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Review article

A review of heavy metal contaminations in urban soils, urban road dusts and agricultural soils from China

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ABSTRACT

This paper reviews quite a few heavy metal contamination related studies in several cities from China over the past 10 years. The concentrations, sources, contamination levels, sample collection and analytical tools of heavy metals in urban soils, urban road dusts and agricultural soils were widely compared and discussed in this study. The results indicate that nearly all the concentrations of Cr, Ni, Cu, Pb, Zn, As, Hg and Cd are higher than their background values of soil in China. Among the cities, the contamination levels of the heavy metals vary in a large range. The geoaccumulation index shows that the contamination of Cr, Ni, Cu, Pb, Zn and Cd is widespread in urban soils and urban road dusts of the cities. Generally, the contamination levels of Cu, Pb, Zn and Cd are higher than that of Ni and Cr. Agricultural soils are also significantly influenced by Cd, Hg and Pb derived from anthropogenic activities. The integrated pollution index (IPI) indicates that the urban soils and urban road dusts of the developed cities and the industrial cities have higher contamination levels of the heavy metals. The comparison of the IPIs of heavy metals in urban soils and urban road dusts of Shanghai, Hangzhou, Guangzhou and Hongkong reveals that the contamination levels of the metals in urban road dusts are higher than that in urban soils in the cities. Moreover, the main sources of the metals in urban soils, urban road dusts and agricultural soils are also different.

Contents

1. Introduction

The properties of heavy metals in urban soils, urban road dusts and agricultural soils are still topical. This fact can be well documented in enhancing the count of article in recent years [1]. The enhancement is probably attributed to the potential public health risk associated with

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intake of heavy metals. In urban area, heavy metals in urban soils and urban road dusts can be accumulated in human body via directly inhalation, ingestion and dermal contact absorption [2–10]. However, intake of heavy metals via the soil-crop system has been considered as the predominant pathway of human exposure to environmental heavy metals in agricultural area [11]. According to numerous studies, the pollution sources of heavy metals in environment are mainly derived from anthropogenic sources. In urban soils and urban road dusts, the anthropogenic sources of heavy metals include traffic emission (vehicle exhaust particles, tire wear particles, weathered street surface particles, brake lining wear particles), industrial emission (power plants, coal combustion, metallurgical industry, auto repair shop, chemical plant, etc.), domestic emission, weathering of building and pavement surface, atmospheric deposited and so on [9,10,12–26]. However, the anthropogenic sources of heavy metals in agricultural soils include mining, smelting, waste disposal, urban effluent, vehicle exhausts, sewage sludge, pesticides, fertilizers application and so on [27–31].

In China, heavy metal pollution in urban soils, urban road dusts and agricultural soils becomes serious with the rapidly industrialization and urbanization during the last two decades. Cheng (2003) reported that the geological background levels of heavy metals are low in China, while soil, water, air and plants are polluted by heavy metals in some studied cases and even affect human health through the directly intake or the food chain because of anthropogenic activities in recent decades [32]. Therefore, quite a few studies associated with heavy metal contamination in urban soils, urban road dusts and agricultural soils in several cities have been carried out during the past decade. The related cities are presented in the schematic map of China (Fig. 1). However, the quantitative data on heavy metal concentrations, their contamination levels and their pollution sources have not been systematically gathered and intercompared. Therefore, this study focuses on heavy metal contamination in urban soils, urban road dusts and agricultural soils in China. The sources, concentrations, contamination levels, sample collection and analytical tools of heavy metals are elucidated in this paper. The spatial distribution of the integrated pollution index (IPI) of heavy metals in urban soils and urban road dusts in the cities from China are also discussed.

2. Sampling strategy and sample processing method

The sampling strategy, analytical tools and determined metals of the related studies are listed in Tables 1–3. The urban soil and agricultural soil samples were mainly collected to a depth of 10 cm or 20 cm. The urban soil samples were mainly collected from urban parks, green lands and roadside of the cities. Several soil samples were taken and then mixed thoroughly to obtain a bulk sample for each sampling site in Beijing, Yangzhou and some others. The road dust samples were mainly collected by sweeping an area of about 1 m^2 from road surface using a clean plastic dustpan and brushes for each sampling site. The soil samples and the road dust samples were dried thoroughly and then sieved through a <2 mm sieve. Then, the sieved soil samples and road dust samples were digested with a mixed acid such as HF, $HClO_4$, HNO_3, H_2O_2, Aqua regia, H_2SO_4 or Boric acid. Finally, the total concentrations of Cd, Cr, Cu, Ni, Pb, Zn, As and Hg were determined by ICP, ICP-MS, ICP-AES, ICP-OES, CV-AAS, AAS, XFS or XRF. These sample processing methods and analytical tools are all acceptable.

