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Pollution Characteristics and Health Risk Assessment of Airborne Heavy Metals Collected from Beijing Bus Stations

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Abstract: Airborne dust, which contains high levels of toxic metals, is recognized as one of the most harmful environment component. The purpose of this study was to evaluate heavy metals pollution in dustfall from bus stations in Beijing, and to perform a risk assessment analysis for adult passengers. The concentrations of Cd, Co, Cr, Cu, Mo, Ni, Pb, V and Zn were determined by inductively coupled plasma mass spectroscopy (ICP-MS). The spatial distribution, pollution level and potential health risk of heavy metals were analyzed by Geographic Information System (GIS) mapping technology, geo-accumulation index and health risk assessment model, respectively. The results indicate that dust samples have elevated metal concentrations, especially for Cd, Cu, Pb and Zn. The nine metals can be divided into two categories in terms of spatial distribution and pollution level. Cd, Cr, Cu, Mo, Pb and Zn reach contaminated level and have similar spatial patterns with hotspots distributed within the Fifth Ring Road. While the hot spot areas of Co and V are always out of the Fifth Ring Road. Health risk assessment shows that both carcinogenic and non-carcinogenic risks of selected metals were within the safe range.

1. Introduction

With the rapid urbanization and the accelerated industrialization in the last decades, heavy metals originating from anthropogenic activities such as vehicular traffic, heating systems, building construction or renovation, *etc.* have been greatly enhanced [1,2]. Dust, which contains high levels of toxic metals, contaminates terrestrial and aquatic ecosystem when deposited in place, and contributes to atmospheric pollution as they re-suspended back into the atmosphere [3,4]. Airborne dust is recognized as one of the most harmful environment component and has important environmental indications significance [5,6].

Most publications about dust heavy metals were focused on materials pollution characteristics, spatial distribution patterns and sources identification [7–12]. In fact, heavy metals can accumulate in human body and do harm to human health [13], due to their toxicity and non-degradability, long residence time and long biological half-lives for elimination from the body [14]. According to the Clean Air Act Amendments [15], heavy metals of As, Cd, Co, Cr, Hg, Mn, Ni, Pb, Sb and Se were listed as hazard air pollutants. Among them, As, Cd, Cr and Ni were included in the carcinogen classification [16] and had been proven scientifically to cause cancer in humans. The EPA health risk assessment method has been successfully employed to determine the quantitative risks of heavy metals exposure [17–21].

At present, buses are still an integral part of urban transportation, and are the most preferred trip mode for the majority. By the end of 2013, Beijing Public Transport Group has 30,570 public vehicles and 1020 bus lines under operation. Average daily passenger volume is 1.27 million person time and annual passenger volume can reach 4.63 billion person time. An adult passenger takes buses 250 days per year on average and at least spends ten minutes waiting at bus stations every day [22]. In fact, metals levels in street dusts are generally higher than those in other media [23] and are easily re-suspended back into atmosphere [24]. Passengers are directly exposed to the toxicants in street dusts during waiting process. Airborne dusts and re-suspended fraction are easily adhere to the exposed skin surfaces, and then entrance into human body through dermal contact, inhalation or ingestion by unconscious hand to mouth contact [13,25]. Thus, the health risk assessment is necessary and the results have significant reference for residents in taking protective measures. However, there is a lack of information relating health risks of metals and bus station dust.

The main objectives of this study were: (1) to determine the concentrations and spatial patterns of Cd, Co, Cr, Cu, Mo, Ni, Pb, V and Zn in dustfall from bus stations; (2) to evaluate the heavy metals' pollution level of using Geo-accumulation Index; and (3) to develop a quantitative estimate of the carcinogenic and non-carcinogenic risks for passengers via bus stations dustfall exposure.

