Toxin Reviews

ISSN: 1556-9543 (Print) 1556-9551 (Online) Journal homepage: http://www.tandfonline.com/loi/itxr20

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To cite this article: Abdolkazem Neisi, Gholamreza Goudarzi, Ali Akbar Babaei, Mehdi Vosoughi, Hassan Hashemzadeh, Abolfazl Naimabadi, Mohammad Javad Mohammadi & Bayram Hashemzadeh (2016) Study of heavy metal levels in indoor dust and their health risk assessment in children of Ahvaz city, Iran, Toxin Reviews, 35:1-2, 16-23, DOI: 10.1080/15569543.2016.1181656

To link to this article: http://dx.doi.org/10.1080/15569543.2016.1181656

http://informahealthcare.com/txr
ISSN: 1556-9543 (print), 1556-9551 (electronic)

Toxin Reviews

Toxin Rev, 2016; 35(1–2): 16–23

DOI: 10.1080/15569543.2016.1181656

RESEARCH ARTICLE

Study of heavy metal levels in indoor dust and their health risk assessment in children of Ahvaz city, Iran

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Abstract

The concentration of heavy metals in household dust and their health risks on children living in different areas of Ahvaz city was investigated during November 2013 to October 2014 in Iran. Totally, 108 dust samples were taken from their houses in three different areas including S_1 (industrial), S_2 (heavy traffic) and S_3 (residential zone far away from industrial and traffic emission sources). The samples were analyzed for eight selected heavy metals (Cr, Ni, Cu, Mn, Pb, Zn, Co and Cd) using an inductively coupled plasma optical emission spectroscopy (ICP-OES, Spectro Arcos Model, Germany). Exposure and risk assessment of these metals were estimated using USEPA's exposure parameters. Results showed that the mean values of all heavy metals in tempered months were significantly higher than the other months ($p < 0.05$). Cancer risk and non-carcinogenic risk (hazard index) of Ni, Cr, Cd and Pb from indoor dust exposure were estimated for children via three exposure pathways (ingestion, inhalation and dermal contact). The non-cancer risks to children in all samples were lower than acceptable level of 1, while the potential cancer risks from Ni intake in S_1 and S_2 were 1.57E − 06 and 1.19E − 06, respectively, and for Cr in S_1 and S_2, it was 1.43E − 06 and 1.15E − 06, respectively, which these values were slightly higher than the acceptable level (1×10^{-6}). In conclusion, household dust of Ahvaz city would probably have a significant potential to cause cancer in most exposed children.

Keywords

Heavy metals, health risk, indoor dust, children, Ahvaz

History

Received 11 February 2016
Revised 18 April 2016
Accepted 19 April 2016
Published online 16 May 2016

Introduction

Indoor dust is a heterogeneous mixture of gases, vapors and particles that originate from indoor and outdoor sources (Darus et al., 2012; Morawska 2004). It has been estimated that about 85% of indoor dust comes from outside (Kurt-Karakus, 2012), such as crustal materials, road dusts, construction activities, fossil fuel burning, industrial emissions and vehicular traffic (Yang et al., 2015b). Furthermore, house activities, such as renovation or heating, have an important role in the entry of pollutants into indoors (Morawska 2004). Heavy metals have long been recognized as serious pollutants in environment due to their toxicity, persistence and non-degradability (Kamkar et al., 2010; Yang et al., 2015a). Previous studies reported that the heavy metals such as Pb and Cd have carcinogenic potential in humans (Kamkar et al., 2010). Moreover, they suspected to have some adverse effects on human health such as cardiovascular, nervous system, blood and bone diseases (Dargahi et al., 2016; Zheng et al., 2013). Some metals such as Zn and Cu are essential for human health, but excessive dietary intake of them may be responsible for adverse effects in both humans and animals (Brewer, 2010). Metals of indoor dust can enter the human body via inhalation, ingestion and dermal contact absorption routes, and then can accumulate (Darus et al., 2012). The home dust ingestion is one of the most common routes of exposure to heavy metals for general population (Hogervorst et al., 2007). Babies and toddlers are at especially high risk compared to adults (Chattopadhyay et al., 2003). Since the babies spend most of their time at houses, they are exposed to soils or indoor dusts such as dusts caused by contact with floors, engage in greater hand-to-mouth activity, toys or the consumption of food contaminated by hands (Darus et al., 2012; Goudarzi et al., 2014).

