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ORIGINAL PAPER

Overview of heavy metal pollution and health risk assessment of urban soils in Yangtze River Economic Belt, China

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Abstract Using national multi-purpose regional geochemical survey (NMPRGS) data, this overview systematically summarizes the pollution levels and health risks posed by 8 heavy metals (As, Cd, Pb, Zn, Hg, Cu, Cr and Ni) in urban soils of 86 cities above the prefecture level in Yangtze River Economic Belt (YREB). Meanwhile, the spatial distribution and main sources of heavy metal pollutants in urban soils of key cities are described in detail. On a regional scale, Hg and Cd contamination in urban soils of YREB is most prominent, and As, Cu, Pb and Zn contamination exists in several cities, while Cr and Ni contamination is almost not shown. The type of industrialization and the history of urbanization affect the soil heavy metal pollution in majority cities, and the influence of geological background on the content of heavy metals in urban soils cannot be ignored. Specifically, the urban pollution of Cd, As, Pb and Zn is mainly concentrated in Hunan and Hubei Provinces, which are highly developed in mining industry, especially in Zhuzhou, Chenzhou, Huangshi and Xiangtan cities, while the major soil Hg pollution occurs in Zhejiang and Jiangsu Provinces with rapid economic development, where Shaoxing, Ningbo, Suzhou and Wuxi are the key polluted cities. Heavy metals in the urban soils investigated generally posed low non-carcinogenic and carcinogenic risks to the adults. However, the non-carcinogenic risk to minors in some cities (e.g., Chenzhou and Huangshi) should be given cautious attention.

Keywords Urban soil · Heavy metal · Contamination · Health risk assessment · Yangtze River Economic Belt

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Introduction

Soil is not only the feculence absorption and purification field of urban space, but also the secondary pollution source of urban water, air and other environmental systems. Being an important part of the urban ecosystem health, heavy metal pollution in urban soil should receive extensive attention.

In European and American countries, research on heavy metals in urban soils started early, and studies on the characteristics, classification and restoration of urban soils have been carried out successively (Carey et al., 1980; Madrid et al., 2002; Manta et al., 2002; Wilcke et al., 1998). In recent years, relevant studies have been carried out in China and rapidly developed (Chen et al., 2005; Cheng et al., 2014; Luo et al., 2012; Pan et al., 2018; Wong et al., 2006). The process of urbanization is closely related to soil heavy metal pollution. It has been reported that metal pollution in urban soils is to a large extent linked to traffic emissions and specific industrial activities in the surrounding area, for both developing (Al-Shayeb, 2003; Loredo et al., 2003; Mller et al., 2005) and developed countries (Cicchella et al., 2008; Mielke et al., 2011). Exposure to urban air is the main factor determining the contents of heavy metals in urban surface soil. Studies on the effects of urbanization on soil heavy metal concentration indicated that up to 59.0% of the anthropogenic heavy metals in urban soils resulted from atmospheric deposition throughout the city. Approximately 15.3% derived from other input loads such as indoor volatilization, waste discharge, fertilization and irrigation, which significantly related to the density of local population and road (Peng et al., 2013). The diffusion patterns of these pollutants and the proximity of urban soils to humans increase the risk of human exposure through ingestion, inhalation or dermal contact (Abrahams, 2002; Ajmone-Marsan & Biasioli, 2010).

Yangtze River Economic Belt (YREB), which stretches across the three major regions of China's east, middle and west, is a major national strategic development region and a pioneering demonstration region for ecological civilization construction. It covers 11 provinces and cities including Shanghai, Jiangsu, Zhejiang, Anhui, Jiangxi, Hubei, Hunan, Chongqing, Sichuan, Yunnan and Guizhou, with a total area of about 2,052,300 km^2, accounting for 21.4% of China, and the population and GDP both exceed 40% of China (National Bureau of Statistics of China, 2020). There are 162 prefecture-level cities in the YREB, and the existing researches on heavy metal pollution of these urban soils are mainly concentrated in the Xiangjiang River Basin, while the researches on cities in other regions are still few and scattered (Deng et al., 2019; Li et al., 2012, 2013; Wang & Lu, 2011; Wang et al., 2008; Wu et al., 2009; Zhang et al., 2006, 2009, 2014). Moreover, most studies indicate that sampling schemes and analytical methods used in these urban soil geochemical surveys are not uniform. These differences hinder meaningful comparisons between studies and highlight the urgent need to harmonize approaches to produce comparable datasets in different locations.

Systematic geochemical mapping is the best method to evaluate the content of chemical elements on the earth's surface. In 1999, China launched the National multi-purpose regional geochemical survey (NMPRGS) (Li et al., 2014). In NMPRGS, a double-layer grid is applied to collect top and deep soil samples. Generally, topsoil at a depth of 0–20 cm is collected at a density of 1 sample/km^2, while the deep soil at a depth of 150–180 cm is collected at a density of 1 sample/4 km^2 to reflect the geological background. To reduce the cost of analysis, 4 km^2 of topsoil samples and 16 km^2 of deep soil samples are synthesized for analysis and testing. All samples are measured by a unified analytical method for 54 elements and indexes, which ensure that the data could be compared (Zhang, 2005).

This study used high-precision data collected by NMPRGS (7354 topsoil samples, 1860 deep soil samples) and conducted research on soil pollution of As, Cd, Cr, Cu, Hg, Ni, Pb, Zn and health risks in 86 urban planning areas above the prefecture level in the YREB (Fig. 1). In addition, research on the distribution pattern and source identification of heavy metals in key cities has been carried out in detail. So far, this is a relatively comprehensive and systematic research result of soil heavy metal pollution and health risk assessment in urban areas of YREB. This research will provide important basic information for urban land use management and pollution prevention in the YREB.

Data processing

The geo-accumulation index (***I***$_{geo}$)

An overview of the heavy metal contamination levels in the topsoil of each city was obtained by using the geo-accumulation index (I_{geo}) values introduced by (Müller, 1969). The I_{geo} was calculated using the following equation:

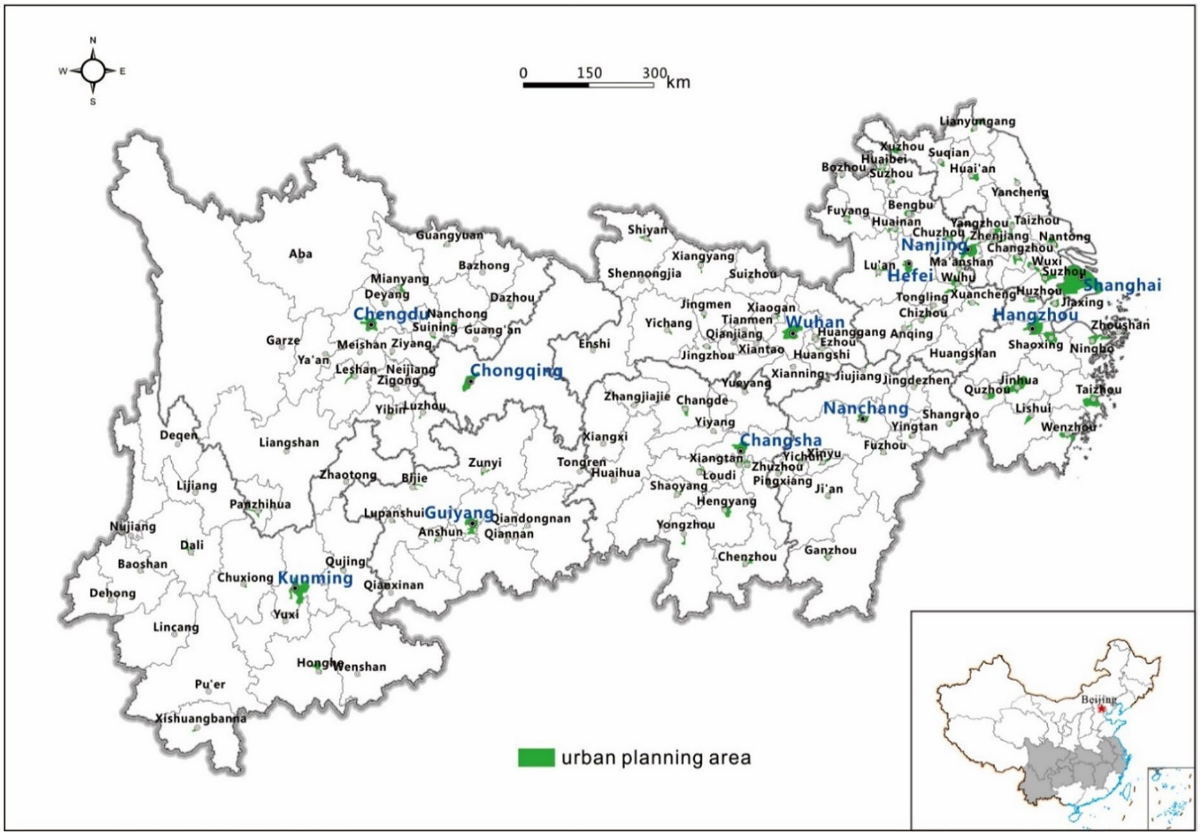


Fig. 1 Schematic diagram for urban planning area of cities above the prefectural level in YREB

$$I_{\text{geo}} = \log_2\left(C_n/1.5B_n\right)$$

where C_n is the measured concentration of heavy metals in the topsoil and B_n is the geochemical background for the corresponding heavy metals. In this study, the median concentrations of different metals in all 1860 urban deep soil samples were computed as the geochemical background values. A constant 1.5 was introduced to compensate for background value changes that might be caused by petrogenetic variations. Pollution degrees are classified into seven levels based on I_{geo} values:

$I_{geo} \leq 0$, uncontaminated; $0 < I_{geo} \leq 1$, uncontaminated to moderately contaminated; $1 < I_{geo} \leq 2$, moderately contaminated; $2 < I_{geo} \leq 3$, moderately to heavily contaminated; $3 < I_{geo} \leq 4$, heavily contaminated; $4 < I_{geo} \leq 5$ heavily to extremely contaminated; and $I_{geo} \geq 5$, extremely contaminated.

Pollution indexes (*PI*) and the integrated pollution index (*IPI*)

The pollution index *PI* and the integrated pollution index *IPI* were used to evaluate the pollution levels of heavy metals in urban soil (Lee et al., 2006; Luo et al., 2012). The *PI and IPI* were calculated using the following equation:

$$\text{PI}_i = C_i/T_i$$

$$\text{IPI}_N = \left[\left(\text{IPI}^2_{\text{avg}} + \text{PI}^2_{\max}\right)/2\right]^{1/2}$$

where C_i is the concentration of a given metal in topsoil samples and T_i is the corresponding management target value of the metal. IPI_avg is the average value of PI_i of all heavy metals involved in statistics, and PI_max

is the maximum value. Pollution degrees are classified into five levels based on IPI_N values:

$IPI_N \leq 0.7$, safe; $0.7 < IPI_N \leq 1.0$, precaution; $1.0 < IPI_N \leq 2.0$, slight pollution; $2.0 < IPI_N \leq 3.0$, moderate pollution; and $IPI_N \geq 3.0$, heavy pollution.

China has a vast territory, and the geological background of soil in different cities varies greatly. Some studies have proposed a robust statistical method to describe the variation range of geochemical background values by using median (Me) and median absolute deviation (MAD) (Reimann and Filzmoser, 2000; Thompson, 2011). In this study, Me ± 3MAD of all the urban deep soil samples in the study area is used to represent the variation range of the background value of each element, and the upper limit of the background value is taken as the management target value of the corresponding element.

Human health risk assessment

Human health risk assessment is to estimate the type and probability of health hazards of residents exposed to chemicals in a polluted environment (National Research Council, 1983). Due to behavioral and physiological differences, this study divided urban population into minors and adults to assess and analyze their health risks from exposure to urban soil.

Exposure assessment

The exposure assessment methods used in the research are generally based on the recommendations provided by several US and Canadian publications (HC, 2004; USEPA, 1989; USEPA, 2002; USEPA, 2011; USEPA, 2019). The human body is generally exposed to environmental pollutants through three ways: oral ingestion, inhalation and dermal contact (USEPA, 2011). However, for heavy metals in the soil, oral ingestion and dermal contact are considered to be the main routes of exposure (Ferreira-Baptista & Miguel, 2005; Fryer et al., 2006). Following formulas are used to calculate the average daily intake (ADI) of urban population exposed to soil heavy elements through the above two channels. Related parameter values are shown in Table 1.

$$\mathrm{ADI}_{\mathrm{oral}} = \frac{C \times \mathrm{IR}_{\mathrm{ing}} \times \mathrm{EF} \times \mathrm{ED}}{\mathrm{BW} \times \mathrm{AT}} \times 10^{-6}$$

$$\mathrm{ADI}_{\mathrm{dermal}} = \frac{C \times \mathrm{SA} \times \mathrm{SAF} \times \mathrm{ABS} \times \mathrm{EF} \times \mathrm{ED}}{\mathrm{BW} \times \mathrm{AT}} \times 10^{-6}$$

Non-carcinogenic risk assessment

Non-carcinogenic risk is usually characterized by the risk quotient (HQ), which is defined as the ratio of the daily ingested dose of a particular chemical

Table 1 Definition and reference value of some parameters for health risk assessment of heavy metals in urban soils

Parameters	Definition	Unit	Value[a,b,c] Adult	Value[a,b,c] Minor
IRing	Ingestion rate	$mg \bullet d^{-1}$	100	200
EF	Exposure frequency	$d \bullet a^{-1}$	350	350
ED	Exposure duration	a	30	6
BW	Body weight	kg	70	20
AT	Averaging time: for non-carcinogens	d	ED × 365	
	Averaging time: for carcinogens		70(lifetime) × 365	
SA	Exposed skin area	cm^2	5700	2800
SAF	Skin adherence factor	$mg \bullet cm^{-2}$	0.07	0.2
ABS	Dermal absorption factor	–	As: 0.03; Cd: 0.001; Cr: 0.04; Cu: 0.06; Hg: 0.05; Ni: 0.091; Pb: 0.006; Zn: 0.02	

[a]United States Environmental Protection Agency (USEPA) (2002)

[b]United States Environmental Protection Agency (USEPA) (2011)

[c]Health Canada (HC) (2004)

substance to the reference dose (RfD). The equation is as follows:

$$HQ = \frac{ADI}{RfD}$$

where, RfD is the reference dose of a specific chemical substance. Hazard index (HI) is used to evaluate the potential non-carcinogenic risk caused by a variety of chemical substances. Hazard index (HI) is calculated by the following formula.

$$HI = \Sigma HQi = \Sigma \frac{ADI_i}{RfD_i}$$

If the HI value is less than 1, the exposed individual will not be affected by obvious adverse health effects. If the HI value is greater than 1, non-carcinogenic health hazards may occur, and this possibility tends to increase as the HI value increases. Since there is currently no reference dose value that can be used to evaluate dermal absorption exposure to environmental pollutants, the USEPA (2002) provides a method for assessing dermal risk, multiplying the oral reference dose by a gastrointestinal absorption coefficient. Related reference values are shown in Table 2.

Carcinogenic risk assessment

The carcinogenic risk is estimated by calculating the incremental probability of an individual suffering from cancer due to exposure to potential carcinogens in his lifetime. The slope factor (SF) converts the average daily intake of a certain toxic substance over a lifetime into the carcinogenic risk (CR) of an individual. If exposed to multiple carcinogenic pollutants, the cancer risks from all pollutants and routes are summed. CR calculation formula is as follows:

$$CR = ADI \times SF$$

A CR value below 1×10^{-6} has no significant effect on human health. A CR value between 1×10^{-6} and 1×10^{-4} is generally acceptable, while a CR value above 1×10^{-4} indicates a lifetime carcinogenic risk to an individual. The SF of the heavy metals through oral ingestion and dermal contact is also shown in Table 2.

Results and discussion

Heavy metal concentrations in urban soils

The heavy metal concentrations in urban topsoils and deep soils in all of the investigated cities in YREB are presented in Tables 3, 4, 5, 6. Among the cities, the concentrations of the heavy metals varied over a large range. The median concentrations of As, Cd, Cr, Cu, Hg, Ni, Pb and Zn in deep soils are 9.2, 0.110, 82, 27.5, 0.049, 35.0, 26.1 and 78 mg kg^{-1}, respectively. The ratios of the above contents in deep soils and the corresponding background values in Chinese soil (CEMS, 1990) are, respectively, 0.82, 1.13, 1.34, 1.20, 0.75, 1.30, 0.97 and 1.05, indicating the contents of both are relatively consistent, and generally in the order of Cr/Zn > Ni/Cu/Pb > As > Cd/Hg.