3. Heavy metal concentrations

The concentrations of Cd, Cr, Cu, Ni, Pb and Zn in urban soils and urban road dusts are shown in Tables 4 and 5, respectively. The concentrations of Cd, Cr, Cu, Ni, Pb, Zn, As and Hg in agricultural soils are presented in Table 6. To facilitate evaluation and comparison the values, the background values of the metals in soil derived from Chinese Environmental Protection Administration (CEPA, 1990) [67] and the value for the "maximum permissible concentrations of potential toxic elements (PTE-MPC)" for agricultural soils according to soil quality standards of China (CEPA, 1995) [68] are also shown in the Tables 4–6. Moreover, the mean and the ranges of the metal concentrations of all the cities in China are also shown in the Tables 4–6.

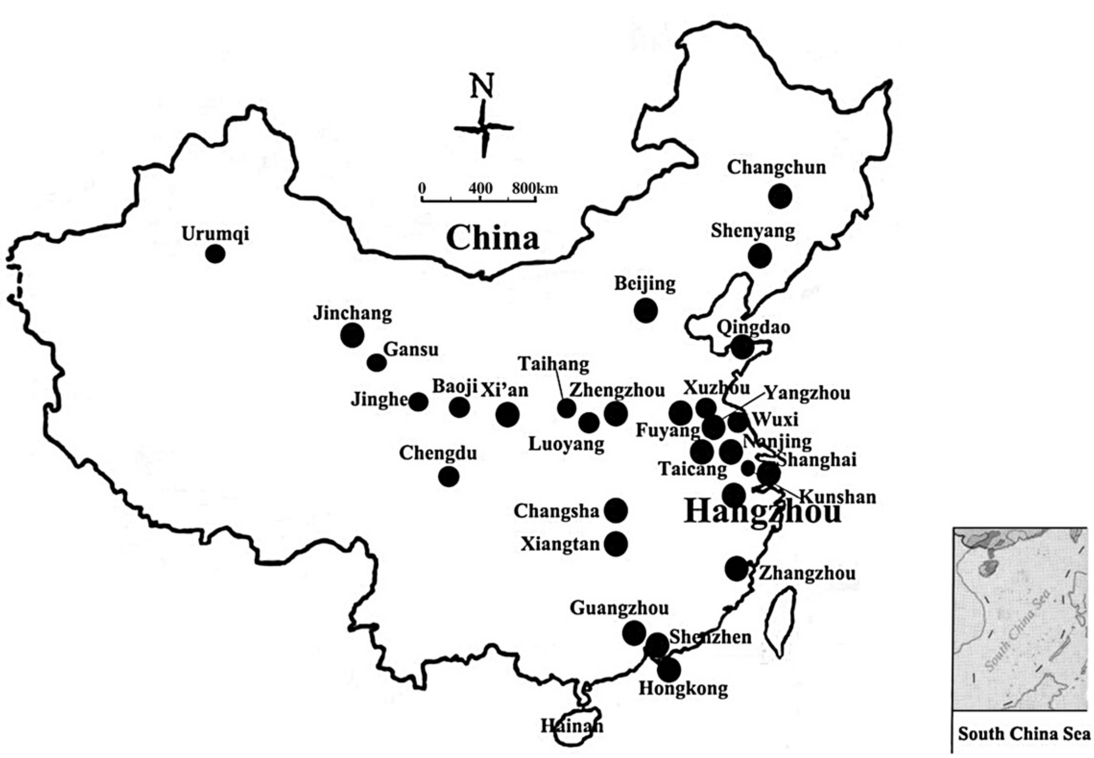

Fig.1. The schematic map of China.

Table 1
Materials and methods of heavy metal contamination in urban soils in the cities from China.

City	No. of samples	Depth (cm)	Digestion	Analysis method and metals	Reference
Beijing	773	20	$HNO_3+H_2O_2$	AAS (Cr, Cu, Ni, Pb, Zn, Cd)	[33]
Changchun	39	20	Aqua regia	FAAS (Cu, Ni, Pb, Zn, Cd)	[34]
Taicang	54	20	$HF+HCLO_4+HNO_3$	ICP (Cr, Cu, Ni, Pb, Zn), AAS (Cd)	[35]
Fuyang	286	20	HNO_3+HCLO_4	ICP-MS (Cd, Cu, Ni, Pb), ICP-OES (Zn)	[36]
Guangzhou	40	10	$HNO_3+HF+HCLO_4$	FAAS (Cu, Ni, Pb, Zn), AAS (Cd)	[37]
Hangzhou	82	10	$HNO_3+HF+HCL$	ICP-AES (Cd, Cr, Cu, Ni, Pb, Zn)	[38]
Luoyang	215	10	$HF+HCLO_4+HNO_3$	AAS (Cd, Cr, Cu, Pb, Zn)	[39]
Nanjing	138	20	$HF+HCLO_4+HNO_3$	ICP (Cr, Cu, Pb, Zn)	[40]
Shanghai	273	10	$HF+HCLO_4+HNO_3$	AAS (Cr, Cu, Ni, Pb, Zn), GFAAS (Cd)	[41]
Wenzhou	21	20	$HF+HCLO_4+HNO_3$	AAS (Cd, Cu, Pb, Zn)	[42]
Changsha	110	20	$HF+HCLO_4+HNO_3$	AAS (Cd, Cr, Cu, Pb, Zn)	[43]
Xiangtan	54	20	$HF+HCLO_4+HNO_3$	AAS (Cd, Cr, Cu, Pb, Zn)	[44]
Zhangzhou	108	20	$HF+H_2SO_4+HNO_3$	XFS (Cr, Cu, Ni, Pb, Zn), GFAAS (Cd)	[45]
Shenyang	20	20	$HF+HCLO_4+HNO_3$	AAS (Cd, Cu, Pb, Zn)	[46]
Hongkong	48	15	$HF+HCLO_4+HNO_3$	ICP-AES (Cd, Cr, Cu, Ni, Pb, Zn)	[47]
Qingdao	319	10	$HF+HCLO_4+HNO_3$	ICP-MS + XRF (Cd, Cr, Cu, Ni, Pb, Zn)	[48]
Baoji	10	10	Boric acid	XRF (Cr, Cu, Ni, Pb, Zn)	[49]
Jinchang	30	10	$HNO_3+H_2O_2$	AAS (Cd, Cr, Cu, Ni, Pb, Zn)	[50]
Shenzhen	25	20	$HF+HCLO_4+HNO_3$	AAS (Cu, Pb, Zn), GFAAS (Cd)	[51]
Xuzhou	21	10	$HF+HCLO_4+HNO_3$	ICP-MS + ICP-AES (Cd, Cr, Cu, Ni, Pb, Zn)	[52]

