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Non-Carcinogenic Risk Assessment of Heavy Metals Through Exposure to the Household Dust (Case Study: City of Khorramabad, Iran)

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Abstract

Background: Household dust is known as an important source of toxic heavy metals for all age groups particularly for children and this problem is a major concern around the world.
Objectives: This study was designed to assess the non-carcinogenic risk of cadmium (Cd), chromium (Cr), lead (Pb), and nickel (Ni) in indoor dust collected from 20 private residences in the city of Khorramabad, west of Iran, during year 2017.
Methods: In this study, a total of 80 household dust specimens were collected using a brush and plastic spatula. After dust samples were naturally air-dried and sieved through a nylon mesh and then acid digested, the element contents were measured using inductively coupled plasma spectrometer. Also, the non-carcinogenic risk was calculated based on the models developed by the United States Environmental Protection Agency.
Results: The results showed that the maximum concentrations of elements in dust samples were 17.72 mg/kg for Cd, 22.55 mg/kg for Cr, 101.65 mg/kg for Pb, and 89.47 mg/kg for Ni. Also, based on the results, ingestion (oral) of dust particles was the main exposure pathway to elements. On the other hand, the non-carcinogenic risk levels of all analyzed metals were lower than the allowable limit.
Conclusions: Due to adverse effects of toxic heavy metals on human health, it is recommended to pay special attention to other toxic elements of household dust that citizens have long-term exposure to.

Keywords: Non-Carcinogenic Risk, Heavy Metals, Household Dust, Iran

1. Background

Nowadays, since more than 50% of the world's population lives in urban areas, these environments are known as the main habitats for humans. Urbanization and also other activities, such as industry and agriculture, can cause discharge of pollutants, especially persistent toxic substances into the environment and consequently degradation of environmental qualities (1).

As heavy metals are usually transported and emitted in particulate forms, studies of outdoor and indoor dusts are good indicators of heavy metal accumulation, and assess the distribution, origin, and content of elements in surface environments (1, 2). As the literature indicates during the last decades, extensive studies on heavy metals contamination of soil and dust have been performed due to their effects on humans and environmental health (2-16).

Exposure to cadmium (Cd), as a non-essential element, can cause kidney damage, hypertension, tumors and hepatic dysfunction and also poor reproductive capacity (17, 18). However, trivalent chromium (Cr (III)), as an essential mineral, plays an important role in metabolism of the protein, lipid, and carbohydrate, yet Cr (VI), as a human carcinogen agent, can cause adverse effects, such as shortness of breath, nose ulcers, asthma, and wheezing (19, 20). Lead (Pb) is known as an agent of deficits in intelligence quotient, development of abnormalities, neurotoxicity problems, colic, anemia, and constipation, particularly in nursery and primary school children (21-24). However, a few trace amounts of nickel (Ni) play an important role in the body, especially activating some enzyme systems and the synthesis of red blood cells, yet, liver damage, heart damage, nervous system damage, respiratory problems, and lung cancer are the results of exposure to a high amount of this element (25).

As mentioned above, re-emission possibility and the complex chemistry of dust can affect human health. In particular, among various types of dust, indoor dusts are dangerous to human health, especially children, as people usually spend more than 70% of their time in indoor environments (2, 26). It is known that long-term exposure to airborne particulate matter (PM), especially the fine particles contaminated with heavy metals, may threaten human health through osteoporosis, renal dysfunction, incidence of bone fractures, and lung cancer (2, 27).

2. Objectives

Since rapid urban and industrial development of the city of Khorramabad during the last decade has led to the degradation of environmental quality, and also due to the limited number of studies conducted for health risk assessment of indoor dust available for developing regions, the objective of the current study was to assess non-carcinogenic risk of Cd, Cr, Pb, and Ni via exposure to indoor dust samples from private households in the study region.

3. Methods

3.1. Study Area

City of Khorramabad is located in the west of Iran at an altitude of 1147 m above sea level with an urban area of 35 km^2 (28).

3.2. Sampling and Analytical Methods

In the current study, a total of eighty dust samples were collected from private households in twenty residential quarters of the study area, using a brush and plastic spatula, during the spring season of 2017. All collected dust samples were transported to the laboratory (29).

