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ORIGINAL ARTICLE

Levels and spatial distribution of heavy metals in urban dust in China

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Abstract Many studies have been conducted on heavy metal concentrations in urban outdoor dust in China, showing that differences exist in the metal concentrations of different cities. However, no report has studied the distribution of heavy metals across Chinese cities. This work presents the spatial distribution of heavy metals in urban outdoor dust in Chinese cities and discusses the causes for the differences in heavy metal levels across cities by analyzing and summarizing data for 20 provincial capitals from the published scientific literature. The results show that the geometric mean values of Ni and Cr in urban dust of China are lower than or comparable to crustal levels, whereas levels of Cd, Cu, Pb, and Zn are significantly greater than crustal levels. The spatial distributions of Cu, Pb, and Zn in urban dust all exhibit a pattern in which heavy metal levels are greater in cities located in the south of China than in the north. Commercial areas and residential-education areas accumulate more Cd in their dust than industrial areas and traffic areas, and industrial areas and residential-education areas accumulate more Pb than commercial areas and traffic areas. The Zn level in dust from industrial areas is significantly greater than in other areas, and Cu exhibits no significant difference between different functional areas. A positive correlation exists between Cd and Zn in urban dust and population density. Urban dust Pb in Chinese cities is lower than the world average as calculated using data for thirteen cities in different countries. Cd, Cu, and Zn levels in China are close to world averages.

Keywords Heavy metal · Spatial distribution · Urban dust · Cities · China

1 Introduction

Dust is the most pervasive and important environmental factor affecting human health (Duong and Lee 2011). Outdoor dust often contains elevated concentrations of a range of heavy metals (Tong and Lam 2000). Exposure to metal-contaminated dust through skin contact and hand-to-mouth contact can adversely affect human health, particularly through unintentional uptake by children in playgrounds and city streets (Saeedi et al. 2012). Nearly half of the world population lives in urban areas, and their health issues and living environment have become a major concern (Shi et al. 2008). Considerable attention has been paid to metal pollution in urban street- and roadside dust throughout the world, and studies have revealed that city dust contains a range of heavy metals, including Cd, Cu, Pb, and Zn (Ordóñez et al. 2003; Ferreira-Baptista and de Miguel 2005; Saeedi et al. 2012). In China, recent rapid urbanization, industrialization, and increased vehicular traffic have resulted in heavy metal accumulation in urban dust (Duzgoren-Aydin et al. 2006; Han et al. 2008; Li et al. 2012a, b). Most studies have shown that metal concentrations in dusts vary between different cities with level of development and environmental characteristics, but still lacking is a comprehensive characterization of the distribution of heavy metal levels in Chinese cities. A review from Wei and Yang (2010) of heavy metal contamination in urban soils, urban road dusts, and agricultural soils of

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China showed that Cd, Cr, Cu, Ni, Pb, and Zn are widespread in urban soils and urban road dusts. In China, the development of capital cities is much higher than other cities. The increases in anthropogenic Pb, Zn, Cu, Ni, and Cr in street dusts can most likely be attributed to rapid development (Ahmed and Ishiga 2006).

The primary aim of this paper is to present a characterization of the spatial distribution of heavy metals including Cd, Cr, Cu, Ni, Pb, and Zn in urban outdoor dust in capital cities in China and to discuss the causes of the differences in heavy metal levels between cities by summarizing and analyzing data for 20 provincial capitals from the published scientific literature.

2 The level and accumulation of heavy metals in urban dust in China

2.1 The level of heavy metals in urban dust

Properties of material in dust are highly variable in time and space, affecting the choices of sampling procedure, digestion procedure, and analysis method (Ferreira-Baptista and de Miguel 2005).

In the reviewed investigations (Table 1), dust samples were almost unanimously collected by brush; digested using HNO_3–HF–$HClO_4$; and analyzed by AAS, ICP-MS, ICP-AES, and/or XRF, all of which are acceptable.

