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Concentration, spatial distribution, contamination degree and human health risk assessment of heavy metals in urban soil across China between 2003 and 2019—A Systematic Review

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Abstract: This study provided an overview of studies on heavy metals pollution regarding As, Cd, Cr, Hg, Pb, Cu, Zn and Ni in the 76 urban soils throughout China based on the online literatures datas, during the period 2003 to 2019.The concentrations, spatial distribution, contamination degree and health risks of heavy metals in the urban soils were evaluated. The results demonstrated that the mean values of eight heavy metals all exceeded the soil background values of China, the kriging interpolation method showed that the hot-spot cities of heavy metals in urban soils mainly concentrated in the southwest, southcentral, southeast coast, northcentral and northwest regions of China. The geoaccumulation index (Igeo) indicated that Hg and Cd ranked moderately contaminated levels, and the other six metals ranked uncontaminated levels; the pollution index (PI) showed that Cd and Hg reached high contamination levels, and the other metals reached moderate contamination levels; the integrated pollution index(IPI) and potential ecological risk index (*PRI*) indicated that the integral urban soils in the study areas ranked high contamination level and considerable ecological risk degree, respectively, and Cd and Hg should be labeled as the priority control metals in the urban soils around China. The human health risk assessment for heavy metals indicated that ingestion was the dominated exposure pathway to pose adverse effects on human health, the mean HI values of eight heavy metals all presented unlikely adverse effects on human health, and the mean CR values of As, Cr and Ni for children and adults all suggested an acceptable carcinogenic risk to human beings, in addition, children exposed more serious non-carcinogenic and carcinogenic health threaten compared with adults. The results provide useful information to control heavy metals pollution and mitigate adverse effect on residents for environmental regulators in national urban regions.

Keywor: Urban soil; Heavy metals; Spatial distribution; Contamination degree; Health risk

1. Introduction

As a crucial component of urban ecosystems, soil plays a principal role in biochemical transformations, the cycling of elements, supporting plants and many recreational activities, in addition, it is meanwhile considered as a mixture of heavy metals, mineral constituents, organic matter (humus), living organism, air, and water [1-3]. Urban areas are the hotspots for environmental hazards at multiple scales, as a result of increased population, industrial growth and vehicle transport[4]. With the rapid development of urbanization and the increase of urban population, the disturbance of human activities on urban soil environment has led to the varying degrees of the deterioration of urban soil environment quality. Urban soils acting as a reservoir of contaminants are

excellent indicators of pollution[5],and heavy metals in soil are considered as important indicators to monitor the impact of human activities on soil environmental quality.[6-8].

Owing to the toxic effects, long persistence, and bio-magnification traits even at low concentrations, heavy metals pollution have attracted widespread focus of attention, and are considered to be the most important pollutants among the multitudinous soil contaminants [9-11]. Urban soils can be served as recipients of large amounts of heavy metals from multiple sources, heavy metals accumulation in soils are simultaneously originated from natural and other anthropogenic sources[6, 12].Urban soils differ greatly from natural ones as they are more strongly influenced by anthropogenic activities[1, 13],thus anthropogenic sources are considered to be the primary source that lead to soil contamination ,for instance, industrial waste, automobile exhaust and domestic waste have been as a major cause of increased content of potentially toxic elements (PTEs) such as Pb, Cd, Cu, Zn[4, 14].As a result, they are more prone to contain and accumulate high concentrations of heavy metals in comparison with the natural soils[5]. The accumulation of heavy metals in soils can inevitably affect the environmental quality such as urban soils ,water and crops contaminations ,and transferred into the human body through the food chain, ultimately pose directly or indirectly health hazards to the human beings in the long-term[15, 16].For example, heavy metals accumulated in the tissues and internal organs of human body, can affect the central nervous system and may act as cofactors, initiators, or promoters of other diseases[3, 17]. Furthermore, exposure from mixed metal can result in numerous adverse health effects on human due to synergistic interactions even when concentrations of the individual metals are below their ecotoxicological benchmark levels[18].The adverse effects of heavy metals on human health are mainly transferred through three pathways such as ingestion, inhalation and dermal contact absorption, numerous studies have shown that ingestion is the primary exposure pathway for human health risk ,in addition ,children are especially susceptible to health risks from heavy metals toxicity [17, 19-21].