Ahvaz city with an area of 220 km^2 is the second largest city in terms of land area in Iran, which has more than one million people. It is the capital of the Khuzestan province with petrochemical, metal and non-metal industries, power

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plants, heavy traffic and with hot and humid weather in most seasons of the year. In recent years, dust storms from southwestern of Iran have been added to this city as an anthropogenic source of air pollution (Goudarzi et al., 2014). Ahvaz city is one of the most polluted cities in the world, which polluted air can enter homes and cause adverse effects on residential health. There is very little information available about heavy metal concentrations and their health risks on residential buildings close to the pollution sources such as industrial activities and roads with heavy traffic compared to residential buildings away from pollutant sources. There are no studies examining the concentration of heavy metals and their health effects of indoor dust on children.

Therefore, this is the first study reporting the concentration of eight kinds of heavy metals such as copper (Cu), lead (Pb), cadmium (Cd), zinc (Zn), chromium (Cr), manganese (Mn), cobalt (Co) and nickel (Ni) of indoor dust from different functional areas in Ahvaz, Iran. The effect of non-carcinogenic health risk associated with exposure to heavy metals and potential cancer of Ni, Cr, Pb and Cd through three different exposure pathways on children were studied.

Materials and methods

Study areas

Ahvaz is a city in the south of Iran by latitude 31′32, longitude 48′68, which has very hot weather. The monthly average low and high temperature in this city varies from 7.2–17.5 °C in June to 28.6–46.3 °C in July. It should be noted that the highest temperature reaches 52 °C in September (Heidari-Farsani et al., 2014).

Sampling sites for household dust were selected according to the industrial activity and road traffic. This study focused on heavy metals levels in household dust from three zones of Ahvaz city: S_1, Bahonar zone (nearby the steel plant); S_2, Naderi zone (heavy traffics); S_3, Moinzadeh zone (low traffic and far from industrial areas) (Figure 1).

Sample collection

One hundred and eight samples of indoor dust were taken from reception hall of studied houses where children spend most of their time. The concentrations of heavy metals of dust samples and their health risks were studied during November 2013 and October 2014. In Ahvaz city, the warm season occurs (WM) from April to September, while temperate months (TM) are October, February and March. Moreover, cold months (CM) include November, December and January. Data were collected using a questionnaires containing dwelling type and aging, number of occupants, duration of occupancy, building painting, number, type and area of windows, air conditioning and kitchen facilities, type of heating and cooling systems, and smoking, which affect the concentration of heavy metals in indoor air.

Figure 1. Study areas and sampling locations. S1, nearby the steel plant area (Bahonar); S2, heavy traffics area (Naderi); S3, low traffic and far from industrial areas (Moinzadeh).

Table 1 shows the characteristics of studied houses. Indoor dust samples were collected from floor surfaces of indoor house by sweeping. Samples were collected in first week of each month during a year from selected houses in each area. Dust samples were transferred to laboratory of School of Public Health, Ahvaz Jundishapur University of Medical sciences and placed in desiccators for 48 h, sieved with a 63-μm polystyrene sieve, and finally dried using an oven at 105 °C for 24 h.