Table 2
Materials and methods of heavy metal contamination in urban road dust in the cities from China.

City	No. of samples	Digestion	Analysis method and metals	Reference
Xi'an	65	$HF+H_2SO_4+HNO_3+HCLO_4$	AAS (Cr, Cu, Pb, Zn)	[17]
Hangzhou	25	$HF+H_2SO_4+HCL$	ICP-AES (Cd, Cr, Cu, Ni, Pb, Zn)	[53]
Shanghai-1	273	$HF+HNO_3+HCLO_4$	AAS (Cr, Cu, Ni, Pb, Zn), GFAAS (Cd)	[41]
Shanghai-2	201	$HF+HNO_3+HCLO_4$	AAS (Cu, Ni, Pb, Zn)	[54]
Shanghai-3	237	$HF+HNO_3+HCLO_4$	AAS (Cr, Cu, Ni, Pb, Zn)	[55]
Guangzhou	30	$HF+HNO_3+HCLO_4$	ICP-MS (Cd, Cr, Cu, Ni, Pb, Zn)	[15]
Baoji	38	Boric acid	XRF (Cu, Ni, Pb, Zn)	[19]
Urumqi	169	$HF+HNO_3+HCLO_4$	ICP-MS (Cd, Cr, Cu, Ni, Pb, Zn)	[56]
Hongkong	45	HNO_3	ICP-AES (Cd, Cu, Pb, Zn)	[57]

According to the intercomparison of the heavy metal concentrations in urban soils, urban road dusts and agricultural soils, the concentrations of the metals in different environments are followed a descending order as: urban road dusts > urban soils > agricultural soils. The ranges of the metal concentrations are also very wide among the cities.

3.1. Heavy metal concentrations in urban soils

In all the cities from China, the mean concentrations of Cr, Cu, Pb, Zn, Ni, and Cd in urban soils are 78.43, 115.07, 1350.51, 266.40, 99.48 and 1.58 mg/kg, respectively. The concentration ranges of the metals are observed to be 23.1–194.7, 23.3–1226.3, 28.6–25380.55, 65.6–1964.12, 27.8–910.3 and 0.15–8.59 mg/kg (Table 4). It is also significantly apparent that the concentrations of Cd, Cu, Pb and Zn in the urban soils in all the cities exceed their background values. All the other metals exhibit values below or slightly above the background values. The concentrations of Cr, Cu, Pb, Zn and Ni in urban soils in Shenyang, Baoji and Jinchang are much higher than their PTE-MPC. The highest concentrations of the metals are also found in the three cities. This may be attributed to the urban soil samples which were mainly collected from industrial areas in Shenyang, Baoji and Jinchang. The concentrations of Cd in the cities are all higher than their PTE-MPC with an exception of Taicang and Beijing.

3.2. Heavy metal concentrations in urban road dusts

The mean concentrations of Cr (109.16), Cu (149.62), Pb (238.66), Zn (655.94), Ni (56.75) and Cd (2.03) mg/kg in urban road dusts of all the cities from China are much higher than their background values in soil of China. The concentration ranges of the metals are observed to

Table 3
Materials and methods of heavy metal contamination in agricultural soil in the cities from China.