Table 1 The level of heavy metals in urban dust in China

Cities	Sampling area	N	Heavy metal average value (mg/kg)						Collection, digestion and detection for dust	Ø (μm)	Ref
			Cd	Cr	Cu	Ni	Pb	Zn			
Changchun[g]	Urban area	232	0.624	94.5	68.4	/	93.6	417	Brush, detected by XRF and AAS	/	(Yang et al. 2010)
Shenyang	Urban area	61	4.35	/	81.3	/	106	334	Brush, HNO_3-HF-$HClO_4$, AAS	<1000*	(Li et al. 2008)
Urumqi	Urban area	/	/	110	81.1	/	82.7	549	Brush, HNO_3-HF-$HClO_4$, AAS	<75	(Liu et al. 2009)
	Urban area	169	1.17	54.3	94.5	43.3	53.5	295	Brush, HNO_3- H_2SO_4- HF, ICP-MS	<149	(Wei et al. 2009)
Shijiazhuang	Urban area	63	11.0	91.9	/	/	64.7	256	Brush, HNO_3-HF-$HClO_4$, AAS	<150	(Zhao 2008)
Beijing	School, square[a]	30	0.632	/	49.5	27.1	56.6	196	Brush, HNO_3-Microwave,ICP-MS,AAS	<100	(Li et al. 2010),
	Urban area	220	0.47	77.5	64.2	23.7	50.4		Cleaner, Microwave, ICP-MS	<500*	(Tang et al. 2013)
Lanzhou[b]	One district	47	2.17	128	57.0	129	98.7	278	Brush, HNO_3-HF-$HClO_4$, AAS	<125	(Qin 2008)
Xi'an	Urban area	65	/	167	95.0	/	231	422	Brush, F-H_2SO_4-HNO_3-$HClO_4$. AAS	<1000*	(Han et al. 2006)
Jinan	Urban area	57	/	58.7	54.1	/	59.2	206	Brush, HF-HNO_3-$HClO_4$. AAS	<1000*	(Chen et al. 2013)
Shanghai[a]	Urban area	273	1.23	159	197	84.0	295	734	Brush, HNO_3-HF-$HClO_4$, AAS	/	(Shi et al. 2008)
Hangzhou	Urban area	25	1.11	/	81.0	/	141	225	Brush, HNO_3-HF-$HClO_4$, AAS	<2000*	(Zhang and Zhang 2007)
Nanjing	Urban area	35	1.10	126	123	55.9	103	394	Vacuum cleaner, HNO_3-HF-$HClO_4$-Microwave, ICP-AES, MS	230	(Hu et al. 2011)
Changsha[g]		57	3.36	/	71.9	/	185	626	Brush, HNO_3-HF-$HClO_4$, ICP-MS	<1000*	(Long et al. 2010)
Nanchang	Urban area	31	3.17	139	170	42.0	51.2	2716	HNO_3-HF-$HClO_4$-Microwave, ICP-AES	<125	(Tang 2010)
Hefei	Urban area	52	4.53	96.9	67.5	/	132	2333	Brush, HNO_3-HF-$HClO_4$, AAS	<150	(Li et al. 2011)
Guangzhou[b]	Urban area	15	1.30	50.3	79.0	15.6	185	492	Brush, HNO_3-HF, ICP-MS	<2000*	(Duzgoren-Aydin et al. 2006)
Chongqing	Urban area	16	/	233	261	61.4	255	296	Brush, aqua regia- $HClO_4$, HNO_3-HF-$HClO_4$, AAS	/	(Wang 2008)
Chengdu[g]	Urban area	299	4.40	114	244	88.1	375	1117	Brush	<75	(Wang 2004)
Guiyang[a]	Urban area	66	1.28	/	133	50.0	93.2	435	Brush, HNO_3-$HClO_4$, ICP-MS	<106	(Li 2013)
Kunming	Urban area	60	/	79.4	167	21.5	97.5	317	Brush, XRF	<1000*	(Liang et al. 2011)
Hong Kong[a]	Urban area	45	3.61	/	126		160	1173	Brush, HNO_3-Microwave,ICP-AES	<1000*	(Li et al. 2001)
CV %			97.4	42.1	52.7	63.1	50.0	91.4			
Geomean			2.03	105	103	47.1	121	483			
Crustal levels			0.2	100	55	75	12.5	70			(Zhao and Zhang 1988)
R			10.2	1.1	1.9	0.6	9.7	7.0			

R Geomean/crustal levels, / no data, *N* sample number, [g]represents dust sampling from near ground include the windowsill of first or second floor and the top horizontal of the newspaper kiosk, [a]arithmetic mean, [b]median, * Sample was ground prior to digestion. *XRF* X-ray fluorescence spectrometry, *AAS* atomic absorption spectrum, *ICP-AES* inductively coupled plasma atomic emission spectrometer, *ICP-MS* inductively coupled plasma mass spectrometry

Although the particle size retained for analysis is different, direct comparisons among the results of different investigations are reasonable under such similar sampling, digestion, and analysis methods.

The concentration ranges of Cd, Cr, Cu, Ni, Pb, and Zn in urban dust in the studied Chinese cities were 0.47–11.0, 50.3–233, 49.5–261, 15.6–129, 50.4–375 and 196–2716 mg/kg, respectively. The highest levels of Cd, Cr, Cu, Ni, Pb, and Zn appeared in Shijiazhuang, Chongqing, Lanzhou, Chengdu, and Nanchang, respectively, with values 23.4, 4.63, 5.27, 8.27, 7.44 and 13.9-fold higher than the lowest values, respectively. The variations of Cd and Zn in city dust were considerably larger than that of other heavy metals. The data in Beijing from two investigations is similar in spite of different particle sizes being retained for analysis, while results of two investigations in Urumqi display some difference.

The geometric mean values of Ni and Cr in urban dust of China were similar to or less than the crustal levels, and those of Cd, Cu, Pb, and Zn were considerably higher than crustal levels. In particular, the geometric mean values of Cd, Pb, and Zn were respectively 10.2, 9.7, and 7.0 times crustal levels, demonstrating their heavy accumulation in urban dust in China. The following discussion will focus on the four elements with higher-than-crustal mean levels.

2.2 The spatial distributions of Cd, Cu, Pb, and Zn in urban dust

Spatial distributions of Cd, Cu, Pb, and Zn were mapped using ArcGIS v.9.1 (ESRI Co, Redlands, USA). The distribution of Cd showed no apparent spatial pattern, with a maximum value appearing in the north and a minimum in the northeast. A clear pattern of higher accumulation in southern cities than in northern ones was seen in the distributions of Cu, Pb, and Zn. The levels of Cu and Pb in cities in the southwest and east of China were higher than in the central and southern parts of China, and the highest level of Zn appeared in central China. A possible reason behind the spatial differences of heavy metal contents will be discussed in Sect. 3.