Sample preparation and analysis

An amount 0.2 g of dried samples was weighed (0.001 mg precision, Sartious Micro, Japan) and transferred to a polypropylene test tube. Eight milliliters of nitric acid (65%) and 2 mL of hydrofluoric acid (48%) were added into lined digestion vessels. The samples were exposed to microwave radiation using a three-stage microwave digestion procedure. In the first stage, the vessels were heated at 140 °C for 60 min, and then 1 mL of $HClO_4$ was added followed by heating at 160 and 180 °C for 60 and 45 min, respectively (Yang et al., 2015b). After cooling, the samples were filtered through 0.45 μm 11-mm Whathman filter paper. Next, the filtered solutions were diluted with distilled water in a volumetric flask (50 mL) and stored in plastic falcon tubes in refrigerator before analysis. Metal analyses (Zn, Mn, Cd, Cr, Co, Cu, Ni and Pb) were performed using an inductively coupled plasma optical emission spectroscopy (ICP-OES) (Spectro Arcos Model, Germany) under the optimum operational conditions. Detection limits for Cd, Cr, Cu, Ni, Pb, Zn, Co and Mn were 0.005, 0.010, 0.010, 0.010, 0.005, 0.010, 0.005 and 0.010, respectively (Meza-Figueroa et al., 2007).

Health risk assessment method

The potential health risk due to human exposure to heavy metals from indoor dust through inhalation (via mouth and nose), dermal contact and ingestion pathways was calculated according to the following (Equations (1)–(3)) (USEPA, 1996; Zheng et al., 2010b) (Table 2):

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

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

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

All variables are described in Table 3.

Hazard index (HI) method and cancer risk method were used to assess the health risk due to human exposure to heavy metals from indoor dust in Ahvaz city. Before calculating HI, a hazard quotient (HQ) based on non-cancer toxic risk was calculated for individual metals according to the following equation (Kong et al., 2011):

$$\text{Hazard quotient (HQ)} = \frac{D}{\text{RfD}}. \tag{4}$$

In order to assess overall potential of non-carcinogenic effects posed by more than one metal, the calculated values of HQ for each metal were summed, which expressed the hazard index (Equation (5)) (Wcisło et al., 2002).

$$\text{HI} = \sum\nolimits_1^i \text{HQ}, \tag{5}$$

where i shows each contaminant.

To interpret the results of HQ and HI, values >1 indicate that there is a chance for non-carcinogenic effects, and hazard risk values of ≤ 1 indicate that there is no significant risk for non-carcinogenic health effects (Wcisło et al., 2002). The estimation of cancer risks was calculated according to Equation (6) (Kong et al., 2011):

$$\text{Carcinogenic Risk} = D \times \text{SLF}. \tag{6}$$

Slop factors for Pb, Cd, Cr and Ni were assumed to be 4.2E − 02, 6.30E + 00, 4.2E + 01 and 8.40E − 01 ($\text{mg kg}^{-1}\,\text{day}^{-1}$), respectively. The tolerable risk for regulatory purposes was in the range 10^{-6} (1 in 1,000,000)–10^{-4} (1 in 10,000) (Ferreira-Baptista & De Miguel, 2005). Reference doses of heavy metals for three exposure pathways are shown in Table 3.

Statistical analysis

The obtained data were analyzed using analysis of variance. The significant difference between the mean concentrations of metals in different area studies was investigated using the Duncan's multiple range test with SPSS software (SPSS version 16; SPSS Inc., Chicago, IL).

Results and discussion

Concentrations of heavy metals in house dust in cold and warm months

The concentrations of heavy metals (Cd, Co, Cr, Cu, Mn, Zn, Pb and Ni) from indoor dust in Ahvaz are summarized in Table 4. Among the eight kinds of heavy metals, Zn showed the highest average concentration, which were 696,

Table 1. Characteristics of sampling locations (houses) in Ahvaz (dry weight, μg/g dw).

Site	Area	Number of houses	Size (m^2)	Floor	No. of occupants	Smoking allowed	Type of fuel	Street	Painting of building	Area of windows (m^2)	Cooling systems
S1	Industrial areas	3	90–110	Second	3–4	No	LPG[a]	Paved	No	3.5–4	Air conditioning
S_2	Heavy traffics	3	90–110	Second	3–4	No	LPG	Paved	No	3.5–4	Air conditioning
S_3	Low traffic and far from industrial areas	3	90–110	Second	3–4	No	LPG	Paved	No	3.5–4	Air conditioning

[a] Liquid petroleum gas.

Table 2. Variables definition in Equations (1)–(6).