As the largest developing country in the world, China has been witnessing a dramatic growth of urbanization since 1978 with the unprecedented economic growth[22], however, heavy metal pollution has become a serious environmental problem in different functional regions such as urban soils, urban road dust and agricultural soils with the rapidly industrialization and urbanization during the last two decade[23, 24]. The national soil pollution survey bulletin of china in 2014 showed that the total exceeded rate of soil around China was 16.1%, among which the proportion of slight, mild, moderate and the severe pollution spots was 11.2%,2.3%,1.5% and 1.1% respectively. Therefore, to provide guidance for the prevention and remediation of soil pollution in China in the next 30 years, the Chinese government issued a regulation 'Soil Contamination Prevention and Control Action Plan' in 2016 [9].

Studies of urban soils in China started in the 1980s, while discussions of the impact of urbanization on soil resources in China have been more recent ,in addition ,more than 100 cities have been studied [22, 25, 26].In China, numerous researches have been conducted on metal concentrations, spatial distribution, contamination assessment, source identification and health risks assessment, while the vast majority of studies have focused on heavy metals in urban soil of a single city[19, 27-30]. In recent decades, elevated research has paid attention on the extensive range of heavy metals pollution in urban soil across China. For example, Pan reviewed heavy metal pollution levels and health risk assessment of urban soils in 32 Chinese cities[31] , Wei and Yang took a review of heavy metal contaminations in urban soils, urban road dusts and agricultural soils from China[32],Luo examined trace metals concentrations, pollution levels, sources identification from 21 Chinese cities[1], Zhang conducted the spatial distribution of metal pollution of soils of Chinese provincial capital cities[33], Guo reported the spatial distribution and pollution assessment of heavy metals in urban soils from southwest China[6].However, very limited quantity and scope of the city sites the aforementioned studies regarding the assessment of the urban soils, thus, it is urgently needed to carry out a further, comprehensive and national scale study across China.

Therefore, the study focuses on the concentrations, contamination, spatial distribution and human health risks of heavy metals in the urban soils throughout China on a national scale basing on the online literatures data, the main objectives of this study are:(1) to determine the concentrations, spatial distribution of As, Cd, Cr, Hg, Pb, Cu, Zn and Ni eight heavy metals in urban soils; (2)to

evaluate the pollution characteristics of the heavy metals using the geoaccumulation index (*Igeo*), pollution index (*PI*) and integrated pollution index(*IPI*); (3) to discriminate the possible hot-spots of heavy metals contamination in urban soils; (4) to investigate the potential ecological risks degree and detect the risk factor that contribute most to the national urban soils contaminant using the potential ecological risk index (*PRI*) ; (5) to evaluate the human health risk risk on children and adults community through different exposure pathways.

2. . Data source and research methods

2.1. Data Source

2.1.1. Searching Method

The study chose As, Cd, Cr, Hg, Pb, Cu, Zn and Ni eight elements as the target contaminants, all of which were listed as priory control pollutants by the United States Environmental Protection Agency (USEPA). The information sources for systematic literature review were searched from three databases including China National Knowledge Internet (CNKI), Web of Science and Google Scholar. We conducted three categories of keywords by connecting the same group with "OR" and combining the different group with "AND", which were comprised the following: (*a*) metals—heavy metals, metal element, trace element, metallic element; (*b*) status—concentration, levels, contents, contamination, pollution, degree, quality, spatial distribution, health risk, assessment, evaluation ,condition; (*c*) settings—urban, soil, city, capital, metropolitan, district, region, functional zone, area, China, Chinese. The eligible and exclusion criteria are shown in Table 1.

Table 1. The eligible and exclusion criteria for the review.