2. Materials and Methods

2.1. Sampling and Analytical Methods

A total of 48 bus stations in the south central region of Beijing were selected for the collection of dust samples (Figure 1). Sampling campaign was conducted during dry season between November 2013 and January 2014. Samples were collected by dust traps (plastic vessels with 7 cm in diameter and 10.5 cm in height) at a height of 2.5 m above ground surface. Then dust traps were sealed with sealing cover for transport and storage. The traps were washed by demineralized distilled water and the wash was collected in glass vessels. After spontaneously vaporized, all samples were finely grounded in an agate mortar until the bulk samples could be sieved through 100 mesh sieve.
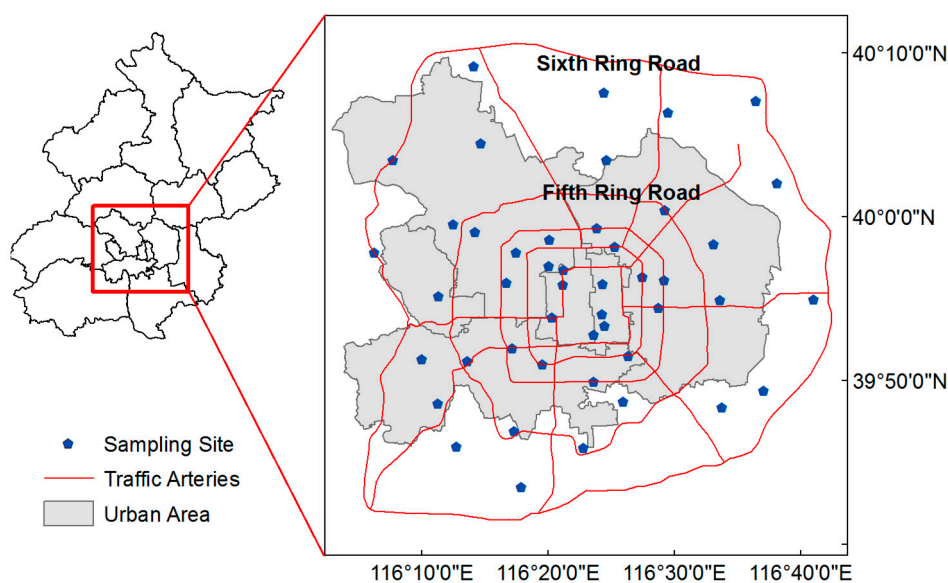

Figure 1. Location of sampling sites.

To analyze metal concentrations, 40 mg powers of each dust samples with a mixture of 2 mL HNO_3 and 0.6 mL HF were transferred into Teflon flask vessel and then heated to 150 °C for 24 h. After cooling to room temperature, 0.5 mL $HclO_4$ was added to vessel, which was then heated uncapped on electrical hot plate (150 °C) until nearly dry. Subsequently, sample was re-dissolved with 1 mL high pure water and 1 mL HNO_3 for 12 h. Finally, the solution was transferred to clean flask and diluted with high-purity water to 40 mL for following analysis. The concentrations of Cd, Co, Cr, Cu, Mo, Ni, Pb, V and Zn in dust samples were determined using inductively coupled plasma mass spectroscopy (ICP-MS). For quality assurance and control (QA/QC), duplicate samples and standard reference materials (GBW07315, GBW07316, BCR-2 and BHVO-2) were performed with the same procedure. The precision, based on the relative standard deviation (RSD), was <6.5%. The accuracy, based on the relative error, was <5%.

2.2. Pollution Level Analysis

Geo-accumulation index (I_{geo}, $I_{geo} = \log_2(C_n/1.5B_n)$, C_n is the measured concentration of the heavy metals in the environment; B_n is the geochemical background value in soil [26]) is a widely used

method to assess the pollution levels of heavy metals in sediment, urban soil, agriculture soil and urban road dusts [27–29]. This index not only considerate the impact of the geological process to the natural background values, but also evaluates the influence of human activities on the heavy metals pollution. The I_{geo} for each metal is calculated and classified in 7 classes [30]: class 0, uncontaminated ($I_{geo} \leq 0$); class 1, uncontaminated to moderately contaminated ($0 < I_{geo} \leq 1$); class 2, moderately contaminated ($1 < I_{geo} \leq 2$); class 3, moderately contaminated to heavily contaminated ($2 < I_{geo} \leq 3$); class 4, heavily contaminated ($3 < I_{geo} \leq 4$); class 5, heavily contaminated to extremely contaminated ($4 < I_{geo} \leq 5$); class 6, extremely contaminated ($I_{geo} \geq 5$).

2.3. Health Risk Assessment Model

Health risk assessment model used in this study is based on the method developed by the Environmental Protection Agency of the United States [31–33].The intake doses via three main paths (ingestion, inhalation, and dermal contact) are calculated according to the equations listed below.

$$AD_{ing} = \frac{C \times IR_{ing} \times F \times EF \times ED \times CF}{BW \times AT} \tag{1}$$

$$AD_{inh} = \frac{C \times IR_{inh} \times F \times EF \times ED}{PEF \times BW \times AT} \tag{2}$$

$$AD_{der} = \frac{C \times CF \times SA \times AF \times ABS \times F \times EF \times ED}{BW \times AT} \tag{3}$$

Where AD ($mg \cdot kg^{-1} \cdot day^{-1}$) is the absorbed dose of exposure to metals through ingestion (AD_{ing}), inhalation (AD_{inh}) and dermal contact (ADder); C ($mg \cdot kg^{-1}$) is the concentration of metals in dust. Parameters used in average daily dose estimation are shown in Table 1.