The median concentrations of As, Cd, Cr, Cu, Hg, Ni, Pb and Zn in topsoils are 9.3, 0.210, 80, 33.0, 0.130, 32.7, 34.1 and 97 mg kg^{-1}, respectively. The contents of heavy metals in urban topsoils are arranged in the following order Zn > Cr > Ni/Cu/

Table 2 Summary of reference dose (RfD) and slope factor (SF) of heavy metals through oral ingestion and dermal contact

Metals	GIABS[a,b]	Oral RFD[a,b] (mg kg^{-1} day^{-1})	Dermal RFD (mg kg^{-1} day^{-1})	Oral SF[b,c] (mg kg^{-1} day^{-1})	Dermal SF[b,c] (mg kg^{-1} day^{-1})
As	1	3.00E−04	3.00E−04	1.50 E+00	3.66 E+00
Pb	1	1.40E−03	1.40E−03	–	–
Cd	0.025	1.00E−03	2.50E−05	5.01E−01	2.00 E+01
Cr	0.013	1.50E+00	1.95E−02	–	–
Cu	1	4.00E−02	4.00E−02	–	–
Zn	1	3.00E−01	3.00E−01	–	–
Ni	0.04	2.00E−02	8.00E−04	–	–
Hg	0.07	3.00E−04	2.10E−05	–	–

[a]United States Environmental Protection Agency (USEPA) (2019)

[b]Ferreira-Baptista L and Miguel E (2005)

[c]United States Environmental Protection Agency (USEPA) (2011)

Table 3 Statistical summaries of heavy metal concentrations in urban topsoil (0–20 cm) from cities in study area (mg kg^{-1})

Municipalities /province	City	n	As				Cd			
			Min	Max	Mean	Median	Min	Max	Mean	Median
Shanghai	Shanghai	1009	3.9	23.8	8.1	7.9	0.053	20.245	0.352	0.190
Chongqing	Chongqing	204	1.1	19.1	5.8	4.8	0.063	1.623	0.305	0.299
Anhui	Anqing	38	7.3	20.2	11.0	10.6	0.101	0.953	0.250	0.182
	Bengbu	56	6.6	17.1	10.3	9.8	0.064	0.294	0.154	0.142
	Chizhou	48	5.2	87.2	17.1	15.6	0.172	2.486	0.546	0.403
	Chuzhou	68	5.8	31.1	10.6	10.2	0.088	0.382	0.129	0.116
	Fuyang	64	6.4	16.9	10.8	10.0	0.079	0.266	0.159	0.153
	Hefei	127	5.9	18.5	10.2	10.1	0.053	0.540	0.135	0.102
	Huainan	54	8.3	15.3	10.5	10.5	0.068	0.419	0.134	0.122
	Liu'an	59	2.5	13.2	10.1	10.6	0.062	0.539	0.110	0.103
	Ma'anshan	47	6.1	25.1	10.1	9.9	0.112	3.611	0.306	0.178
	Tongling	29	9.2	610.6	46.5	17.7	0.237	1.915	0.618	0.418
	Wuhu	137	6.1	93.1	10.8	9.6	0.090	3.260	0.336	0.262
	Suzhou	41	6.7	20.0	11.0	10.5	0.112	0.327	0.171	0.151
	Xuancheng	47	6.9	46.1	12.6	12.3	0.082	0.497	0.264	0.274
Guizhou	Bijie	35	7.9	29.1	15.8	14.2	0.212	0.608	0.385	0.373
	Guizhou	193	4.4	111.0	22.5	18.8	0.140	2.190	0.435	0.380
Hubei	Ezhou	27	4.7	48.5	13.2	11.9	0.146	1.211	0.358	0.291
	Enshi	22	1.2	14.0	5.8	5.3	0.059	0.702	0.292	0.251
	Huanggang	22	6.6	14.0	9.7	9.4	0.133	0.505	0.234	0.213
	Huangshi	24	8.9	1001.2	77.5	35.0	0.396	88.700	5.222	0.974
	Jingmen	28	7.1	30.9	13.5	12.8	0.151	0.712	0.258	0.224
	Jingzhou	35	6.3	15.8	11.5	11.7	0.191	1.293	0.367	0.334
	Suizhou	35	3.5	12.0	7.5	7.4	0.089	0.257	0.168	0.160
	Wuhan	267	5.5	39.6	13.6	13.0	0.080	4.980	0.340	0.280
	Xianning	24	9.0	37.8	15.9	11.7	0.117	0.517	0.226	0.217
	Xiangyang	47	7.2	15.6	11.2	11.4	0.087	1.752	0.313	0.254
	Xiaogan	34	5.8	11.5	8.2	8.3	0.110	0.300	0.151	0.150
	Yichang	28	4.9	30.7	10.1	8.2	0.118	0.367	0.228	0.228
Hunan	Changde	69	7.1	18.5	11.2	10.7	0.148	0.888	0.336	0.342
	Chenzhou	61	0.1	494.3	120.1	65.2	0.238	9.246	1.886	1.237
	Hengyang	98	8.4	125.0	34.3	24.9	0.240	88.580	2.479	0.820
	Loudi	42	6.0	29.0	14.9	14.0	0.180	2.370	0.601	0.465
	Shaoyang	12	13.0	29.0	20.2	19.5	0.250	0.550	0.391	0.375
	Xiangtan	44	13.6	43.5	22.6	19.6	0.380	10.800	1.306	0.875
	Yiyang	34	10.3	147.9	30.8	17.6	0.282	1.780	0.529	0.430
	Yueyang	28	10.2	19.3	14.1	13.7	0.127	2.060	0.297	0.214
	Changsha	170	8.5	82.2	18.4	15.4	0.160	6.622	0.809	0.499
	Zhuzhou	60	10.0	94.6	24.7	20.9	0.410	51.200	3.575	1.765

Table 3 (continued)

Municipalities /province	City	n	As				Cd			
			Min	Max	Mean	Median	Min	Max	Mean	Median
Jiangsu	Changzhou	74	6.1	18.6	8.8	8.5	0.110	0.880	0.218	0.185
	Huai ‘an	81	6.4	18.6	10.2	9.9	0.110	0.280	0.157	0.150
	Lianyungang	64	3.2	18.1	9.9	9.5	0.048	0.690	0.165	0.150
	Nanjing	274	4.0	151.0	11.4	10.3	0.090	4.790	0.303	0.240
	Nantong	82	5.7	12.1	8.0	7.7	0.099	0.300	0.151	0.140
	Suzhou	139	6.8	29.2	12.2	10.5	0.060	22.800	0.353	0.160
	Taizhou	55	3.7	13.1	7.3	7.6	0.110	0.380	0.180	0.160
	Wuxi	78	7.9	18.9	10.2	9.9	0.084	1.660	0.259	0.200
	Suqian	46	7.7	49.1	11.4	10.4	0.082	0.360	0.141	0.130
	Xuzhou	77	7.7	19.2	11.4	11.4	0.033	0.830	0.212	0.180
	Yancheng	30	4.7	10.1	8.1	8.7	0.094	0.190	0.134	0.130
	Yangzhou	69	3.2	10.9	6.8	6.8	0.090	0.330	0.163	0.150
	Zhenjiang	47	7.1	13.7	9.4	9.2	0.100	0.550	0.203	0.170
Jiangxi	Fuzhou	40	4.6	29.0	9.3	8.2	0.037	0.400	0.128	0.110
	Ganzhou	51	2.5	31.1	11.3	10.3	0.117	1.287	0.361	0.292
	Ji’an	40	4.6	25.1	9.5	8.9	0.089	0.470	0.190	0.175
	Jiujiang	16	7.6	15.9	11.6	12.0	0.135	0.483	0.249	0.205
	Nanchang	99	3.7	26.1	9.9	9.2	0.060	1.890	0.209	0.170
	Shangrao	31	3.7	18.4	8.9	8.7	0.120	1.890	0.550	0.380
	Yingtan	23	2.3	22.5	6.8	5.7	0.070	0.400	0.212	0.200
Sichuan	Bazhong	10	5.8	8.9	7.3	7.1	0.134	0.412	0.250	0.245
	Chengdu	231	5.8	27.4	12.6	10.8	0.070	0.710	0.211	0.190
	Deyang	35	5.1	11.6	9.3	9.3	0.200	1.360	0.553	0.520
	Leshan	51	3.3	12.6	6.8	6.8	0.160	1.300	0.458	0.420
	Luzhou	26	3.2	11.0	6.0	5.6	0.161	0.564	0.306	0.297
	Meishan	22	7.2	17.1	9.6	8.9	0.180	0.440	0.248	0.230
	Mianyang	61	5.7	17.2	11.4	11.2	0.160	1.350	0.298	0.250
	Nanchong	47	3.0	15.4	10.9	11.0	0.128	0.393	0.259	0.260
	Neijiang	15	2.5	6.4	4.0	3.9	0.203	0.499	0.348	0.337
	Suining	38	6.6	14.3	9.2	9.1	0.181	0.468	0.334	0.320
	Ya’an	21	5.3	11.3	7.9	7.8	0.190	0.550	0.283	0.260
	Yibin	34	3.2	10.0	6.3	6.3	0.104	0.987	0.295	0.286
	Ziyang	22	3.3	11.6	7.4	8.0	0.267	1.702	0.415	0.329
	Zigong	27	2.1	19.2	6.9	6.0	0.141	1.380	0.464	0.387
Yunnan	Kunming	385	1.4	90.0	12.6	10.9	0.062	69.867	1.062	0.457
	Yuxi	23	6.9	32.6	14.1	12.9	0.119	3.008	0.722	0.561
	Zhaotong	18	6.3	11.5	8.4	8.0	0.319	0.698	0.470	0.476

Table 3 (continued)

Municipalities /province	City	n	As				Cd			
			Min	Max	Mean	Median	Min	Max	Mean	Median
Zhejiang	Hangzhou	234	3.8	18.1	7.1	6.9	0.053	1.321	0.179	0.158
	Huzhou	62	5.3	26.2	9.3	8.4	0.122	0.954	0.223	0.203
	Jiaxing	70	6.3	11.0	8.5	8.5	0.080	0.287	0.149	0.146
	Jinhua	271	1.7	23.6	8.2	7.7	0.093	0.564	0.189	0.182
	Lishui	63	3.1	16.7	6.0	5.6	0.113	0.351	0.189	0.181
	Ningbo	132	3.8	16.7	8.1	8.0	0.108	0.432	0.197	0.189
	Quzhou	79	2.9	14.7	6.5	6.0	0.057	0.567	0.209	0.190
	Shaoxing	127	4.5	34.3	9.9	9.0	0.095	0.631	0.215	0.198
	Taizhou	189	4.4	19.1	8.9	8.4	0.087	6.153	0.220	0.175
	Wenzhou	92	4.5	15.3	7.7	7.2	0.108	4.255	0.397	0.270
All cities		7354	0.1	1001.2	12.2	9.3	0.033	88.700	0.429	0.210
Target Value						16.9				0.203
NBSV*					11.2				0.097	

Municipalities /province	City	n	Cr				Cu			
			Min	Max	Mean	Median	Min	Max	Mean	Median
Shanghai	Shanghai	1009	68	1341	95	89	17.9	420.0	39.3	33.2
Chongqing	Chongqing	204	47	282	74	69	10.5	92.4	28.8	27.8
Anhui	Anqing	38	35	105	77	78	18.2	68.7	34.8	31.6
	Bengbu	56	50	106	70	69	19.6	65.7	28.0	25.8
	Chizhou	48	12	111	76	78	13.5	161.1	46.3	41.3
	Chuzhou	68	47	93	69	68	17.8	54.6	29.9	27.2
	Fuyang	64	56	90	75	75	15.5	63.0	27.0	26.1
	Hefei	127	54	112	71	70	21.8	92.7	31.2	28.2
	Huainan	54	57	95	72	71	21.4	58.9	30.8	29.3
	Liu'an	59	51	138	72	71	7.8	50.2	23.8	23.5
	Ma'anshan	47	58	104	77	75	25.5	116.9	43.7	37.1
	Tongling	29	47	105	73	73	44.2	598.8	116.9	69.1
	Wuhu	137	52	115	85	84	26.4	143.4	42.1	40.0
	Suzhou	41	65	110	75	73	19.8	53.2	28.9	27.4
	Xuancheng	47	50	74	61	62	15.1	40.0	24.3	24.3
Guizhou	Bijie	35	54	192	114	109	15.1	89.8	50.0	53.2
	Guizhou	193	53	173	110	113	13.6	128.0	52.5	50.3

Table 3 (continued)

Municipalities /province	City	n	Cr				Cu			
			Min	Max	Mean	Median	Min	Max	Mean	Median
Hubei	Ezhou	27	42	106	81	82	22.4	105.1	45.4	38.7
	Enshi	22	13	74	39	32	4.4	35.4	16.0	13.0
	Huanggang	22	66	108	84	80	23.6	54.6	34.7	33.2
	Huangshi	24	53	344	118	97	29.5	10,170.0	619.7	81.6
	Jingmen	28	54	91	76	78	19.2	43.0	27.4	26.8
	Jingzhou	35	66	112	87	84	25.3	58.8	40.5	39.5
	Suizhou	35	35	123	63	61	15.1	46.7	27.4	26.6
	Wuhan	267	59	271	90	88	18.8	1440.0	48.0	41.7
	Xianning	24	46	85	73	76	16.5	36.2	26.8	27.3
	Xiangyang	47	61	88	75	74	21.8	47.8	32.0	31.1
	Xiaogan	34	51	78	67	67	22.7	30.5	26.2	26.1
	Yichang	28	42	105	71	69	13.2	45.8	24.5	24.0
Hunan	Changde	69	56	90	74	75	19.5	36.5	27.3	27.8
	Chenzhou	61	47	198	99	94	22.1	131.0	56.8	50.0
	Hengyang	98	53	105	78	77	23.3	125.2	43.1	40.4
	Loudi	42	36	123	85	85	11.8	49.6	29.4	28.9
	Shaoyang	12	58	106	79	73	24.6	34.8	31.3	32.1
	Xiangtan	44	66	105	84	84	30.5	78.9	44.6	43.6
	Yiyang	34	79	461	129	99	24.5	64.9	35.2	30.6
	Yueyang	28	71	86	76	76	24.8	53.6	33.0	30.4
	Changsha	170	69	250	109	100	24.2	116.5	39.2	35.9
	Zhuzhou	60	64	171	100	93	31.9	173.2	52.2	48.6
Jiangsu	Changzhou	74	73	116	86	85	26.9	95.3	40.7	36.3
	Huai ‘an	81	59	105	71	69	15.4	57.5	23.1	21.7
	Lianyungang	64	23	106	67	69	8.7	70.9	28.6	29.0
	Nanjing	274	29	188	81	78	9.6	157.0	40.7	36.8
	Nantong	82	63	80	71	71	16.6	46.0	23.5	22.0
	Suzhou	139	60	180	87	86	21.3	106.0	38.2	34.6
	Taizhou	55	56	155	76	72	13.8	61.9	25.6	22.8
	Wuxi	78	70	133	83	81	21.3	80.3	40.0	34.5
	Suqian	46	57	81	68	67	16.6	30.4	22.3	21.9
	Xuzhou	77	58	167	76	74	17.6	474.0	36.6	29.7
	Yancheng	30	70	91	77	75	20.4	45.7	25.0	23.9
	Yangzhou	69	50	88	69	68	13.8	62.5	26.3	24.8
	Zhenjiang	47	62	105	76	74	23.6	94.0	35.3	30.5

Table 3 (continued)

Municipalities /province	City	n	Cr				Cu			
			Min	Max	Mean	Median	Min	Max	Mean	Median
Jiangxi	Fuzhou	40	31	82	59	59	14.4	34.0	22.8	23.1
	Ganzhou	51	35	1474	82	54	18.3	244.9	38.8	30.6
	Ji’an	40	36	127	65	64	16.8	72.2	28.9	26.0
	Jiujiang	16	59	102	79	79	22.2	128.0	44.5	33.1
	Nanchang	99	21	106	71	73	9.9	127.7	30.6	28.0
	Shangrao	31	25	88	45	43	11.5	70.0	30.2	28.9
	Yingtan	23	18	82	38	36	9.7	41.2	21.9	19.2
Sichuan	Bazhong	10	70	80	75	75	22.7	36.5	29.3	28.9
	Chengdu	231	52	145	79	79	21.2	311.0	45.5	39.9
	Deyang	35	68	209	102	97	19.0	87.4	36.9	35.9
	Leshan	51	43	229	85	83	17.2	105.5	38.5	33.3
	Luzhou	26	66	141	79	77	22.1	45.6	34.7	35.8
	Meishan	22	42	76	60	58	23.5	83.8	34.4	31.9
	Mianyang	61	57	93	69	69	20.5	47.7	31.9	30.4
	Nanchong	47	62	97	80	81	23.1	47.9	29.4	28.7
	Neijiang	15	65	95	74	73	22.2	38.6	30.7	31.0
	Suining	38	61	91	76	77	21.5	42.0	31.6	32.2
	Ya’an	21	72	129	102	100	16.8	61.0	32.3	31.6
	Yibin	34	57	97	77	77	16.7	95.4	33.7	28.8
	Ziyang	22	62	189	80	76	29.4	62.7	34.9	33.1
	Zigong	27	53	88	75	75	22.4	74.4	34.8	30.6
Yunnan	Kunming	385	68	420	114	102	20.0	462.2	119.3	104.3
	Yuxi	23	36	110	85	84	23.1	174.1	52.9	41.0
	Zhaotong	18	49	141	99	105	15.6	131.5	69.4	73.0
Zhejiang	Hangzhou	234	43	98	63	62	8.4	133.4	30.6	29.6
	Huzhou	62	50	93	70	70	20.4	42.9	30.1	29.3
	Jiaxing	70	66	345	89	85	25.5	57.0	36.9	36.1
	Jinhua	271	13	91	46	46	7.1	76.0	19.7	18.7
	Lishui	63	14	50	28	27	8.4	59.3	19.6	18.7
	Ningbo	132	34	117	85	88	16.5	111.6	46.4	41.7
	Quzhou	79	14	83	40	38	7.9	55.7	19.9	16.7
	Shaoxing	127	53	172	77	78	16.1	113.4	41.2	37.1
	Taizhou	189	20	109	75	82	9.0	453.9	46.3	36.3
	Wenzhou	92	29	454	88	87	8.5	192.0	42.6	35.8
All cities		7354	12	1474	82	80	4.4	10,170.0	42.9	33.0
Target Value						114				42.9
NBSV*					61				23.0	

*The national background soil value in China (CEMS, 1990)

Table 4 Statistical summaries of heavy metal concentrations in urban topsoil (0–20 cm) from cities in study area (mg kg^{-1})

Municipalities /province	City	n	Hg				Ni			
			Min	Max	Mean	Median	Min	Max	Mean	Median
Shanghai	Shanghai	1009	0.024	3.350	0.220	0.180	26.4	66.1	37.6	37.4
Chongqing	Chongqing	204	0.026	0.680	0.109	0.083	14.6	71.1	30.9	30.4
Anhui	Anqing	38	0.031	0.240	0.108	0.106	12.9	50.0	30.9	29.6
	Bengbu	56	0.028	0.431	0.060	0.051	18.2	112.6	30.5	28.5
	Chizhou	48	0.036	0.378	0.091	0.073	9.2	49.8	31.1	30.9
	Chuzhou	68	0.030	0.198	0.057	0.046	17.5	42.6	30.4	29.9
	Fuyang	64	0.022	0.185	0.056	0.044	20.6	42.3	32.3	31.6
	Hefei	127	0.010	1.867	0.102	0.057	18.6	59.4	26.6	26.2
	Huainan	54	0.025	0.664	0.080	0.053	24.0	42.5	29.5	28.2
	Liu'an	59	0.024	0.764	0.077	0.051	19.0	37.5	29.9	30.3
	Ma'anshan	47	0.035	1.099	0.143	0.102	21.5	46.1	31.6	31.4
	Tongling	29	0.041	0.358	0.112	0.092	21.2	51.3	30.8	29.1
	Wuhu	137	0.032	0.770	0.106	0.083	20.0	52.4	36.4	36.1
	Suzhou	41	0.022	0.315	0.068	0.047	26.2	41.1	31.1	30.3
	Xuancheng	47	0.046	0.942	0.117	0.089	15.1	35.0	22.9	22.4
Guizhou	Bijie	35	0.073	0.261	0.130	0.121	16.9	86.4	45.7	45.4
	Guizhou	193	0.044	5.590	0.270	0.210	13.0	171.0	40.0	39.7
Hubei	Ezhou	27	0.055	0.178	0.091	0.082	14.1	47.7	31.2	32.6
	Enshi	22	0.007	0.218	0.057	0.052	3.5	34.9	15.4	12.8
	Huanggang	22	0.041	0.150	0.071	0.061	25.0	55.9	35.2	32.0
	Huangshi	24	0.059	4.149	0.413	0.163	16.1	70.1	37.3	35.3
	Jingmen	28	0.030	0.149	0.060	0.054	25.4	64.9	35.0	34.6
	Jingzhou	35	0.065	1.737	0.330	0.203	26.8	51.3	37.2	35.5
	Suizhou	35	0.030	0.280	0.086	0.064	13.0	158.2	37.0	25.5
	Wuhan	267	0.028	2.618	0.177	0.104	23.5	58.6	37.7	37.8
	Xianning	24	0.042	0.224	0.110	0.093	16.3	33.0	25.2	24.9
	Xiangyang	47	0.023	0.854	0.123	0.064	24.5	41.9	33.2	33.5
	Xiaogan	34	0.042	0.210	0.097	0.095	22.4	36.3	28.1	27.9
	Yichang	28	0.020	0.115	0.054	0.048	14.1	37.8	24.9	23.9
Hunan	Changde	69	0.085	0.580	0.222	0.194	20.6	33.7	27.4	27.5
	Chenzhou	61	0.079	0.680	0.200	0.164	14.7	156.5	57.4	52.0
	Hengyang	98	0.029	4.040	0.230	0.176	19.8	258.0	37.5	31.3
	Loudi	42	0.029	0.850	0.199	0.170	10.5	68.7	35.8	36.0
	Shaoyang	12	0.140	0.450	0.223	0.205	24.8	46.9	33.2	32.4
	Xiangtan	44	0.119	1.520	0.318	0.227	21.2	40.6	30.3	30.8
	Yiyang	34	0.107	2.400	0.291	0.195	21.3	75.6	30.8	28.4
	Yueyang	28	0.044	0.200	0.087	0.075	24.5	30.5	27.0	26.4
	Changsha	170	0.057	0.950	0.198	0.166	17.2	109.0	27.6	25.3
	Zhuzhou	60	0.113	2.490	0.401	0.248	21.2	51.7	32.1	31.2

