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HEALTH RISK ASSESSMENT OF METAL(LOID)S EXPOSURE VIA INDOOR DUST FROM URBAN AREA IN CHELYABINSK, RUSSIA

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ABSTRACT: Purpose of the study deals with the health risk assessment of metal(loid)s (Cr, Ni, Cu, Zn, As and Pb) contamination in 17 household dust from urban area of Chelyabinsk, Russia. Risk assessment models described by United States Environmental Protection Agency (USEPA) was applied. The concentrations of metal(loid)s in the indoor dust determined in previous studies were used for calculating. The study showed that both children and adults having individual health quotient (HQ)<1 for all metal(loid)s are at negligible non-carcinogenic risk. The combined total exposure hazard index (HI) value for children was 1.07. It is indicating that the metal(loid)s detected would harm the children. The cancer risk for adults from exposure to As and Cr was found to be the acceptable or tolerable, their carcinogenic risk assessment (CRA) was in the range of $1 \cdot 10^{-6} \ldots 1 \cdot 10^{-4}$. The cancer risk for children from exposure to As and Cr was found to be harmful to human beings (CRA > $1 \cdot 10^{-4}$), As and Cr had CRA for children $1.36 \cdot 10^{-4}$ and $2.81 \cdot 10^{-4}$, respectively.

Keywords: Health risk assessment, Metal(loid)s, Indoor dust, Urban area

1. INTRODUCTION

People spend indoors a large amount of time: 88% of the day for adults and 71–79% of the day for children [1]. Pollution of the indoor environment has a negative impact on human health. Indoor dust is one the most important sources of indoor contaminants. Many metals and metal(loid)s, including, chromium, zinc, copper, nickel, lead, arsenic, cadmium and mercury, accumulate in indoor dust [2]-[4].

Melal(loid)s find their way into household either as airborne dust or through items used or activities carried out within the house [4]. Dust becomes airborne by the friction of tires moving on unpaved dirt roads and dust-covered paved roads [5]-[7], industrial emission [8], [9] and surface particles erosion of buildings 9]. Melal(loid)s emitted from indoor materials and activities (e.g., paint, cleaning agents, cooking, and heating) can also accumulate on house dust [10].

At high concentration melal(loid)s are toxic and are potential cofactors, initiators, or promoters in other diseases, notably, cardiovascular diseases and cancer [11].

In previous studies [12], we have studied the contamination of metal(loid)s (Cr, Ni, Cu, Zn, As and Pb) in household dust from Chelyabinsk as typical industrial Russian city. The study has shown that Zn has highest content in road dust whilst in household dust, both As and Ni have the highest content. Cu, Pb, Zn and Cr contamination were significantly elevated in outdoor and indoor dust.

The aim of this work to estimate human health risk of metal(loid)s contamination in indoor dust collected from the Chelyabinsk urban area.

2. METHODS

2.1 Study Area and Sampling Sites

Chelyabinsk, which is located east of the Ural Mountains on the border of Europe and Asia, is one of the major industrial centers of Russia. Heavy industry predominates, especially metallurgy: the Chelyabinsk Metallurgical Combinate, Chelyabinsk Electrode plant, Chelyabinsk Tube Rolling Plant included in the "Big Eight" pipe producers in Russia, produces large-diameter pipes for pipelines, and Chelyabinsk Zinc Plant produces about 2% of the world and over 60% of Russian zinc.

This urban area extends over 500 km^2 and has a population of approximately 1 million inhabitants. The climate in the Chelyabinsk region is continental with pretty rough winter (average -15˚C/5˚F in January with drops down to -40˚C/F and lower) and short, moderate summer (average of 15˚C/60˚F in July). The number of motor vehicles in Chelyabinsk is estimated at 390 thousand [12].

Sampling was carried out in August 2017. A total of 17 indoor dust samples were collected from urban area [13]. Figure 1 shows the study area and the locations of sampling sites. The concentrations (mg·kg^{-1} dw) of metal(loid)s (Cr, Ni, Cu, Zn, As and Pb) on a dry weight basis in indoor dusts from Chelyabinsk were determined in previous paper [13] by Atomic Absorption Spectroscopy (AAS).