Table 1. Parameters applied in exposure assessment model.

Parameters	Definition	Unit	CarcinogenicEffects	Non-Carcinogenic Effects	References
ABS	Absorption Factor	--	0.01	0.01	[34]
AF	Adherence Factor	$mg \cdot cm^2$	0.07	0.07	[33]
AT	Averaging Time	days	70×365	$ED \times 365$	[31]
BW	Body Weight	kg	70	70	[31]
CF	Conversion Factor	$kg \cdot mg^{-1}$	10^{-6}	10^{-6}	[31]
ED	Exposure Duration	years	50	40	[31]
EF	Exposure Frequency	$day \cdot year^{-1}$	250	250	[22]
F	Fraction of Time Spent at Bus Station in a Day	‰	6.94	6.94	[22]
PEF	Particle Emission Factor	$m^3 \cdot kg^{-1}$	1.36×10^9	1.36×10^9	[32]
SA	Exposed Skin Surface Area	$cm^2 \cdot day^{-1}$	4350	4350	[35]
IRing	Ingestion Rate	$mg \cdot day^{-1}$	100	100	[32]
IRinh	Inhalation Rate	$m^3 \cdot day^{-1}$	20	20	[36]

Then the doses of non-carcinogenic metals are divided by the corresponding reference doses (RfD) to yield a hazard quotient (HQ), whereas the doses for carcinogens are multiplied by the corresponding slope factor (SF) to produce a cancer risk (RI). Hazard Index ($HI = \sum_1^i HQ$) indicates the overall

potentialnon-carcinogenic effects posed by more than one chemical. Total Hazard Index ($HI_t = HI_{ing} + HI_{inh} + HI_{der}$) refers to the sum of more than one HI for multiple pathways. There is no significant risk of non-carcinogenic effects when these indexes are no more than 1, whereas experiencing adverse health effects is possible when these indexes are more than 1. The acceptable or tolerable risk is in the range of 10^{-6}–10^{-4} for carcinogens. The RfD and SF values of analyzed metals [17,24,37,38] are listed in Table 2.

Table 2. The reference RfD and SF of heavy metals.

	RfDing (mg·kg^{-1}·day^{-1})	RfDinh (mg·kg^{-1}·day^{-1})	RfDder (mg·kg^{-1}·day^{-1})	SFinh (kg·day·mg^{-1})
Cd	1.00×10^{-3}	1.00×10^{-3}	1.00×10^{-5}	6.10
Cr	3.00×10^{-3}	2.86×10^{-5}	6.00×10^{-5}	4.10×10
Ni	2.00×10^{-2}	2.06×10^{-2}	5.40×10^{-3}	8.40×10^{-1}
Co	3.00×10^{-4}	5.71×10^{-6}	1.60×10^{-2}	9.80
Cu	4.00×10^{-2}	4.02×10^{-2}	1.20×10^{-2}	
Mo	5.00×10^{-3}	4.95×10^{-3}	1.90×10^{-3}	
Pb	3.50×10^{-3}	3.52×10^{-3}	5.25×10^{-4}	
V	5.04×10^{-3}	7.00×10^{-3}	7.00×10^{-5}	
Zn	3.00×10^{-1}	3.00×10^{-1}	6.00×10^{-2}	