2.3 Dust heavy metals in different city functional areas

Several studies reported heavy metal concentrations in urban dust for different city functional areas, but the reported functional areas were not the same for all cities. We chose four major functional areas, including industrial areas (IA), commercial areas (CA), traffic areas (TA), and residential-educational areas (REA), to study the distribution of heavy metals in the urban dust of different functional areas within cities. Urban dust heavy metal data for four functional areas of seven cities—Urumqi (Liu et al. 2009), Shenyang (Li et al. 2008), Xi'an (Han et al. 2008), Taiyuan (Cao 2012), Nanjing (Hu et al. 2011), Guiyang (Li 2013)—were collected, and the ratios of their geometric means to the crustal levels were calculated (Table 2). CA and REA had more Cd in their dust than did IA and TA. No significant difference was detected for Cu in different functional areas. Pb and Zn in IA were significantly higher than in the other three functional areas. Pb levels were higher in REA than in CA and IA, but Zn levels showed no obvious difference between those three functional areas.

Table 2 The ratios of the geometric means of heavy metals to the crustal levels

Functional area	Cd	Cu	Pb	Zn
IA	7.70	2.31	14.30	7.68
CA	9.79	1.95	8.30	5.51
TA	8.44	2.00	7.61	5.15
REA	10.2	1.90	10.1	5.31

For the urban area as a whole, as shown by Duong and Lee (2011), heavy metals in dust have a variety of sources that vary between different functional areas. Industrial activity is among the main factors affecting heavy metal levels in urban street dust, and Qin (2008) showed that the concentrations of Cu, Pb, and Zn in industrial dust in the city of Lanzhou were 368, 152, and 582 mg/kg, respectively, and industrial activity contributed 61.5 % of the heavy metals in urban dust.

The heavy metal levels in urban dust in TA was mainly affected by traffic activity, including abrasion of tires, brakes, and other auto parts; tail pipe emissions; and re-raised and sedimented road dust (Apeagyei et al. 2011). Zn release mainly results from the abrasion of tires, to which zinc oxide is added as a catalyzer during the vulcanizing process (Adachi and Yoshiaki 2004). Cu comes from brake abrasion (Apeagyei et al. 2011), and Pb may come from lead tire weights and tail pipe emissions (Caravanos et al. 2006).

Composition of resedimented road dust is more complex, containing harmful heavy metals from varied sources. Quantitative estimates calculated by Kumar et al. (2001) indicate that road dust contributes 41 % to resedimented dust, vehicular emissions 15 %, marine aerosols 15 %, metal industries 6 %, and coal combustion 6 %. Thus the resedimentation of dust is a common source of multiple heavy metals in TA.

Heavy metals in urban dust in CA come from soil, atmospheric deposition, and transportation activity. Heavy metal levels in CA are also related to peeling of urban paints (Turner and Sogo 2012), goods abrasion, and human-mediated transport of dust-containing heavy metals. Moreover, the contribution of pedestrian traffic to transporting and redistributing dust and heavy metals cannot be ignored (Hunt et al. 2006).