After natural air-drying of dust samples for 14 days, all samples were sieved using a 0.15-mm nylon mesh to remove small stones. Then, 25.0 g of each dust sample was digested using a mixture of 3 mL of concentrated HNO_3 (Sigma-Aldrich, Spain), 6 mL of concentrated $HClO_4$ (Sigma-Aldrich, Spain) and 14 mL of concentrated HF (Sigma-Aldrich, Spain), and diluted with HNO_3 to 50 mL after filtering via Whatman grade 542 (11, 13, 30). Finally, the contents of studied elements were measured using ICP-OES (710-ES, Varian, Australia) with three replications.

3.3. Health Risk Assessment Model

Exposure dose: In this work, the model that was suggested by U.S.EPA (31) was applied to assess the human health risk through exposure to elements from indoor dust samples. Based on the assumptions of this model, oral or ingestion (D_{ing}), inhalation (D_{inh}), and dermal absorption (D_{dermal}) are the main route that expose human beings to indoor dust. Also, the total non-carcinogenic risk for each analyzed metal can be computed by summing the individual risks obtained from the above-mentioned routes (32, 33).

The exposure dose contacted via oral, inhalation, and the dermal route was computed in accordance with Equations 1-3 (31):

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

Where D_{ing} and C are the dose contacted through ingestion of indoor dust (mg/kg/day) and exposure point content (mg/kg) of the analyzed elements, respectively. Also, IngR (mg/day) is the ingestion rate (200 for children and 100 for adults), while EF (days/year), ED (years), BW (kg) and AT are the exposure relative frequency (300), exposure duration (six for children and 24 for adults), average body weight (15.0 for children and 70 for adults) and averaging time (exposure duration × 365 days for non-carcinogens), respectively (32, 34, 35).

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

Where D_{inh} (mg/kg/day) is the dose contacted through inhalation of indoor dust; InhR (m^3/day) is the inhalation rate (7.60 for children and 20.00 for adults). Also, PEF (m^3/kg) represents the particle emission factor (1.36 × 109) (10, 31).

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

Where D_{dermal} (mg/kg/day) is the dose absorbed via dermal contact with indoor dust; SA (cm^2), SL (mg/cm^2/day), and ABS are the exposed skin area, (2800 for children and 5700 for adults), skin adherence factor (0.2 for children and 0.07 for adults), and dermal absorption factor (0.001) for all analyzed elements, respectively (32, 34, 36).

3.4. Risk Characterization

After the exposure dose, contacted through ingestion, inhalation and dermal routes, were calculated, the non-carcinogenic risks of metals were computed through Equation 4 and 5 respectively:

$$HQ = \frac{D}{RfD} \quad (4)$$

$$HI = \sum HQi \quad (5)$$

Where hazard quotient (HQ) indicate the non-cancer risk; while D is the average daily dose and RfD indicates a specific reference dose as shown in Table 1 (35, 37, 38). The Hazard Index (HI) was used to estimate the health risk of oral, inhalation, and dermal exposure routes. Here, HI ≤ 1 indicates no adverse health effects, whereas HI > 1 indicates the possible health effects (39).

Table 1. Reference Dose and Slope Factor (SF) of Elements (10, 11, 31)

Element	Cd	Cr	Pb	Ni
RfD_{ing}	1.00E-03	3.00E-03	3.50E-03	2.00E-02
RfD_{inh}	1.00E-03	2.86E-05	3.52E-03	2.06E-02
RfD_{dermal}	1.00E-05	6.00E-05	5.25E-04	5.40E-03

4. Results

Based on the results of the analyzed samples, cadmium, chromium, lead, and nickel were measured in amounts ranging from 8.00 mg/kg to 17.70 mg/kg, 3.50 mg/kg to 22.50 mg/kg, 10.30 mg/kg to 101.60 mg/kg, and 25.00 mg/kg to 89.50 mg/kg, respectively.

Health risk assessment results of elements in household dust from the study area for children and adults are presented in Table 2. As Table 2 indicates, the maximum exposure doses were 1.11 E-03 mg/kg/day for children and 1.19 E-04 mg/kg/day for adults, both for Pb. Here, although children were exposed to elements in indoor dust by all routes more than adults, the average daily doses of Cd, Cr, Pb, and Ni by the oral pathway were about 1.5 to 2.0 times higher compared to other exposure routes for both children and adults.

5. Discussion

Cadmium can gradually accumulate inside the human body, particularly in the kidneys. Thus, in people affected by Cd poisoning, the occurrence of kidney stones is increased (40). The results showed that the highest mean concentration of Cd (15.95 mg/kg) was found in the station with heavy traffic volume. This could be due to the corrosion of the brake lining and automotive emissions (28, 41) contributing to indoor contamination of heavy metals in the city of Khorranabad. Considering the content of heavy metals in indoor dust, the results of another study showed that the mean concentration of Cd (mg/kg) in household dust collected from Guangzhou was 0.43 (2). Also, the mean content of this element in household dust collected from Japanese residences was found to be 1.02 mg/kg (12).