3. Results and Discussion

3.1. Heavy Metals Concentrations in Dustfall

Descriptive statistical analysis was performed by SPSS19.0. As shown in Table 3, the order for the mean concentrations of nine heavy metals is followed as Zn > Cu > Cr > Pb > V > Ni > Co > Mo > Cd. The concentrations of Cd, Co, Cr, Cu, Mo, Ni, Pb, V and Zn vary between 0.90 and 6.72, 10.90 and 18.72, 85.90 and 219.71, 75.89 and 523.66, 2.89 and 38.59, 30.66 and 95.85, 40.26 and 174.39, 53.38 and 100.22, 234.62 and 982.37 mg·kg^{-1}, respectively. Except for Co and V, the mean and maximum concentrations of other seven heavy metals notably exceed the soil background values [26] for Beijing. Among them, the values of Cd, Cu, Pb and Zn are more than four times the corresponding background values. In fact, even the minimum of Cd and Cu are more than three times the background values. Compared with ambient air quality standards [39], the mean concentrations of Cd and Pb notably exceed primary standard (0.005 µg·m^{-3} for Cd, 0.5 µg·m^{-3} for Pb). In fact, primary standards provide public health protection, including protecting the health of "sensitive" populations such as asthmatics, children, and the elderly. In comparison with environmental quality standards for soil pollutants, the mean concentrations of Cd, Cu, Ni, Pb and Zn in dustfall greatly exceed the secondary standard [40], which provides public health protection and agricultural production. Thus, such serious pollution situation should be highly valued. And it has proved to a certain degree that health risk assessment is necessary. In addition, the coefficient variations are very large for Cd (0.43), Cu (0.52) and Mo (0.67), indicating the severe disturbance and noticeable emissions from anthropogenic inputs.

Table 3. Descriptive statistical analysis of heavy metals.

Elements	Min (mg·kg^{-1})	Max (mg·kg^{-1})	Mean (mg·kg^{-1})	Standard Deviation	Coefficient Variation	Skewness	Kurtosis	Background Value
Cd	0.90	6.72	2.46	1.06	0.43	1.70	5.04	0.07
Co	10.90	18.72	14.65	1.91	0.13	0.10	−0.68	17.00
Cr	85.90	219.71	128.13	28.60	0.22	1.19	2.01	68.10
Cu	75.89	523.66	206.94	106.61	0.52	1.25	1.36	23.60
Mo	2.89	38.59	8.45	5.71	0.67	3.44	16.91	4.10
Ni	30.66	95.85	56.68	16.00	0.28	0.84	−0.11	29.00
Pb	40.26	174.39	107.98	28.89	0.27	0.11	0.08	25.40
V	53.38	100.22	78.96	9.84	0.12	−0.37	0.20	79.20
Zn	234.62	982.37	525.17	174.36	0.33	0.56	0.33	102.60

3.2. Pollution Assessment of Heavy Metals in Dustfall

The I$_{geo}$ values for the heavy metals of dustfall selected from bus stations were presented in Figure 2. The average I$_{geo}$ values for heavy metals were 4.42 for Cd, 1.13 for Cr, −1.52 for Co, 2.40 for Cu, 0.28 for Mo, 0.34 for Ni, 1.45 for Pb, −0.58 for V, and 1.69 for Zn respectively. The maximum I$_{geo}$ values for Cr and V are less than zero, which are both ranked as an "uncontaminated" level. The I$_{geo}$ values for the other seven metals such as Cd, Cu, Zn, Pb, Co, Ni and Mo are all greater than 0, indicating that dustfall in the study areas is polluted by these seven metals with varying degrees. Among them, Cd is ranked as "heavily to extremely contaminated" level. According to the previous research [38], the high Cd concentration in urban was attribute to heavily population density and their complicated activities. Cu is ranked as "moderately contaminated to heavily contaminated" level. Based on the published research [38,41], the Cu concentration exist a considerable increasing tendency, which also need more attention. The dusts are scarcely contaminated by Mo and Ni, and are moderately contaminated by Co and Pb.
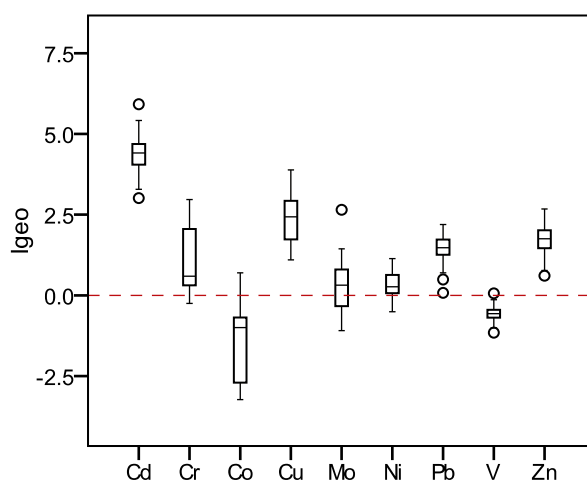

Figure 2. The I$_{geo}$ of heavy metals of dustfall.