Variable	Definition	Scale	References	Variable	Definition	Scale	References
C	Concentration of metal	mg/kg	USEPA (1997)	D_{ing}	Daily dose ingestion	mg/kg day	USEPA (1997)
D	Dose contacted	mg/kg day	USEPA (1997)	D_{inh}	Daily intake through inhalation	mg/kg day	USEPA (1997)
EF	Exposure frequency	365 days/year	Shi et al. (2011)	D_{dermal}	Daily intake through absorption	mg/kg day	USEPA (1997)
AT	Averaging time	70 × 365 days	Shi et al. (2011)	InhR	Inhalation rate	7.6 m^3/day	USEPA (1997)
ED	Exposure duration	6 years	Shi et al. (2011)	SA	Exposed skin area	2800 cm^2	Zheng et al. (2010b)
SL	skin adherence factor	0.07 mg/cm^2.h	Zheng et al. (2010a)	BW	Body weight	15 kg	Kurt-Karakus (2012)
ABS	Dermal absorption factor	0.001	Kurt-Karakus (2012)	PEF	Particle emission factor	1.36×10^9 m^3/kg	Yang et al. (2015a)
RfD	Reference doses	–	Kurt-Karakus (2012)	SLF	Slope factor	mg/kg day	Ferreira-Baptista & De Miguel (2005)

435 and 216 μg/g in S_1, S_2 and S_3, respectively. Zn concentration was lower in S_3 site than other two studied sites ($p < 0.05$). Relative low concentration of Zn in S_3 area might be attributed to being located away from industrial areas and heavy traffic (Latif et al., 2014). There was a statistical significant difference in metal concentration between S_3 and other sampling sites (S1 and S_2) ($p < 0.05$), while there was no significant difference in metal concentration between two studied seasons ($p = 0.167$). In S_1, Zn was followed by Cu, Mn, Pb, Cr, Ni, Co and Cd with mean concentration of 115, 93, 63, 15, 11, 9.5and 0.5 μg/g, respectively. In S_2, Zn exhibited highest concentrations, which its mean concentration was 435 μg/g, followed by Cu (99 μg/g), Mn (94 μg/g), Pb (88 μg/g), Cr (13 μg/g), Ni (9 μg/g), Co (8.3 μg/g) and Cd (0.4 μg/g). Mean Pb concentration in S_2 was higher than that of other areas, which this can be attributed to the proximity of studied houses to roads with heavy traffic. Although the use of leaded fuels has been forbidden for many years in Iran, there are still their residues as a main source of lead for some urban areas (Latif et al., 2014; Najafi et al., 2014). Therefore, the high concentration of lead in dust samples in our result may be originated from the lead residues (Kamani et al., 2015). In S_3, heavy metal levels increased according to the following priority: $Zn > Mn \sim Cu > Pb > Cr > Ni > Co > Cd$. Results showed that the lowest concentration of heavy metals obtained at area with low traffic and away from industrial areas. The concentrations of heavy metals in this study were compared with those reported in literature from some other cities in the world (Table 4).

The concentration of heavy metals in the indoor dust was less than in indoor dust samples those reported for previous studies in different regions of the world. In this study, the factors that can effect on the concentration of indoor heavy metals were removed. This confounding factors are building painting, smoking, professional people, furnishing and so on, which were not considered in previous studies (e.g. paints and smoking are the most important sources of Pb and Cd in household dust) (Chattopadhyay et al., 2003; Kurt-Karakus, 2012; Latif et al., 2014). Results of this study compared with Kurt-Karakus et al. study indicated that the concentrations of Cd and Cu in indoor dust were high in building painting (Kurt-Karakus, 2012). Also, Böhlandt et al. have measured the concentrations of cadmium, cerium and lanthanum in indoor air. They reported that Cd concentration in smokers' households was higher than those found in non-smoker's households (Böhlandt et al., 2012).

Concentrations of heavy metals in indoor dust in temperate months

To investigate the seasonal variation of heavy metals from indoor dust, a year was divided into three periods. Arithmetic mean with standard deviation of metals levels in indoor environment in three different sampling periods is presented in Table 5.