Table 4 (continued)

Municipalities /province	City	n	Hg				Ni			
			Min	Max	Mean	Median	Min	Max	Mean	Median
Jiangsu	Changzhou	74	0.067	1.440	0.314	0.230	25.1	43.9	34.2	33.9
	Huai ‘an	81	0.020	0.900	0.112	0.070	19.9	40.7	27.6	26.5
	Lianyungang	64	0.019	0.370	0.059	0.045	6.4	57.5	31.8	31.5
	Nanjing	274	0.038	8.090	0.229	0.110	10.7	58.8	36.0	35.1
	Nantong	82	0.061	0.360	0.147	0.140	21.1	33.5	26.4	26.6
	Suzhou	139	0.050	5.910	0.460	0.320	19.1	48.9	37.6	38.4
	Taizhou	55	0.049	0.830	0.173	0.130	19.5	41.5	28.0	25.9
	Wuxi	78	0.120	1.700	0.356	0.310	23.2	115.0	36.9	34.8
	Suqian	46	0.019	0.240	0.053	0.032	22.3	41.4	28.2	26.9
	Xuzhou	77	0.034	0.640	0.120	0.091	21.3	40.7	30.3	29.9
	Yancheng	30	0.024	0.310	0.059	0.037	28.0	40.0	33.6	33.5
	Yangzhou	69	0.073	4.600	0.376	0.220	19.1	40.8	27.9	27.3
	Zhenjiang	47	0.047	0.960	0.171	0.130	24.9	54.7	35.0	33.8
Jiangxi	Fuzhou	40	0.074	0.490	0.182	0.170	10.0	37.7	20.3	20.4
	Ganzhou	51	0.049	2.629	0.229	0.118	8.2	264.5	24.9	20.1
	Ji’an	40	0.070	0.610	0.197	0.150	10.2	48.9	23.6	22.5
	Jiujiang	16	0.062	0.400	0.143	0.098	24.6	48.4	34.0	32.6
	Nanchang	99	0.026	0.906	0.189	0.134	8.4	33.4	24.4	25.7
	Shangrao	31	0.062	0.410	0.136	0.120	8.3	65.8	21.3	18.5
	Yingtan	23	0.029	0.150	0.071	0.068	5.6	32.9	14.6	14.2
Sichuan	Bazhong	10	0.031	0.117	0.061	0.050	27.9	39.0	34.4	35.8
	Chengdu	231	0.060	15.400	0.411	0.240	24.3	51.9	38.0	37.7
	Deyang	35	0.040	0.580	0.185	0.150	23.6	40.8	32.7	32.9
	Leshan	51	0.020	0.630	0.112	0.100	13.0	80.1	32.5	31.7
	Luzhou	26	0.033	0.320	0.109	0.081	24.5	35.7	30.0	30.2
	Meishan	22	0.030	0.310	0.121	0.105	20.9	34.8	27.2	27.1
	Mianyang	61	0.020	2.320	0.148	0.090	26.5	40.9	35.8	36.3
	Nanchong	47	0.017	0.201	0.076	0.061	23.1	49.5	35.9	35.8
	Neijiang	15	0.040	0.376	0.110	0.073	28.4	39.0	35.0	35.4
	Suining	38	0.032	1.500	0.150	0.076	26.5	54.4	41.1	41.0
	Ya’an	21	0.040	0.320	0.106	0.080	25.2	43.8	34.7	34.5
	Yibin	34	0.022	0.345	0.094	0.070	18.8	40.5	29.1	29.4
	Ziyang	22	0.021	0.173	0.065	0.048	34.0	52.4	41.7	42.6
	Zigong	27	0.037	0.334	0.136	0.096	25.5	51.3	36.3	35.9
Yunnan	Kunming	385	0.021	2.981	0.152	0.079	20.8	186.8	55.2	52.8
	Yuxi	23	0.037	0.272	0.122	0.092	7.8	48.8	26.4	26.0
	Zhaotong	18	0.049	0.229	0.138	0.135	15.6	52.8	35.2	36.6

Table 4 (continued)

Municipalities /province	City	n	Hg				Ni			
			Min	Max	Mean	Median	Min	Max	Mean	Median
Zhejiang	Hangzhou	234	0.018	3.549	0.321	0.241	17.0	46.0	26.3	25.0
	Huzhou	62	0.082	0.913	0.256	0.217	20.0	48.0	29.2	28.0
	Jiaxing	70	0.105	3.654	0.326	0.226	29.0	45.0	37.1	37.0
	Jinhua	271	0.022	0.426	0.099	0.089	4.1	33.7	13.7	13.3
	Lishui	63	0.035	0.681	0.092	0.067	4.9	16.5	9.8	9.2
	Ningbo	132	0.094	3.421	0.572	0.387	12.0	52.4	33.9	35.0
	Quzhou	79	0.015	0.616	0.118	0.081	5.7	29.6	13.2	12.1
	Shaoxing	127	0.042	4.040	0.629	0.520	18.0	72.7	30.2	30.0
	Taizhou	189	0.044	0.366	0.138	0.130	5.8	61.4	31.3	33.3
	Wenzhou	92	0.061	17.553	0.505	0.217	9.1	76.0	32.5	33.5
All cities		7354	0.007	17.553	0.209	0.130	3.5	331.0	33.5	32.7
Target Value						0.109				53.3
NBSV*					0.065				27.0	

Municipalities /province	City	n	Pb				Zn			
			Min	Max	Mean	Median	Min	Max	Mean	Median
Shanghai	Shanghai	1009	18.9	2521.0	45.7	32.4	61	1454	138	112
Chongqing	Chongqing	204	16.5	107.6	32.3	30.9	49	380	98	93
Anhui	Anqing	38	24.8	69.8	36.1	31.5	55	168	90	83
	Bengbu	56	21.0	82.5	32.3	29.4	47	158	74	70
	Chizhou	48	29.2	135.5	54.7	46.9	56	205	113	101
	Chuzhou	68	20.6	44.9	27.4	26.3	49	237	71	62
	Fuyang	64	22.6	38.3	28.0	27.5	55	94	69	66
	Hefei	127	22.1	90.8	31.7	27.6	41	279	73	59
	Huainan	54	23.9	56.2	30.5	29.3	50	224	79	72
	Liu'an	59	24.0	34.6	28.2	28.1	47	135	60	58
	Ma'anshan	47	25.5	104.7	34.6	30.0	66	334	102	84
	Tongling	29	30.7	152.1	50.7	40.8	65	574	131	96
	Wuhu	137	23.1	194.4	35.4	32.7	63	504	104	96
	Suzhou	41	21.3	49.5	28.0	26.5	51	574	95	72
	Xuancheng	47	21.7	80.4	30.0	28.8	36	125	71	71
Guizhou	Bijie	35	20.3	43.4	31.5	31.1	46	127	89	90
	Guizhou	193	15.6	168.0	46.9	43.1	43	249	116	116

Table 4 (continued)

Municipalities /province	City	n	Pb				Zn			
			Min	Max	Mean	Median	Min	Max	Mean	Median
Hubei	Ezhou	27	26.6	103.0	39.1	36.0	60	454	120	107
	Enshi	22	9.4	33.8	19.7	18.1	15	102	49	46
	Huanggang	22	21.3	40.0	31.7	32.4	65	130	91	85
	Huangshi	24	32.0	2675.0	324.8	118.2	102	1590	377	252
	Jingmen	28	28.8	65.5	38.0	37.0	48	168	84	75
	Jingzhou	35	21.7	55.5	36.7	34.4	69	184	110	108
	Suizhou	35	15.6	38.9	26.2	25.5	47	105	69	69
	Wuhan	267	22.6	461.0	46.7	37.9	56	2180	134	105
	Xianning	24	17.2	57.5	31.8	30.8	48	138	79	78
	Xiangyang	47	21.6	80.4	32.8	30.5	58	169	97	93
	Xiaogan	34	24.3	38.5	29.2	29.3	47	121	65	60
	Yichang	28	20.2	54.2	26.9	24.9	37	143	80	78
Hunan	Changde	69	26.5	48.4	33.7	33.6	64	131	91	90
	Chenzhou	61	49.7	1017.0	242.6	104.4	94	1256	267	191
	Hengyang	98	33.4	572.3	66.0	50.5	68	1153	156	125
	Loudi	42	26.6	107.5	45.9	39.7	39	306	118	109
	Shaoyang	12	28.5	44.1	35.2	34.1	72	146	96	95
	Xiangtan	44	41.1	202.0	72.1	62.8	83	350	149	134
	Yiyang	34	29.6	103.0	44.2	39.2	68	189	105	95
	Yueyang	28	28.3	60.6	35.8	32.2	69	135	93	86
	Changsha	170	26.0	216.4	47.3	39.4	66	542	131	103
	Zhuzhou	60	40.5	936.7	138.9	92.6	97	2389	283	183
Jiangsu	Changzhou	74	25.0	1932.0	82.3	34.4	60	233	100	91
	Huai ‘an	81	17.6	63.6	27.2	25.1	53	196	73	69
	Lianyungang	64	20.8	125.0	36.8	34.1	54	234	100	101
	Nanjing	274	21.3	233.0	40.1	34.1	44	823	112	97
	Nantong	82	17.2	78.0	24.2	22.6	63	152	81	75
	Suzhou	139	26.3	198.0	45.4	37.4	58	271	104	94
	Taizhou	55	19.3	1502.0	52.8	24.8	56	169	81	75
	Wuxi	78	28.0	288.0	50.0	37.7	57	293	116	91
	Suqian	46	17.2	52.5	22.5	20.9	36	100	63	62
	Xuzhou	77	20.7	76.1	32.8	30.7	55	346	94	80
	Yancheng	30	21.7	33.1	24.9	24.3	69	101	79	75
	Yangzhou	69	20.0	124.0	31.2	27.0	54	256	85	80
	Zhenjiang	47	21.8	78.1	32.6	30.4	60	321	97	78

Table 4 (continued)

Municipalities /province	City	n	Pb				Zn			
			Min	Max	Mean	Median	Min	Max	Mean	Median
Jiangxi	Fuzhou	40	23.1	61.4	33.0	30.3	48	138	77	72
	Ganzhou	51	18.8	554.4	50.1	36.2	48	206	90	85
	Ji'an	40	20.6	84.6	36.2	33.5	38	127	75	69
	Jiujiang	16	24.0	147.3	39.5	30.1	68	134	91	80
	Nanchang	99	20.6	134.1	39.2	34.8	31	321	90	81
	Shangrao	31	25.7	78.8	42.3	37.5	33	194	92	87
	Yingtan	23	12.0	44.4	27.3	24.7	20	88	49	41
Sichuan	Bazhong	10	22.2	35.0	26.9	26.5	74	121	91	88
	Chengdu	231	21.0	311.0	47.5	42.0	67	517	124	117
	Deyang	35	22.4	65.9	34.2	32.5	61	177	97	92
	Leshan	51	18.7	140.9	44.6	38.7	46	337	100	94
	Luzhou	26	25.4	66.5	36.2	34.4	73	166	103	97
	Meishan	22	24.1	41.5	31.9	32.2	59	104	81	82
	Mianyang	61	23.1	52.9	31.4	29.6	58	136	89	85
	Nanchong	47	19.9	35.9	26.6	27.0	79	117	101	101
	Neijiang	15	23.8	39.8	30.2	29.8	82	125	101	100
	Suining	38	19.1	42.1	27.6	27.8	71	120	97	98
	Ya'an	21	28.3	52.0	35.6	34.9	58	141	96	93
	Yibin	34	24.3	39.2	29.8	29.6	54	125	89	93
	Ziyang	22	24.0	46.0	30.7	29.6	85	138	103	102
	Zigong	27	25.3	122.0	39.1	33.7	87	213	120	107
Yunnan	Kunming	385	13.2	335.1	53.5	42.7	48	1353	130	117
	Yuxi	23	26.8	88.5	56.5	52.0	44	224	119	109
	Zhaotong	18	28.1	57.5	42.0	40.9	53	153	106	113
Zhejiang	Hangzhou	234	15.5	196.4	37.3	34.5	45	655	99	89
	Huzhou	62	26.0	189.8	42.4	34.3	51	160	94	89
	Jiaxing	70	24.8	63.7	33.1	31.9	80	172	98	96
	Jinhua	271	19.9	62.2	33.8	32.6	32	183	70	68
	Lishui	63	25.3	92.5	41.0	38.4	46	181	75	70
	Ningbo	132	30.0	132.5	47.9	44.7	62	234	123	117
	Quzhou	79	16.1	72.0	33.5	31.4	27	144	68	69
	Shaoxing	127	16.4	314.8	61.8	54.1	59	294	133	124
	Taizhou	189	26.0	153.0	43.1	39.0	68	460	115	109
	Wenzhou	92	34.0	241.0	65.0	56.0	75	400	148	136
All cities		7354	9.4	2675.0	45.0	34.1	15	3179	112	97
Target Value						36.6				126
NBSV*					27.0				74	

*The national background soil value in China (CEMS, 1990)

Table 5 Statistical summaries of heavy metal concentrations in urban deep soil (150–180 cm) from cities in study area (mg kg^{-1})

Municipalities / province	City	n	As				Cd			
			Min	Max	Mean	Median	Min	Max	Mean	Median
Shanghai	Shanghai	247	4.9	15.6	7.8	7.6	0.059	0.800	0.115	0.100
Chongqing	Chongqing	53	2.6	16.4	6.0	5.4	0.055	0.234	0.122	0.114
Anhui	Anqing	8	8.0	11.6	9.4	9.3	0.047	0.219	0.134	0.150
	Bengbu	15	9.2	13.3	11.9	12.3	0.054	0.153	0.103	0.101
	Chizhou	12	7.6	24.9	12.8	12.7	0.055	0.229	0.131	0.112
	Chuzhou	15	8.3	12.8	10.4	10.6	0.054	0.105	0.078	0.077
	Fuyang	23	7.8	14.2	11.6	11.7	0.059	0.158	0.078	0.070
	Hefei	30	7.9	14.9	12.4	13.0	0.039	0.095	0.064	0.063
	Huainan	15	10.0	11.9	11.2	11.3	0.053	0.120	0.067	0.061
	Liu'an	7	5.3	12.2	8.8	9.2	0.031	0.097	0.054	0.037
	Ma'anshan	12	8.5	12.7	10.1	9.9	0.044	0.196	0.116	0.109
	Tongling	8	8.8	140.1	29.0	12.6	0.050	0.561	0.179	0.126
	Wuhu	34	3.5	14.6	9.3	9.4	0.064	0.342	0.191	0.198
	Suzhou	13	11.1	21.3	13.8	13.4	0.066	0.187	0.097	0.093
	Xuancheng	12	9.6	16.0	13.0	12.7	0.042	0.446	0.162	0.088
Guizhou	Bijie	9	6.3	27.8	15.7	15.5	0.071	0.243	0.159	0.147
	Guizhou	49	8.0	73.4	25.9	18.7	0.057	1.970	0.367	0.220
Hubei	Ezhou	5	8.0	11.3	9.4	9.4	0.065	0.285	0.184	0.211
	Enshi	8	1.0	11.5	6.8	7.2	0.054	0.971	0.213	0.084
	Huanggang	5	6.5	10.2	8.9	9.2	0.064	0.239	0.148	0.129
	Huangshi	5	13.2	29.9	19.4	17.5	0.055	0.761	0.340	0.289
	Jingmen	6	10.1	34.6	20.3	19.3	0.081	0.315	0.180	0.160
	Jingzhou	8	6.2	15.9	10.9	10.6	0.088	0.288	0.202	0.209
	Suizhou	10	5.7	11.4	8.1	7.9	0.053	0.083	0.068	0.067
	Wuhan	65	5.2	21.1	12.0	11.8	0.040	0.590	0.158	0.130
	Xianning	7	8.7	37.9	18.6	13.6	0.053	0.152	0.079	0.064
	Xiangyang	11	6.8	25.9	11.5	11.4	0.058	0.317	0.152	0.132
	Xiaogan	8	7.1	14.5	11.8	13.3	0.021	0.075	0.051	0.054
	Yichang	8	3.8	25.5	9.8	8.8	0.074	0.182	0.136	0.134
Hunan	Changde	17	6.2	14.9	9.3	9.4	0.069	0.473	0.231	0.252
	Chenzhou	18	22.4	255.9	99.1	73.1	0.246	3.693	1.194	0.847
	Hengyang	22	6.8	60.2	20.7	17.7	0.075	0.850	0.231	0.135
	Loudi	15	5.5	28.6	13.0	13.4	0.097	0.470	0.246	0.230
	Shaoyang	3	11.8	28.5	21.4	23.8	0.300	0.970	0.607	0.550
	Xiangtan	9	9.7	24.4	17.3	16.6	0.042	0.390	0.161	0.110
	Yiyang	8	8.6	52.2	20.1	15.6	0.080	0.346	0.152	0.110
	Yueyang	7	11.7	36.8	19.0	16.5	0.034	0.220	0.084	0.067
	Changsha	40	6.9	31.7	14.1	13.0	0.042	0.868	0.128	0.083
	Zhuzhou	14	7.2	52.7	15.3	13.1	0.032	1.500	0.229	0.130