It has been shown that chromium is a renal, neurological, and developmental toxicant at certain contents (42). Welding, polishing, and grinding of stainless steel are known as the main sources of discharge of this element to the environment (28). Based on the results, the highest mean content of Cr (21.90 mg/kg) was found in the station with heavy traffic density. Similarly, Chen et al. reported that the hot-spot areas of Cr in campus dust (nurseries and primary schools) are mainly associated with heavy traffic density (11). In another study, the mean content of chromium in household dust collected from Guangzhou, China, and from Xi'an, China were found to be 188.03 mg/kg and 94.60 mg/kg, respectively (2, 14).

As the literature shows, exposure to Pb can cause peripheral neuropathy, kidney disease, and encephalopathy (11, 43). The dust Pb exhibited a wide range from 10.30 mg/kg to101.60 mg/kg with an average value of 32.10 $\pm$ 20.60 mg/kg. In spite of the wide use of unleaded gasoline in the last 20 years in Iran (28), the high dust Pb concentrations were found in station with heavy traffic volume, while the lowest dust Pb concentrations were found in the station with low traffic volume. This demonstrates the importance of anthropogenic sources contributing to indoor contamination of heavy metals in the city of Khorranabad and also accumulation of Pb in urban soil due to pollution from the past (44). Similarly, the results of the study of Wan et al. showed that the high pollution of Pb in household dust collected from heavy traffic areas of Xi'an, China, corresponds to the influence of Pb residues from gasoline combustion in the past years (14). Consequently, the spatial variations of Pb between different stations may reflect the potential sources of pollution and/or geological backgrounds as shown others in previous studies (9, 45). Concerning this, Huang et al. found that the mean value of Pb in indoor air-conditioner (AC) filter dust collected from Guangzhou, China was 699.05 mg/kg (2). Also, another studies showed that the mean value of Pb in campus dust and typical industrial area was 180.90 mg/kg and 92.90 mg/kg, respectively (11, 14). However, the mean content of Pb in house dust of Japanese residences was 57.90 mg/kg (12). Also, content of Pb in Chinese rural household dust were measured in amounts ranging from 18 mg/kg to 2510 mg/kg (9). On the other hand, the results of the study of Lin et al. showed that content of Pb in household dust collected from China, ranged from 112.80 mg/kg to 947.43 mg/kg (13).

It has been proved that exposure to a high amount of nickel may cause the formation of free radicals in various tissues of human as well as cancer of bones, nose and lungs, altered calcium and various modifications to DNA bases. Moreover, it may cause extreme weakness, headache, dermatitis, dizziness, and also respiratory distress (46-48). Based on the results of the current study, Ni in household dust samples was measured in amounts rang-

Table 2. Daily Doses (mg/kg/day), Hazard Quotient (HQ) and Hazard Index (HI) of Elements in Household Dust of the City of Khorramabad