As shown in Table 5, total levels of heavy metals in the temperate months were in the range 0.8–890 μg/g, 0.65–701 μg/g and 0.42–386 μg/g in S_1, S_2 and S_3,

Table 3. Reference doses of heavy metals for three exposure routes (Kong et al., 2011; Zheng et al., 2010b).

Items	$Pb_{non\text{-}carcinogen}$	$Cd_{non\text{-}carcinogen}$	Zn	Cu	$Cr_{non\text{-}carcinogen}$	Co	$Ni_{non\text{-}carcinogen}$	Mn
RfD_{Oral}	3.50E – 03	1.00E – 03	3.00E – 01	4.00E – 02	3.00E – 03	2.00E – 02	2.00E – 02	4.60E – 02
RfD_{Dermal}	5.25E – 04	1.00E – 05	6.00E – 02	1.20E – 02	6.00E – 05	1.60E – 02	5.40E – 04	1.84E – 03
RfD_{Inhal}	3.52E – 03	1.00E – 03	3.00E – 01	4.02E – 02	2.86E – 05	5.71E – 06	2.06E – 02	1.43E – 05

Table 4. Ahvaz and global distribution of heavy metals in indoor dust (μg/g).

Location	Pb	Cd	Zn	Cu	Cr	Co	Ni	Mn	N	Reference
S_1^a	63	0.5	696	115	15	9.5	11	93	27	This study
S_2^a	88	0.4	435	99	13	8.3	9	94	27	This study
S_3^a	47	0.25	216	63	10	5.8	5	63	27	This study
S_1^b	84	0.8	890	159	26	11.5	20	139	9	This study
S_2^b	124	0.65	701	131	25	10	18	129	9	This study
S_3^b	39.6	0.42	386	72	20	6.1	10	82.6	9	This study
Plymouth (UK)	169	110	1.6	565	64	400	NA	46	7	Turner & Ip (2007)
Shah Alam, Malaysia	30.19	31.24	n.a.	148.71	16.88	n.a.	n.a.	9	9	Darus et al. (2012)
Ottawa, Canada	157	222	4.3	633	69	267	8.8	52	50	Rasmussen (2004)
Kwun Tong, China	806	308	39	2120	n.a.	283	n.a.	n.a.	34	Tong & Lam (2000)
Warsaw, Poland	109	124	n.a.	1070	90	n.a.	n.a.	30	27	Lisiewicz et al. (2000)
Sydney, Australia	93	76	1.6	372	65	48	n.a.	15	82	Chattopadhyay et al. (2003)
Istanbul, Turkey	156	28	0.8	832	55	136	5	263	31	Kurt-Karakus (2012)
Selangor, Malaysia	n.a.	850	190	430	n.a.	n.a.	n.a.	830	31	Latif et al. (2014)

[a] Average heavy metals levels in cold and warm months.

[b] Average heavy metals levels in temperate months.

respectively. As can be seen from Table 5, the levels of heavy metals in TM period were significantly ($p < 0.05$) higher than other two sampling period. In other words, dust metals were low in both cold and warm seasons. This could be attributed to the use of gas/electric heaters in cold weather and air conditioner in warm months by Ahwaz families. In recent years, energy prices have risen by implementing ''targeted subsidies program'' in Iran and this phenomenon encouraged citizens to save energy. In this regard, in order to minimize air exchange between outdoors and indoors, all gaps of windows and doors are closed by residents; therefore, the penetration of dust containing heavy metals from outdoor to indoor is reduced in cold seasons. Our finding is agreement with Darus et al.'s finding. Their results showed that in residential, commercial and industrial areas in seasons in which windows and doors are open for natural ventilation, the concentration of heavy metals in household dust was mainly high (Darus et al., 2012). Also, our results are in agreement with Pekey et al. findings. They showed that the concentration of elements in summer season was higher than those of winter (Pekey et al., 2010).

As presented in Figure 2, In October, the temperature of the outside air reduced below 25 °C, and the heavy metals concentration was high toward other warm and cold months. This condition was also observed in February and March months. This phenomenon can be attributed to the opening windows and doors for cooling and ventilation during these months (Darus et al., 2012; Zheng et al., 2013).