Table 5 (continued)

Municipalities / province	City	n	As				Cd			
			Min	Max	Mean	Median	Min	Max	Mean	Median
Jiangsu	Changzhou	17	7.0	13.0	9.7	9.7	0.063	0.120	0.083	0.084
	Huai 'an	19	8.6	14.7	10.6	10.0	0.068	0.110	0.091	0.094
	Lianyungang	17	5.6	15.6	10.9	10.7	0.051	0.170	0.094	0.097
	Nanjing	70	2.7	28.9	10.6	10.4	0.036	0.470	0.157	0.140
	Nantong	22	3.4	5.8	4.6	4.6	0.065	0.120	0.089	0.085
	Suzhou	30	7.6	17.3	10.0	9.6	0.055	0.140	0.077	0.073
	Taizhou	15	3.0	14.4	6.8	6.0	0.061	0.220	0.099	0.085
	Wuxi	20	7.3	14.9	10.9	11.0	0.044	0.130	0.089	0.087
	Suqian	12	7.8	10.2	8.8	9.0	0.070	0.100	0.082	0.081
	Xuzhou	17	6.4	14.2	10.2	9.8	0.066	0.120	0.096	0.093
	Yancheng	8	6.5	10.6	8.8	8.8	0.063	0.095	0.079	0.078
	Yangzhou	17	1.6	14.2	6.3	4.3	0.061	0.240	0.112	0.100
	Zhenjiang	13	8.2	13.2	10.5	10.6	0.072	0.290	0.147	0.130
Jiangxi	Fuzhou	10	2.6	31.5	10.3	8.6	0.028	0.094	0.065	0.080
	Ganzhou	14	4.7	24.7	11.9	11.8	0.036	0.224	0.144	0.125
	Ji'an	11	6.8	16.1	11.7	12.3	0.055	0.110	0.082	0.083
	Jiujiang	3	9.3	15.5	12.8	13.7	0.092	0.150	0.127	0.140
	Nanchang	25	3.6	17.2	8.7	8.6	0.036	0.190	0.096	0.070
	Shangrao	6	6.2	12.2	8.1	7.6	0.053	0.160	0.120	0.135
	Yingtan	8	6.1	16.4	9.5	9.0	0.036	0.130	0.072	0.066
Sichuan	Bazhong	2	6.4	7.0	6.7	6.7	0.175	0.191	0.183	0.183
	Chengdu	59	1.6	26.8	12.3	11.3	0.080	0.290	0.135	0.120
	Deyang	9	7.0	14.4	10.8	10.8	0.140	0.510	0.281	0.260
	Leshan	26	3.0	8.0	5.6	5.5	0.090	0.400	0.169	0.140
	Luzhou	17	2.4	8.7	4.7	4.3	0.078	0.194	0.117	0.106
	Meishan	5	8.0	17.3	12.3	11.1	0.080	0.240	0.132	0.100
	Mianyang	17	9.5	16.1	12.4	12.0	0.080	0.230	0.135	0.130
	Nanchong	12	8.3	15.7	10.2	9.9	0.123	0.236	0.195	0.202
	Neijiang	4	3.2	4.4	3.9	4.0	0.123	0.512	0.245	0.173
	Suining	10	7.2	11.3	9.3	9.3	0.111	0.256	0.189	0.191
	Ya'an	4	4.7	10.2	7.2	7.0	0.100	0.370	0.213	0.190
	Yibin	8	4.1	9.6	5.5	5.0	0.110	0.230	0.159	0.149
	Ziyang	7	3.1	14.1	8.0	8.3	0.073	0.210	0.142	0.139
	Zigong	14	2.5	8.1	4.9	4.4	0.094	0.172	0.128	0.120
Yunnan	Kunming	93	1.8	107.2	11.0	8.2	0.042	14.868	0.495	0.184
	Yuxi	6	5.2	13.1	7.2	6.1	0.031	0.392	0.160	0.106
	Zhaotong	5	6.4	19.2	12.5	14.6	0.110	0.432	0.289	0.299

Table 5 (continued)

Municipalities / province	City	n	As				Cd			
			Min	Max	Mean	Median	Min	Max	Mean	Median
Zhejiang	Hangzhou	66	2.8	21.0	6.2	4.6	0.055	0.374	0.114	0.106
	Huzhou	16	3.3	13.6	6.8	6.3	0.054	0.152	0.107	0.106
	Jiaxing	19	4.3	12.6	7.8	6.9	0.076	0.161	0.112	0.110
	Jinhua	70	2.9	15.5	9.0	9.0	0.073	0.347	0.124	0.120
	Lishui	14	5.2	15.3	7.6	7.1	0.094	0.173	0.123	0.117
	Ningbo	29	6.1	13.3	9.0	8.9	0.071	0.189	0.121	0.119
	Quzhou	19	4.9	13.2	7.5	7.2	0.065	0.207	0.131	0.124
	Shaoxing	38	1.9	52.6	7.4	6.0	0.070	0.320	0.120	0.108
	Taizhou	47	4.6	16.5	8.8	8.4	0.071	0.480	0.150	0.145
	Wenzhou	24	4.4	12.2	7.2	6.4	0.080	0.230	0.153	0.147
All cities		1860	1.0	255.9	11.2	9.2	0.021	14.868	0.165	0.110

Municipalities / province	City	n	Cr				Cu			
			Min	Max	Mean	Median	Min	Max	Mean	Median
Shanghai	Shanghai	247	69	158	88	88	15.5	68.5	27.4	27.2
Chongqing	Chongqing	53	62	117	81	80	15.5	51.4	26.5	24.6
Anhui	Anqing	8	68	87	81	83	24.9	32.6	28.4	28.4
	Bengbu	15	72	83	77	79	20.2	27.7	24.7	25.4
	Chizhou	12	34	97	78	81	10.8	45.2	30.7	28.4
	Chuzhou	15	61	87	75	77	21.0	33.6	27.6	27.1
	Fuyang	23	17	82	47	27	14.8	625.2	334.6	528.4
	Hefei	30	65	88	83	83	21.3	29.6	27.6	27.8
	Huainan	15	77	86	82	85	24.4	28.8	27.0	27.0
	Liu'an	7	63	88	76	76	16.5	26.1	23.5	24.9
	Ma'anshan	12	68	99	81	82	23.8	41.2	30.8	30.8
	Tongling	8	69	96	79	76	25.9	182.1	51.2	30.5
	Wuhu	34	73	98	84	84	24.0	40.5	31.0	30.6
	Suzhou	13	75	89	81	80	22.4	35.0	26.7	26.0
	Xuancheng	12	52	83	67	65	16.9	28.5	22.6	21.8
Guizhou	Bijie	9	64	276	135	119	23.3	83.0	52.5	51.7
	Guizhou	49	57	203	108	103	14.4	115.0	55.6	49.1

Table 5 (continued)

Municipalities / province	City	n	Cr				Cu			
			Min	Max	Mean	Median	Min	Max	Mean	Median
Hubei	Ezhou	5	64	96	82	83	21.4	43.0	33.3	34.9
	Enshi	8	13	82	47	42	6.4	42.4	18.1	13.6
	Huanggang	5	71	99	82	82	22.3	41.3	30.9	30.6
	Huangshi	5	60	91	73	69	25.1	53.3	36.4	33.5
	Jingmen	6	71	94	81	80	24.0	34.0	28.8	28.4
	Jingzhou	8	81	105	91	90	29.6	54.9	41.1	39.1
	Suizhou	10	50	94	68	66	17.8	37.4	24.5	22.6
	Wuhan	65	62	117	89	89	24.8	53.8	34.8	33.9
	Xianning	7	69	86	76	77	22.4	26.4	25.1	25.8
	Xiangyang	11	65	100	72	69	21.6	67.5	30.9	26.7
	Xiaogan	8	62	87	78	80	19.7	30.2	25.9	26.3
	Yichang	8	57	73	65	64	15.0	26.9	20.3	19.9
Hunan	Changde	17	57	187	87	77	17.8	30.1	25.1	26.6
	Chenzhou	18	68	149	96	85	22.2	247.6	56.0	48.3
	Hengyang	22	55	92	74	75	18.6	40.9	28.3	28.1
	Loudi	15	31	95	65	67	8.5	33.0	23.1	23.4
	Shaoyang	3	66	95	81	81	21.4	22.9	22.4	22.8
	Xiangtan	9	70	94	86	87	18.0	30.0	24.9	24.8
	Yiyang	8	72	146	101	93	23.2	28.8	25.0	24.7
	Yueyang	7	64	93	81	84	23.8	34.5	29.5	28.4
	Changsha	40	66	138	93	89	14.9	41.3	26.2	24.6
	Zhuzhou	14	79	144	105	101	23.7	51.0	32.5	30.7
Jiangsu	Changzhou	17	77	92	86	87	27.3	36.8	31.1	30.3
	Huai ‘an	19	56	85	65	62	15.2	26.7	19.7	17.9
	Lianyungang	17	31	116	87	91	10.9	38.2	29.3	30.4
	Nanjing	70	39	128	83	81	11.5	208.0	33.4	30.4
	Nantong	22	64	75	69	68	9.4	18.7	14.6	15.2
	Suzhou	30	78	99	89	90	25.5	54.1	31.1	30.0
	Taizhou	15	65	86	74	73	7.5	37.9	17.7	16.8
	Wuxi	20	78	94	88	88	24.9	49.9	31.4	30.9
	Suqian	12	56	66	60	60	14.2	20.1	17.0	16.7
	Xuzhou	17	51	81	64	62	12.1	29.1	20.2	19.2
	Yancheng	8	68	91	76	75	18.8	26.8	21.8	20.8
	Yangzhou	17	57	86	71	70	7.9	31.2	17.4	14.7
	Zhenjiang	13	72	86	79	79	21.5	37.5	29.0	28.5

Table 5 (continued)

Municipalities / province	City	n	Cr				Cu			
			Min	Max	Mean	Median	Min	Max	Mean	Median
Jiangxi	Fuzhou	10	38	95	64	61	12.3	25.3	20.3	22.2
	Ganzhou	14	45	116	63	62	17.6	35.0	27.0	27.3
	Ji'an	11	56	80	67	61	16.9	28.9	21.1	19.8
	Jiujiang	3	71	90	83	89	24.7	36.4	28.8	25.3
	Nanchang	25	44	163	73	72	13.4	54.0	24.6	23.2
	Shangrao	6	34	45	41	41	13.7	33.8	21.0	19.8
	Yingtan	8	38	70	53	52	14.4	38.4	22.1	20.5
Sichuan	Bazhong	2	65	72	68	68	24.2	24.5	24.4	24.4
	Chengdu	59	45	148	82	82	15.1	41.2	29.2	29.2
	Deyang	9	77	135	106	102	23.9	42.3	33.8	33.5
	Leshan	26	65	188	97	92	16.3	96.8	42.5	41.0
	Luzhou	17	68	83	76	76	18.3	45.1	29.6	28.2
	Meishan	5	82	99	91	93	21.7	34.7	28.3	30.5
	Mianyang	17	69	105	84	84	21.0	35.0	25.8	25.2
	Nanchong	12	74	97	85	84	21.8	30.6	27.4	28.5
	Neijiang	4	60	71	67	69	28.0	30.8	29.3	29.2
	Suining	10	61	88	73	71	25.8	35.1	31.7	33.0
	Ya'an	4	79	106	95	98	24.0	31.1	28.1	28.7
	Yibin	8	56	109	81	81	24.2	39.6	29.5	27.0
	Ziyang	7	65	80	74	75	24.5	35.9	31.4	33.0
	Zigong	14	58	81	70	71	23.1	51.6	29.8	27.2
Yunnan	Kunming	93	73	396	117	105	21.4	269.9	106.2	90.2
	Yuxi	6	60	105	89	95	22.6	35.7	30.4	31.9
	Zhaotong	5	60	136	101	105	18.0	93.1	57.5	49.7
Zhejiang	Hangzhou	66	40	127	68	58	7.1	84.3	18.9	15.3
	Huzhou	16	64	130	90	87	12.2	47.8	26.8	26.7
	Jiaxing	19	65	120	91	89	17.0	55.1	28.0	24.8
	Jinhua	70	19	88	50	48	10.1	55.8	18.6	16.8
	Lishui	14	16	50	32	29	8.6	18.0	12.6	12.1
	Ningbo	29	58	135	112	116	17.7	64.6	33.2	33.0
	Quzhou	19	25	65	44	47	9.4	19.4	13.7	12.5
	Shaoxing	38	45	106	76	76	8.8	101.5	28.3	24.0
	Taizhou	47	25	118	86	94	7.2	40.9	27.2	28.7
	Wenzhou	24	38	106	83	83	11.5	42.9	25.4	22.9
All cities		1860	13	396	82	82	6.4	625.2	36.0	27.5

Table 6 Statistical summaries of heavy metal concentrations in urban deep soil (150–180 cm) from cities in study area (mg kg^{-1})

Municipalities / province	City	n	Hg				Ni			
			Min	Max	Mean	Median	Min	Max	Mean	Median
Shanghai	Shanghai	247	0.028	0.420	0.070	0.056	26.4	64.2	38.2	38.4
Chongqing	Chongqing	53	0.019	0.099	0.051	0.046	20.2	50.0	32.4	31.6
Anhui	Anqing	8	0.026	0.092	0.045	0.039	32.8	38.4	35.0	34.6
	Bengbu	15	0.007	0.019	0.011	0.010	29.7	42.4	35.6	35.1
	Chizhou	12	0.019	0.408	0.084	0.050	14.5	43.3	32.9	33.4
	Chuzhou	15	0.006	0.019	0.012	0.011	25.1	41.6	35.9	36.0
	Fuyang	23	0.001	0.036	0.010	0.002	25.2	522.4	233.1	330.9
	Hefei	30	0.010	0.144	0.025	0.015	23.2	42.4	34.8	35.2
	Huainan	15	0.011	0.021	0.015	0.015	32.3	38.3	35.7	35.8
	Liu'an	7	0.012	0.040	0.020	0.016	27.0	38.1	32.9	33.8
	Ma'anshan	12	0.013	0.056	0.037	0.039	25.3	45.8	35.0	35.7
	Tongling	8	0.024	0.092	0.049	0.044	28.1	34.4	30.5	29.9
	Wuhu	34	0.014	0.100	0.044	0.041	29.3	43.8	36.9	36.9
	Suzhou	13	0.011	0.032	0.016	0.014	32.3	42.7	36.3	35.7
	Xuancheng	12	0.030	1.968	0.238	0.065	19.9	37.4	27.6	28.8
Guizhou	Bijie	9	0.038	0.425	0.183	0.138	21.8	108.4	55.3	49.8
	Guizhou	49	0.029	0.730	0.215	0.190	19.0	120.0	50.9	47.1
Hubei	Ezhou	5	0.033	0.131	0.068	0.057	24.0	44.8	34.0	33.5
	Enshi	8	0.008	0.161	0.064	0.044	5.4	45.7	21.6	15.8
	Huanggang	5	0.034	0.068	0.052	0.051	28.9	42.7	34.9	36.3
	Huangshi	5	0.020	0.107	0.054	0.043	20.3	38.9	29.2	29.1
	Jingmen	6	0.017	0.077	0.031	0.023	31.5	60.2	43.5	42.3
	Jingzhou	8	0.038	0.978	0.197	0.062	35.6	51.4	42.0	41.2
	Suizhou	10	0.006	0.079	0.026	0.020	19.3	77.8	35.5	27.0
	Wuhan	65	0.014	0.184	0.053	0.046	28.0	56.8	39.7	38.9
	Xianning	7	0.040	0.085	0.059	0.060	23.7	29.3	26.0	26.0
	Xiangyang	11	0.015	0.313	0.058	0.024	24.4	50.5	34.5	33.2
	Xiaogan	8	0.019	0.038	0.024	0.022	26.2	43.1	35.2	34.4
	Yichang	8	0.013	0.114	0.038	0.030	17.6	31.7	24.6	24.4
Hunan	Changde	17	0.052	1.070	0.171	0.105	20.4	33.4	29.0	30.2
	Chenzhou	18	0.102	0.220	0.155	0.146	24.3	159.1	63.7	49.0
	Hengyang	22	0.036	0.323	0.097	0.069	20.0	35.3	28.2	29.0
	Loudi	15	0.028	0.160	0.093	0.108	10.9	38.8	30.2	32.1
	Shaoyang	3	0.076	0.203	0.130	0.110	29.6	36.6	32.4	31.1
	Xiangtan	9	0.055	0.108	0.088	0.090	21.1	41.7	29.0	27.8
	Yiyang	8	0.048	0.117	0.073	0.072	26.3	30.2	28.3	28.8
	Yueyang	7	0.033	0.084	0.052	0.053	22.4	34.1	29.8	31.8
	Changsha	40	0.034	1.058	0.095	0.065	14.0	39.9	26.3	26.4
	Zhuzhou	14	0.041	0.470	0.114	0.067	21.1	39.4	29.9	29.1

Table 6 (continued)