City	No. of samples	Depth (cm)	Digestion	Analysis method and metals	Reference
Zhengzhou	8	20	$HF+HNO_3+HCLO_4$	FAAS (Cd, Cr, Pb), CV-AAS (As, Hg)	[11]
Yangzhou	76	20	$HF+HNO_3+HCLO_4+HCL$	XFS (Cr, Ni, Pb, Zn), CV-AAS (As, Hg) GFAAS (Cd)	[58]
Wuxi	102	20	HNO_3+HCL	FAAS (Cd, Cr, Cu, Pb, Zn), CV-AAS (Hg), AFS (As)	[59]
Guangzhou	70	20	$HF+HNO_3+HCLO_4$	FAAS (Cu, Zn), GFAAS (Cd, Pb), CV-AAS (Hg), AFS (As)	[60]
Taihang	100	20	$HNO_3+HCL+H_2O_2$	FAAS (Cr, Cu, Ni, Zn), GFAAS (Cd, Pb), AFS (As, Hg)	[31]
Gansu	60	20	$HNO_3+H_2SO_4+K_2Cr_2O_7$	ICP-MS (Cr, Cu, Pb, As), CV-AFS (Hg)	[30]
Beijing	6	20	Aqua regia	ICP-OES + ICP-MS (Cd, Cr, Cu, Pb, Zn)	[61]
Chengdu	30	10	$HF+HNO_3+HCLO_4$	AAS (Cd, Cr, Cu, Pb, Zn), AFS (As, Hg)	[62]
Hainan	26	20	$HF+HNO_3+HCLO_4$	ICP-MS (Cd, Cr, Cu, Ni, Pb, Zn, As)	[63]
Jinghe	14	20	$HF+HNO_3+H_2SO_4$	AAS (Cd, Cr, Pb), AFS (As),	[64]
Kunshan	240	20	$HF+HNO_3+H_2SO_4$	AAS (Cd, Cr, Cu, Pb, Ni, Zn), CV-AAS (As, Hg)	[65]
Xuzhou	20	20	$HF+HNO_3+HCLO_4$	AAS (Cd, Cr, Cu, Pb, Zn)	[66]

Table 4
Concentrations of heavy metals in urban soils in the cities from China (mg/kg) (PTE-MPC = "maximum permissible concentrations of potential toxic elements" for agricultural soils of China; China B. = background values in soil of China).

City	Cr	Cu	Pb	Zn	Ni	Cd	Reference
Beijing	35.6	23.7	28.6	65.6	27.8	0.15	[33]
Changchun		41.85	54.81	109.69	73.50	2.92	[34]
Taicang	63.61	32.37	17.98	92.01	29.95	0.11	[35]
Fuyang		40.77	40.59	159.85	21.92	0.37	[36]
Guangzhou		62.57	108.55	169.24	25.67	0.50	[37]
Hangzhou	47.5	41.0	75.7	148	24.1	1.30	[38]
Luoyang	71.42	85.40	65.92	215.75		1.71	[39]
Nanjing	84.7	66.1	107.3	162.6			[40]
Shanghai	107.9	59.25	70.69	301.4	31.14	0.52	[41]
Wenzhou		34.59	65.22	169.40			[42]
Changsha	121	51.4	89.4	276		6.9	[43]
Xiangtan	84	37.5	65	127		0.46	[44]
Zhangzhou	29.7	32.6	75.9	106.7	12.8	0.35	[45]
Shenyang		209.06	470.19	599.92		8.59	[46]
Hongkong	23.1	23.3	94.6	125	12.4	0.62	[47]
Qingdao	54	55.0	62	201	17.3	0.3	[48]
Baoji	102.4	112.14	25380.55	1964.12	72.1		[49]
Jinchang	194.7	1226.3	40.3	118.0	910.3	1.11	[50]
Shenzhen		28.33	53.59	72.68		0.39	[51]
Xuzhou	78.4	38.2	43.3	144.1	34.3	0.54	[52]
Range	23.1–194.7	23.3–1226.3	28.6–25380.55	65.6–1964.12	27.8–910.3	0.15–8.59	
Mean	78.43	115.07	1350.51	266.40	99.48	1.58	
China B.	61	22.6	26	100	26.9	0.097	[67]
PTE-MPC	200	100	300	250	50	0.3	[68]

be 51.29–167.28, 94.98–196.8, 53.33–408.4, 294.47–1450, 23–86.26 and 1.17–3.77 mg/kg. The mean concentrations of Cu, Zn, Ni and Cd are also higher than their PTE-MPC (Table 5). Similarly, the concentrations of the metals in urban road dust of each city are higher than their background values with an exception of Cr in Hangzhou and Urumqi, and Ni in Guangzhou and Hangzhou. Moreover, the concentrations of Cu, Zn and Cd in each city exceed their PTE-MPC with an exception of Cu concentrations in urban road dusts of Xi'an and Urumqi. However, the concentrations of Cr in road dusts of all the cities are lower than the PTE-MPC. The highest concentrations of Cu, Zn and Ni are found in Shanghai, while the highest concentrations of Cr, Pb and Cd are found in Xi'an, Baoji and Hongkong, respectively. Table 5 also shows that the concentrations of Cu, Pb, Zn and Ni vary little in Shanghai among the three studied cases.

3.3. Heavy metal concentrations in agricultural soils

The mean concentrations of Cu (31.71), Pb (37.55), Zn (117.72), Ni (27.53), Cd (0.43) and Hg (0.24) mg/kg in agricultural soils of all the 12 cities are higher than their background values, while the mean concentrations of Cr (58.87) and As (10.18) mg/kg are lower than their background values (Table 6). In most of the cities, the concentrations of Cr, Cu, Pb, Zn, Ni, Cd, Hg and As in agricultural soils are higher than their background values. However, the metal concentrations in agricultural soils of all the cities are lower than their PTE-MPC with an exception of Cd concentrations in Xuzhou and Chengdu, and Hg concentrations in Guangzhou and Chengdu.

