; Marzouni et al. 2017; Al-Khashman 2004; Ayrault et al. 2010; De Roos et al. 2003; Khaniabadi et al. 2017c; Geravandi et al. 2017). The most important factors that depend on health endpoint in exposure to heavy metal are emission sources, the locations, and individual susceptibility (Shen et al. 2014; Goudarzi et al. 2017; Ebi and Hess 2017; Lai 2016; Khaniabadi et al. 2017a). Cardiovascular diseases, allergic skin, nervous system diseases, thrombotic effects, decreased body weight, low IQ at age 3 years, asthmatics, nausea, eye irritation, irritation, diarrhea, vomiting, impaired lung function, genotoxicity, incremental lifetime cancer risk, and blood and bone diseases are the main health endpoint of exposure to heavy metal (Kumar et al. 2016; Maragkidou et al. 2016; Kim et al. 2013; Alawi and Azeez 2016; Balcıoğlu 2016; Agency 2012; Avagyan and Westerholm 2017; Boström et al. 2002; Chen and Liao 2006; Goudarzi et al. 2017; Tsai et al. 2001; Tseng et al. 2014; Dor et al. 2000; Ferguson et al. 2017; Li et al. 2017a; Li et al. 2017b; Pruneda-Álvarez et al. 2016b; Guerreiro et al. 2016; Hu et al. 2007; Watanabe et al. 2009; Pruneda-Álvarez et al. 2016a; Dargahi et al. 2016; Zheng et al. 2013). Eating food containing milk, vegetable, and meat, drinking water, soil, dietary sources, coke-oven, iron-foundry, ingestion, inhalation, dermal contact, breathing exhaust fumes, and absorption routes are the most ways HM enter to the human body (Rudel and Perovich 2009; Chetwittayachan et al. 2002; Ali et al. 2016; Oliveira et al. 2016; Kim et al. 2013; Abdel-Shafy and Mansour 2016; Hasanati et al. 2011; Hu et al. 2017; Li et al. 2016; Liu et al. 2015; Naksen et al. 2017; Pruneda-Álvarez et al. 2016a; Ramesh et al. 2014; Rastegari Mehr et al. 2016; Özcan et al. 2012; Rahman et al. 2014; Salama and Radwan 2005; Saracoglu et al. 2004; Zhu et al. 2011; Darus et al. 2012; Lee et al. 2007). Based on the report of international organization, Ahvaz is one of the most polluted metropolitans in Iran and in the world and that this issue can have adverse effects on residents (Yari et al. 2016; Khaefi et al. 2016; Davar et al. 2014; Geravandi et al. 2015).

Duan and Tan studied situation, sources, and control policies of atmospheric heavy metals in China (Duan and Tan 2013). In 2002, Voutsa and Samara studied the labile and bioaccessible fractions of estimated heavy metals in the airborne particulate matter from urban and industrial areas in the Greater Thessaloniki area, northern Greece (Voutsa and Samara 2002).

The objective of this study was to estimate the characteristics and health risks of atmospheric PM_{10}-bound heavy metal (chromium (Cr), nickel (Ni), zinc (Zn), and lead (Pb)) levels in outdoor air in Ahvaz (located in southwest of Iran), during the year 2016.

Materials and methods

Methods

In this cross-sectional study, we used an active sampling system for measuring the amount of heavy metal in three main areas (S1: industrial, S2: high-traffic, and S3: residential areas) at southwest of Iran during the autumn and winter seasons of 2016.

Sampling

PM_{10}-bound heavy metal samples were used for high-volume air samplers (Tisch Environmental Inc., USA Company; 6070 model) equipped with quartz fiber filters (8 in. × 10 in. quartz filter paper and air flow rate 6.4 s/100 ml/in.^{2}) (Fig. 1). Particle-bound HM concentrations were sampled from industrial, high-traffic, and residential areas in Ahvaz region from autumn and winter seasons of 2016. Air sampling was done at the same time the day before and time duration was 24 h.