Municipalities / province	City	n	Hg				Ni			
			Min	Max	Mean	Median	Min	Max	Mean	Median
Jiangsu	Changzhou	17	0.023	0.350	0.075	0.044	34.2	40.5	37.8	38.0
	Huai 'an	19	0.009	0.180	0.031	0.021	21.6	38.0	26.8	25.4
	Lianyungang	17	0.014	0.120	0.039	0.031	14.2	53.3	40.5	45.2
	Nanjing	70	0.014	0.440	0.052	0.028	17.5	60.8	38.7	37.8
	Nantong	22	0.021	0.063	0.034	0.035	21.4	28.6	24.9	25.1
	Suzhou	30	0.024	6.850	0.306	0.060	33.7	41.8	37.2	37.1
	Taizhou	15	0.016	0.190	0.049	0.030	22.7	39.4	27.6	24.9
	Wuxi	20	0.024	0.150	0.052	0.040	31.2	99.3	42.4	39.3
	Suqian	12	0.010	0.031	0.018	0.017	22.0	28.8	24.2	23.2
	Xuzhou	17	0.010	0.160	0.045	0.033	18.7	40.2	27.7	25.7
	Yancheng	8	0.015	0.051	0.026	0.023	29.3	43.6	33.7	32.1
	Yangzhou	17	0.014	0.390	0.059	0.043	21.3	40.8	28.8	25.9
	Zhenjiang	13	0.017	0.380	0.061	0.026	30.6	41.7	38.0	38.3
Jiangxi	Fuzhou	10	0.035	0.130	0.085	0.087	12.9	28.6	22.2	24.1
	Ganzhou	14	0.030	0.104	0.055	0.046	14.1	61.8	25.2	23.4
	Ji'an	11	0.041	0.300	0.086	0.066	18.2	33.2	24.9	24.5
	Jiujiang	3	0.044	0.130	0.095	0.110	27.9	35.9	31.1	29.4
	Nanchang	25	0.024	1.613	0.112	0.041	18.1	41.6	27.3	26.5
	Shangrao	6	0.037	0.120	0.055	0.045	14.1	20.2	16.2	15.5
	Yingtan	8	0.033	0.046	0.041	0.041	12.2	27.7	20.5	21.1
Sichuan	Bazhong	2	0.023	0.043	0.033	0.033	27.2	35.4	31.3	31.3
	Chengdu	59	0.008	0.550	0.052	0.030	23.2	54.9	36.8	38.1
	Deyang	9	0.040	0.140	0.068	0.050	30.8	45.8	36.5	36.0
	Leshan	26	0.020	0.100	0.054	0.050	16.6	66.3	33.2	31.6
	Luzhou	17	0.025	0.105	0.049	0.039	18.5	33.7	29.4	29.0
	Meishan	5	0.020	0.100	0.060	0.050	26.5	45.9	34.1	33.7
	Mianyang	17	0.020	0.110	0.043	0.040	27.9	44.1	35.4	35.5
	Nanchong	12	0.015	0.109	0.042	0.028	31.1	50.9	41.0	42.3
	Neijiang	4	0.032	0.063	0.048	0.048	33.5	38.1	35.6	35.4
	Suining	10	0.021	0.095	0.045	0.039	36.0	51.0	43.4	43.9
	Ya'an	4	0.030	0.130	0.058	0.035	26.6	34.3	31.1	31.8
	Yibin	8	0.029	0.064	0.040	0.037	23.6	38.3	32.3	32.8
	Ziyang	7	0.009	0.059	0.028	0.018	31.6	45.5	38.8	40.3
	Zigong	14	0.022	0.059	0.043	0.049	31.1	40.5	36.0	36.1
Yunnan	Kunming	93	0.017	1.235	0.098	0.067	21.7	127.6	58.5	59.8
	Yuxi	6	0.046	0.080	0.060	0.055	16.3	33.3	25.1	25.6
	Zhaotong	5	0.058	0.167	0.109	0.093	25.8	56.8	44.7	43.3

Table 6 (continued)

Municipalities / province	City	n	Hg				Ni			
			Min	Max	Mean	Median	Min	Max	Mean	Median
Zhejiang	Hangzhou	66	0.021	4.091	0.134	0.052	13.7	52.8	28.1	26.2
	Huzhou	16	0.028	0.175	0.060	0.045	24.9	44.9	32.7	31.4
	Jiaxing	19	0.030	0.051	0.039	0.039	29.1	48.3	39.0	39.2
	Jinhua	70	0.020	0.224	0.050	0.044	6.4	29.1	15.6	14.3
	Lishui	14	0.015	0.071	0.034	0.032	5.5	19.4	10.2	9.3
	Ningbo	29	0.041	0.293	0.096	0.067	22.7	51.4	44.0	44.0
	Quzhou	19	0.022	0.188	0.059	0.043	7.9	19.6	13.0	11.4
	Shaoxing	38	0.031	2.001	0.224	0.133	17.3	39.3	30.9	31.8
	Taizhou	47	0.042	0.267	0.069	0.060	8.5	49.6	36.4	38.7
	Wenzhou	24	0.052	0.410	0.134	0.093	17.4	46.4	36.0	34.6
All cities		1860	0.001	6.850	0.079	0.049	5.4	522.4	37.6	35.0

Municipalities / province	City	n	Pb				Zn			
			Min	Max	Mean	Median	Min	Max	Mean	Median
Shanghai	Shanghai	247	17.9	51.8	26.4	26.1	72	177	104	103
Chongqing	Chongqing	53	19.8	42.1	26.0	26.1	57	117	80	79
Anhui	Anqing	8	22.6	31.7	26.5	25.5	61	83	73	74
	Bengbu	15	19.5	28.4	24.9	25.0	58	76	66	65
	Chizhou	12	22.8	53.3	31.5	29.9	56	111	81	72
	Chuzhou	15	18.7	27.4	23.5	23.5	50	75	64	63
	Fuyang	23	17.8	116.8	71.9	100.7	54	300	167	225
	Hefei	30	19.9	31.2	25.9	26.0	44	67	60	61
	Huainan	15	23.2	27.6	25.3	25.7	56	69	63	63
	Liu'an	7	22.4	27.5	24.3	23.5	56	75	64	62
	Ma'anshan	12	19.7	30.7	23.7	23.5	51	107	74	77
	Tongling	8	22.3	67.1	34.0	25.4	54	160	82	66
	Wuhu	34	16.3	29.8	24.1	24.0	62	94	79	78
	Suzhou	13	21.5	28.5	24.4	24.1	57	86	64	62
	Xuancheng	12	22.2	29.5	25.2	24.3	39	99	63	56
Guizhou	Bijie	9	17.6	36.3	27.5	26.4	39	158	98	99
	Guizhou	49	23.0	83.7	38.5	35.0	45	179	112	106

Table 6 (continued)

Municipalities / province	City	n	Pb				Zn			
			Min	Max	Mean	Median	Min	Max	Mean	Median
Hubei	Ezhou	5	21.6	34.1	28.2	27.0	58	116	88	88
	Enshi	8	11.9	28.7	18.8	17.4	15	103	52	45
	Huanggang	5	20.0	29.0	25.4	26.1	66	107	83	83
	Huangshi	5	22.4	126.2	65.2	70.0	53	185	130	150
	Jingmen	6	26.3	50.0	34.8	30.5	59	184	98	84
	Jingzhou	8	21.7	39.0	28.5	25.9	61	143	92	85
	Suizhou	10	17.9	24.8	21.7	22.0	50	74	60	57
	Wuhan	65	16.7	38.3	25.6	24.6	53	118	82	77
	Xianning	7	23.7	28.6	26.3	26.1	54	77	66	64
	Xiangyang	11	16.4	25.9	20.7	21.5	62	184	81	68
	Xiaogan	8	21.6	26.2	23.8	24.0	46	71	59	59
	Yichang	8	14.1	23.5	20.1	20.7	38	75	57	54
Hunan	Changde	17	20.0	30.7	25.4	26.1	66	113	91	96
	Chenzhou	18	42.7	415.3	143.8	77.1	90	378	185	156
	Hengyang	22	24.7	57.0	33.4	30.9	55	118	85	81
	Loudi	15	21.4	45.5	27.7	26.2	36	126	77	79
	Shaoyang	3	24.3	25.2	24.8	25.0	71	95	81	76
	Xiangtan	9	21.1	47.6	33.1	30.7	50	125	80	72
	Yiyang	8	25.7	33.9	29.2	29.1	68	91	79	80
	Yueyang	7	22.7	31.1	26.8	26.8	59	86	74	73
	Changsha	40	19.8	55.1	28.2	25.4	36	121	74	67
	Zhuzhou	14	20.1	110.9	34.3	29.6	59	249	85	72
Jiangsu	Changzhou	17	22.5	34.6	24.9	24.0	64	86	72	73
	Huai ‘an	19	15.3	27.1	20.1	19.1	47	69	56	55
	Lianyungang	17	23.8	39.7	31.1	31.2	63	120	95	98
	Nanjing	70	2.9	52.6	24.9	23.1	47	154	80	77
	Nantong	22	13.5	18.4	15.7	15.1	48	65	57	58
	Suzhou	30	21.3	41.1	25.9	25.2	62	85	72	72
	Taizhou	15	12.4	25.1	17.4	16.3	43	89	58	53
	Wuxi	20	22.3	28.2	25.0	24.8	56	81	72	73
	Suqian	12	14.7	23.4	18.0	18.2	45	59	50	50
	Xuzhou	17	15.7	29.1	21.0	18.1	40	71	55	54
	Yancheng	8	20.1	28.6	22.4	21.1	60	88	71	68
	Yangzhou	17	10.4	24.5	16.9	15.6	40	83	58	56
	Zhenjiang	13	18.1	49.0	25.4	22.7	63	94	77	77

Table 6 (continued)

Municipalities / province	City	n	Pb				Zn			
			Min	Max	Mean	Median	Min	Max	Mean	Median
Jiangxi	Fuzhou	10	17.6	40.8	30.5	31.4	40	103	71	72
	Ganzhou	14	21.9	49.6	33.0	32.6	43	93	68	70
	Ji'an	11	19.3	36.7	28.3	28.8	47	89	66	65
	Jiujiang	3	19.6	29.0	24.2	23.9	65	89	73	66
	Nanchang	25	17.9	90.7	29.7	27.1	43	149	73	70
	Shangrao	6	22.0	30.8	24.9	22.9	43	76	57	54
	Yingtan	8	15.8	37.4	26.3	26.4	34	87	57	56
Sichuan	Bazhong	2	20.7	21.8	21.3	21.3	67	72	70	70
	Chengdu	59	15.0	37.6	23.7	23.0	42	112	78	78
	Deyang	9	21.9	36.8	26.7	25.7	71	95	81	81
	Leshan	26	18.0	37.0	26.4	25.3	38	104	74	70
	Luzhou	17	21.4	32.1	27.5	28.6	58	93	77	77
	Meishan	5	23.1	29.8	26.0	24.7	60	91	75	75
	Mianyang	17	23.0	29.2	25.9	25.6	56	97	73	70
	Nanchong	12	21.0	29.1	25.3	24.9	69	108	96	100
	Neijiang	4	24.1	39.8	30.0	28.1	81	115	93	88
	Suining	10	22.1	29.3	25.7	25.6	76	110	93	94
	Ya'an	4	20.3	27.0	23.7	23.8	64	82	74	76
	Yibin	8	19.6	29.0	25.0	25.4	59	93	78	78
	Ziyang	7	24.2	28.1	26.5	26.5	67	95	85	89
	Zigong	14	24.6	31.7	28.1	27.1	70	90	81	81
Yunnan	Kunming	93	17.4	112.3	37.9	34.3	30	197	99	99
	Yuxi	6	27.0	50.5	36.5	36.9	49	82	68	70
	Zhaotong	5	29.9	37.8	33.7	33.5	56	132	101	103
Zhejiang	Hangzhou	66	12.7	201.4	25.2	20.5	33	134	69	61
	Huzhou	16	19.1	51.5	28.3	27.7	41	108	76	75
	Jiaxing	19	18.9	32.9	24.9	24.5	65	110	88	89
	Jinhua	70	18.3	40.4	29.0	28.9	36	103	61	60
	Lishui	14	25.8	69.2	34.9	34.2	48	81	62	62
	Ningbo	29	23.3	37.3	31.0	30.5	74	116	100	100
	Quzhou	19	17.3	41.7	27.3	26.7	29	84	57	61
	Shaoxing	38	14.5	88.7	30.2	27.5	51	147	84	81
	Taizhou	47	25.0	115.0	40.1	35.0	64	147	101	103
	Wenzhou	24	31.0	76.0	45.3	45.5	83	128	107	107
All cities		1860	2.9	415.3	29.6	26.1	15	378	84	78

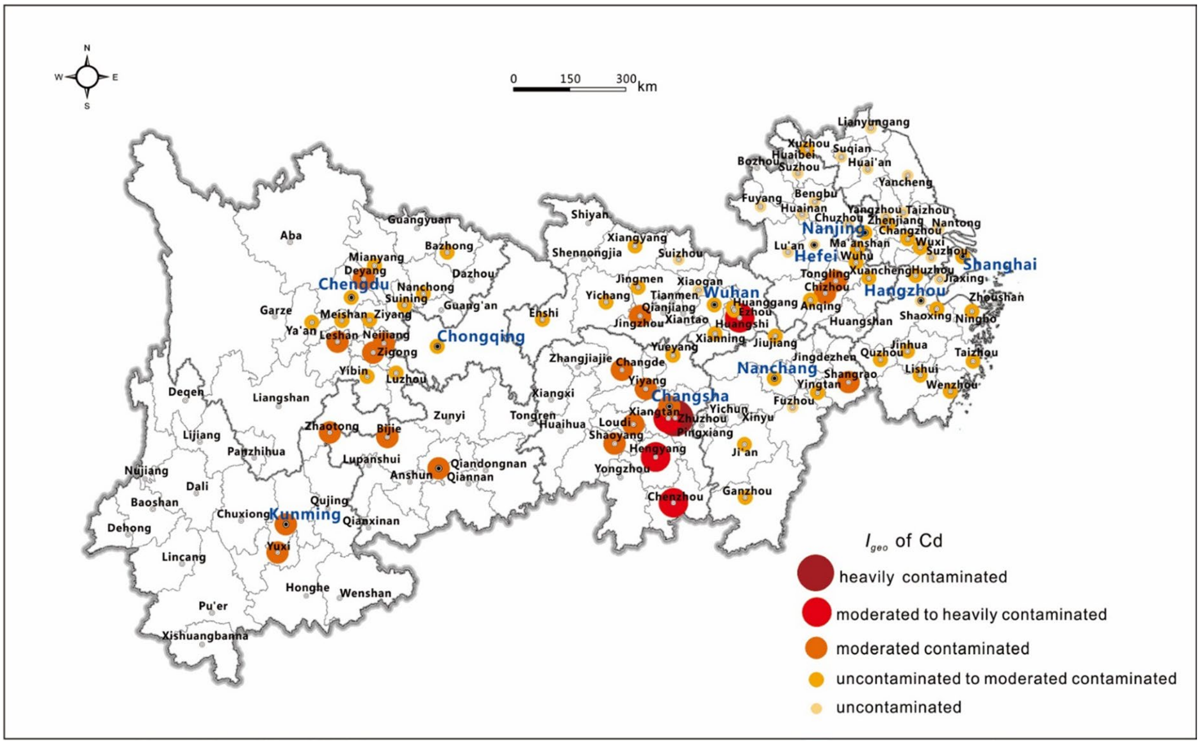


Fig. 2 Cd pollution level map of cities in YREB

Hg pollution or above, accounting for 31.40% (Fig. 3).

In addition, soil As displays moderate to heavy contamination in Chenzhou (2.24) and moderate contamination in Huangshi (1.35). Soil Cu is moderately contaminated in Kunming (1.34). Huangshi (1.59), Chenzhou (1.42) and Zhuzhou (1.24) are moderately contaminated by Pb. Soil Zn shows moderate contamination in Huangshi (1.10). Soil Cr and Ni basically show no contamination in all cities.

In YREB, there are complex associations between metal pollutants which vary greatly between different cities. According to the I_{geo} value, Chenzhou, Zhuzhou, Xiangtan and Huangshi exposed the combined pollution of As, Cd, Cu, Pb, Zn and Hg, while Kunming is polluted by Cd, Cu, Pb, Ni and Hg, Hengyang by Cd, As, Pb, Zn and Hg, Guiyang and Tongling by Cd, As, Pb, Cu and Hg, other cities are, respectively, polluted by 4 or 3 or 2 or 1 element. In total, 12 cities showed no pollution of all eight metals, accounting for only 13.95%.

Integrated pollution index (*IPI*) reveal that the soil in 7 cities in YREB is heavily polluted, 10 are moderately polluted, 51 are slight polluted, 17 are on precaution, and only one is safe. The 7 heavily polluted cities are Zhuzhou ($IPI = 7.51$, the same below), Chenzhou (5.44), Huangshi (4.36), Shaoxing (4.28), Xiangtan (3.83), Hengyang (3.58) and Ningbo (3.22), and the 10 moderately polluted cities are Suzhou (2.69), Wuxi (2.61), Yuxi (2.48), Deyang (2.31), Changsha (2.25), Kunming (2.20), Zhaotong (2.18), Loudi (2.11), Chengdu (2.08) and Hangzhou (2.04). Cd and Hg are also decisive pollution indexes in the above cities.

Distribution patterns and source identification in key cities

Zhuzhou City

The I_{geo} of soil Cd in Zhuzhou ranks first in the cities of YREB and has reached a heavily contaminated level, and the I_{geo} of soil Pb is in the third place,

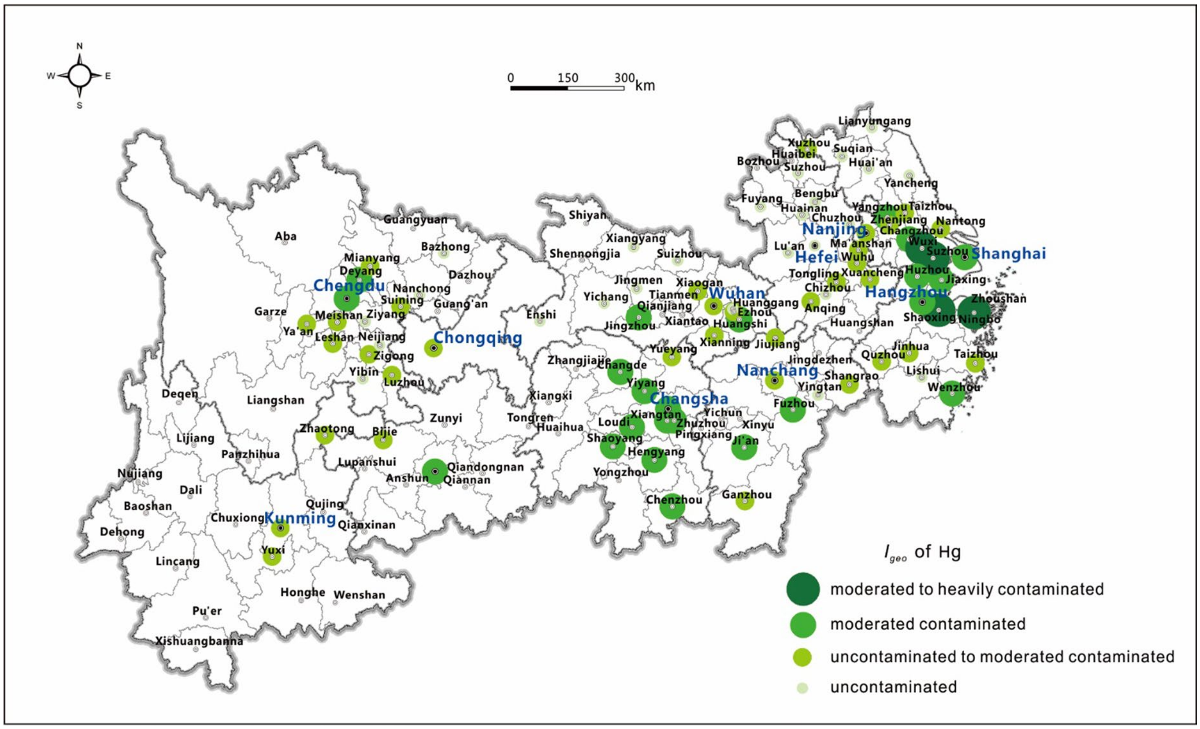


Fig. 3 Hg pollution level map of cities in YREB

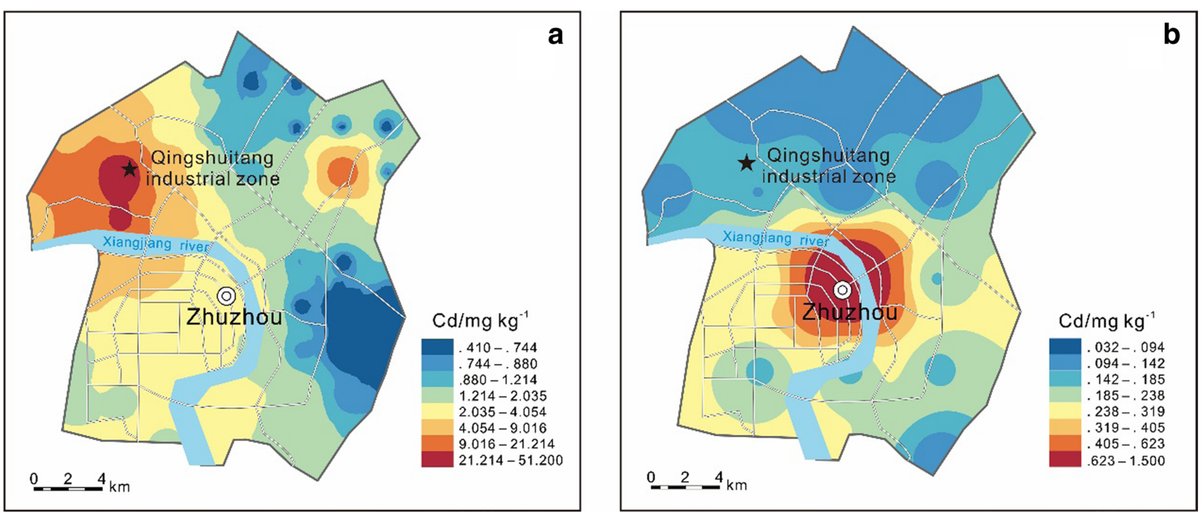


Fig. 4 Distribution of Cd in the topsoil **a** and deep soil **b** of Zhuzhou

Pb > As > Cd > Hg, which are consistent with the deep/background values, indicating geological background is of great significance in determining heavy metal contents in urban soils.