3.3. Spatial Distribution of Heavy Metals in Dustfall

Figure 3 presents the spatial distribution of nine heavy metals in dustfall based on geostatistical analysis and Geographic Information System (GIS) mapping technology. As showed in Figure 3, similar spatial distribution patterns of Cd, Cr, Cu, Mo, Ni, Pb and Zn are found in the geochemical maps. Hot-spots of elevated concentration are mainly distributed within the Fifth Ring Road with several peaks scattered in the suburban areas. While the distribution patterns of Co and V are contrary to characteristic above mentioned. These two metals are enriched in the areas without the Fifth Ring Road.
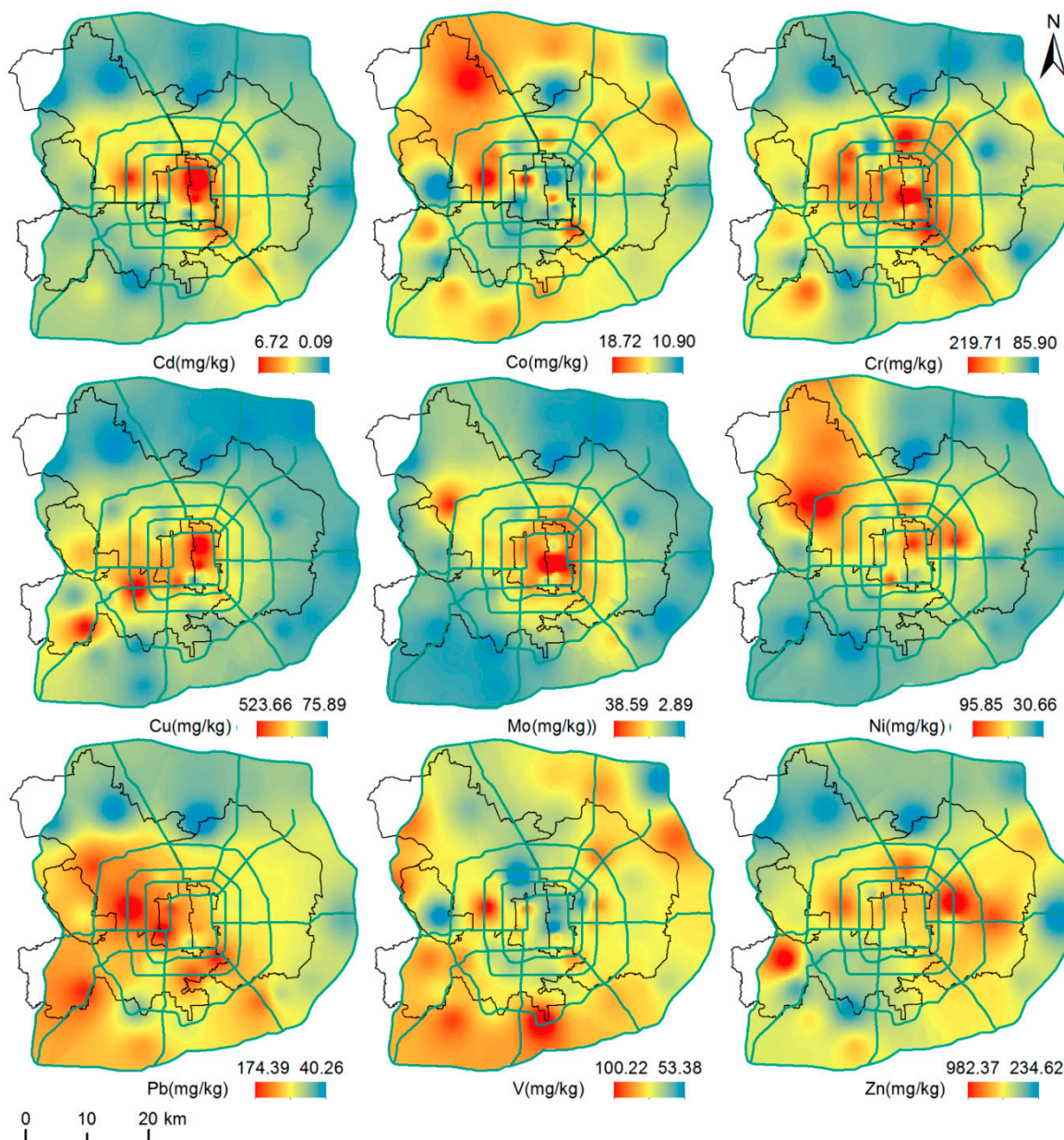
Figure 3. Spatial distributions of heavy metals.