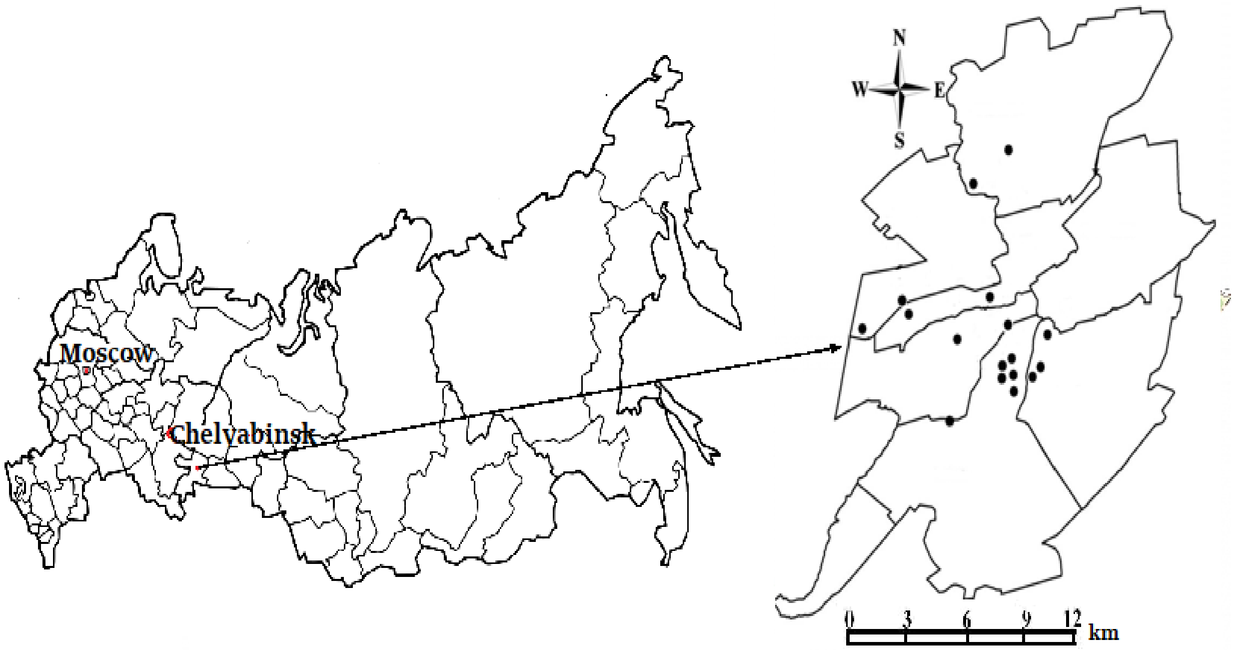

Fig. 1 The study area and the locations of all sampling sites.

2.2. Exposure Assessment Via Ingestion, Dermal Contact and Inhalation

The exposure health influence of metal(loid)s in the street and household dust to the human body is used by the US Environmental Protection Agency (EPA) human health evaluation method [14]. There are three major exposure pathways for adults and children to metal(loid)s in dust: (1) ingestion, (2) inhalation, and (3) dermal contact [15], [16].

In this study Cr, Ni, Cu, Zn, As and Pb were identified as potential contaminant with respect to human health. Arsenic is classified as a Group A human carcinogen by US Environmental Protection Agency [17], [18]. Cr, Ni, Cu, Zn and Pb are classified as noncarcinogenic by Agency for Toxic Substances and Disease Registry [18], [19].

The average daily dose (ADD) (mg kg^{-1} day^{-1}) for metal(loid)s in household dust was calculated separately for three exposure pathways using Eqs. (1)–(3) [17].

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

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

$$ADD_{dermal} = C \times \frac{SA \times AF \times ABF \times EF \times ED}{PEF \times BW \times AT} \times 10^{-6}, \quad (3)$$

where the ADD_{ing}, ADD_{inh} and ADD_{dermal} are the average daily dose (mg kg^{-1} day^{-1}) exposure to metal(loid)s through ingestion, inhalation and dermal contact, respectively, C is concentration of metals in dust from our previous research [13] (Table 1), IngR is ingestion rate of dust, EF is exposure frequency. ED is exposure duration, BW is average body weight. AT is average time. InhR is inhalation rate of dust, PEF is particular emission factor, SA is surface area of skin exposed to dust, AF is skin adherence factor, ABF is absorption factor (dermal). The detailed description of the values of exposure factors for children and adults applied to the Eqs (1)-(3) are given in Table 2.

2.3. Risk Calculation

2.3.1. Non-carcinogenic risk

In order to evaluate the human health non-carcinogenic risk of individual metals exposure from indoor dusts in Chelyabinsk, the HQ (hazard quotient) was applied [14], [20]-[22]:

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

where *RfD* is an estimation of maximum permissible risks to human population through daily exposure by considering sensitive group (children) during a lifetime. If HQ < 1, detrimental health effects would unlikely happen, whereas potential non-carcinogenic effects would occur in case HQ > 1.