Standard preparation and analysis

The sampler collected by high volume (heavy metal air samples) was operated with a flow rate of 36–60 ft^3/min during a 24-h sampling period. Samples are gathered with quartz fiber filter sampling. Samples were transferred to laboratory and placed in desiccators for 48 h, sieved with a 63-μL polystyrene sieve, and finally dried using an oven at 105 °C for 24 h. 0.2 g of dried samples was weighed and transferred to a polypropylene test tube. Eight milliliters of HNO_3 (65%) and 2 mL of HF (48%) were added into lined digestion vessels. Samples were exposed to digestion with used to three-stage microwave. Then for 60 min at 140 °C, the vessels were heated and 1 mL of $HClO_4$ was added followed by heating at 160 and 180 °C for 60 and 45 min, respectively (Yang et al. 2015). The obtained solution was filtered through a Whatman-42 filter paper. The resultant solution was then diluted to 25 mL with distilled water and stored in a clean, sterile, and plastic bottle at 4 °C until further analyses. The digested samples were analyzed for target metals by inductively coupled plasma optical emission spectroscopy (a SPECTRO ICP-OES model, Spectra arcos (Germany)).

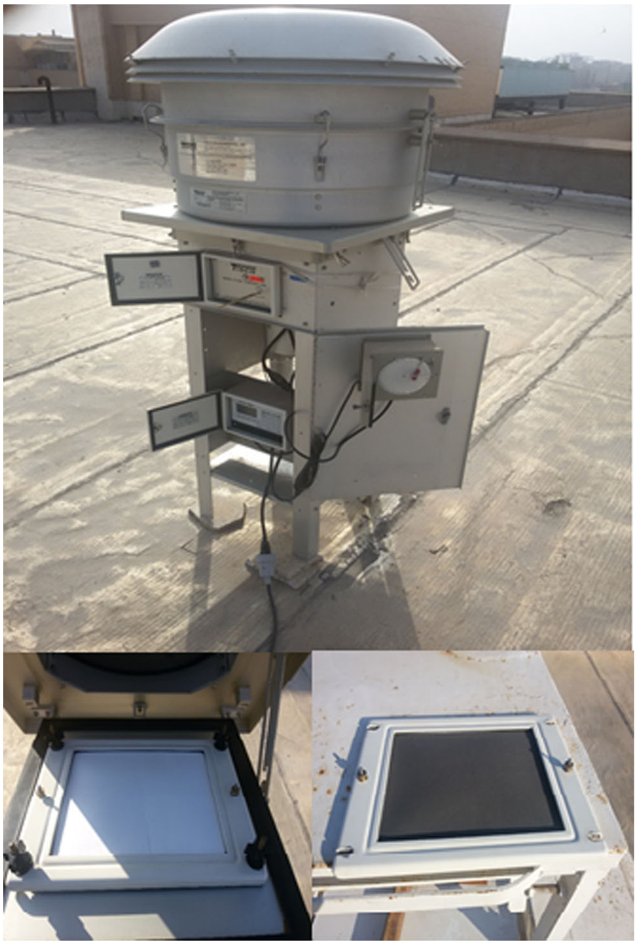

Fig. 1 Schematic of the sampling use in this study

Method validation procedure

Detection limits for heavy metal (Ni, Cr, Zn, and Pb) were 0.010, 0.010, 0.010, and 0.005, respectively (Meza-Figueroa et al. 2007). Blank concentrations of the examined elements (in ng cm^{-2} of the filter) obtained with the three extraction agents ranged between 16 and 17 for Ni, 2.6 and 8.3 for Pb, and 190 and 220 for Zn (Voutsa and Samara 2002). For each HM, the analytical correlation coefficients (R^2) for HM (Ni, Cr, Zn, and Pb) data obtained by instrumental measurements were > 91%. Also, three matrix spikes were 100, 500, and 2000 μg/L. The average Ni, Cr, Zn, and Pb recovery efficiency were in the range of (88–93%), (63–120%), (92–97%), and (93–103%). Limit of quantitation (LOQ) (μg/L) and limit of detection (LQD) **(**$\mu g/m^3$**)** of Ni, Cr, Zn, and Pb were calculated ((1 and 0.3), (1 and 0.3), (1 and 0.3), and (2.2 and 0.7), respectively).