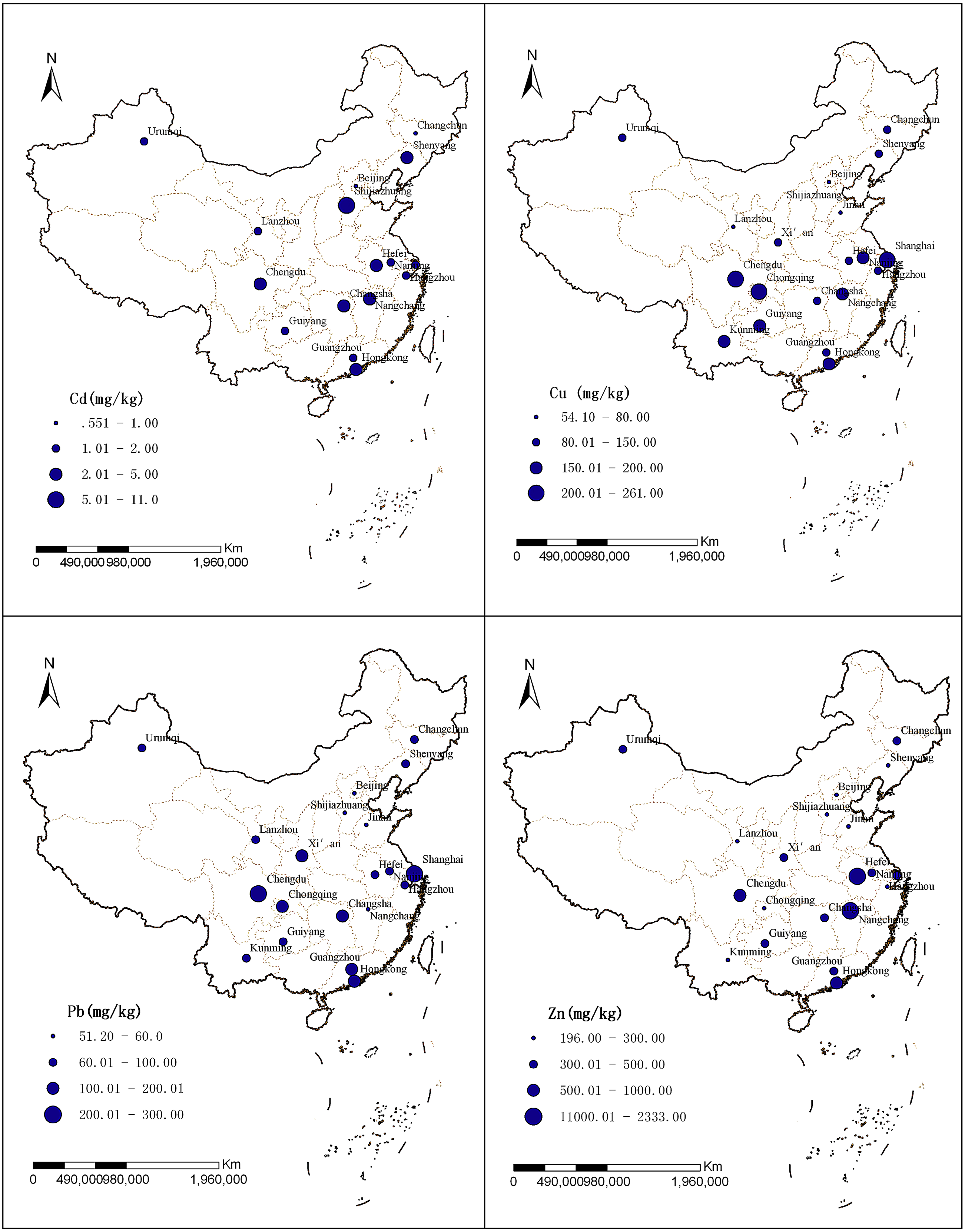

Fig. 1 Spatial distributions of Cd, Cu, Pb, and Zn in urban dust of China

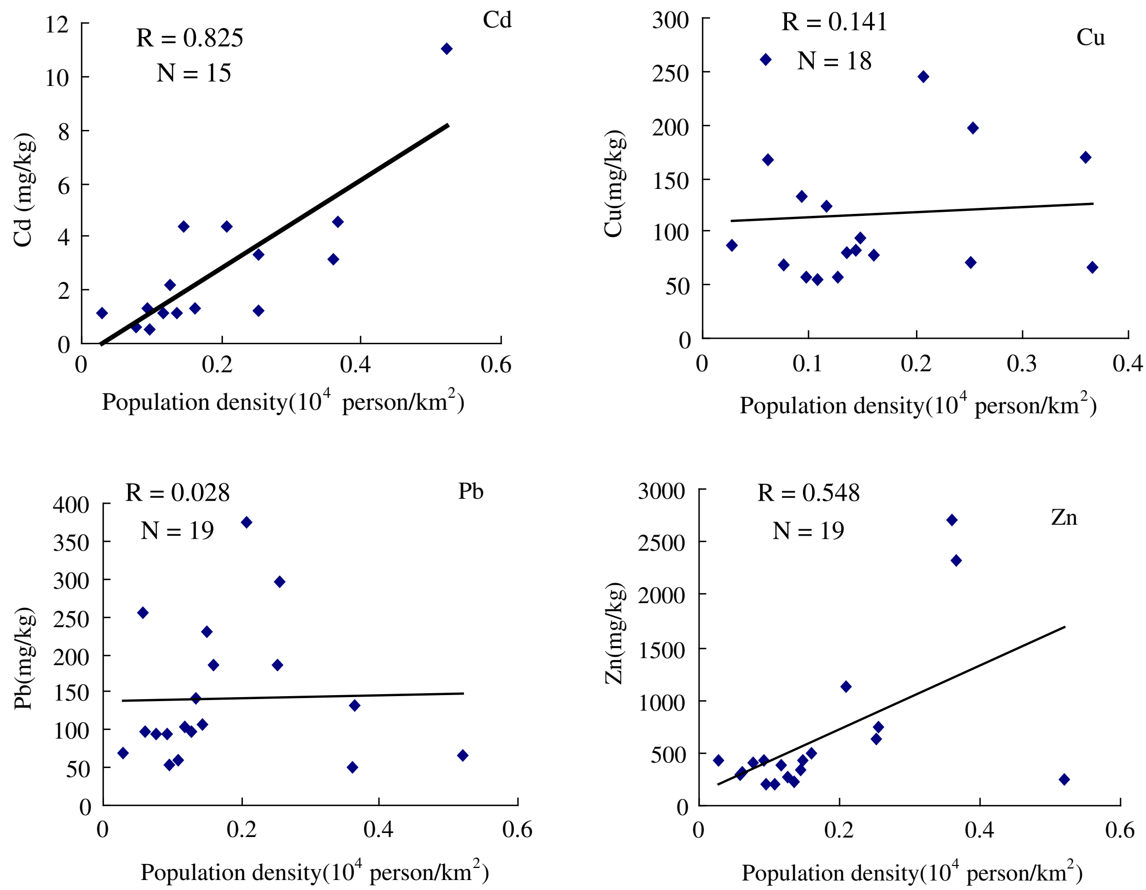

Fig. 2 Correlation between heavy metal levels in urban dust and population density (*R* relation ratio, *N* number of the data)

The sources of heavy metals in CA and in REA partially overlap, but REA have a unique source that is almost absent in other areas—indoor dust. Some indoor articles and materials may contain heavy metals (Lisiewicz et al. 2000), and construction abrasion, furniture, and cosmetics can increase heavy metal content in indoor dust as well. The metals in indoor dust may travel outside through windows and balconies or through dumping of trash. The levels of Pb, Cd, and other elements in indoor dust have been reported to be higher than in outside dust and soil (Liggans and Nriagu 1998; Tong and Lam 2000). Our work shows that the dust levels of Pb and Cd in REA are higher than in CA and TA, which may reflect the influence of indoor dust.