Table 1 The concentrations of metal(loid)s indoor (n=17) dust from Chelyabinsk urban area ($mg \cdot kg^{-1}$ dw) [13].

Metal(loid)	As	Ni	Cu	Pb	Zn	Cr
Mean	7.1	34	29	129	956	44
Min	3.9	21.0	15.0	27	330	28
Max	15.9	57.0	45.0	520	2240	71

Table 2 Values of exposure factors for metal(loid)s doses for children and adults.

Factor	Unit	Value		**References**
		Children	Adults	
IngR	mg/day	200	100	[14], [23]
EF	days/year	350	350	[20], [21], [28]
ED	years	6	24	[14], [20], [21], [23]
BW	kg	15	70	[20], [21], [23], [24], [28]
AT non-carc	days	365×ED	365×ED	[20], [21], [23], [24]
InhR	m^3/days	7.6	12.8	[14], [20], [21], [26]-[28],
PEF	m^3/kg	1.36×10^9	1.36×10^9	[14], [20], [21], [23], [28]
SA	cm^2	2,800	5,700	[16], [21]
AF	mg/cm^2	0.2	0.07	[16], [17], [28]
ABF	unitless	0.001	0.001	[14], [20], [21], [23],

To assess the cumulative potential non-carcinogenic effects posed by many contaminants, the HQ value of each target chemical was summed (assuming additive effects) and expressed

Since the contaminants could enter into human through different pathways, the total exposure hazard index (HI) was used to reflect the aggregative non-cancer risks through multi-pathways and expressed as follow [14],[20]-[22]:

$$\boldsymbol{HI = \sum HQi}. \quad (5)$$

Experiencing chronic risks are assumed unlikely if HI < 1, whereas there may be concern for potential non-cancer risks when HI > 1. A further analysis segregating the contaminants and separating the HI would then be preferable if the HI > 1.

2.3.2. Carcinogenic risk

CRA (carcinogenic risk assessment), for individual metals were calculated using Eq 6 [14], [20]- [22]:

$$CRA = ADDing/inh/dermal \cdot SF, \quad (6)$$

where SF is slope factor. Total cancer risk (CRAsum) is the sum of CRA for three pathways:

$$CRAsum = ADDing \times SFing + ADDinh \times SFinh + ADDdermal \times SFdermal. \quad (7)$$

The carcinogenic risk is the probability of an individual developing any type of cancer from lifetime exposure to carcinogenic hazards. It is recommended that the value of CRA < $1 \cdot 10^{-6}$ can be regarded as negligible, whereas CRA > $1 \cdot 10^{-4}$ is likely to be harmful to human beings. The acceptable or tolerable risk for regulatory purposes is in the range of $1 \cdot 10^{-6} \ldots 1 \cdot 10^{-4}$ [14], [20].

Cr and As were treated as potential carcinogenic contaminants, whereas other metal(loid)s were regarded as non-carcinogenic, on the basis of the order of classification group defined by the and US EPA [29]. The toxicity value of Cr(VI), much more toxic than Cr(III), was used to figure out the worst situation of Cr, and the SF and RfD of Cr(VI) were assumed as for total Cr [16].

3. RESULTS

3.1 Non-cancer Risk Characteristics

The toxic effect of the studied metal(loid)s is presented in the Table 3. Tables 4 and 5 are shown human health risk assessment of individual metal(loid)s in the household dusts.

Table 3 Toxicity of metal(loid)s [30].