4. Contamination levels of heavy metals

The contamination levels of heavy metals in urban soils, urban road dusts and agricultural soils are assessed by using geoaccumulation index (I_{geo}) introduced by Muller (1969). The method has been widely employed in European trace metal studies since the late 1960s [69]. The I_{geo} is used to assess heavy metal contamination in urban soils by comparing current and pre-industrial concentrations, although it is not always easy to reach pre-industrial sediment layers. It is also employed in pollution assessment of heavy metals in urban road dust. Geoaccumulation index is computed using the following equation [69,70]:

$$I_{geo} = \log_2(C_n / 1.5B_n) \quad (1)$$

where C_n is the measured concentration of the element in environment, B_n is the geochemical background value in soil. In this study, the background geochemical compositions of the city soil types [67] are

Table 5
Concentrations of heavy metals in urban road dusts in the cities from China (mg/kg) (PTE-MPC = "maximum permissible concentrations of potential toxic elements" for agricultural soils of China; China B. = background values in soil of China).

City	Cr	Cu	Pb	Zn	Ni	Cd	Reference
Xi'an	167.28	94.98	230.52	421.46	–	–	[17]
Hangzhou	51.29	116.04	202.16	321.4	25.88	1.59	[53]
Shanghai	159.3	196.8	294.9	733.8	83.98	1.23	[41]
Shanghai1	–	182	264	673	86	–	[54]
Shanghai2	144.01	190.01	273.45	708.25	86.26	–	[55]
Guangzhou	78.8	176	240	586	23	2.41	[15]
Baoji	–	123.17	408.41	715.10	48.83	–	[19]
Urumqi	54.28	94.54	53.53	294.47	43.28	1.17	[56]
Hongkong	–	173	181	1450	–	3.77	[57]
Range	51.29–167.28	94.98–196.8	53.33–408.41	294.47–1450	23–86.26	1.17–3.77	
Mean	109.16	149.62	238.66	655.94	56.75	2.03	
China B.	61	22.6	26	100	26.9	0.097	[67]
PTE-MPC	200	100	300	250	50	0.3	[68]

Table 6
Concentrations of heavy metals in agricultural soils in the cities from China (mg/kg) (PTE-MPC = "maximum permissible concentrations of potential toxic elements" for agricultural soils of China; China B. = background values in soil of China).

City	Cr	Cu	Pb	Zn	Ni	Cd	Hg	As	Reference
Zhengzhou	60.67	–	17.11	–	–	0.12	0.08	6.69	[11]
Yangzhou	77.2	33.9	35.7	98.1	38.5	0.3	0.2	10.2	[58]
Wuxi	58.6	40.4	46.7	112.9	–	0.14	0.16	14.3	[59]
Guangzhou	64.65	24.0	58.0	162.6	–	0.28	0.73	10.9	[60]
Taihang	57.77	21.22	18.80	69.96	25.04	0.15	0.08	6.16	[31]
Gansu	38.82	27.20	21.44	–	–	–	0.15	11.17	[30]
Beijing	75.74	28.05	18.48	81.10	–	0.18	–	–	[61]
Chengdu	59.50	42.52	77.27	227.00	–	0.36	0.31	11.27	[62]
Hainan	22.67	30.25	48.01	52.17	15.51	0.28	–	8.06	[63]
Jinghe	44.21	–	22.44	–	–	0.14	–	14.89	[64]
Kunshan	87.73	34.27	30.48	105.93	31.08	0.20	0.20	8.15	[65]
Xuzhou	–	35.28	56.20	149.68	–	2.57	–	–	[66]
Range	22.67–87.73	21.22–42.52	17.11–77.27	52.17–227	15.51–38.5	0.12–2.57	0.08–0.73	6.16–14.89	
Mean	58.87	31.71	37.55	117.72	27.53	0.43	0.24	10.18	
China B.	61	22.6	26.0	74.2	26.9	0.097	0.065	11.2	[67]
PTE-MPC	200	100	300	250	50	0.3	0.3	30	[68]

chosen as the background values for calculating the I_{geo} values. The constant 1.5 allows us to analyze natural fluctuations in the content of a given substance in the environment and to detect very small anthropogenic influences [67,68]. According to Muller (1969) [69], the I_{geo} for each metal is calculated and classified as: uncontaminated ($I_{geo} \leq 0$); uncontaminated to moderately contaminated ($0 < I_{geo} \leq 1$); moderately contaminated ($1 < I_{geo} \leq 2$); moderately to heavily contaminated ($2 < I_{geo} \leq 3$); heavily contaminated ($3 < I_{geo} \leq 4$); heavily to extremely contaminated ($4 < I_{geo} \leq 5$); extremely contaminated ($I_{geo} \geq 5$). The I_{geo} values for the metals in urban soils, urban road dusts and agricultural soils for each city are presented in Tables 7–9, respectively.