The contents of above heavy metals in urban topsoils are 1.01, 1.91, 0.98, 1.20, 2.65, 0.93, 1.31 and 1.24 times of urban deep soils. The general increase in the contents of heavy metals in topsoils suggests

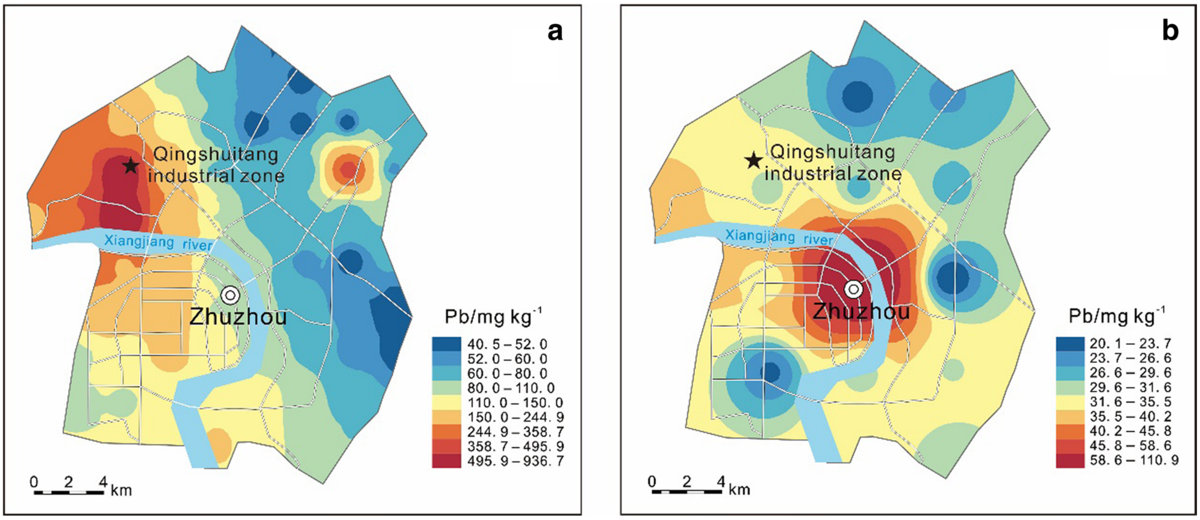


Fig. 5 Distribution of Pb in the topsoil **a** and deep soil **b** of Zhuzhou

the influence of human activities in urban areas, and among the eight heavy metals, human activities have the most significant impact on the changes of Cd and Hg contents.

In terms of contents, cities with prominent high contents of Cd, As, Pb and Zn are mainly concentrated in Hunan and Hubei Province, and cities with major high Cr, Cu and Ni contents occur in Yunnan and Guizhou Provinces, while cities in Zhejiang and Jiangsu Province principally display remarkable high contents of soil Hg.

Degree of contamination with heavy metals in urban soils

The geo-accumulation index (I_{geo}), pollution indexes (*PI*) and integrated pollution index (*IPI*) of all of the investigated cities are presented in Table 7.

The overall statistical results show that the I_{geo} of eight heavy metals in urban soils decreases in order of Hg (0.82) > Cd (0.35) > Pb (−0.20) > Zn (−0.27) > Cu (−0.32) > As (−0.57) > Cr (−0.63) > Ni (−0.68), indicating that on a regional scale, urban soils in YREB are uncontaminated to moderately contaminated by Hg and Cd, while As, Cr, Cu, Ni, Pb and Zn are uncontaminated.

Cd in Zhuzhou has the highest degree of pollution, showing heavily contaminated (I_{geo} = 3.42, the same below). Soil Cd shows moderate to heavy contamination in 4 cities: Chenzhou (2.91), Huangshi (2.56), Xiangtan (2.41) and Hengyang (2.31). Eighteen cities soil Cd display moderately contaminated level, namely Yuxi (1.77), Deyang (1.66), Changsha (1.60), Zhaotong (1.53), Loudi (1.49), Kunming (1.47), Yiyang (1.38), Leshan (1.35), Tongling (1.34), Chizhou (1.29), Zigong, (1.23), Guiyang (1.20), Shangrao (1.20), Shaoyang (1.18), Bijie (1.18), Changde (1.05), Neijiang (1.03) and Jingzhou (1.02). In general, there are 23 cities with moderate Cd pollution or above, accounting for 26.74% (Fig. 2).

Four cities reveal moderate to heavy contamination of Hg in urban soils, namely Shaoxing (2.82), Ningbo (2.39), Suzhou (2.12) and Wuxi (2.08). Besides, 23 cities are moderately contaminated by Hg, respectively, Zhuzhou (1.75), Hangzhou (1.71), Chengdu (1.71), Changzhou (1.65), Xiangtan (1.63), Jiaxing (1.62), Yangzhou (1.58), Huzhou (1.56), Wenzhou (1.56), Guiyang (1.51), Shaoyang (1.48), Jingzhou (1.47), Yiyang (1.40), Changde (1.40), Shanghai (1.29), Hengyang (1.26), Loudi (1.21), Fuzhou (1.21), Changsha (1.18), Chenzhou (1.15), Huangshi (1.14), Deyang (1.03) and Ji'an (1.03). Totality, there are 27 cities with moderate

Table 7 Geo-accumulation indexes (I_{geo}) and pollution indexes (PIs) of heavy metals in urban soils from cities in study area

Municipalities / province	City	I_{geo}							
		Cd	As	Cr	Cu	Hg	Ni	Pb	Zn
Shanghai	Shanghai	0.20	−0.81	−0.47	−0.31	1.29	−0.49	−0.27	−0.07
Chongqing	Chongqing	0.86	−1.53	−0.83	−0.57	0.17	−0.79	−0.34	−0.33
Anhui	Anqing	0.14	−0.38	−0.67	−0.38	0.52	−0.83	−0.31	−0.50
	Bengbu	−0.22	−0.49	−0.84	−0.68	−0.52	−0.88	−0.42	−0.73
	Chizhou	1.29	0.18	−0.67	0.00	−0.02	−0.77	0.26	−0.21
	Chuzhou	−0.51	−0.43	−0.86	−0.60	−0.69	−0.81	−0.57	−0.91
	Fuyang	−0.11	−0.46	−0.71	−0.66	−0.73	−0.73	−0.51	−0.82
	Hefei	−0.69	−0.45	−0.82	−0.55	−0.37	−1.00	−0.50	−0.99
	Huainan	−0.44	−0.40	−0.80	−0.49	−0.47	−0.90	−0.42	−0.70
	Liu'an	−0.68	−0.37	−0.80	−0.81	−0.51	−0.79	−0.48	−1.01
	Ma'anshan	0.11	−0.48	−0.72	−0.15	0.47	−0.74	−0.38	−0.48
	Tongling	1.34	0.36	−0.76	0.74	0.32	−0.85	0.06	−0.30
	Wuhu	0.67	−0.52	−0.55	−0.04	0.18	−0.54	−0.26	−0.29
	Suzhou	−0.13	−0.39	−0.75	−0.59	−0.65	−0.80	−0.56	−0.70
	Xuancheng	0.73	−0.16	−1.00	−0.76	0.28	−1.23	−0.44	−0.72
Guizhou	Bijie	1.18	0.05	-0.18	0.37	0.71	-0.21	-0.33	-0.38
	Guizhou	1.20	0.45	-0.13	0.29	1.51	-0.40	0.14	-0.01
Hubei	Ezhou	0.82	−0.21	−0.59	−0.09	0.16	−0.69	−0.12	−0.14
	Enshi	0.61	−1.38	−1.93	−1.67	−0.51	−2.04	−1.11	−1.35
	Huanggang	0.36	−0.56	−0.62	−0.31	−0.27	−0.71	−0.27	−0.47
	Huangshi	2.56	1.35	−0.35	0.98	1.14	−0.57	1.59	1.10
	Jingmen	0.44	−0.11	−0.67	−0.62	−0.46	−0.60	−0.08	−0.64
	Jingzhou	1.02	−0.24	−0.55	−0.06	1.47	−0.56	−0.19	−0.12
	Suizhou	−0.04	−0.90	−1.03	−0.63	−0.20	−1.04	−0.62	−0.76
	Wuhan	0.76	−0.08	−0.48	0.02	0.50	−0.47	−0.05	−0.16
	Xianning	0.40	−0.24	−0.71	−0.59	0.34	−1.07	−0.35	−0.58
	Xiangyang	0.62	−0.27	−0.74	−0.41	−0.20	−0.65	−0.36	−0.34
	Xiaogan	−0.14	−0.73	−0.87	−0.66	0.37	−0.91	−0.42	−0.97
	Yichang	0.46	−0.75	−0.83	−0.78	−0.61	−1.14	−0.66	−0.59
Hunan	Changde	1.05	−0.36	−0.72	−0.57	1.40	−0.93	−0.22	−0.38
	Chenzhou	2.91	2.24	−0.39	0.28	1.15	−0.01	1.42	0.70
	Hengyang	2.31	0.86	−0.68	−0.03	1.26	−0.75	0.37	0.10
	Loudi	1.49	0.02	−0.54	−0.51	1.21	−0.54	0.02	−0.10
	Shaoyang	1.18	0.50	−0.75	−0.36	1.48	−0.70	−0.20	−0.31
	Xiangtan	2.41	0.51	−0.55	0.08	1.63	−0.77	0.68	0.19
	Yiyang	1.38	0.35	−0.32	−0.43	1.40	−0.89	0.00	−0.30
	Yueyang	0.37	−0.01	−0.71	−0.44	0.03	−0.99	−0.28	−0.45
	Changsha	1.60	0.17	−0.31	−0.20	1.18	−1.05	0.01	−0.19
	Zhuzhou	3.42	0.60	−0.41	0.24	1.75	−0.75	1.24	0.64

Table 7 (continued)

Municipalities / province	City	I_{geo}							
		Cd	As	Cr	Cu	Hg	Ni	Pb	Zn
Jiangsu	Changzhou	0.17	−0.69	−0.54	−0.19	1.65	−0.63	−0.19	−0.36
	Huai 'an	−0.14	−0.47	−0.84	−0.93	−0.07	−0.99	−0.64	−0.77
	Lianyungang	−0.14	−0.53	−0.84	−0.51	−0.71	−0.74	−0.20	−0.22
	Nanjing	0.54	−0.42	−0.67	−0.16	0.58	−0.58	−0.20	−0.27
	Nantong	−0.24	−0.83	−0.80	−0.91	0.93	−0.98	−0.79	−0.65
	Suzhou	−0.04	−0.39	−0.52	−0.25	2.12	−0.45	−0.07	−0.32
	Taizhou	−0.04	−0.86	−0.77	−0.85	0.82	−1.02	−0.66	−0.64
	Wuxi	0.28	−0.48	−0.61	−0.26	2.08	−0.60	−0.06	−0.36
	Suqian	−0.34	−0.41	−0.88	−0.91	−1.20	−0.96	−0.91	−0.92
	Xuzhou	0.13	−0.27	−0.74	−0.47	0.31	−0.81	−0.35	−0.54
	Yancheng	−0.34	−0.66	−0.71	−0.79	−0.99	−0.65	−0.69	−0.64
	Yangzhou	−0.14	−1.02	−0.86	−0.73	1.58	−0.94	−0.54	−0.55
	Zhenjiang	0.04	−0.58	−0.74	−0.44	0.82	−0.64	−0.36	−0.60
Jiangxi	Fuzhou	−0.58	−0.74	−1.07	−0.84	1.21	−1.36	−0.37	−0.71
	Ganzhou	0.82	−0.42	−1.19	−0.43	0.68	−1.39	−0.11	−0.46
	Ji'an	0.08	−0.63	−0.96	−0.66	1.03	−1.22	−0.22	−0.76
	Jiujiang	0.31	−0.19	−0.64	−0.32	0.42	−0.69	−0.38	−0.54
	Nanchang	0.04	−0.58	−0.75	−0.56	0.87	−1.03	−0.17	−0.53
	Shangrao	1.20	−0.67	−1.53	−0.51	0.71	−1.50	−0.06	−0.43
	Yingtan	0.28	−1.28	−1.78	−1.10	−0.11	−1.89	−0.66	−1.50
Sichuan	Bazhong	0.57	−0.95	−0.73	−0.51	−0.55	−0.55	−0.57	−0.41
	Chengdu	0.20	−0.35	−0.64	−0.05	1.71	−0.48	0.10	0.00
	Deyang	1.66	−0.56	−0.34	−0.20	1.03	−0.67	−0.27	−0.34
	Leshan	1.35	−1.01	−0.57	−0.31	0.44	−0.73	−0.02	−0.32
	Luzhou	0.85	−1.31	−0.69	−0.21	0.14	−0.80	−0.19	−0.27
	Meishan	0.48	−0.63	−1.08	−0.37	0.51	−0.95	−0.28	−0.51
	Mianyang	0.60	−0.30	−0.83	−0.44	0.29	−0.53	−0.40	−0.46
	Nanchong	0.66	−0.32	−0.60	−0.52	−0.27	−0.55	−0.54	−0.21
	Neijiang	1.03	−1.84	−0.76	−0.41	−0.01	−0.57	−0.39	−0.23
	Suining	0.96	−0.60	−0.68	−0.36	0.04	−0.35	−0.50	−0.26
	Ya'an	0.66	−0.83	−0.31	−0.38	0.12	−0.61	−0.17	−0.33
	Yibin	0.79	−1.13	−0.67	−0.52	−0.08	−0.84	−0.41	−0.34
	Ziyang	0.99	−0.77	−0.69	−0.32	−0.61	−0.30	−0.40	−0.21
	Zigong	1.23	−1.20	−0.72	−0.43	0.39	−0.55	−0.22	−0.13
Yunnan	Kunming	1.47	−0.34	−0.28	1.34	0.10	0.01	0.13	0.00
	Yuxi	1.77	−0.10	−0.56	−0.01	0.32	−1.01	0.41	−0.11
	Zhaotong	1.53	−0.78	−0.23	0.83	0.88	−0.52	0.06	−0.05

Table 7 (continued)

Municipalities / province	City	I_{geo}							
		Cd	As	Cr	Cu	Hg	Ni	Pb	Zn
Zhejiang	Hangzhou	−0.06	−1.00	−0.99	−0.48	1.71	−1.07	−0.18	−0.40
	Huzhou	0.30	−0.71	−0.82	−0.49	1.56	−0.91	−0.19	−0.39
	Jiaxing	−0.18	−0.70	−0.54	−0.19	1.62	−0.50	−0.29	−0.29
	Jinhua	0.14	−0.84	−1.41	−1.14	0.28	−1.98	−0.26	−0.80
	Lishui	0.13	−1.29	−2.22	−1.14	−0.14	−2.51	−0.03	−0.75
	Ningbo	0.20	−0.78	−0.48	0.02	2.39	−0.58	0.19	−0.01
	Quzhou	0.20	−1.21	−1.70	−1.30	0.15	−2.11	−0.32	−0.77
	Shaoxing	0.26	−0.61	−0.67	−0.15	2.82	−0.81	0.47	0.09
	Taizhou	0.08	−0.71	−0.58	−0.18	0.82	−0.66	−0.01	−0.10
	Wenzhou	0.71	−0.94	−0.51	−0.20	1.56	−0.65	0.52	0.22