Meteorology data

Concentration of air pollutant, daily temperature atmospheric pressure, relative humidity, and wind speed used in this study were collected by Ahvaz Environmental Protection Agency (AEPA).

Description of study area

Ahvaz, a typical city of heavy reliance on petroleum and diesel as a source of heat and power, is located in the southwest of Iran with a population of approximately 1.2 million. The urban land areas of Ahvaz are about 528 km^2 and Ahvaz is one of the metropolitans in Iran (Goudarzi et al. 2016; Goudarzi et al. 2015; Neisi et al. 2016; Geravandi et al. 2015; Nashibi et al. 2017). The detailed location of the three sampling sites is presented in Fig. 2.

Health risk assessment of heavy metal exposure

Health risk assessment of heavy metal exposure for adult (inhalation) was calculated using the following equation (Zheng et al. 2010).

$$D_{\mathrm{inh}} = C \times \frac{InhR \times EF \times ED}{PEF \times BW \times AT} \qquad (1)$$

where D_{inh} is daily intake through inhalation (mg/kg-day); C is the concentration of metal (mg/kg); EF is exposure frequency (= in this study 365 day/year); ED is exposure duration (= 25 years for adult in this study); PEF is particle emission factor (= in this study 1.36×10^9 m^3/kg); BW is body weight (kg) (= 50–70 kg in this study); AT is averaging time (= in this study 70 years or 25,550 day), and InhR is inhalation rate (= 25 m^3/day in this study) (Konz et al. 1989; Brochu et al. 2014).

After calculating dose contacted of HM (D), hazard index (HI) method and cancer risk method were used to assess the health risk due to human exposure to heavy metals in citizenship. Then, we used a Monte Carlo simulation for calculating hazard quotient (HQ). Monte Carlo analysis enables probabilistic approximations based on stochastic outcomes. HQ is the ratio of exposure to a certain substance of concern to its corresponding reference dose (RfD) (Lakind and Naiman 2008; Kong et al. 2011).

$$HQ = \frac{D}{RfD} \qquad (2)$$

where D is the dose contacted of HM (mg/kg-day) and RfD the reference dose for this chemical compound (= in this study $Pb_{\text{non-carcinogen}}$ (3.52E-03); $Ni_{\text{non-carcinogen}}$ (20.6E-02); Zn (3.00E-01), and $Cr_{\text{non-carcinogen}}$ (2.86E-05) $\mu g\ g^{-1}\ day^{-1}$) (Kong et al. 2011; Zheng et al. 2010). If D is lower than the RfD (HQ < 1), it is likely that there will be an adverse effect, whereas if the D is higher than the RfD (HQ > 1), it is likely that the factor in question will induce a morbid response