These two distinctly different spatial distributions are likely to be caused by various pollution sources. The former might be associated with higher population density and various human activities. Semivariogram analysis revealed that the autocorrelation distance of Cd and Cu is close to the diameter of the Fourth Ring Road, ranged between 15 and 20 km, implying strongly influence from

urban activities [11]. Previous reports support that Cu, Zn, Ni and Pb mainly originate from traffic emission and coal burning, and Cd is mainly derived from industrial emissions, coal combustion and oil burning, while Co and V are mainly from crustal source [3].

3.4. Potential Health Risk Assessment

Daily exposure doses of metals through three pathways are listed in Table 4. In terms of mean total exposure amounts, Cu and Zn are in the same order of magnitude (1.00×10^{-6} mg·kg^{-1}·day^{-1}), and are 1–2 orders of magnitude higher than Cd, Cr, Ni, Co, Mo, Pb and V. The highest exposure dose is 6.87×10^{-6} mg·kg^{-1}·day^{-1} for Zn, and the lowest exposure amount is 6.28×10^{-9} mg·kg^{-1}·day^{-1} for Cd. Although the pollution level of Cd in the study area is highest, the daily exposure doses for adult turn out the opposite. Thus, the exposure amounts are determined by metals concentrations rather than pollutant level. In the case of three exposure pathways, ingestion is the dominant route for nine metals, which is similar to other reports [42].

Potential health risk assessment results of metals are statistically summarized in Table 5. On the whole, the non-carcinogenic risk values of different metals through three pathways are various. The mean HQ values of metals (except for Cd, Cr and Co) for three pathways decrease in the following order ingestion > dermal contact > inhalation. This ranking is consistent with the other studies [23,43]. While ingestion of airborne dust is still the main exposure route for Cd, Cr and Co. All metals included, the HI value for ingestion is the highest, followed by dermal contact and inhalation, indicating that ingestion is the main route for heavy metals that were adverse to human health. The aggregation risks of three exposure routes (HIt) for all analyzed metals are far below the safe level and decrease in the order Cr > V > Co > Pb > Cd > Cu > Ni > Zn > Mo. Integrating all exposure pathways and all heavy metals, the maximum HI value is only 2.93×10^{-3}, much lower than the safe level. This result implies that adults face no potential non-carcinogenic health risks from the heavy metals in dustfall when waiting for buses.

Cd, Co, Cr and Ni are considered as carcinogens only through inhalation [24]. Thus, these four metals are assessed only through inhalation exposure mode for the carcinogenic risk. Table 5 shows that the mean carcinogenic risk of the study metals decrease in the following order: Cr > Co > Ni > Cd. Among the four metals, Cr contributes the majority proportion to the overall RI. While, even the highest RI value for Cr is lower than the safe level (1.00×10^{-6}), indicating that there's no carcinogenic risk exposure from Cd, Co, Cr and Ni in dustfall for adult passengers when they waiting for buses at bus stations.

Table 4. Average daily exposure doses of metals in dustfall to adult ($mg \cdot kg^{-1} \cdot day^{-1}$).