Municipalities / province	City	PI								
		Cd	As	Cr	Cu	Hg	Ni	Pb	Zn	IPI
Shanghai	Shanghai	1.10	0.55	0.86	0.88	2.02	0.79	0.98	1.02	1.60
Chongqing	Chongqing	1.74	0.33	0.67	0.74	0.93	0.65	0.93	0.84	1.37
Anhui	Anqing	1.06	0.74	0.75	0.84	1.19	0.63	0.95	0.75	1.04
	Bengbu	0.83	0.68	0.67	0.68	0.58	0.61	0.89	0.64	0.80
	Chizhou	2.34	1.08	0.75	1.09	0.81	0.65	1.42	0.92	1.84
	Chuzhou	0.68	0.71	0.66	0.72	0.51	0.63	0.79	0.56	0.73
	Fuyang	0.89	0.70	0.73	0.69	0.50	0.67	0.83	0.60	0.80
	Hefei	0.59	0.70	0.68	0.75	0.64	0.56	0.83	0.53	0.75
	Huainan	0.71	0.73	0.68	0.78	0.60	0.60	0.89	0.65	0.80
	Liu'an	0.60	0.74	0.68	0.62	0.58	0.64	0.85	0.53	0.76
	Ma'anshan	1.03	0.69	0.72	0.98	1.15	0.67	0.91	0.76	1.01
	Tongling	2.43	1.23	0.71	1.83	1.03	0.62	1.23	0.87	1.93
	Wuhu	1.52	0.67	0.81	1.06	0.93	0.77	0.99	0.87	1.27
	Suzhou	0.88	0.73	0.71	0.72	0.53	0.64	0.80	0.66	0.80
	Xuancheng	1.59	0.86	0.60	0.64	1.00	0.47	0.87	0.65	1.27
Guizhou	Bijie	2.17	0.99	1.05	1.41	1.35	0.96	0.94	0.82	1.76
	Guizhou	2.21	1.31	1.09	1.33	2.36	0.84	1.30	1.05	1.95
Hubei	Ezhou	1.69	0.83	0.79	1.02	0.92	0.69	1.09	0.97	1.39
	Enshi	1.46	0.37	0.31	0.34	0.58	0.27	0.55	0.42	1.10
	Huanggang	1.24	0.65	0.77	0.88	0.69	0.68	0.98	0.77	1.05
	Huangshi	5.66	2.44	0.93	2.16	1.83	0.75	3.57	2.28	4.36
	Jingmen	1.30	0.89	0.75	0.71	0.60	0.73	1.12	0.68	1.10
	Jingzhou	1.94	0.82	0.81	1.05	2.28	0.75	1.04	0.98	1.83
	Suizhou	0.93	0.52	0.58	0.70	0.72	0.54	0.77	0.63	0.81
	Wuhan	1.63	0.91	0.85	1.10	1.17	0.80	1.15	0.95	1.38
	Xianning	1.26	0.81	0.73	0.72	1.04	0.53	0.93	0.71	1.07
	Xiangyang	1.48	0.79	0.71	0.82	0.72	0.71	0.92	0.84	1.21
	Xiaogan	0.87	0.58	0.65	0.69	1.07	0.59	0.89	0.54	0.92
	Yichang	1.32	0.57	0.67	0.64	0.54	0.51	0.75	0.71	1.06

Table 7 (continued)

Municipalities / province	City	PI								
		Cd	As	Cr	Cu	Hg	Ni	Pb	Zn	IPI
Hunan	Changde	1.99	0.75	0.72	0.74	2.18	0.58	1.02	0.82	1.73
	Chenzhou	7.19	4.55	0.91	1.32	1.84	1.10	3.15	1.73	5.44
	Hengyang	4.77	1.74	0.75	1.07	1.98	0.66	1.53	1.14	3.58
	Loudi	2.70	0.98	0.82	0.76	1.91	0.76	1.20	0.99	2.11
	Shaoyang	2.18	1.36	0.71	0.85	2.30	0.69	1.03	0.86	1.85
	Xiangtan	5.09	1.37	0.81	1.16	2.55	0.65	1.90	1.21	3.83
	Yiyang	2.50	1.22	0.96	0.81	2.19	0.60	1.18	0.86	1.99
	Yueyang	1.24	0.96	0.73	0.80	0.84	0.56	0.97	0.78	1.07
	Changsha	2.90	1.08	0.96	0.95	1.87	0.54	1.19	0.94	2.25
	Zhuzhou	10.26	1.46	0.90	1.29	2.78	0.66	2.80	1.66	7.51
Jiangsu	Changzhou	1.08	0.59	0.82	0.96	2.58	0.72	1.04	0.83	1.98
	Huai ‘an	0.87	0.69	0.67	0.57	0.79	0.56	0.76	0.62	0.79
	Lianyungang	0.87	0.66	0.66	0.77	0.51	0.67	1.03	0.91	0.91
	Nanjing	1.40	0.72	0.75	0.97	1.24	0.74	1.03	0.88	1.20
	Nantong	0.81	0.54	0.68	0.58	1.57	0.56	0.68	0.68	1.24
	Suzhou	0.93	0.73	0.83	0.92	3.60	0.81	1.13	0.85	2.69
	Taizhou	0.93	0.53	0.70	0.60	1.46	0.55	0.75	0.68	1.17
	Wuxi	1.16	0.69	0.78	0.91	3.48	0.74	1.14	0.83	2.61
	Suqian	0.76	0.72	0.65	0.58	0.36	0.57	0.63	0.56	0.68
	Xuzhou	1.05	0.79	0.72	0.79	1.02	0.63	0.93	0.73	0.95
	Yancheng	0.76	0.61	0.73	0.63	0.42	0.71	0.73	0.68	0.71
	Yangzhou	0.87	0.47	0.66	0.66	2.47	0.58	0.82	0.73	1.86
	Zhenjiang	0.99	0.64	0.71	0.81	1.46	0.72	0.92	0.70	1.20
Jiangxi	Fuzhou	0.64	0.57	0.57	0.61	1.91	0.43	0.91	0.65	1.46
	Ganzhou	1.70	0.72	0.52	0.81	1.33	0.43	1.09	0.77	1.37
	Ji’an	1.02	0.62	0.61	0.69	1.69	0.48	1.01	0.63	1.33
	Jiujiang	1.19	0.84	0.77	0.88	1.10	0.69	0.91	0.73	1.05
	Nanchang	0.99	0.64	0.71	0.74	1.51	0.54	1.05	0.74	1.23
	Shangrao	2.21	0.60	0.41	0.76	1.35	0.39	1.13	0.79	1.70
	Yingtan	1.16	0.40	0.35	0.51	0.76	0.30	0.75	0.38	0.92

Table 7 (continued)

Municipalities / province	City	PI								
		Cd	As	Cr	Cu	Hg	Ni	Pb	Zn	IPI
Sichuan	Bazhong	1.42	0.50	0.72	0.76	0.56	0.76	0.80	0.80	1.15
	Chengdu	1.10	0.75	0.76	1.06	2.70	0.80	1.27	1.06	2.08
	Deyang	3.02	0.65	0.94	0.95	1.69	0.70	0.98	0.84	2.31
	Leshan	2.44	0.48	0.80	0.88	1.12	0.67	1.17	0.85	1.88
	Luzhou	1.73	0.39	0.74	0.95	0.91	0.64	1.04	0.88	1.38
	Meishan	1.34	0.62	0.56	0.84	1.18	0.57	0.97	0.75	1.12
	Mianyang	1.45	0.78	0.67	0.80	1.01	0.77	0.90	0.77	1.21
	Nanchong	1.51	0.77	0.78	0.76	0.69	0.76	0.82	0.92	1.24
	Neijiang	1.96	0.27	0.70	0.82	0.82	0.75	0.90	0.91	1.52
	Suining	1.86	0.63	0.75	0.85	0.85	0.87	0.84	0.89	1.47
	Ya'an	1.51	0.54	0.96	0.84	0.90	0.73	1.05	0.84	1.25
	Yibin	1.66	0.44	0.75	0.76	0.78	0.62	0.89	0.84	1.32
	Ziyang	1.91	0.56	0.74	0.88	0.54	0.90	0.89	0.92	1.50
	Zigong	2.25	0.42	0.72	0.81	1.08	0.76	1.02	0.97	1.74
Yunnan	Kunming	2.66	0.76	0.98	2.76	0.89	1.12	1.29	1.06	2.20
	Yuxi	3.26	0.90	0.81	1.08	1.03	0.55	1.57	0.99	2.48
	Zhaotong	2.77	0.56	1.01	1.93	1.52	0.78	1.24	1.03	2.18
Zhejiang	Hangzhou	0.92	0.48	0.60	0.78	2.71	0.53	1.04	0.81	2.04
	Huzhou	1.18	0.59	0.68	0.78	2.43	0.59	1.04	0.81	1.86
	Jiaxing	0.85	0.59	0.82	0.95	2.54	0.78	0.97	0.87	1.94
	Jinhua	1.06	0.54	0.45	0.49	1.01	0.28	0.99	0.61	0.89
	Lishui	1.05	0.39	0.26	0.49	0.75	0.20	1.16	0.63	0.93
	Ningbo	1.10	0.56	0.85	1.10	4.34	0.74	1.35	1.06	3.22
	Quzhou	1.10	0.42	0.37	0.44	0.91	0.26	0.95	0.62	0.90
	Shaoxing	1.15	0.63	0.75	0.98	5.84	0.64	1.63	1.13	4.28
	Taizhou	1.02	0.59	0.80	0.96	1.46	0.71	1.18	0.99	1.24
	Wenzhou	1.57	0.50	0.84	0.95	2.43	0.71	1.69	1.24	1.93

reaching a moderately contaminated level. The distribution patterns of Cd and Pb in the top and deep soils of Zhuzhou city are recorded in Figs. 4 and 5. The maps demonstrate that the spatial distribution of Cd and Pb show a similar pattern. However, the high value areas of Cd and Pb in topsoils are highly consistent with the Qingshuitang industrial zone, showing different spatial distribution patterns from deep soils.

Zhuzhou is the second largest city in Hunan Province, belonging to the Chang-Zhu-Tan Metropolitan Region (a group of cities, in which Changsha, Zhuzhou and Xiangtan are the core cities). Zhuzhou is a typical heavy industry base, and its industrial development began in the 1930s. Qingshuitang industrial zone, adjacent to Xiangjiang River, is a well-known smelting and chemical industry base in China. The emission of heavy metal pollutants, such as Cd, Pb and As, had been at a high level for a long time. Since 2007, Zhuzhou became a demonstration area of China's two-oriented society (environmentally friendly and economically efficient), and its environmental quality improved significantly, but heavy industry production over the past decades has caused serious damage to the local environment. Until 2017, the contents of Cd, Pb and As in the sediments of the ponds in Qingshuitang industrial area were still 657, 44 and 12 times of the background values of the soil in Hunan (Yang et al., 2019).

Cd and Pb are the representative elements of non-ferrous metallurgy emission (Wang et al., 2014). The statistical results in this study reflect that the contents of Cd and Pb are 3.58 and 138.94 mg kg^{-1} in Zhuzhou's overall topsoils corresponding to 0.23 and 34.31 mg kg^{-1} in the deep soils. The contents of Cd and Pb in topsoil are 15.56 and 4.05 times of that in the deep soil, respectively. Meanwhile, the contents of Cd and Pb in the topsoils are 12.46 and 361.23 mg kg^{-1} corresponding to 0.13 and 33.25 mg kg^{-1} in the deep soil of Qingshuitang industrial area. The contents of Cd and Pb in topsoil are as high as 95.85 and 10.86 times of that in the deep soil in this area. As shown in Pearson correlation analysis (Table 8), Cd, As, Pb, Zn, Cu and Hg in Zhuzhou's topsoils are all significantly positively correlated, indicating that they are of the similar origin, while Cr and Ni are poorly correlated with other metals.

According to Jinhe Wang's and Kai Zhang's reports, the annual deposition fluxes of Cd, Pb, As, Hg and Cr in Zhuzhou in 2012 were 140.09, 1074.91, 59.69, 0.87 and 9.80 mg/(m^2·year). Compared with other cities in China, the concentrations of Cd, Pb, As and Hg in atmospheric dustfall of Zhuzhou were much higher, while the concentration of Cr was close or lower (Wang et al., 2018; Zhang et al., 2014). Moreover, compared with commercial and residential areas, industrial areas have a significantly higher degree of atmospheric pollution (Wang et al., 2017). Combined with the above analysis, it could be concluded that industrial activities are the main source of soil Cd, Pb and other elements pollution in Zhuzhou.

Xiangtan City

The I_{geo} of soil Cd in Xiangtan ranks the fourth among the cities in YREB and has reached moderately to heavily contaminated level. As an important part of Chang-Zhu-Tan Metropolitan Region, Xiangtan is also a momentous industrial city in Hunan Province. Geographically, Changsha, Xiangtan and Zhuzhou are distributed along the Xiangjiang River from north to south.

The links between Cd contamination in Xiangtan's urban topsoils and the background in deep soils are exhibited in Fig. 6. The maps exhibit that there is a certain consistency in the spatial distribution patterns of Cd in the top and deep soils. The Cd content of the topsoil in Xiangtan is 1.306 mg kg^{-1} corresponding to 0.161 mg kg^{-1} in the deep soil. As 8.11 times that of deep soils, soil Cd content showed obvious accumulation in surface soil. Moreover, it is noteworthy that the distribution of high Cd content in topsoil emerge an obvious trend of migration along the Xiangjiang River.

Sediment samples along the Xiangjiang River also existed combined metal pollution of Cd, As, Pb and Hg (Liu et al., 2016; Wang et al., 2008), and the concentration of heavy metals in Zhuzhou section was the highest, followed by Xiangtan section and Changsha section (Mao et al., 2013; Zeng et al., 2015), which confirmed the influence of industrial activities in Zhuzhou on downstream cities.

According to Kai Zhang's report, the concentrations of As, Cd and Pb in atmospheric particles in Zhuzhou and Xiangtan sampling sites were obviously higher than that of Changsha in 2012 (Zhang et al., 2014). Also, research shows that bedrock has little contribution to soil heavy metal pollution in Chang-Zhu-Tan region (Deng et al., 2019; Wu et al., 2007). It can be inferred that, in addition to local

Table 8 Correlation coefficient of heavy metals in topsoil of Zhuzhou

	As	Cd	Cr	Cu	Hg	Ni	Pb	Zn
As	1	.820**	−.259*	.734**	.730**	.024	.859**	.811**
Cd		1	−.129	.899**	.850**	.075	.910**	.966**
Cr			1	.156	−.088	.758**	−.160	−.091
Cu				1	.833**	.357**	.832**	.897**
Hg					1	.167	.851**	.786**
Ni						1	.035	.089
Pb							1	.910**
Zn								1

**: Significantly correlated at 0.01 level (both sides); *: Significantly correlated at 0.05 level (both sides)

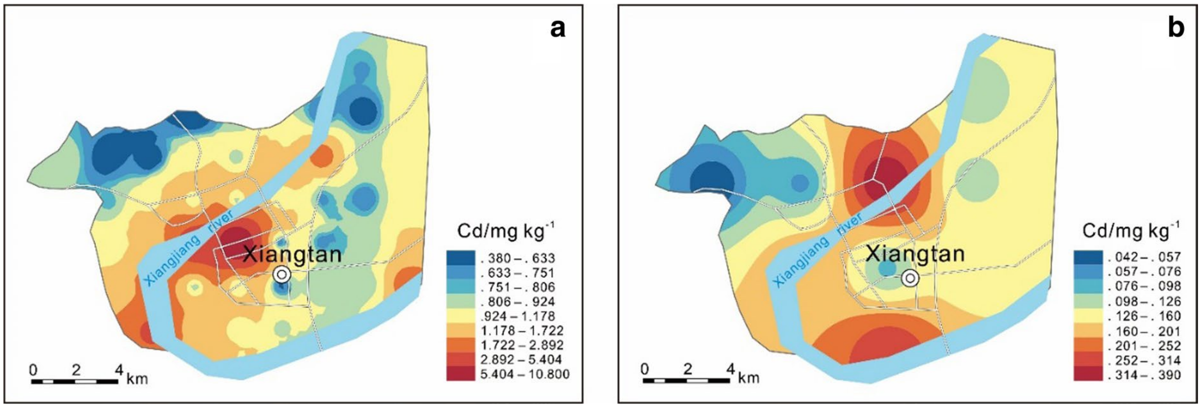


Fig. 6 Distribution of Cd in the topsoil **a** and deep soil **b** of Xiangtan

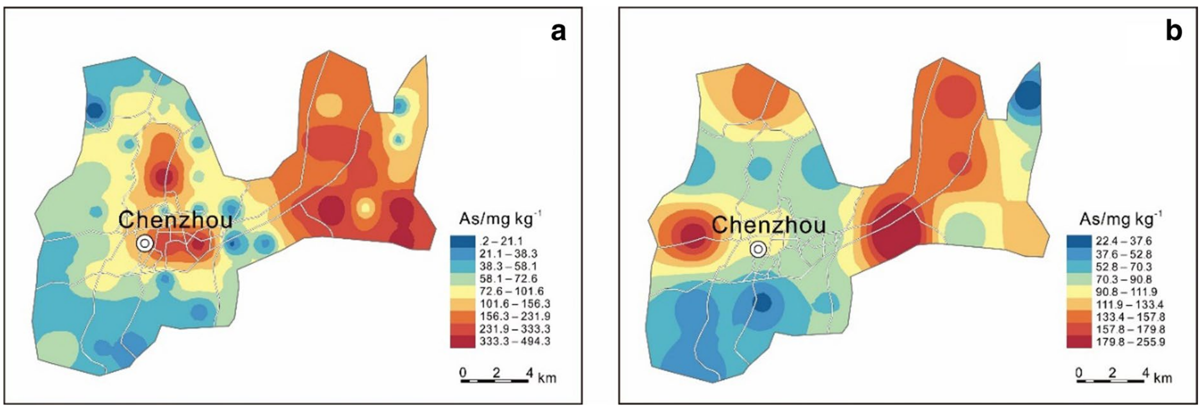


Fig. 7 Distribution of As in the topsoil **a** and deep soil **b** of Chenzhou

industrial activities, soil Cd pollution in Xiangtan is also affected by the industrial wastewater and waste gas discharge from Zhuzhou.

Chenzhou City

The I_{geo} of soil As and Cd in Chenzhou ranks the first and second in the cities in YREB and has reached a moderately to heavily contaminated level, and the I_{geo} of soil Pb is in the second place, reaching a moderately contaminated level.

Chenzhou, located in the upper reach of Xiangjiang River in Hunan Province, is a famous hometown of non-ferrous metals in China, with more than 30 large polymetallic deposits such as Shizhuyuan, Huangshaping and Shuikou Mountain. The heavy metal pollution of soil in Chenzhou has been reported in some literatures, among which As is the most concerned (Liao et al., 2005). It has been reported that As content of farmland soil in the Shizhuyuan mining area reached 87.71–1351.9 mg kg^{-1}(Zeng et al., 2006) and widespread cases of excessive heavy metals in crops existed (He et al., 2007; Liu et al., 2005). The mining and smelting of minerals are considered to be the main cause of heavy metal pollution in the soil (Duan et al., 2018; Lei et al., 2008).

In this study, the distribution patterns of As, Cd and Pb in the top and deep soils of Chenzhou are relatively consistent (Fig. 7, Cd and Pb are not shown). The As, Cd and Pb contents of the topsoil in Chenzhou are 120.1, 1.886 and 242.6 mg kg^{-1} corresponding to 99.1, 1.194 and 143.8 mg kg^{-1} in the deep soil, and the rates are only 1.21, 1.58 and 1.69. In the box plot of heavy metal content in deep soils of key cities, the contents of As, Cd and Pb in deep soil of Chenzhou are significantly higher than other cities (Fig. 8). The above indicates that the heavy metal pollution in Chenzhou's urban soil is mainly controlled by geological background and superimposed with man-made pollution factors.

Huangshi City

The I_{geo} of soil Pb and Zn in Huangshi ranks first in the cities of YREB and has reached a moderately contaminated level, the I_{geo} of soil As is in the second place, reaching a moderately contaminated level, and I_{geo} of soil Cd is in the third place, reaching a moderately to heavily contaminated level. Huangshi has the most types of heavy metal elements that have reached a moderate pollution level and above, showing a serious situation of polymetallic compound contamination.