Figure 2 shows the average concentration of heavy metals in S_1, S_2 and S_3. The average concentration of Ni in industrial area (S_1) in cold months (13 μg/g) was higher than warm months (9 μg/g). However, this difference was not statistically *significant* ($p = 0.113$). As previously mentioned, S_1 area is an industrial area, which was close to Khuzestan steel plant. This industry plant uses gas and fuel oil for incineration in warm and cold months, respectively. Households use gas for cooking and heating. Therefore, the oil fuels in steel plant could increase Ni level in cold months (Filby & Branthaver, 1987). This metal is originated from other sources such as corrosion of cars, mechanical abrasion/erosion of metallic surfaces and heavy oil combustion (Okuda et al., 2007). In this study, since S_1 area was away from heavy traffic pollutions, this level of metal may be caused by iron production plant.

Health risk assessment of heavy metals exposure to household dusts

The three main pathways of exposure in households include oral ingestion, dermal contact and inhalation. The health risk of heavy metals to children was brought forward to give integrated information about heavy metal pollution in the Ahvaz city. Results of non-carcinogenic health risks from exposure to metals in indoor dust via different pathways (ingestion, dermal and inhalation) are shown in Table 6.

As shown in Table 5, the concentration of all heavy metals within indoor dust in temperate months was higher than those in both warm and cold months. Therefore, the results of temperate months were used to calculate HQ, HI and carcinogenic risk from indoor dust. Health effect of all heavy metals was decreased according to the following order: Pb non-carcinogenic > Cr non-carcinogen > Cu > Zn > Mn > Cd non-carcinogenic > Ni non-carcinogenic > Co; Pb non-carcinogenic > Cr non-carcinogen > Cu > Mn > Zn > Cd non-carcinogenic > Ni non-carcinogenic > Co; Pb non-carcinogenic > Cr non-carcinogen > Cu > Mn > Cd non-carcinogenic > Ni non-carcinogenic > Co > Zn for S_1, S_2 and

Table 5. Metal concentrations in different seasons and locations.

Element	Season	S1 Mean	S1 SD	S2 Mean	S2 SD	S3 Mean	S3 SD
Pb	WM	61	±7.1	86.7	±7.4	46	±6.3
	TM	84	±9.1	124	±11.3	39.6	±5.4
	CM	65	±8.3	89.3	±9	48.5	±7.5
Cd	WM	0.46	±0.1	0.43	±0.11	0.26	±0.08
	TM	0.8	±0.13	0.65	±0.12	0.42	±0.11
	CM	0.53	±0.11	0.38	±0.1	0.24	±0.7
Co	WM	9.2	±1.5	8.1	±1.7	5.6	±1.4
	TM	11.5	±2.1	10	±1.8	6.1	±1.5
	CM	9.7	±1.9	8.5	±2.1	5.9	±1.8
Zn	WM	675	±95	438	±74	213	±52
	TM	890	±115	701	±93	386	±48
	CM	716	±110	433	±78	219	±59
Ni	WM	9	±1.6	10	±1.9	4.6	±0.5
	TM	20	±2.1	18	±1.5	10	±1.1
	CM	13	±1.8	8.5	±1.7	5.3	±0.6
Mn	WM	97	±16	92	±18	59	±11
	TM	139	±27	129	±25	82.6	±17
	CM	90	±14.5	96	±14	67	±10.3
Cu	WM	113	±28	102	±26.2	65	±15
	TM	159	±31	131	±23	72	±16.4
	CM	117	±25.1	96	±21.3	61	±13
Cr	WM	16	±2.4	14	±2.1	9	±1.9
	TM	26	±3.1	25	±3.3	10	±1.8
	CM	14.5	±2.1	12	±1.8	11	±1.9