3 The cause of heavy metal level differences between cities

3.1 Natural background

Soil is one of the sources of dust (Hunt et al. 2006). It is an interesting question to examine whether heavy metal concentrations in dust are related to their background values in soils. Background values of the heavy metals were collected from literature (Ref Yang et al. 2010; Li et al. 2008, 2010, 2011; Wei et al. 2009; Zhao 2008; Qin 2008; Han et al. 2006; Chen et al. 2013; Shi et al. 2008; Zhang and Zhang 2007; Tang 2010 in Table 1) and from Background Value of Soil Elements in China (The National Environmental Protection Agency 1990). Correlation analysis conducted with SPSS 13.0 showed that the concentrations of Cd ($P = 0.001$), Cr ($P = 0.016$), and Cu ($P = 0.004$) in dust were significantly correlated with their background values in soils. Zn, Pb, and Ni concentrations in soil showed no significant correlation with those in dust, which might be influenced by more factors, e.g., industry types, traffic activity, climatic conditions, etc., than the corresponding soils.

3.2 Industrial activity

Besides element background values in soils, the heavy metal variation between the cities could be attributed to city history, industrial types and distributions, energy types and consumption, population, vehicles, and many other factors (Ordóñez et al. 2003). Industry related to

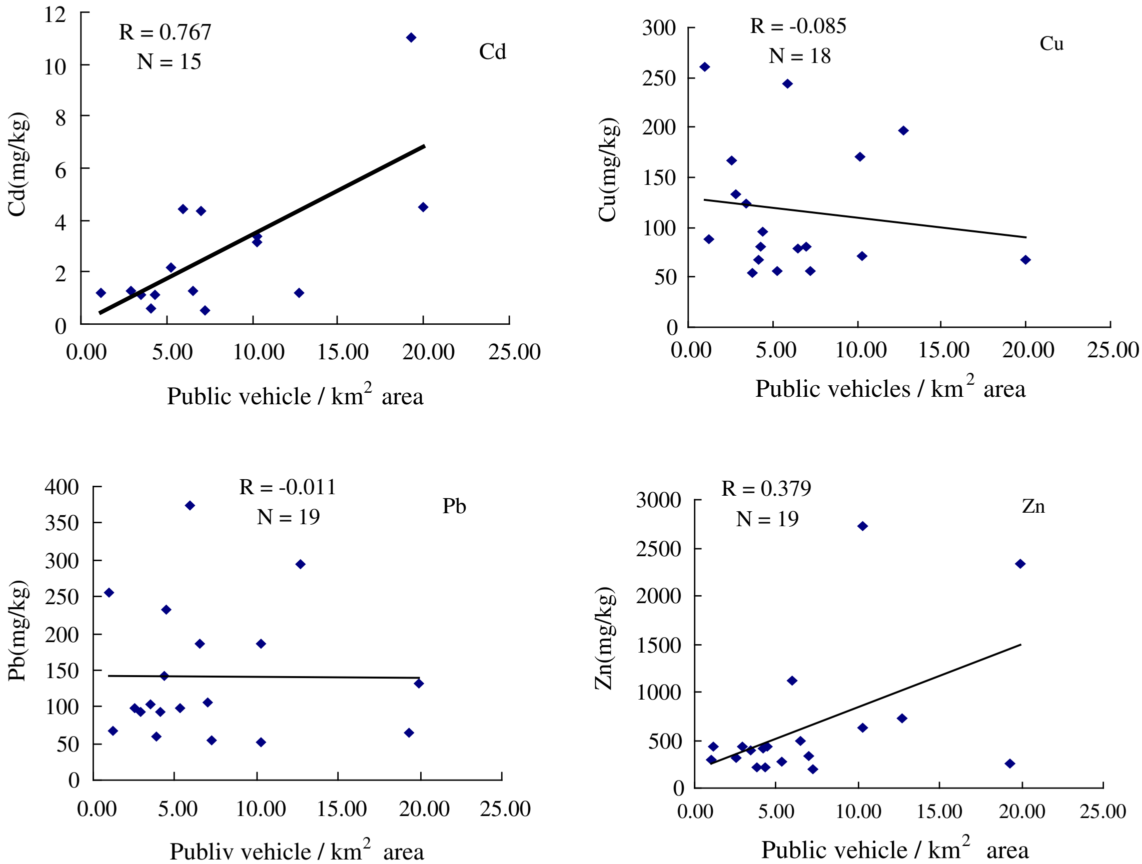

Fig. 3 Correlation between heavy metal levels in urban dust and public vehicular density (per km^2)

metallurgical activity, metal-processing, and transportation of raw materials is the most important factor influencing the metal level in dust. Different types of industry may release different heavy metals (Long et al. 2010; Liu et al. 2012). The most common element released by the iron and steel industry is Zn, and the automobile industry may increase the levels of Cu and Zn in urban dust (Meng et al. 2007). Machinery and electrofacing may be related to the release of Cd, and the thermal power industry may be connected to the release of many elements, including Pb. The distribution pattern of higher accumulations of Cu, Pb, and Zn in southern cities than in northern ones may be partly due to relatively more smelting and processing of metals in southern cities.