Huangshi, located in the southeast of Hubei Province, is in the center of the polymetallic ore deposit belt in the lower reaches of the Yangtze River. With a large number of industrial bases such as steel works, cement factories and smelters, Huangshi is known as the "hometown of bronze," "cradle of iron and steel" and "hometown of cement" in China.

The spatial distribution patterns of soil Zn, Pb, Cd and As in Huangshi are similar, and there are some differences in the distribution patterns of the four elements in the topsoils from the deep soils (Fig. 9, Pb, Cd and As are not shown). The Zn, Pb, Cd and As contents of the topsoils in Huangshi are 377, 324.8, 5.222 and 77.5 mg kg^{-1}, corresponding to 2.9, 5.0, 15.36 and 4.0 times of that in the deep soils. The contents of Cd, Pb and Zn in the deep soils of Huangshi are slightly higher than that in other cities (Fig. 8), indicating that the geological background has a certain contribution to the accumulation of the above elements in the topsoils. Meanwhile, the differences of heavy metal content distribution between top and deep soils demonstrate that human activities have reshaped the distribution pattern of heavy metals in the topsoils of Huangshi.

In 2012, the contents of Zn, Pb, and Cd in atmospheric dustfall in Huangshi were 2122.53, 949.30 and 41.35 mg kg^{-1}, which were, respectively, 25.4, 35.5 and 240.4 times of the background value of soil elements in Hubei Province and much higher than other cities in China and abroad (Liu et al., 2014). Zn content reached its maximum value in industrial zone and Pb content in commercial zone (Yao et al., 2016). Moreover, Xianjun Xie's evaluation results point out that the mine wastewater and beneficiation wastewater in this area have been seriously polluted, and Zn, Mn, etc., are the leading factors in water environmental pollution (Xie & Han, 2003). Considering the long-term mining and industrial activities in Huangshi, it could be concluded that the heavy metal pollution in the soil of Huangshi is mainly related to the local human behaviors such as mining and smelting, fossil fuel burning, automobile exhaust emissions and so on.

Kunming City

The I_{geo} of soil Cu in Kunming ranks first in the cities of YREB and have reached a moderately contaminated level. Located in the middle of the Yun-Gui Plateau, Kunming is the capital city of Yunnan Province and in general a tourist city with less industry. Studies have reported that the average Cu content in street dust in Kunming is 166.6 mg kg^{-1}, with the highest potential ecological risk coefficient (Liang et al., 2011). The contents of heavy metal elements in dust, atmosphere and precipitation in Kunming have a clear accumulation trend in the dry season, and relatively decreases in the rainy season (Liang et al., 2011; Shen et al., 2016; Shi et al., 2018). Cu, Hg, Pb, and Zn in topsoils are highest in vicinity of the smelter and in urban traffic congestion areas (Liao et al., 2015). Research suggests that soil pollution in Kunming is dominated by industrial area pollution, and the pollutants are mainly related to dust reduction, waste residue and wastewater from smelters. At the same time, the impact of traffic pollution on the city's soil quality cannot be underestimated (Miao et al., 2015).

In this study, the Cu content of the topsoil in Kunming is 119.3 mg kg^{-1} corresponding to 106.2 mg kg^{-1} and 1.12 times of that in the deep soil, and the distribution patterns of Cu in the top and deep soils of Kunming are extremely consistent (Fig. 10). In addition, background content of Cu in the deep soil of Kunming is significantly higher than other cities (Fig. 8). All these indicates that the Cu pollution in Kunming urban soil is mainly controlled by geological background and anthropogenic pollution has little influence.

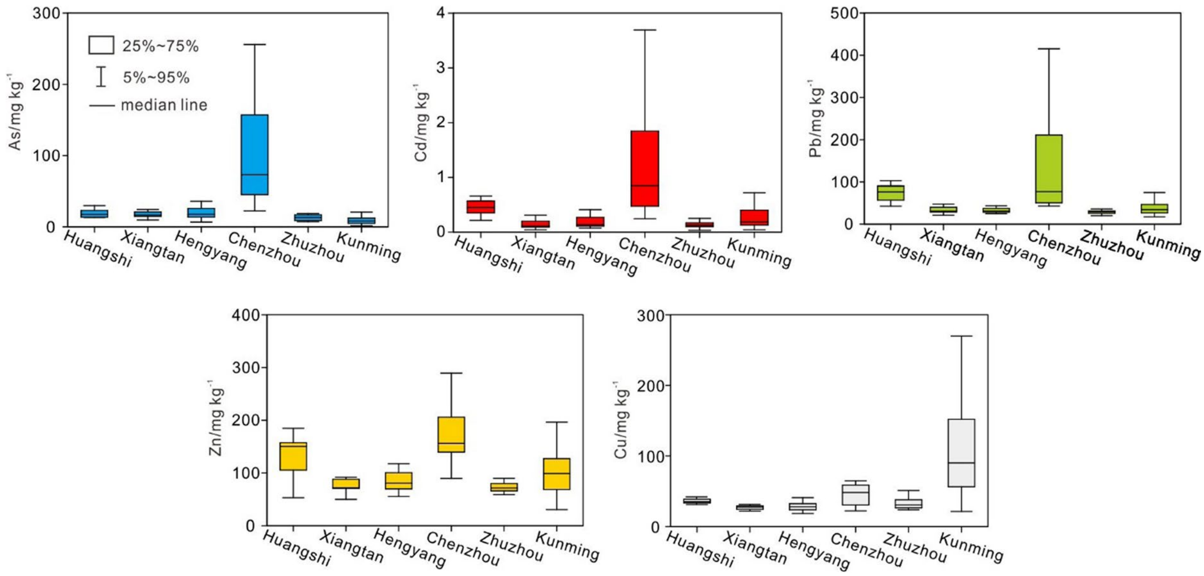
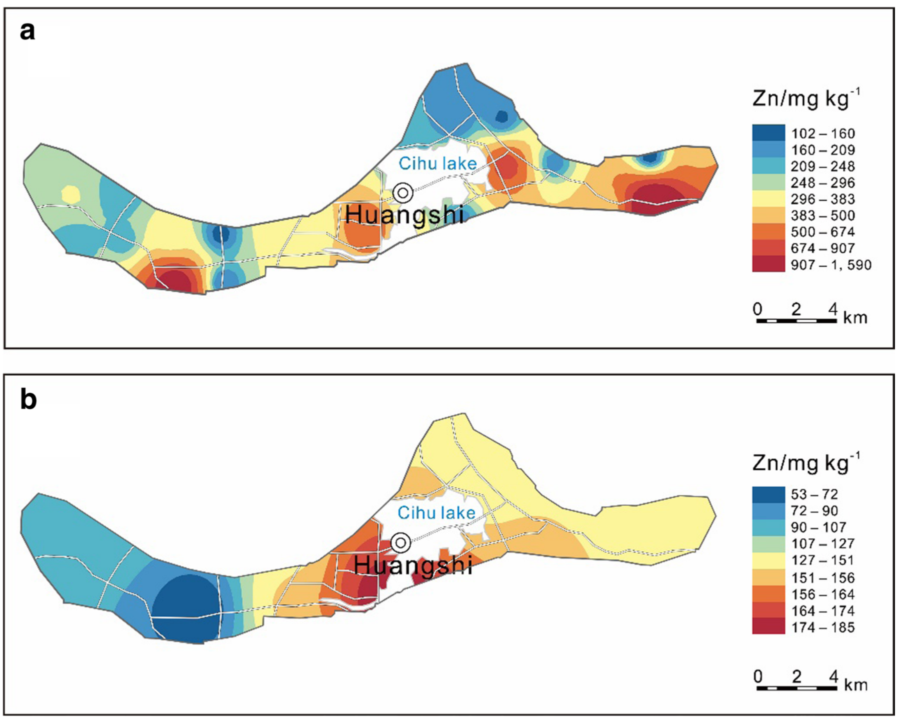


Fig. 8 Box comparison chart of As, Cd, Pb, Zn and Cu contents in deep soils of key cities

Fig. 9 Distribution of Zn in the topsoil **a** and deep soil **b** of Huangshi



Shaoing City, Ningbo City, Suzhou City, Wuxi City

Shaoxing, Ningbo, Suzhou and Wuxi are the top four cities in the I_{geo} of soil Hg in YREB, all of which have reached moderately to heavily contaminated levels. Shaoxing, Ningbo, Suzhou and Wuxi have Hg contents of 0.629, 0.572, 0.460 and 0.356 mg kg^{-1} in the topsoil and 0.224, 0.096, 0.306 and 0.052 mg kg^{-1} in the deep soil. The Hg content in topsoil corresponds to 2.81, 5.96, 1.50 and 6.85 times of that in deep soil, respectively. The Hg high value zones in the above cities are mainly concentrated in the central or old urban areas, and the trend of Hg content decline from the downtown to the suburbs can be observed (Figs. 10 and 11, take Shaoxing and Ningbo for example). Meanwhile, similar phenomenon can be observed in other cities of YREB. The studies of other scholars also confirmed that among the different heavy metals, Hg changed mostly with the variation of distance to build-up area, indicating that it is greatly affected by human activities (Fang et al., 2011; Han et al., 2006; Li et al., 2013; Tan et al., 2006).

China is the world's largest emitter of Hg (Pacyna et al., 2006, 2010; Pirrone et al., 2010), several studies have shown that Hg emissions from fossil fuels are the largest source of anthropogenic Hg in China (Feng, 2005; Jiang et al., 2006). It has been reported that from 1978 to 2014, China's anthropogenic Hg emissions totaled 13,294 tons, and the annual Hg emissions increased from 147 to 530 tons (Wu et al., 2016). These Hg emissions may accumulate and deposit in topsoils and enter urban areas through atmospheric deposits. In this study, cities with high levels of soil Hg pollution are mainly concentrated in Jiangsu and Zhejiang Province, which are the two most economically developed provinces in YREB. This confirms that human activities (such as three wastes) in the process of urban expansion and economic development are the main sources and pathways leading to the migration and enrichment of soil Hg.

Non-carcinogenic risk assessment

Non-carcinogenic risk assessment results show that the hazard index (HI) of adults in all cities ranges from 0.06 to 0.48, and the HI values are all less than 1, which would not cause obvious adverse effects on adult health. For minors, the HI values of Chenzhou, Huangshi, Zhuzhou, Hengyang, Xiangtan, Guiyang, Shaoyang, Tongling, Yiyang and Chizhou are greater than 1, and their values are 3.23, 2.22. 1.55, 1.37, 1.28, 1.14, 1.07, 1.04, 1.02 and 1.01, respectively, indicating that minors in the above 10 cities may be exposed to soil environments with potential non-carcinogenic risks. The HI values of minors in all the other cities are less than 1. Due to behavioral and physiological characteristics, minors are more sensitive to environmental pollutants per unit weight than adults (DHAenC, 2012). This is the main reason why minors' hazard index is greater than that of adults in

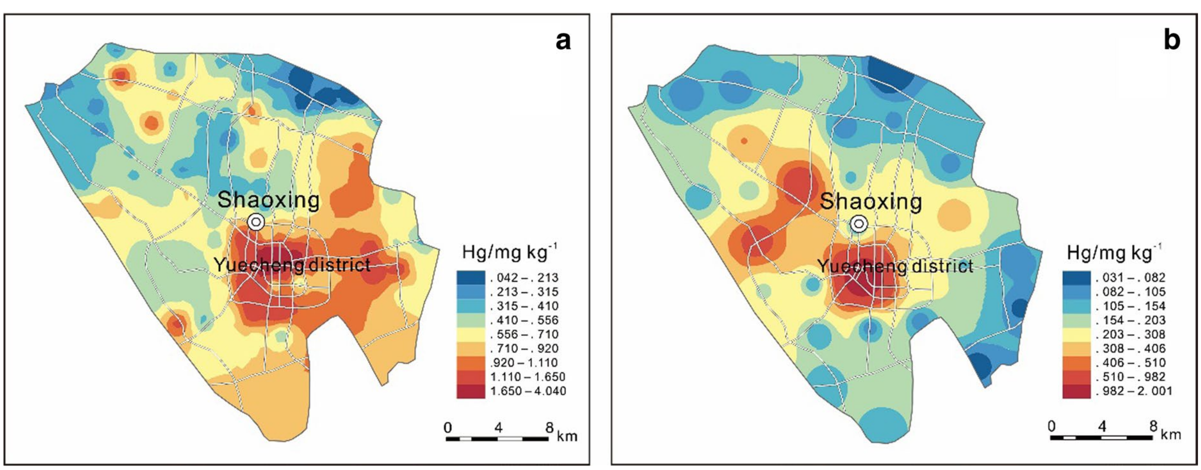


Fig. 10 Distribution of Hg in the topsoil **a** and deep soil **b** of Shaoxing

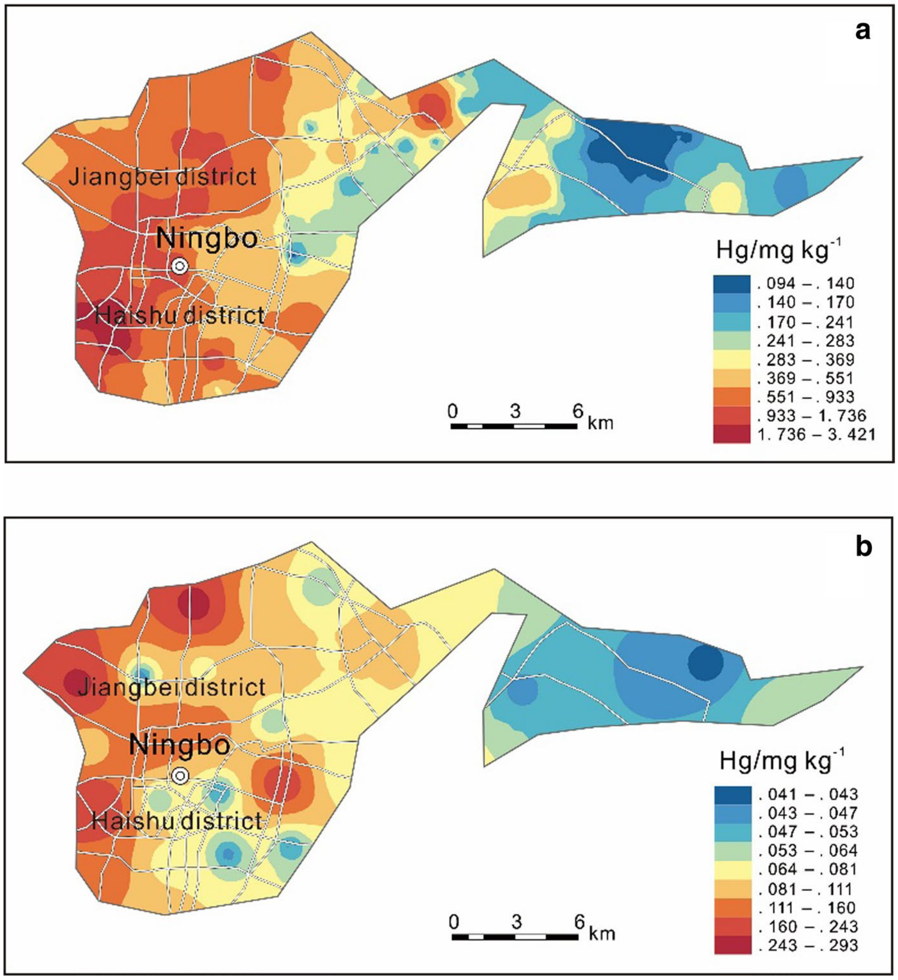


Fig. 11 Distribution of Hg in the topsoil **a** and deep soil **b** of Ningbo

all cities. Similar conclusion has also been confirmed in other related studies (Liu et al., 2015; Pan et al., 2018).

Intake is the main exposure route of urban population to the 8 heavy metal elements in this study. The median of the risk quotients of the eight elements is ranked as follows: As > Pb > Ni > Hg > Cu > Cr > Zn > Cd. For the two types of exposed people, the sum of the risk quotients of As, Pb, and Ni accounted for more than 90% of the hazard index, indicating that the intake of As, Pb and Ni in soil is the main factor causing the non-carcinogenic risk of the urban public.

Carcinogenic risks assessment

The carcinogenic risks were only estimated for As and Cd here due to lack of a carcinogenic SF for other heavy metal elements. The carcinogenic risk (CR) values of As and Cd for adults range from 4.38E − 06 to 7.42E − 05 and 3.48E − 08 to 6.02E − 07. For minors, the CR values of As and Cd range from 5.72E − 06 to 9.69E − 05 and 4.67E − 08 to 8.08E − 07. This indicates that Cd in urban soil has no carcinogenic risk for the two groups of people, while the impact of soil As on human health is within an acceptable range, and the exposure risk of minors is significantly higher than that of adults no matter what kind of heavy metal elements.

Conclusions

Soil is an important part of the urban ecosystem, and its quality should be recognized. According to geo-accumulation index, on a regional scale, urban soils in YREB are uncontaminated to moderately contaminated by Hg and Cd. Cities with moderate pollution or above of soil Cd and Hg accounted for 26.74 and 31.40% in YREB. Meanwhile, As, Pb, Zn and Cu in a part of cities show different levels of contamination, while Cr and Ni in all urban soils are basically free from contamination. The type of industrialization and the history of urbanization affect the soil heavy metal pollution in majority cities in YREB, and the influence of geological background on the content of heavy metals in urban soils cannot be ignored. The pollution level of heavy metals in the urban soils generally shows the following rule: industrial cities > rapidly developing cities > metropoles > underdeveloped cities. Anthropogenic activities, especially wastewater, waste gas, and waste solid discharged from industrial factories are the main causes of heavy metal soil pollution in cities, although many factories have been closed or moved to other locations in recent years.

Heavy metals in the urban soils investigated generally posed low non-carcinogenic and carcinogenic risks to the adults. However, the non-carcinogenic risk to minors in some cities (e.g., Chenzhou and Huangshi) should be given cautious attention, and the intake of As, Pb and Ni in soil is the main factor causing the non-carcinogenic risk for both adults and minors.

It is suggested to carry out a detailed survey of urban soil pollution in cities with moderate to severe comprehensive pollution, find out the status of soil pollution and the distribution of contaminated land plots, establish contaminated land plot lists and priority control area lists to implement pollution control, restoration and remediation. For cities where soil exposure poses a potential non-carcinogenic risk to minors, the development trend of the risk should be continuously assessed in the future.

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Availability of data and material The data supporting the results of this article are included within the article.

Declarations

Conflict of interest We declare that we do not have any commercial or associative interest that represents a conflict of interest in connection with the work submitted.

Ethical approval No human or animal research is involved.

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