4.1. Contamination levels of heavy metals in urban soils

In general Cr and Ni appear to be the least contaminated elements in all the cities, while Cu, Pb, Zn and Cd show the highest I_{geo} values for most cities (Table 7). In all the cities, ranges in I_{geo} values for the metals are very wide, confirming the variability of urban soils properties and pollution sources of heavy metals.

Among the cities, Beijing, Taicang, Xiangtan and Zhangzhou appear to be the least contaminated cities with low I_{geo} values for Cr, Cu, Pb, Zn, Ni and Cd, while Shenyang, Baoji and Jinchang, three heavy industrial cities, show the highest I_{geo} values for the metals. The I_{geo} values for Cr in Changsha, Qingdao, Baoji and Jinchang are 0.12, 0.15, 0.11 and 0.74, respectively. This indicates that the urban soils in these cities are uncontaminated to moderately contaminated by Cr, while the urban soils in the other cities are uncontaminated by Cr. Except for Beijing, Taicang, Xiangtan, Zhangzhou, Shenyang, Baoji and Jinchang, the I_{geo} values for Cu, Pb, Zn and Cd in the other cities are in the range from 0 to 3. This indicates that the urban soils in these cities are uncontaminated to moderately contaminated by the metals. The highest I_{geo} values for Pb (6.48) and Zn (2.87) are found in Baoji. The highest I_{geo} values for Cu (3.70) and Ni (3.12) are found in Jinchang, while the highest I_{geo} value for Cd (3.60) is found in Changsha. This indicates that the urban soils in these cities are significantly contaminated by the corresponding metals.

Moreover, the mean I_{geo} values for Cr, Cu, Pb, Zn, Ni and Cd in urban soils of all the cities from China are −0.15, 1.22, 3.54, 0.57, 0.90 and 2.39, respectively. The data suggests that Cr falls into the category of "uncontaminated". Cu, Zn and Ni fall into the category of "uncontaminated to moderately contaminated", while Pb and Cd fall into the category of "moderately contaminated to heavily contaminated" in China.

4.2. Contamination levels of heavy metals in urban road dusts

Nearly all the I_{geo} values for Cr, Cu, Pb, Zn, Ni and Cd in urban road dusts in the cities are higher than 0 (Table 8). This indicates that the urban road dusts in these cities are contaminated by the metals derived from anthropogenic sources. The I_{geo} values for Pb, Zn, Cu and Cd indicate that contamination levels of the metals in urban road dusts of the developed cities (Shanghai and Guangzhou) and the industrial cities (Baoji) are higher than that of the other cities. The I_{geo} values for Cr and Ni indicate that the urban road dusts in all the cities are lowly contaminated by the two metals. Xi'an, Hongkong and

Table 7
Geo-accumulation index of heavy metals in urban soils in the cities from China.

City	Cr	Cu	Pb	Zn	Ni	Cd
Beijing	−0.23	−0.17	−0.25	−0.27	−0.37	−0.18
Changchun	–	0.53	1.51	0.34	0.60	3.35
Taicang	−0.44	−0.05	−0.53	−0.17	−0.38	−0.46
Fuyang	–	0.27	−0.10	0.28	−0.55	0.57
Guangzhou	–	0.90	0.70	0.87	−0.45	2.20
Hangzhou	−0.86	0.14	0.70	0.28	−0.68	1.98
Luoyang	−0.27	1.09	0.83	0.90	–	2.43
Nanjing	−0.04	0.31	1.06	0.32	–	–
Shanghai	−0.04	0.32	0.62	0.88	−0.41	0.98
Wenzhou		0.34	0.18	0.37	–	–
Changsha	0.12	0.23	0.70	0.67	–	3.60
Xiangtan	−0.24	−0.09	0.38	−0.11	–	0.89
Zhangzhou	−0.80	−0.05	0.20	−0.19	−0.76	1.15
Shenyang		1.74	2.65	1.91	–	3.58
Hongkong	−1.38	−0.37	0.88	0.12	−1.18	1.45
Qingdao	0.15	1.02	0.29	0.66	−0.06	0.43
Baoji	0.11	1.20	6.48	2.87	0.58	–
Jinchang	0.74	3.70	0.39	0.06	3.12	2.13
Shenzhen		−0.18	0.74	0.30	–	0.99
Xuzhou	−0.14	0.53	0.59	0.74	−0.05	1.68
Mean	−0.15	1.22	3.54	0.57	0.90	2.39

Table 8
Geo-accumulation index of heavy metals in urban road dusts in the cities from China.

City	Cr	Cu	Pb	Zn	Ni	Cd
Xi'an	0.60	1.03	1.78	1.33	–	–
Hangzhou	−0.78	1.18	1.68	1.05	−0.61	2.18
Shanghai	0.35	1.52	2.04	1.77	0.59	1.84
Shanghai1	–	1.45	1.93	1.68	0.61	–
Shanghai2	0.25	1.49	1.97	1.73	0.61	–
Guangzhou	0.04	1.93	1.49	2.11	−0.56	3.77
Baoji	–	1.29	2.35	1.86	0.19	–
Urumqi	−0.31	0.86	0.61	1.05	0.08	1.87
Hongkong	–	1.63	1.53	2.57	–	3.25
Mean	0.18	1.48	1.81	1.48	0.34	2.64

Table 9
Geo-accumulation index of heavy metals in agricultural soils in the cities from China.