Element	D_{ing}	D_{inh}	D_{derm}	HQ_{ing}	HQ_{inh}	HQ_{derm}	HI
Children							
Cd							
Min	8.79E-05	2.46E-09	2.46E-07	8.79E-02	2.46E-06	2.46E-02	1.12E-01
Max	1.94E-04	5.42E-09	5.44E-07	1.94E-01	5.42E-06	5.44E-02	2.48E-01
Mean	1.24E-04	3.47E-09	3.48E-07	1.24E-01	3.47E-06	3.48E-02	1.59E-01
Cr							
Min	3.82E-05	1.07E-09	1.07E-07	1.27E-02	3.74E-05	1.78E-03	1.45E-02
Max	2.47E-04	6.90E-09	6.92E-07	8.23E-02	2.41E-04	1.15E-02	9.40E-02
Mean	1.29E-04	3.62E-09	3.62E-07	4.30E-02	1.26E-04	6.03E-03	4.91E-02
Pb							
Min	1.13E-04	3.15E-09	3.15E-07	3.23E-02	8.95E-07	6.00E-04	3.29E-02
Max	1.11E-03	3.11E-08	3.12E-06	3.17E-01	8.83E-06	5.94E-03	3.23E-01
Mean	3.51E-04	9.82E-09	9.84E-07	1.00E-01	2.79E-06	1.87E-03	1.02E-01
Ni							
Min	2.74E-04	7.65E-09	7.67E-07	1.37E-02	3.71E-07	1.42E-04	1.38E-02
Max	9.80E-04	2.74E-08	2.74E-06	4.90E-02	1.33E-06	5.07E-04	4.95E-02
Mean	6.60E-04	1.84E-08	1.85E-06	3.30E-02	8.93E-07	3.42E-04	3.33E-02
Adults							
Cd							
Min	9.42E-06	1.38E-09	3.76E-08	9.42E-03	1.38E-06	3.76E-03	1.32E-02
Max	2.08E-05	3.06E-09	8.30E-08	2.08E-02	3.06E-06	8.30E-03	2.91E-02
Mean	1.33E-05	1.96E-09	5.31E-08	1.33E-02	1.96E-06	5.31E-03	1.86E-02
Cr							
Min	4.10E-06	6.03E-10	1.63E-08	1.37E-03	2.11E-05	2.72E-04	1.66E-03
Max	2.65E-05	3.89E-09	1.06E-07	8.83E-03	1.36E-04	1.77E-03	1.07E-02
Mean	1.39E-05	2.04E-09	5.53E-08	4.63E-03	7.13E-05	9.22E-04	5.62E-03
Pb							
Min	1.21E-05	1.77E-09	4.82E-08	3.46E-03	5.03E-07	9.18E-05	3.55E-03
Max	1.19E-04	1.75E-08	4.76E-07	3.40E-02	4.97E-06	9.07E-04	3.49E-02
Mean	3.77E-05	5.54E-09	1.50E-07	1.08E-02	1.57E-06	2.86E-04	1.11E-02
Ni							
Min	2.93E-05	4.32E-09	1.17E-07	1.46E-03	2.10E-07	2.17E-05	1.48E-03
Max	1.05E-04	1.54E-08	4.19E-07	5.25E-03	7.47E-07	7.76E-05	5.33E-03
Mean	7.07E-05	1.04E-08	2.82E-07	3.53E-03	5.05E-07	5.22E-05	3.58E-03

ing from 25 mg/kg to 89.50 mg/kg. These values were lower than findings that reported the variation in Ni content in household samples collected from Guangzhou, China (2) and also collected from Xi'an, China (14). However, the results of another study showed that the mean content of Ni (mg/kg) in household dust collected from China was 34.60 and 40.00, respectively (11, 13). The presence of Ni in analyzed samples may result from the lubricants corrosion of cars, engine wear, tire abrasion, and brake dust (28, 49). Also, the petrochemical activities or geological backgrounds may be known as the potential pollution sources of this element in indoor dust samples of study area (28).

The results of the hazard quotient values of different exposure routes and health index of the analyzed elements in the dust samples from the city of Khorramabad are presented in Table 2. As Table 2 shows, for non-carcinogenic risk, oral route of dust particles was the main source of exposure to elements in the dust compared to other pathways, similar to other reports (11, 16, 32, 34). Meanwhile, the lowest and highest D_{ing} values were 4.10E-06 for Cr and 1.11E-03 for Pb. Therefore, inhalation exposure to the dust for Cd, Cr, Pb, and Ni was almost negligible compared with the ingestion and dermal pathways. Although, some differences were found between the values of HIs for Cd, Cr, Pb, and Ni in the dust samples to children and adults, the mean values of HIs for these elements in household dust decrease in the order of Cd > Pb > Cr > Ni. In other words, since the mean HIs values for all elements through exposure to contaminated dust were within safe levels suggested by USEPA (1989), no non-carcinogenic health risk was found for children and adults. Meanwhile, since the hazard quotient values of all three exposure pathways and particularly health index values of Cd, Cr, Pb, and Ni for children were found to be 10 times higher than that for adults, it can be concluded that health risk through exposure to contaminated dust may have been more threatened in children compared with adults.

5.1. Conclusions

This study was conducted for non-carcinogenic risk assessment of some elements (Cd, Cr, Pb and Ni) in household dust from the city of Khorramabad, Iran. Based on the results, the indoor dust element contents increase in the following descending order: Ni > Pb > Cr > Cd. Also, the maximum levels of HI in children with 3.23E-01 and in adults with 3.49E-02 both for Pb were all lower than the acceptable range, although, children may have more potential non-cancer risk than adults do. Also, based on the HQ values, oral is the main exposure route of citizens to elements in household dust. Therefore, it is recommended that special attention must be given to other trace elements concentration of indoor dust that citizens have long-term exposure to.

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Footnotes

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