3.3 Population and vehicle

A comparison study of two cities of a large urban area with population of 2.3 million and a small one with population of 0.3 million (Charlesworth et al. 2003) shows that the levels of some hazard elements in large urban areas are higher than those in smaller ones, and comparison of the populations of the cities with heavy metal concentrations similarly shows that in general, the larger the population, the higher the heavy metal concentration in street dust. This is particularly true of Cd and Pb (Fig. 1).

Data for population density, area, and public transport vehicle stock (tram, bus, and taxi) of these cities during the sampling year or the year before or after the sampling year were obtained from China City Statistical Yearbook (The National Bureau of statistics, the city social economy investigation division 2004, 2006–2010, 2012). These factors' possible effects on heavy metal (Cd, Cu, Pb, and Zn) levels in urban dust were evaluated. The results are shown in Figs. 2 and 3. Correlation analysis conducted with SPSS 13.0 showed that the concentrations of Cd ($P = 0.000$) and Zn ($P = 0.015$) in dust were significantly correlated with population density; the correlation coefficients (R) were 0.825 and 0.548, respectively. No significant correlation was detected between Cu and Pb concentration and city population. The larger the population, the more complex the urban public facilities are. Urban public facilities (e.g. walls, lamp posts, railings), furniture, and other consumer products (e.g. cosmetics) all likely contain Cd, Cu, Pb, and Zn (Lisiewicz et al. 2000; Turner and Sogo 2012). This work showed the effects of

Table 3 Comparison between urban dust heavy metal levels in China and in selected cities throughout the world

City (country)	Heavy metal (mg/kg)				Collection, digestion and detection for dust	Ø (μm)	Reference
	Cd	Cu	Pb	Zn			
Oslo (Norway)	1.40	123	180	412	brush, HNO_3-HF-$HClO_4$, ICP-MS	<100	(Miguel et al. 1997)
Madrid (Spain)	/	188	1927	476	brush, HNO_3-HF-$HClO_4$, ICP-MS	<100	(Miguel et al. 1997)
Luanda (Angola) n = 92	1.13	42	351	317	brush, HCl–HNO_3–H_2O,ICP-MS	<100	(Ferreira-Baptista and de Miguel 2005)
Seoul (Korea)	2.90	101	245	296	brush, HNO_3-$HClO_4$, ICP-AES	<2000*	(Chon et al. 1995)
Birmingham (UK)	1.62	467	48	534	brush, HNO_3-$HClO_4$-H_2SO_4, AAS	<1000*	(Charlesworth et al. 2003)
Avilés (Spain)[a]	22.3	183	514	4892	brush, HNO_3-HCl, ICP-AES	<2000*	(Ordóñez et al. 2003)
Dhaka (Bangladesh)	/	46	74	154	brush, XRF	<1000*	(Ahmed and Ishiga 2006)
New York (USA)	8.0	355	2582	1811	/	/	(Fergusson and Ryan 1984)
London (UK)	2.7	108	2100	539	/	/	(Harrison et al. 1981)
Ottawa(Canada)[a]	0.33	38.1	33.5	101	brush, ICP-MS	100-250	(Rasmussen et al. 2001)
Kavala (Greece)	0.20	124	301	272	brush, HNO_3-Microwave digestion, AAS	<63	(Christoforidis and Stamatis 2009)
Christchurch (New Zealand)	/	90.8	1223	716	AAS	/	(Fergusson et al. 1986)
Tehran (Iran)	10.7	203	189	791	Broom, HCl–HNO_3–H_2O, AAS	<63	(Saeedi et al. 2012)
The GM of all above	2.19	122	336	497			
China (this study)	2.03	103	121	483			

[a] arithmetic mean, * Sample was ground prior to digestion. *XRF* X-ray fluorescence spectrometry, *AAS* atomic absorption spectrum, *ICP-AES* inductively coupled plasma atomic emission spectrometer, *ICP-MS* inductively coupled plasma mass spectrometry

population on Cd and Zn in the urban dust, but not on Pb and Cu (Table 3).

Cd also significantly correlated with the public vehicle stock. The concentrations of Cu, Pb, and Zn showed little correlation with vehicle stock. Traffic activity is one source of heavy metal in dust; the heavy metal released by traffic activity is also related to traffic flow.

From the analysis shown in the figures above, it could be inferred that population density has a stronger effect on Cd and Zn in urban dust than on Cu and Pb, while the effect on Cu, Pb, and Zn in urban dust by vehicular density is unclear, and may be confused by other factors.

4 Comparison of heavy metal levels in urban dust between China and cities in other countries

Compared with urban dust data from thirteen cities in different countries, the 20 provincial capitals in China were lower in Cd and Cu, comparable in Zn, and lower than most of the cities in Pb except for Birmingham, Dhaka, and Ottawa. Birmingham, Dhaka, and Ottawa are the only cities that have significantly lower heavy metal concentrations than the Chinese average.

Taking the geometric mean of Cd, Cu, Pb, and Zn concentrations in street dust of the 13 cities to represent the world average, means of Cd, Cu, and Zn levels of Chinese cities are close to the world average, and Pb is significantly lower than the world average. According to literature reports and development features of each city, this finding might be related to industry type as well as range and type of paint used in cities. Further discussion on this interesting question could be carried out in a subsequent study.