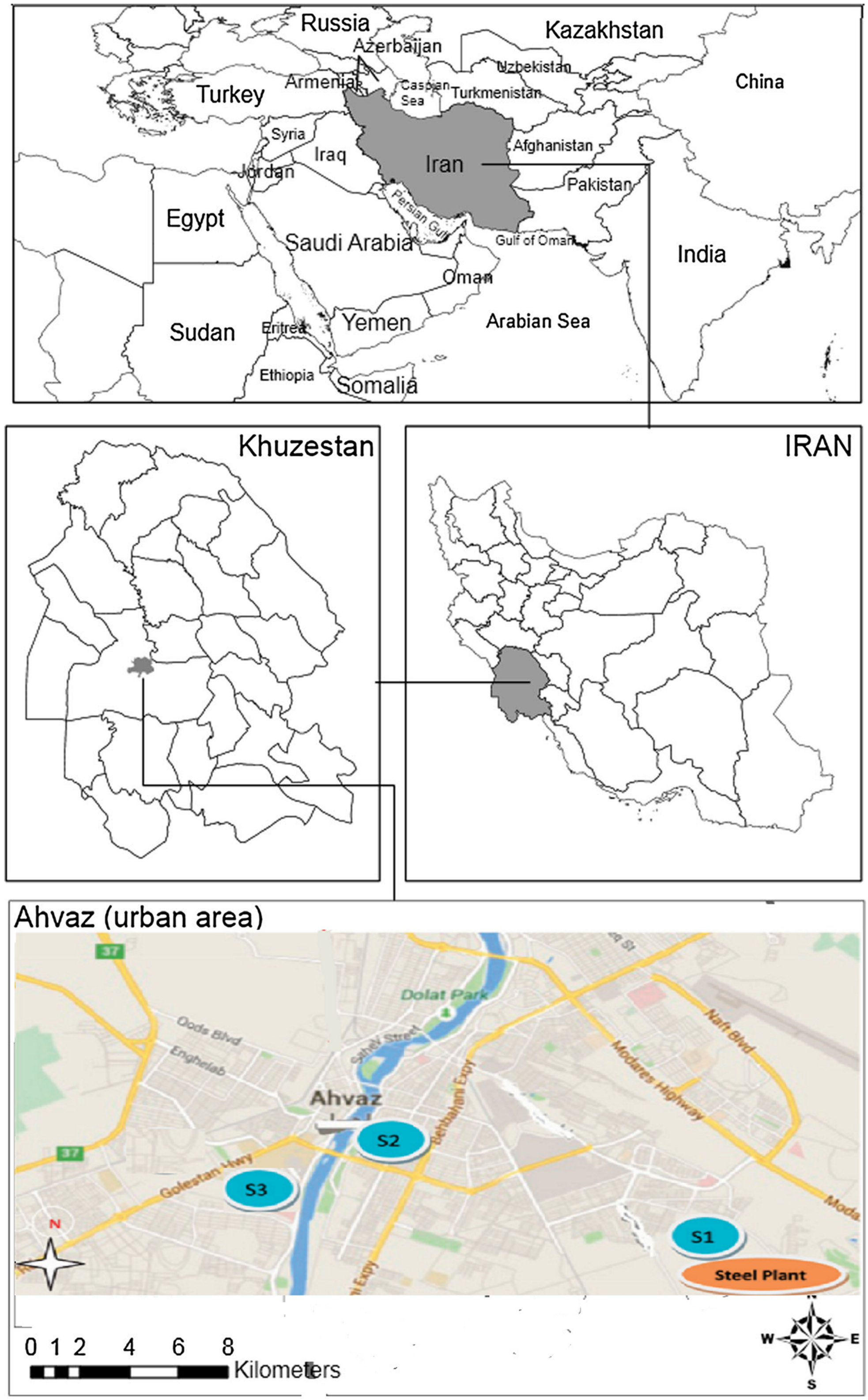

Fig. 2 Locations of air samples from Ahvaz (S1: industrial, S2: high-traffic, and S3: residential areas)

(Pruneda-Álvarez et al. 2016a). The estimation of cancer risks was calculated according to Eq. (3):

$$Carcinogenic\text{–}Risk = D \times SLF \tag{3}$$

where slop factors are 8.40E-01, 4.2E + 01, and 4.2E-02 (mg kg^{-1} day^{-1}) for Ni, Cr, and Pb, respectively. The tolerable risk for regulatory purposes was in the range 10^{-6}–10^{-4} (Ferreira-Baptista and De Miguel 2005). Table 3

Table 1 Heavy metal concentrations (μg m^{-3}) during the autumn and winter seasons of 2016

	Autumn season		Winter season	
Atmospheric PM_{10}-bound	Mean	SD	Mean	SD
Pb	0.363	± 0.0313	0.4698	± 0.0384
Ni	0.747	± 0.346	0.9279	± 0.449
Cr	1.067	± 0.483	1.3086	± 0.512
Zn	111.36	± 24.528	157.5	± 38.89

shows the reference doses of heavy metals for inhalation exposure.

Results

This study was conducted in three main areas at southwest of Iran during the autumn and winter seasons of 2016.