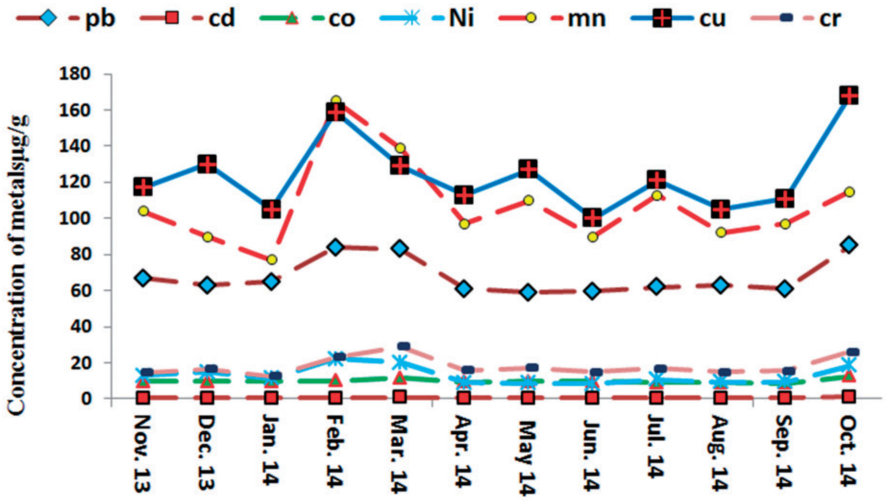

Figure 2. Monthly variation of heavy metals levels of indoor dust in Ahvaz City in November 2013 to October 2014 (12 months studied).

Table 6. Hazard quotient and risk for each element and exposure pathway in household dust.

Site	Items	Pb non-cancer	Cd non-cancer	Zn	Cu	Cr non-cancer	Co	Ni non-cancer	Mn
S1	HQ_{ing}	4.85E – 02	1.97E – 03	5.92E – 03	7.94E – 03	1.84E – 02	1.28E – 03	2.17E – 03	2.90E – 03
	HQ_{inh}	4.49E – 06	1.84E – 07	5.51E – 07	7.36E – 07	1.80E – 04	4.18E – 04	1.96E – 07	1.82E – 03
	HQ_{der}	1.06E – 03	6.44E – 04	9.67E – 05	8.65E – 05	3.01E – 03	5.24E – 06	2.63E – 04	4.97E – 04
	HI	4.95E – 02	2.62E – 03	6.02E – 03	8.03E – 03	2.16E – 02	1.71E – 03	2.43E – 03	5.22E – 03
S2	HQ_{ing}	7.10E – 02	1.68E – 03	4.54E – 03	6.46E – 03	1.78E – 02	1.08E – 03	1.97E – 03	2.82E – 03
	HQ_{inh}	6.58E – 06	1.56E – 07	4.23E – 07	5.99E – 07	1.73E – 04	3.54E – 04	1.78E – 07	1.77E – 03
	HQ_{der}	1.55E – 03	5.48E – 04	7.41E – 05	7.03E – 05	2.90E – 03	4.43E – 06	2.39E – 04	4.83E – 04
	HI	7.26E – 02	2.22E – 03	4.61E – 03	6.53E – 03	2.08E – 02	1.44E – 03	2.21E – 03	5.07E – 03
S3	HQ_{ing}	2.31E – 02	1.18E – 03	4.93E – 04	3.70E – 03	1.51E – 02	7.89E – 04	1.08E – 03	1.74E – 03
	HQ_{inh}	2.14E – 06	1.10E – 07	4.59E – 08	3.43E – 07	1.48E – 04	2.57E – 04	9.81E – 08	1.09E – 03
	HQ_{der}	5.03E – 04	3.87E – 04	8.05E – 06	4.03E – 05	2.47E – 03	3.22E – 06	1.31E – 04	2.98E – 04
	HI	2.36E – 02	1.57E – 03	5.01E – 04	3.74E – 03	1.77E – 02	1.05E – 03	1.22E – 03	3.12E – 03

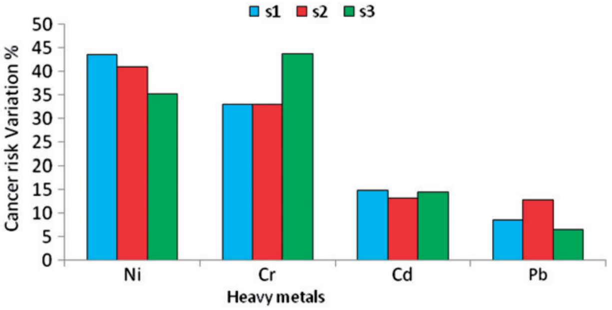

Figure 3. Cancer risk variation of indoor dust in three areas of Ahvaz City.