		Cd	Cr	Ni	Co	Cu	Mo	Pb	V	Zn
	Min	6.09×10^{-9}	5.83×10^{-7}	2.08×10^{-7}	7.40×10^{-8}	5.15×10^{-7}	1.96×10^{-8}	2.73×10^{-7}	3.63×10^{-7}	1.59×10^{-6}
ADing *	Max	4.56×10^{-8}	1.49×10^{-6}	6.51×10^{-7}	1.27×10^{-7}	3.56×10^{-6}	2.62×10^{-7}	1.18×10^{-6}	6.81×10^{-7}	6.67×10^{-6}
	Mean	1.67×10^{-8}	8.70×10^{-7}	3.85×10^{-7}	9.95×10^{-8}	1.41×10^{-6}	5.74×10^{-8}	7.33×10^{-7}	5.36×10^{-7}	3.57×10^{-6}
	Min	8.95×10^{-13}	8.58×10^{-11}	3.06×10^{-11}	1.09×10^{-11}	7.58×10^{-11}	2.89×10^{-12}	4.02×10^{-11}	5.33×10^{-11}	2.34×10^{-10}
ADinh *	Max	6.71×10^{-12}	2.19×10^{-10}	9.57×10^{-11}	1.87×10^{-11}	5.23×10^{-10}	3.85×10^{-11}	1.74×10^{-10}	1.00×10^{-10}	9.81×10^{-10}
	Mean	2.46×10^{-12}	1.28×10^{-10}	5.66×10^{-11}	1.46×10^{-11}	2.07×10^{-10}	8.44×10^{-12}	1.08×10^{-10}	7.88×10^{-11}	5.24×10^{-10}
	Min	6.40×10^{-13}	6.13×10^{-11}	2.19×10^{-11}	7.77×10^{-12}					
ADinh **	Max	4.79×10^{-12}	1.57×10^{-10}	6.84×10^{-11}	1.34×10^{-11}					
	Mean	1.76×10^{-12}	9.14×10^{-11}	4.04×10^{-11}	1.05×10^{-11}					
	Min	1.85×10^{-10}	1.78×10^{-8}	6.34×10^{-9}	2.25×10^{-9}	1.57×10^{-8}	5.97×10^{-10}	8.32×10^{-9}	1.10×10^{-8}	4.85×10^{-8}
Adder *	Max	1.39×10^{-9}	4.54×10^{-8}	1.98×10^{-8}	3.87×10^{-9}	1.08×10^{-7}	7.98×10^{-9}	3.61×10^{-8}	2.07×10^{-8}	2.03×10^{-7}
	Mean	5.10×10^{-10}	2.65×10^{-8}	1.17×10^{-8}	3.03×10^{-9}	4.28×10^{-8}	1.75×10^{-9}	2.23×10^{-8}	1.63×10^{-8}	1.09×10^{-7}
	Min	6.28×10^{-9}	6.01×10^{-7}	2.15×10^{-7}	7.63×10^{-8}	5.31×10^{-7}	2.02×10^{-8}	2.82×10^{-7}	3.74×10^{-7}	1.64×10^{-6}
ADtot	Max	4.70×10^{-8}	1.54×10^{-6}	6.71×10^{-7}	1.31×10^{-7}	3.66×10^{-6}	2.70×10^{-7}	1.22×10^{-6}	7.01×10^{-7}	6.87×10^{-6}
	Mean	1.73×10^{-8}	8.97×10^{-7}	3.97×10^{-7}	1.03×10^{-7}	1.45×10^{-6}	5.92×10^{-8}	7.56×10^{-7}	5.53×10^{-7}	3.68×10^{-6}

Note: ***** is referred to non-carcinogenic effects. ****** is referred to carcinogenic effects.

Table 5. Health risks from heavy metals in dustfall.

		Cd	Cr	Ni	Co	Cu	Mo	Pb	V	Zn	HI
	MIN	6.09×10^{-6}	1.94×10^{-4}	1.04×10^{-5}	2.47×10^{-4}	1.29×10^{-5}	3.92×10^{-6}	7.81×10^{-5}	7.19×10^{-5}	5.31×10^{-6}	6.30×10^{-4}
HQing	MAX	4.56×10^{-5}	4.97×10^{-4}	3.25×10^{-5}	4.24×10^{-4}	8.89×10^{-5}	5.24×10^{-5}	3.38×10^{-4}	1.35×10^{-4}	2.22×10^{-5}	1.64×10^{-3}
	MEAN	1.67×10^{-5}	2.90×10^{-4}	1.92×10^{-5}	3.32×10^{-4}	3.51×10^{-5}	1.15×10^{-5}	2.10×10^{-4}	1.06×10^{-4}	1.19×10^{-5}	1.03×10^{-3}
	MIN	8.95×10^{-10}	3.00×10^{-6}	1.49×10^{-9}	1.91×10^{-6}	1.89×10^{-9}	5.83×10^{-10}	1.14×10^{-8}	7.62×10^{-9}	7.81×10^{-10}	4.93×10^{-6}
HQinh	MAX	6.71×10^{-9}	7.67×10^{-6}	4.65×10^{-9}	3.27×10^{-6}	1.30×10^{-8}	7.79×10^{-9}	4.95×10^{-8}	1.43×10^{-8}	3.27×10^{-9}	1.10×10^{-5}
	MEAN	2.46×10^{-9}	4.47×10^{-6}	2.75×10^{-9}	2.56×10^{-6}	5.14×10^{-9}	1.71×10^{-9}	3.06×10^{-8}	1.13×10^{-8}	1.75×10^{-9}	7.09×10^{-6}
	MIN	1.85×10^{-5}	2.96×10^{-4}	1.17×10^{-6}	1.41×10^{-7}	1.31×10^{-6}	3.14×10^{-7}	1.59×10^{-5}	1.58×10^{-4}	8.09×10^{-7}	4.92×10^{-4}
HQder	MAX	1.39×10^{-4}	7.57×10^{-4}	3.67×10^{-6}	2.42×10^{-7}	9.02×10^{-6}	4.20×10^{-6}	6.87×10^{-5}	2.96×10^{-4}	3.39×10^{-6}	1.28×10^{-3}
	MEAN	5.10×10^{-5}	4.42×10^{-4}	2.17×10^{-6}	1.89×10^{-7}	3.57×10^{-6}	9.20×10^{-7}	4.25×10^{-5}	2.33×10^{-4}	1.81×10^{-6}	7.77×10^{-4}
	MIN	2.46×10^{-5}	4.93×10^{-4}	1.16×10^{-5}	2.49×10^{-4}	1.42×10^{-5}	4.24×10^{-6}	9.40×10^{-5}	2.30×10^{-4}	6.12×10^{-6}	1.13×10^{-3}
HIt	MAX	1.85×10^{-4}	1.26×10^{-3}	3.62×10^{-5}	4.27×10^{-4}	9.79×10^{-5}	5.66×10^{-5}	4.07×10^{-4}	4.31×10^{-4}	2.56×10^{-5}	2.93×10^{-3}
	MEAN	6.77×10^{-5}	7.36×10^{-4}	2.14×10^{-5}	3.34×10^{-4}	3.87×10^{-5}	1.24×10^{-5}	2.52×10^{-4}	3.40×10^{-4}	1.37×10^{-5}	1.82×10^{-3}
	MIN	3.90×10^{-2}	2.51×10^{-9}	1.84×10^{-11}	7.62×10^{-11}						
RI	MAX	2.92×10^{-11}	6.43×10^{-9}	5.74×10^{-11}	1.31×10^{-10}						
	MEAN	1.07×10^{-11}	3.75×10^{-9}	3.40×10^{-11}	1.02×10^{-10}						