City	Cr	Cu	Pb	Zn	Ni	Cd	Hg	As
Zhengzhou	−0.41	–	−0.82	–	–	−0.19	−0.20	−0.92
Yangzhou	−0.17	0	−0.09	−0.13	−0.05	0.72	0.72	−0.50
Wuxi	−0.45	0.18	0.18	0.1	–	−0.04	0.50	−0.16
Guangzhou	−0.35	−0.35	0.40	0.38	–	0.65	2.01	−0.43
Taihang	−0.46	−0.47	−0.73	−0.46	−0.48	0.03	−0.20	−1.00
Gansu	−0.86	−0.22	−0.60	–	–	–	0.43	−0.41
Beijing	−0.19	−0.19	−0.75	−0.32	–	0.21	–	–
Chengdu	−0.43	0.23	0.68	0.71	–	0.91	1.16	−0.40
Hainan	−1.40	−0.11	0.21	−0.76	−0.96	0.65	–	−0.73
Jinghe	−0.73	–	−0.55	–	–	−0.04	–	−0.12
Kunshan	−0.04	0.01	−0.25	−0.05	−0.26	0.32	0.72	−0.72
Xuzhou	–	0.04	0.37	0.30	–	2.87	–	–
Mean	−0.44	−0.07	−0.04	0.06	−0.38	1.08	0.90	−0.50

Guangzhou, three developed cities show the highest I_{geo} values for Cu, Cr, Ni, Zn and Cd, while Baoji, the only one heavy industrial city shows the highest I_{geo} value for Pb.

Moreover, the mean I_{geo} values for Cr, Cu, Pb, Zn, Ni and Cd in urban road dusts of all the cities from China are 0.18, 1.48, 1.81, 1.48, 0.34 and 2.64, respectively. The data indicates that the pollution of Cr, Cu, Pb, Zn, Ni and Cd is widespread in urban road dusts in China.

4.3. Contamination levels of heavy metals in agricultural soils

Table 9 shows that nearly all the I_{geo} values for Cr, Cu, Pb, Zn, Ni and As in agricultural soils of the 12 cities are lower than 0. This indicates that the agricultural soils are uncontaminated or slightly contaminated by the five metals. The I_{geo} values for Cd and Hg in agricultural soils in the cities are higher than 1. This suggests that the agricultural soils in the cities are significantly contaminated by the two metals. The highest I_{geo} values for Cd (2.87) and Hg (2.01) are found in the agricultural soils of Xuzhou and Guangzhou, respectively. In the two cities, the agricultural soils may be considerably contaminated by Cd and Hg. The mean I_{geo} values also indicate that the pollution of Cd and Hg is widespread in agricultural soils in China. However, the agricultural soil in China is lowly contaminated by the other metals.

5. Pollution sources of heavy metals

The concentrations and I_{geo} values of Cd, Cu, Pb, Zn, Cr, Ni, As and Hg in urban soils, urban road dusts and agricultural soils indicate that the contamination of the heavy metals is widespread in the environment in China. In general the sources of Cd, Cu, Pb, Zn, Cr and Ni in urban soils and urban road dusts are mainly derived from traffic emission and industrial emission, while the sources of the metals in agricultural soils may be mainly derived from mining, sewage sludge, pesticides and fertilizers. The main pollution sources of the metals are also different among the cities. The pollution sources of the heavy metals in the urban soils or urban road dusts of Shenyang, Baoji, Guangzhou, Jinchang and Changchun may be mainly derived from industrial emission and traffic emission. However, the pollution sources of the heavy metals in Beijing, Shanghai, Wenzhou, Qingdao and other cities may be mainly derived from traffic emission.

The sources of Cu, Pb, Zn and Ni in the agricultural soils of Xuzhou, Guangzhou and Wuxi may be mainly derived from industrial sources (such as electroplating plant, spring factory, band steel factory, leather factory, petrochemical complex, etc.). In Beijing and Zhengzhou, the sources of the metals in agricultural soils are mainly influenced by sewage irrigation. However, the sources of the metals in agricultural soils in the other cities may be mainly influenced by parent materials, urban effluent and vehicle exhausts. Furthermore, the sources of Cd, Hg and As in agricultural soils in China may be mainly originated from pesticides and fertilizers.

6. Spatial distribution of integrated pollution index (IPI)

To further assess the contamination levels of the metals in the cities in China, an integrated pollution index (IPI) of the metals was calculated in

Fig. 2. Spatial distribution of the integrated pollution index (IPI) in urban soils in the cities from China.

this study. The IPI is defined as the mean value of the pollution index (PI) of an element. In this study, the PI of each element is defined as the ratio of the metal concentration in the city to the background concentration of the corresponding metal as the following formulation [56,71]:

$$PI_i = C_i / B_i \tag{2}$$

where C_n is the concentration of element in environment, B_n is the background value.