	Eligible		Exclusion
a	Published papers including as many as possible of the eight elements of the review	*a*	Papers relating less than 3 elements of the review and not related the content levels of the metals
b	Papers focusing on urban soils with surface layer in a depth of 0–20cm	*b*	Papers relating agricultural, mining soils, etc., and soil depth exceeding 20cm
c	Papers can best reflect the overall soil pollution characteristics of the urban	*c*	Papers that only including one or two functional regions (such as industrial, residential district, etc.)
d	Published between 2003 to 2019 and in the most recent years	*d*	Unscientific and incredible papers
e	Papers with scientific sampling and analytical methods with strict quality assurance or quality control procedures	*e*	Papers with only abstracts or from news reports
f	The area is restricted in urban of China		

2.1.2. Screening Method

A total of 5750 articles were screened from the three databases according to the searching strategy from the period 2003 to 2019, 937 were from China National Knowledge Internet (CNKI), 2093 were from Web of Science and 2720 were from Google Scholar (Figure 1). We tried to select the dates published in the most recent years and those can best reflect the overall soil pollution characteristics of the urban, furthermore, we tried to obtain as many data as possible that can cover every province and present the entire contamination condition of urban soils throughout the country. In addition, the abnormal values were also eliminated, finally, a total of 76 Chinese urban soils heavy metals pollution data including 10399 sample sites covering almost every province across China were collected, with the exception of Taiwan. The distribution of the cities is presented in Figure 2.