Based on the above analyses, exposure to heavy metals in dustfull only during bus waiting periods would not cause serious health impacts. However, the potential health risk due to long-term exposure to dustfall in pollution hotspots cannot be overlooked for sensitive populations, like children, outdoor workers, and bus or taxi drivers [25,44]. In addition, elements of Cr should especially be taken account of for its main contribution (40.44%) to the overall HI and dominant contribution (96.21%) to the total RI. Cr is a neurological, renal and developmental toxicant at certain concentrations [45]. In fact, the potential health risk of Cr is easy to be ignored for it's safe concentration and uncontaminated level in this study. In this way, health risk assessment model is a useful tool even though there are some uncertainties, like ideal assumptions, uncertainties of the exposure parameters and the metal toxicity data, and non-considering other metals and other potential exposure way.

Considering the results of ecological risk and health risk assessments comprehensively, some measures must be taken to eliminate the buildup of Cd and Cr.

4. Conclusions

In this paper, we demonstrate the concentrations, distribution, accumulation and health risk assessment of nine heavy metals (Cd, Co, Cr, Cu, Mo, Ni, Pb, V and Zn) in dustfall from 48 bus stations in the south central region of Beijing. These dusts have elevated metals concentrations, especially of Cd, Cu, Pb and Zn, which are more than four times the soil background value. Taking other indexes into consideration, like coefficient variations, skewness and kurtosis, Cd, Cu and Mo show the severe disturbance and noticeable emissions from anthropogenic sources. The pollution levels of the heavy metals are ordered as follows: Cd > Cu > Zn > Pb > Cr > Ni > Mo > V > Co. Cd is the predominant element among them with the pollution level ranked as "heavily to extremely contaminated". Co and V are present at unpolluted level with the I_{geo} values lower than zero. The spatial distribution patterns of seven elevated metals (Cd, Cr, Cu, Mo, Ni, Pb and Zn) are similar. Hot-spots mainly distribute in the areas within the Fifth Ring Road, associated with heavy traffic density and population probably. While the distribution characteristic in spatial scale of Co and V is the opposite. The heavy metals concentrations in suburban areas are higher than urban areas, indicating that the main sources of those metals are natural materials. Both the carcinogenic and non-carcinogenic health risks are within the acceptable range. For non-carcinogenic effects, ingestion is the primary exposure pathway, followed by dermal contact and inhalation.

Author Contributions

Wenji Zhao had the original idea for the study and, with all co-authors designed and performed the experiments. Xiaoxia Zheng analyzed the data and drafted the manuscript, which was revised mainly by Xing Yan. All authors have read and approved the final manuscript.

Conflicts of Interest

The authors declare no conflict of interest.

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