Based on the result in Table 1, the ranged level of four HM were from 0.362 to 157.5 μg m^{-3} (average 39.65 and 28.49 μg m^{-3} in autumn and winter seasons, respectively). Also in three separate regions in Ahvaz, Zn exhibited highest concentrations, which means concentration was 134.43 μg m^{-3}, followed by Cr (1.187 μg m^{-3}), Ni (0.837 μg m^{-3}), and Pb (0.416 μg m^{-3}) during 2016.

Average concentration of metal in industrial, high-traffic, and residential areas during autumn and winter seasons is shown in Table 2. Based on the result of this study, industrial and residential areas had the highest and the lowest heavy metal concentrations during the winter and autumn seasons of 2016, respectively.

Health risk assessment of heavy metal exposure

Based on result among the four trace elements, Zn has 151 μg/m^3 the highest average concentration and Pb has 0.4695 μg/m^3 the lowest average concentration in three regions studied (Table 3). Different amounts of dose contacted of HM (ng/m^3) (average cold and warm seasons), hazard index (HI), hazard quotient (HQ), and reference dose (RfD) in adults (inhalation) that were calculated based on level of heavy metal in industrial, high-traffic, and residential areas are presented in Table 3.

Discussion

In this study, we assess the health risks of atmospheric PM_{10}-bound heavy metals among citizens living in three separate regions in Ahvaz, southwest Iran.

According to the result, people participating in the study were exposed to levels of HM in residential, high-traffic, and industrial areas, which were higher than WHO air quality guidelines and region standard values (Organization WH 2010; Abdel-Shafy and Mansour 2016; Harrison et al. 2009; Lioy et al. 1988; Neisi et al. 2016; Tchounwou et al. 2012; Zhang et al. 2014). Paying attention to decreasing level of these pollutants is very important for the decrease of health effect exposure to heavy metal (Cr, Ni, Pb, and Zn) on outdoor air.

According to the result of our study, concentration of heavy metal was 10–12 times higher than the standard amount. Result of our study showed that during the autumn and winter seasons, industrial area has the most concentration of HM among other areas. Also, based on the results of this study, the lowest concentrations of heavy metal were seen in residential areas.

The heavy industries such as oil, gas, petrochemical, steel and piping, traffic emission, and dust were the most reasons for the high-level concentrations of HM on outdoor air in this study. Based on the result of our study, the PM_{10}-bound heavy metals were strongly, positively correlated with location of living especially in industry region, as has been previously shown in an HR study of heavy metal levels among the Guatemalan women and children of Ahvaz (Weinstein et al. 2017; Neisi et al. 2016).

In 2013, Duan and Tan, in China, assessed the sources and control policies of atmospheric heavy metals (Duan and Tan 2013). They showed that lead (Pb), vanadium (V), nickel (Ni), chromium (Cr), cadmium (Cd), and zinc (Zn) were the most heavy metals in China (Duan and Tan 2013) that is similar with the result of our study. Pongpiachan and Iijima in 2016 in Bangkok (Thailand) associated heavy metals in the ambient air PM_{10} in urban sites. They reported the maximum concentrations that were obtained from this study (Pongpiachan and Iijima 2016) but the result of a similar study by Wang et al. showed differently from those of Baoshan (Wang et al. 2013). In another study by Voutsa and Samara, they studied the labile and bioaccessible fractions of the estimated heavy metals in the airborne particulate matter from urban and industrial areas (Voutsa and Samara 2002). Based on their result, the highest

Table 2 Heavy metal concentrations in residential, high traffic and industrial areas during the autumn and winter seasons of 2016

Areas	Average (μg m^{-3})	Autumn (μg m^{-3})	Winter (μg m^{-3})
Industrial (extremely polluted)	37.04 ± 4.89	31.482	42.601
High-traffic	34.29 ± 4.37	30.892	37.70
Residential	31.64 ± 3.65	23.212	40.078