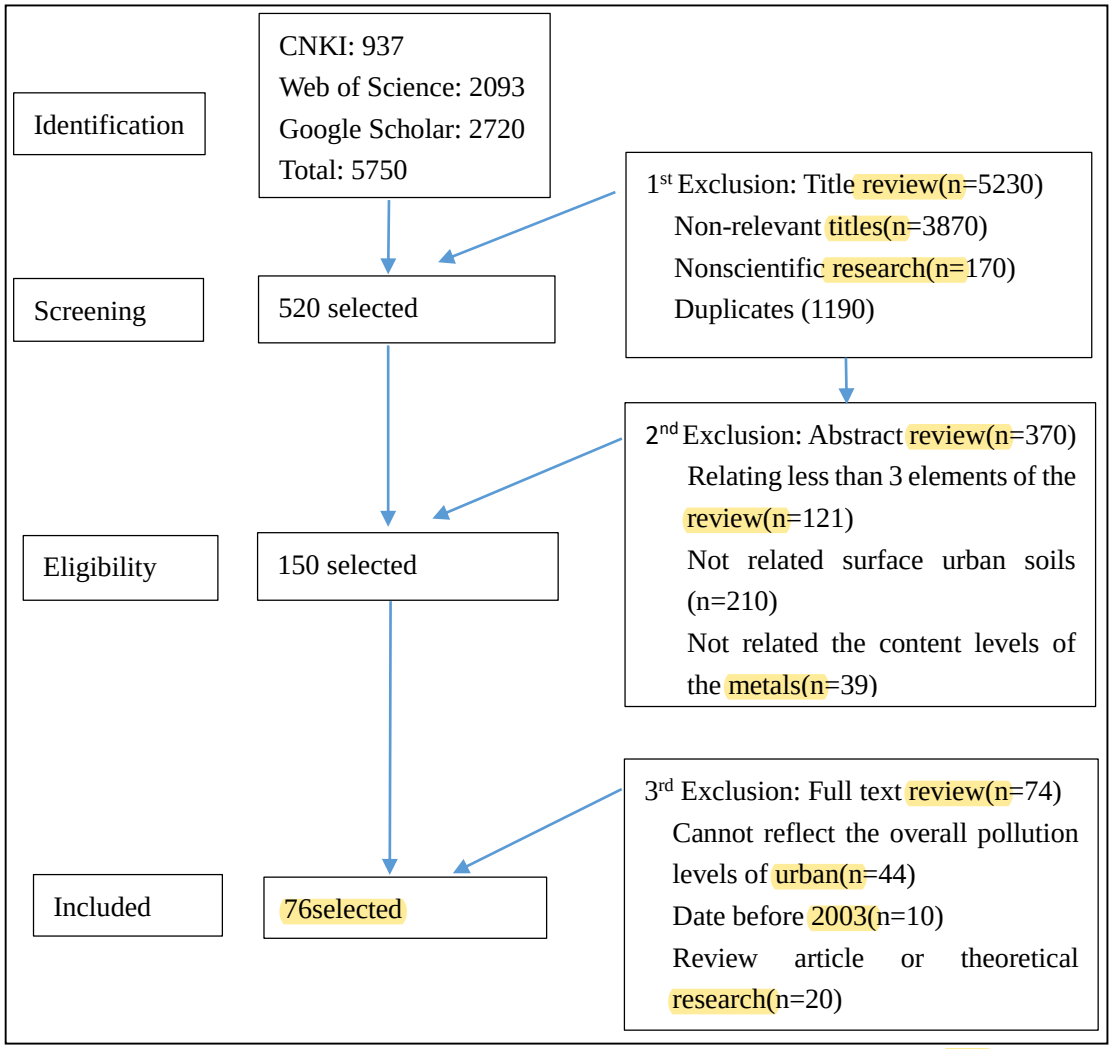


Figure 1. Flowchart for searching and screening procedure.

2.2. Research Methods

2.2.1. Geoaccumulation index (Igeo)

The geoaccumulation index (*Igeo*) is commonly used as a geochemical criterion to evaluate the contamination degree of a single element in envioronmental sediments or soils since 1969, the calculated equation of *Igeo* values was shown as follows[34]:

$$Igeo = log_2 (C_n/1.5B_n) \quad (1)$$

where C_n represents the concentration of the measured element in the sediment and B_n is the geochemical background value of the given metal. The constant 1.5 is a background matrix correction factor considering the natural fluctuations influenced by lithogenic effects. In this study, the geometric means of background values of the corresponding metal in the control district in which the city is located was chosen as the background values. The *Igeo* was divided into seven levels:*Igeo*≤0,uncontaminated;0<*Igeo*≤1,uncontaminated to moderately contaminated;1<*Igeo*≤2, moderately contaminated;2<*Igeo*≤3,moderately to heavily contaminated;3<*Igeo*≤4,heavily contaminated;4<*Igeo*≤5,heavily contaminated to extremely contaminated;5≤*Igeo*,extremely contaminated.

2.2.2. Pollution index

Pollution index (PI) is defined as the ratio of the heavy metal concentration to the geometric means of background concentration, which is generally used to calculate the pollution level of individual elements, the integrated pollution index(IPI) is defined as the mean values for all the PIs of all considered metals, in addition, IPI is used for the determination of heavy metal contamination in individual samples in the area rather than revealing a general contamination degree of the whole area. [11, 35, 36] .The calculation of PI is shown as follows:

$$PI = C_i/B_i \quad (2)$$

where C_i represents the concentration of the measured metal *i* in the sediment, B_i represents the background value of corresponding metal *i*. The PI value of each metal and the IPI value of each sample site are calculated and classified as: low contamination(PI≤1.0), moderate contamination (1.0<PI≤3.0), or high contamination(PI>3.0);low contamination(IPI≤1.0),moderate contamination (1.0<IPI≤2.0), high contamination(2.0<IPI≤5.0), or extremely high contamination (IPI>5)[11, 32, 35].