5 Conclusions

An analysis of heavy metal levels in urban dust in 20 capital cities in China shows that the geometric mean values of Ni and Cr are less than or close to the crustal levels, and those of Cd, Cu, Pb, and Zn are significantly greater than the crustal levels.

The spatial distributions of Cu, Pb, and Zn in urban dust are similar: all exhibit a pattern in which the metal levels in cities located in the south of China are higher than in the northern parts.

Commercial areas and residential-education areas accumulate more Cd in dust than industrial areas and traffic areas, and industrial areas and residential-education areas accumulate more Pb than commercial areas and traffic areas. Zn levels in the dust of industrial areas are significantly higher than in other areas, but Cu levels exhibit no significant difference between functional areas.

A positive correlation exists between Cd and Zn in urban dust and population density, but no obvious correlation was detected between Pb and Cu and population density. Vehicular density (per km^2) has little effect on Cu, Pb, and Zn concentrations in dust.

Urban dust Pb of cities in China is lower than the world average calculated with data of thirteen cities in different countries. Cd, Cu, and Zn levels of China are close to the world average values.

References

Adachi K, Yoshiaki Tainosho (2004) Characterization of heavy metal particles embedded in tire dust. Environ Int 30:1009–1017

Ahmed F, Ishiga H (2006) Trace metal concentrations in street dusts of Dhaka city, Bangladesh. Atmos Environ 40(21):3835–3844

Apeagyei E, Bank MS, Spengler JD (2011) Distribution of heavy metals in road dust along an urban-rural gradient in Massachusetts. Atmos Environ 45:2310–2323

Cao DX (2012) Pollution and environmental risk of heavy metals in surface dust of Taiyuan. Shanxi University, Taiyuan

Caravanos J, Weiss AL, Blaise MJ, Jaeger RJ (2006) A survey of spatially distributed exterior dust lead loadings in New York City. Environ Res 100:165–172

Charlesworth S, Everett M, McCarthy R, Ordonez A, de Miguel E (2003) A comparative study of heavy metal concentration and distribution in deposited street dusts in a large and a small urban area: Birmingham and Coventry, West Midlands, UK. Environ Int 29:563–573

Chen QL, Wang H, Yang BS, Wang XJ, Shao FL, Dai JL (2013) Determination and pollution assessment of heavy metal in surface dust from Jinan City. J Univ Jinan (Sci Technol) 27:428–432

Chon H-T, Kim K-W, Kim J-Y (1995) Metal contamination of soils and dusts in Seoul metropolitan city, Korea. Environ Geochem Health 17(3):139–146

Christoforidis A, Stamatis N (2009) Heavy metal contamination in street dust and roadside soil along the major national road in Kavala's region, Greece. Geoderma 151:257–263

de Miguel E, Llamas JF, Chacón E et al (1997) Origin and patterns of distribution of trace elements in street dust: unleaded petrol and urban lead. Atmos Environ 31(17):2733–2740

Duong TTT, Lee BK (2011) Determining contamination level of heavy metals in road dust from busy traffic areas with different characteristics. J Environ Manag 92:554–562

Duzgoren-Aydin NS, Wong CSC, Aydin A, Song Z, You M, Li XD (2006) Heavy metal contamination and distribution in the urban environment of Guangzhou, SE China. Environ Geochem Health 28:375–391

Fergusson JE, Ryan DE (1984) The elemental composition of street dust from large and small urban areas related to city type, source and particle size. Sci Total Environ 34:101–116

Fergusson JE, Forbes EA, Schroeder RJ et al (1986) The elemental composition and sources of house dust and street dust. Sci Total Environ 50:217–221

Ferreira-Baptista L, de Miguel E (2005) Geochemistry and risk assessment of street dust in Luanda, Angola: a tropical urban environment. Atmos Environ 39:4501–4512

Han Y, Du P, Cao J, Posmentier ES (2006) Multivariate analysis of heavy metal contamination in urban dusts of Xi'an, Central China. Sci Total Environ 355:176–186

Han Y, Cao J, Posmentier ES, Fung K, Tian H, An Z (2008) Particulate-associated potentially harmful elements in urban road dusts in Xi'an, China. Appl Geochem 23:835–845

Harrison RM, Laxen DPH, Wilson SL (1981) Chemical associations of lead, cadmium, copper and zinc in street dusts and roadside soils. Environ Sci Technol 15:1378–1383

Hu X, Zhang Y, Luo J, Wang T, Lian H, Ding Z (2011) Bioaccessibility and health risk of arsenic, mercury and other metals in urban street dusts from a mega-city, Nanjing, China. Environ Pollut 159:1215–1221

Hunt A, Johnson DL, Griffith DA (2006) Mass transfer of soil indoors by track-in on footwear. Sci Total Environ 370:360–371

Kumar AV, Patil RS, Nambi KS (2001) Source apportionment of suspended particulate matter at two traffic junctions in Mumbai, India. Atmos Environ 35(25):4245–4251

Li XY (2013) The influence of season change to the level of heavy metals in outdoor settled dusts in different function areas of Guiyang City. Environ Sci 34:2407–2415

Li XD, Poon CS, Liu PS (2001) Heavy metal contamination of urban soils and street dusts in Hong Kong. Appl Geochem 16:1361–1368