S_3, respectively. The results of non-carcinogenic effect showed that the ingestion of dust particles was the main exposure pathway to indoor dust for Pb, Cd, Zn, Ni, Mn, Co, Cd and Cu followed by dermal contact and inhalation, respectively, while the non-carcinogenic effect of Co and Mn was according to the following order: ingestion contact < inhalation contact < dermal contact. As shown in Table 6, Pb was found to be the most risky element in terms of non-carcinogenic risk, which it was accounted by HQs, and it was about 51%, 62.8% and 45% in S_1, S_2 and S_3, respectively. Our results were inconsistent with Zheng et al. findings. They showed that the street dust was decreased in the following order: Pb > Cd > Zn > Cu > Cr non-carcinogen that was implemented in Zn smelting district (Zheng et al., 2010a). It has been previously found that the health index for Pb was higher than 1, which has been implicated as a potential risk for children. The concentration of Pb in the present study was lower than 1 (7.26E − 02). Moreover, the HI for Pb was below safe limit. It should be noted that contact with Pb at high doses can cause neurological and developmental disorders (Ferreira-Baptista & De Miguel, 2005).

Among the studied areas, S_2 exhibited the highest concentration of Pb. It can be concluded that children living in S_2 are experiencing higher adverse health effect of Pb than those in S_1 and S_3. Cobalt had the lowest potential risk for children population. The results of cancer risk to children living in Ahvaz city are shown in Figure 3. As can be seen, the cancer risk of Cr, Pb, Cd and Ni was estimated through the ingestion, inhalation and dermal exposure modes of indoor dust. Results showed that the carcinogenic risk levels of Cr, Pb, Cd and Ni for children were within acceptable range. The carcinogenic risk from three pathways was in the following order: ingestion > dermal contact > inhalation. As shown in Figure 3, the cancer risk of the studied metals to children was found in the orders of Ni > Cr > Cd > Pb for S_1, S_2 and Cr > Ni > Cd > Pb for S_3. The mean value of carcinogenic risk was 3.6E − 06, 4.8E − 06 and 2.23E − 06, in S_1, S_2 and S_3, respectively. Results revealed that the total carcinogenic risk from Pb, Cd, Cr and Ni in all studied area was less than 1×10^{-4}, and the integrated risks of those elements were also within range of 1E − 06 to 1E − 04; typically, have been judged to be acceptable by USEPA. However, the carcinogenic risk for Ni (in S_1 and S_2) and Cr (in S_3) was above than those of other heavy metals.

Conclusion

The main objective of the research was to determine the concentration of heavy metals in indoor dust in Ahvaz city and their health effects on nearby residential houses. The levels of heavy metals in TM period were significantly ($p < 0.05$) higher than other two sampling period. Mean concentration of Pb in S_2 was higher than S_1 and S_3 in cold and warmer seasons. Our findings suggested that the risk (both carcinogenic and non-carcinogenic) from ingestion pathway with indoor dust was higher than the risk from inhalation and dermal contact. The non-cancer risks to children in all samples were lower than acceptable level of 1, while the potential cancer risks from intake of Ni and Cr were 1.57E − 06, 1.19E − 06 and 1.43E − 06, 1.15E − 06, respectively, in S_1 and S_2 that was slightly higher than the acceptable level of 1×10^{-6}. In conclusion, household dust of Ahvaz city would probably have a significant potential to cause cancer in most exposed children. However, further studies on metal biomarkers in body fluids such as blood and urine are necessary to determine the health adverse effects of metals.

Declaration of interest

The authors would like to thank Vice Chancellery of Research Development and Technology, Ahvaz Jundishapur University of Medical Sciences for funding support and providing necessary facilities (Project No. ETRC-9208).

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