Metal(loid)	Toxicity
As	Arsenic accumulates in the body. Arsenic compounds are irritants to eyes and skin and cause a variety of vascular diseases. Chronic exposure can affect the respiratory tract, central nervous system, liver, kidneys and gastrointestinal system. Arsenic is a known human carcinogen with exposure linked to the development of skin cancer, bladder and lung cancer and acts via genotoxic mechanism.
Ni	Nickel is a potent skin sensitizer. Ingestion of nickel can cause skin reactions in previously sensitized individuals.
Cu	Ingestion of high concentrations of copper results in gastrointestinal disturbances and possible liver, kidney, red blood cell damage. Copper in water has a strongly astringent taste and ingestion of high levels of dissolved copper in water is unlikely to occur as vomiting rids the body of the excess dose. Copper is an irritant of the respiratory tract and high levels of dust exposure may result in coughing and nausea. Copper is an important ecological toxin particularly with respect to aquatic flora and fish.
Pb	Exposure to lead, particularly young children should be minimized. The main target for lead toxicity is the nervous system, both in adults and children. Lead exposure may also cause anemia. At high levels of exposure, lead can severely damage the brain and kidneys in adults or children and ultimately cause death. In pregnant women, high levels of exposure to lead may cause a miscarriage. There is no conclusive proof that lead causes cancer in humans.
Zn	Inhalation of zinc oxide is associate with the occupational 'metal fume fever' which effects the respiratory tract, but it is reversible. Excessive zinc intake results in gastrointestinal irritation. Zinc salts are caustic and may result in severe skin irritation. Zinc exposure can cause decreased absorption of copper and decreased iron stores which results in anemia and leucopoenia.
Cr	Hexavalent chromium can be toxic. Based on studies of workers in chromium processing factories, hexavalent chromium is classified as a known human carcinogen due to chronic inhalation exposures and the occurrence of lung cancer. When swallowed, it can be upset the gastrointestinal tract and damage the liver and kidneys, and is possibly carcinogenic; however, evidence suggests that hexavalent chromium is rapidly converted to the trivalent form after entering the stomach. Cr (II) and Cr (III) have much lower toxicities than Cr (VI) and are threshold contaminants.

Table 4 Individual hazard quotient and hazard index for children.

Metal(loid)	As	Ni	Cu	Pb	Zn	Cr
HQing (mean)	3.03E-01	2.17E-02	9.27E-03	4.71E-01	4.07E-02	1.87E-01
HQinh (mean)	0.84E-05	5.89E-07	2.58E-07	1.3E-05	1.14E-06	5.49E-04
HQderm (mean)	2.07E-03	2.25E-04	0.86E-04	8.79E-03	5.71E-04	3.15E-02
HI (mean)	3.05E-01	2.19E-02	9.36E-03	4.79E-01	4.17E-02	2.185E-01
HQing (min)	1.66E-01	1.34E-02	4.79E-03	0.98E-01	1.4E-02	1.19E-01
HQinh (min)	0.46E-05	3.64E-07	1.33E-07	0.28E-05	3.93E-07	3.49E-04
HQderm (min)	1.13E-03	1.39E-04	0.45E-04	1.84E-03	1.97E-04	2.01E-02
HI(min)	1.67E-01	1.35E-02	4.84E-03	0.99E-01	1.42E-02	1.39E-01
HQing (max)	6.78E-01	3.64E-02	1.44E-02	1.899	9.55E-02	3.02E-01
HQinh (max)	1.88E-05	9.88E-07	3.99E-07	5.27E-05	2.66E-06	8.86E-04
HQderm (max)	4.63E-03	3.78E-04	1.34E-04	3.54E-02	1.34E-03	5.08E-02
HI(max)	6.82E-01	3.68E-02	1.44E-02	1.934	9.68E-02	3.53E-01
RfDing	3.00E-04	2.00E-02	4.00E-02	3.50E-03	3.00E-01	3.00E-03
RfDinh	3.01E-04	2.06E-02	4.02E-02	3.52E-03	3.00E-01	2.86E-05
RfDderm	1.23E-04	5.40E-03	1.20E-02	5.25E-04	6.00E-02	5.00E-05

Table 5 Individual hazard quotient and hazard index for adults.

Metal(loid)	As	Ni	Cu	Pb	Zn	Cr
HQing (mean)	3.24E-02	2.33E-03	9.93E-04	5.05E-02	4.36E-03	2.01E-02
HQinh (mean)	3.06E-06	2.13E-07	9.29E-08	4.72E-06	4.11E-07	1.98E-04
HQderm (mean)	3.15E-04	3.44E-05	1.33E-05	1.34E-03	8.72E-05	4.81E-03
HI (mean)	3.27E-02	2.36E-03	1.01E-03	5.18E-02	4.45E-03	2.49E-02
HQing (min)	1.78E-02	1.44E-03	5.13E-04	1.06E-02	1.51E-03	1.28E-02
HQinh (min)	1.67E-06	1.32E-07	4.8E-08	9.88E-07	1.42E-07	1.26E-04
HQderm (min)	1.73E-04	2.13E-05	6.84E-06	2.82E-04	3.01E-05	3.06E-3
HI(min)	1.79E-02	1.46E-03	5.2E-04	1.09E-02	1.54E-03	1.59E-02
HQing (max)	7.26E-02	3.9E-03	1.54E-03	2.04E-01	1.02E-02	3.24E-02
HQinh (max)	6.81E-06	3.57E-07	1.44E-07	1.9E-05	9.62E-07	3.2E-04
HQderm (max)	7.07E-04	5.78E-05	2.05E-05	5.42E-03	2.04E-04	7.77E-03
HI(max)	7.33E-02	3.96E-03	1.56E-03	2.09E-01	1.04E-02	4.02E-02
RfDing	3.00E-04	2.00E-02	4.00E-02	3.50E-03	3.00E-01	3.00E-03
RfDinh	3.01E-04	2.06E-02	4.02E-02	3.52E-03	3.00E-01	2.86E-05
RfDderm	1.23E-04	5.40E-03	1.20E-02	5.25E-04	6.00E-02	5.00E-05