Li C, Li FY, Zhang Y, Liu TW, Hou W (2008) Spatial distribution characteristics of heavy metals in street dust in Shenyang city. Ecol Environ 17:560–564

Li XY, Chen TB, Lei M, Xie YF, Zhou GD, Song B (2010) Concentrations and risk of heavy metals in surface soil and dust in urban squares and school campus in Beijing. Geogr Res 29:2–9

Li RZ, Zhou AJ, Tong F, Wu YD, Zhang P, Yu J (2011) Distribution of metals in urban dusts of Hefei and health risk assessment. Environ Sci 32:2661–2668

Li XY, Chen P, Cao YJ, Li BD (2012a) The level of As and Ni in street dust fractions of different sizes and its contributions in Guiyang. Earth Environ 40:238–242

Li XY, Li BD, Chen P, Cao YJ (2012b) The distribution characteristics of Cd in different function area of city—Take Guiyang city for example. J Huazhong Agric Univ 31:33–37

Liang T, Shi ZT, Wu F, Gu XM (2011) Heavy metal pollution and the ecological risk assessment of urban street dust in Kunming. Trop Geogr 31:164–170

Liggans GL, Nriagu JO (1998) Lead poisoning of children in Africa, IV: exposure to dust lead in primary schools in south-central Durban, South Africa. Sci Total Environ 221:117–126

Lisiewicz M, Heimburger R, Golimowski J (2000) Granulometry and the content of toxic and potentially toxic elements in vacuum-cleaner collected, indoor dusts of the city of Warsaw. Sci Total Environ 263:69–78

Liu YY, Liu HF, Liu M (2009) Concentrations and health risk assessment of urban surface dust in Urumqi. Arid Zone Res 26:750–754

Liu DH, Wang FY, Zhou WL, Yang YJ (2012) Heavy metal pollution in street dusts from different functional zones of Luoyang City and its potential ecological risk. Environ Sci 33:253–259

Long YZ, Zou HY, Dai TG (2010) Heavy metal pollution in dust of Chang-Zhu-Tan city region. J Central South Univ (Sci Technol) 41:1633–1638

Meng F, Liu M, Hou LJ, Chang J, Jiang HY, Wang HY (2007) Heavy metals in urban dusts and soils of Shanghai and its pollution assessment. J East China Normal Univ (Nat Sci) 4:56–63

Ordóñez A, Loredo J, Miguel ED, Charlesworth S (2003) Distribution of heavy metals in the street dusts and soils of an industrial city in Northern Spain. Arch Environ Contam Toxicol 44:160–170

Qin S (2008) Distribution, source and quality assessment of heavy metals in urban street dust of Xigu Region. Lanzhou University, Lanzhou

Rasmussen PE, Subramanian KS, Jessiman BJ (2001) A multi-element profile of house dust in relation to exterior dust and soils in the city of Ottawa, Canada. Sci Total Environ 267:125–140

Saeedi M, Li LY, Salmanzadeh M (2012) Heavy metals and polycyclic aromatic hydrocarbons: pollution and ecological risk assessment in street dust of Tehran. J Hazard Mater 227–228:9–17

Shi GT, Chen ZL, Xu SY, Zhang J, Wang L, Bi CJ, Teng JY (2008) Potentially toxic metal contamination of urban soils and roadside dust in Shanghai, China. Environ Pollut 156:251–260

Tang FW (2010) Pollution characteristics and chemical speciation study of heavy metal in urban street dust of Nanchang. Nanchang University, Nanchang

Tang RL, Ma KM, Zhang YX, Mao QZ (2013) The spatial characteristics and pollution levels of metals in urban street dust of Beijing, China. Appl Geochem 35:88–98

The National Bureau of Statistics, the City Social Economy Investigation Division, China (2004, 2006, 2007, 2008, 2009, 2010, 2012) City statistical yearbook. China statistics Press, Beijing

The National Environmental Protection Agency (1990) Background value of soil elements in China. Press C.E.S, Beijing

Tong STY, Lam KC (2000) Home sweet home? A case study of household dust contamination in Hong Kong. Sci Total Environ 256:115–123

Turner A, Sogo YSK (2012) Concentrations and bioaccessibilities of metals in exterior urban paints. Chemosphere 86:614–618

Wang PL (2004) The physical characteristics and the spatial distributional characteristics of the air dust near the ground in Chengdu. Chengdu University of Technology, Chengdu

Wang XL (2008) Pollution analyse of street dust in core district of Chongqing. Southwest University, Kenner

Wei BG, Yang LS (2010) A review of heavy metal contaminations in urban soils, urban road dusts and agricultural soils from China. Microchem J 94:99–107

Wei BG, Jiang FQ, Li XM, Mu SY (2009) Spatial distribution and contamination assessment of heavy metals in urban road dusts from Urumqi, NW China. Microchem J 93:147–152

Yang ZP, Lu WX, Liu XR, Xin X (2010) Heavy metal identification for near- surface urban dust in Changchun City. J Arid Land Resour Environ 24:155–160

Zhang HM, Zhang MK (2007) The concentration and availability of pollutants in road dust from different functional zones of Hangzhou City. GuangDong WeiLiang YuanSu KeXue 14:14–18

Zhao Z (2008) Research on heavy metal pollution in the street dusts in Shijiazhuang City. Hebei Normal University, Shijiazhuang

Zhao LS, Zhang BR (1988) Geochemistry. Geological Publishing House, Beijing