The IPI is classified as: IPI ≤ 1 low level of pollution; 1 < IPI ≤ 2 moderate level of pollution; 2 < IPI ≤ 5 high level of pollution; IPI > 5 extreme high level of pollution [56,71]. In this study, the IPIs of the metals in urban soils and urban road dusts are calculated. The spatial distribution of IPIs in urban soils and urban road dusts in the cities in China are presented in Figs. 2 and 3, respectively.

Fig. 2 shows the spatial distribution of the IPIs in urban soils in the cities from China. The results show that Beijing, as not only a rapidly developing city, but also an ancient city with over 1000 years of history and more than 10 million urban residents and more than 1 million vehicle population, appears to be the least contaminated city with an IPI lower than 1. Changchun, Shenyang, Changsha, Baoji and Jinchang, the five heavy industrial cities (approximately 25% of all the cities) appear to be the highest contaminated cities with IPI higher than 5. The heavy metals in these cities are significantly influenced by industrial emission. Qingdao, Taicang, Shenzhen, Wenzhou, Fuyang and Zhangzhou, the developing cities or the moderate cities (approximately 30% of all the cities) are moderately contaminated by the metals. In these cities, the heavy metal pollutants may be mainly derived from traffic emission. Furthermore, Hongkong, Guangzhou, Hangzhou, Shanghai and Nanjing, the developed cities (approximately 40% of all the cities) with high vehicle amounts are highly contaminated by the metals. The soils in these cities may be significantly influenced by traffic sources and industrial sources. Fig. 2 also shows that more than one-half of the cities have high or extremely high heavy metal contamination levels.

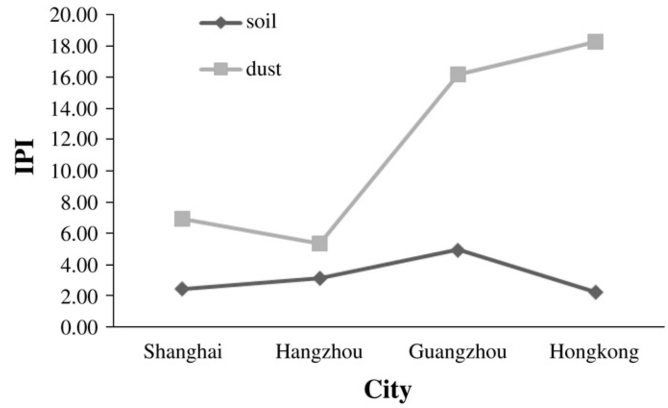

Fig. 4. The comparison of the integrated pollution index (IPI) in urban soils and urban road dusts.

This indicates that the urban soils in the cities from China have been significantly influenced by the heavy metals derived from anthropogenic activities.

The distribution of the IPIs in urban road dusts of Urumqi, Xi'an, Baoji, Shanghai, Hangzhou, Guangzhou and Hongkong are presented in Fig. 3. From Fig. 3, it can be seen that the developed cities (including Shanghai, Guangzhou, Hangzhou, Hongkong and Xi'an) and the industrial city (Baoji) appear to be extremely high pollution levels with IPI higher than 5. This suggests that the urban road dusts in these cities are significantly contaminated by the heavy metals derived from anthropogenic activities. However, the IPI of urban road dust in Urumqi—a rapidly developing city in recent years is in the ranges from 2 to 5. This indicates that the urban road dust is highly contaminated by the heavy metals.

Fig. 4 shows the comparison of the IPIs in urban soils and urban road dusts of Shanghai, Hangzhou, Guangzhou and Hongkong. It is

Fig. 3. Spatial distribution of the integrated pollution index (IPI) in urban road dusts in the cities from China.

found that, in general, the contamination levels of heavy metal in urban road dusts are higher than that in urban soils.

7. Conclusions

Based on the metal concentrations, nearly all the concentrations of the determined metals in urban soils, urban road dusts and agricultural soils in the cities are higher than their background values. The concentrations of Cu, Zn and Cd in urban road dusts in all the cities exceed their PTE-MPC with an exception of Cu in urban road dusts of Xi'an and Urumqi. However, nearly all the concentrations of the metals in urban soils in the cities are lower than their PTE-MPC. Moreover, the concentrations of Cd and As in agricultural soils are higher than their PTE-MPC.

The I_{geo} values suggest that the contamination of Cr, Ni, Cu, Pb, Zn and Cd is widespread in urban soils and urban road dusts in the cities. Agricultural soils are also significantly influenced by heavy metals derived from anthropogenic activities. The contamination levels of Cd and As are higher than that of the other metals.

The main pollution sources of the metals in urban soils, urban road dusts and agricultural soils are different. The sources of heavy metals in urban soils and urban road dusts are mainly derived from traffic sources and industrial sources. However, the sources of heavy metal in agricultural soils are mainly influenced by parent materials, mining, fertilization, pesticide application and so on.

According to the IPI, approximately 65% of all the cities have high or extremely high contamination levels of heavy metals in urban soils and urban road dusts. This indicates that the urban soils and urban road dusts in the cities have been significantly impacted by heavy metals derived from anthropogenic activities. Moreover, the contamination levels of the metals in urban road dusts are higher than that in urban soils.

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