Table 3 Hazard risk and quotient for each element and exposure inhalation

Areas	Items	Zn	$Ni_{non\text{-}cancer}$	$Pb_{non\text{-}cancer}$	$Cr_{non\text{-}cancer}$
Residential	HQ_{inh}	2.86E-08	1.04E-08	1.44E-05	8.22E-06
	HI_{inh}	3.14E-03	8.45E-04	1.60E-02	9.24E-03
High-traffic	HQ_{inh}	3.18E-08	3.13E-07	4.52E-06	1.00E-05
	HI_{inh}	3.66E-04	1.75E-03	5.33E-02	1.62E-02
Industrial	HQ_{inh}	3.78E-07	9.01E-09	3.04E-07	1.20E-04
	HI_{inh}	4.22E-03	1.64E-03	3.22E-02	1.72E-02

concentrations of heavy metals in the airborne particulate matter were determined which were Cd, Cu, Ni, Pb, and Zn (Voutsa and Samara 2002) that is slightly different with our study.

Table 3 shows that the health effect of all heavy metals decreased according to the following order: $Pb_{non\text{-}carcinogenic}$ > $Cr_{non\text{-}carcinogen}$ > Zn > $Ni_{non\text{-}carcinogenic}$; $Pb_{non\text{-}carcinogenic}$ > $Cr_{non\text{-}carcinogen}$ > $Ni_{non\text{-}carcinogenic}$ > Zn; $Pb_{non\text{-}carcinogenic}$ > $Cr_{non\text{-}carcinogen}$ Zn >> $Ni_{non\text{-}carcinogenic}$, for industrial, high-traffic, and residential, respectively. Based on accounted by HQs, the most risky elements in terms of non-carcinogenic risk were Pb and Cr (Table 3). Also, Zheng et al. demonstrate that Pb was the most important risky element between another elements (Zheng et al. 2010) that is similar with our study. According to the result of this study, the level of Pb was lower than 1 (5.33E-02). Also, it should be noted that exposure to Pb at high doses can cause developmental and neurological disorders (Ferreira-Baptista and De Miguel 2005). Based on the result of this study, high-traffic area has the highest concentration of Pb in which it can cause health effects for the inhabitants. The result of our study showed that the total average carcinogenic risk from Pb, Cr, and Ni in three separate regions in Ahvaz, southwest Iran, was less than 1×10^{-4} and acceptable by USEPA because the integrated risks of those elements were also within the range of 1E-06 to 1E-04.

The comparison of the present study with the present existing studies and guidelines shows that the city of Ahvaz due to its neighborhood and affiliation with the oil, gas, petrochemical, and steel and piping industries has a high concentration of air pollutants, especially HM, which can cause health problems.

Limitations and strengths

Low time sample in only during two seasons was the most limitation in this study. Observed trends may not be representative of a wider population because this study had a small sample size. It should be noted that future larger studies are required to verify the observed trends, to perform sub-group analyses and further time period. Also, we can prevent or reduce the exposed heavy metal in the ambient air by medication protocol and education.

Conclusion

This cross-sectional study showed the effect of various ambient exposures to heavy metal between citizens of Golestan, Naderi, and Bahonar areas during the year 2016. Exposure to HM from industry region is the most risk factor for deleterious health outcomes around the metropolitans. Emission and heavy metal product from industries and vehicles increase health effects between citizens in industry cities; hence, paying attention to decrease emission air pollutant is very vital.

The result of this study showed that average amounts of heavy metal were 10–12 times higher than the standard value. In addition, it appears reasonable to the high level of heavy metal observed in Ahvaz, since Iran was associated with industries petroleum and gas, demographic, and climate characteristics in this city. One of the most important pollutants in the air of industry cities is heavy metal nowadays because of industrialization, high consumption of fossil fuels, and metrological phenomena such as dust storm which causes increasing concentration of these pollutants. Also, on the basis of the results of the sensitivity analysis, research should be directed to those parameters that, if better characterized, could most effectively reduce variability in the results. Finally, careful monitoring, application of modern automobiles, develop green area, and controlling the emission of heavy metal will have important roles in decreasing the amount of these dangerous pollutants.

Funding/support This work was a part of a funded PhD thesis of Mohammad Javad Mohammadi, a student of Ahvaz Jundishapur University of Medical Sciences (AJUMS), and the financial support of this study (U-95094) was provided by AJUMS.

Compliance with ethical standards

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

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