Table 6 Total hazard quotient and hazard index for children and adults.

Groups	Noncarcinogenic hazard						HI
	HQing	HQing contributions to HI, %	HQinh	HQinh contributions to HI, %	HQderm	HQderm contributions to HI, %	
Children	1.03E+00	95.5	5.72E-04	0.5	4.32E-02	4.0	1.07E+00
Adults	1.11E-01	94.1	2.06E-04	0.3	6.60E-03	5.6	1.18E-01

Table 7 Summary of carcinogenic risks via dermal contact, ingestion and inhalation exposure of dust on children and adults based on the metal(loid)s concentrations.

		As	Cr (6+)
SFing		1.5	0.5
SFinh		15	290
SFdermal		0.15	0.05
CRAsum	children	1.36E-04	2.81E-04
	adults	1.46E-05	3.01E-05

It was calculated through possible exposure pathways (ingestion, inhalation, and dermal contact) was performed for children and adults based on minimum, mean and maximum concentrations of metal(loid)s (Tables 4 and 5).

Such individual metal(loid)s as As, Pb and Cr displayed the highest HQing, HQinh and HOdemal for both children and adults compared with the other elements. It showed that the potential non-carcinogenic significant risk would be negligible since the HIs were less than 1 for minimum, mean and maximum concentrations of metal(loid)s. The combined HI value for children 1.07 (Table 5) is indicating that the metal(loid)s detected would harm the children. The average hazard quotient values of metal(loid)s for children and adults were in the order of Pb > As > Cr > Zn >Ni > Cu for HQing, Cr > Pb > As > Zn >Ni > Cu for HQinh and Cr > Pb > As > Zn > Ni > Cu for HQdermal.

The HQ values for the different exposure pathways of measured heavy metals in children and adults decreased in the following order: ingestion>dermal contact>inhalation (Table 6). The contributions of the HQing, HQinh and HQdermal to the HI (the total risk of non-cacinogenic exposure) were 95.5%, 0.5% and 4.0% for children and 94.1%, 0.3% and 5.6% for adults, respectively (Table 6).

3.2 Cancer risks

Carcinogenic risks of carcinogens (As and Cr) are shown in Table 7. CRAsum of the dust samples for adults both As and Cr are lower than the maximum acceptable level $1 \cdot 10^{-4}$. It may conclude that the potential carcinogenic health effects would not occur since one to one hundred in a million chance of additional human cancer over a 70 years lifetime (CRAsum $1 \cdot 10^{-6} \ldots 1 \cdot 10^{-4}$) is regarded as an acceptable or tolerable risk [29, 30]. The SF of Cr from ingestion exposure pathway were nearly 10 times higher of that of As, its similar with previous work [32].

Carcinogenic risk of As and Cr contamination in indoor dust was 10 times higher compared to risk for adults. For children As and Cr had CRA $1.36 \cdot 10^{-4}$ and $2.81 \cdot 10^{-4}$, respectively. It was found to be harmful to human beings (CRA > $1 \cdot 10^{-4}$). Compared to As, the potential cancer risk from Cr was slight higher. These results are similar to those reported in literature [31, 32].

4. CONCLUSION

As a result of the study aimed to find health risk implication of human exposure to metal(loid)s (Cr, Ni, Cu, Zn, As and Pb) in indoor dust from Chelyabinsk, Russia. The HQs and HI values for the different exposure pathways also measured performance in the following order: ingestion > dermal contact > inhalation. The individual values for all metal(loid)s were below the safe level (<1) indicating that no significant potential health risk is posed to inhabitants (children and adults) from exposure to metal(loid)s in indoor dusts. The carcinogenic risk for metal(loid)s in Chelyabinsk was found to be harmful to human beings for children and to be the acceptable or tolerable for adults.

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