2.2.3 Potential ecological risk and health risk assessment

Potential ecological risk index (*PRI*) was initially introduced by Hakanson with the purpose to quantify the ecological risk of one or multiple target contaminants in a specific environment medium[11, 36, 37], which reflected the side effects of toxic elements on the environment. The formulas of *PRI* were figured up using the following:

$$E_r^i = T_r^i \times C_f^i, C_f^i = C_s^i / C_n^i \quad (3)$$

$$PRI = \sum_{i=1}^{n} E_r^i \quad (4)$$

Where C_f^i refers to the contamination coefficient of heavy metal *i*, T_r^i is the biological toxic response factor for heavy metal *i*, C_s^i is the measured concentration of heavy metal *i*, C_n^i is the background value of heavy metal *i*, E_r^i refers to the potential ecological risk factor of a single metal, *PRI* refers to the potential ecological risk index of multiple elements. The toxic response factors T_r^i for As, Cd, Cr, Hg, Pb, Cu, Zn and Ni are 10,30,2,40,5,5,1 and 5 respectively[38].The classifications for ecological risk degree are presented as: low ecological risk(E_r^i <40 or *PRI*<150), moderate ecological risk(40≤ E_r^i <80 or 150≤*PRI* <300), considerable ecological risk(80≤ E_r^i <160 or 300≤*PRI* <600), high ecological risk(160≤ E_r^i <320 or 600≤*PRI*), very high ecological risk(320≤ E_r^i)[11, 39].

Human health risk assessment was widely used to quantify the exposure of human to chemical elements including carcinogenic and noncarcinogenic risks through via ingestion, inhalation and dermal contact as three exposed pathways[15, 35].In this study,the exposure model was based on the method developed by the Environmental Protection Agency of the United States [40]. The calculation formulas for average daily doses (*ADD*) (mg kg^{-1} d^{-1}) of potentially toxic metals to adults and children via three exposure pathways were presented as following[41, 42]:

$$ADD_{ing}=(C\times IngR\times CF\times EF\times ED)/(BW\times AT) \quad (5)$$

$$ADD_{inh}=(C\times InhR\times EF\times ED)/(PEF\times BW\times AT) \quad (6)$$

$$ADD_{derm}=(C\times SA\times CF\times SL\times ABS\times EF\times ED)/(BW\times AT) \quad (7)$$

Where ADD_{ing}, ADD_{inh}, ADD_{derm} are the average daily doses expose to toxic metals through ingestion (mg kg^{-1} d^{-1}), inhalation (mg kg^{-1} d^{-1}) and dermal contact (mg kg^{-1} d^{-1}) of the three pathways, respectively. The exposure parameters for three models were listed in Table 2 based on the USEPA（2001）[43] and Environmental site assessment guideline in China (2009)[44].

The Hazard index(*HI*) was introduced to assess overall potential noncarcinogenic risks induced by the toxic metals, carcinogenic risks(*CR*) was regarded as the probability of an individual developing any type of cancer in the whole lifetime due to exposure to carcinogenic hazards[45, 46]. In this study, eight heavy metals As, Cd, Cr, Hg, Pb, Cu, Zn and Ni were all considered existing noncarcinogenic risks, furthermore, the carcinogenic risk of As, Cr and Ni were evaluated due to the unavailable carcinogenic slope factors of other toxic metals. The calculations of Hazard index (*HI*) and carcinogenic risks (*CR*) were stated as follows:

$$HI=\sum HQ_i=\sum ADD_i/RfD_i \quad (8)$$

$$CR=\sum ADD_i\times SF_i \quad (9)$$

where *RfD* (mg kg^{-1} d^{-1}) is the reference dose for each heavy metals, *SF* (mg kg^{-1} d^{-1}) $^{-1}$ is the carcinogenic risk probability, and the parameter values of *RfD* and *SF* for the toxic metals were derived from the research conducted in China(Table 3)[15, 17, 47].*HQ* refers to the hazard quotient generating from each element and exposure pathway, *HI* is the comprehensive noncarcinogenic risk qual to the total of *HQ*. When the value *HI* is less than 1, the adverse health effects is unlikely to yield, when the value *HI* is more than 1, the adverse health effects may occur. If $CR<10^{-6}$, carcinogenic risk were considered to be negligible, if $CR>10^{-4}$, there is high risk of developing cancer in human beings, when $10^{-6}<CR<10^{-4}$, there is an acceptable risk to human beings.[17, 45, 48].

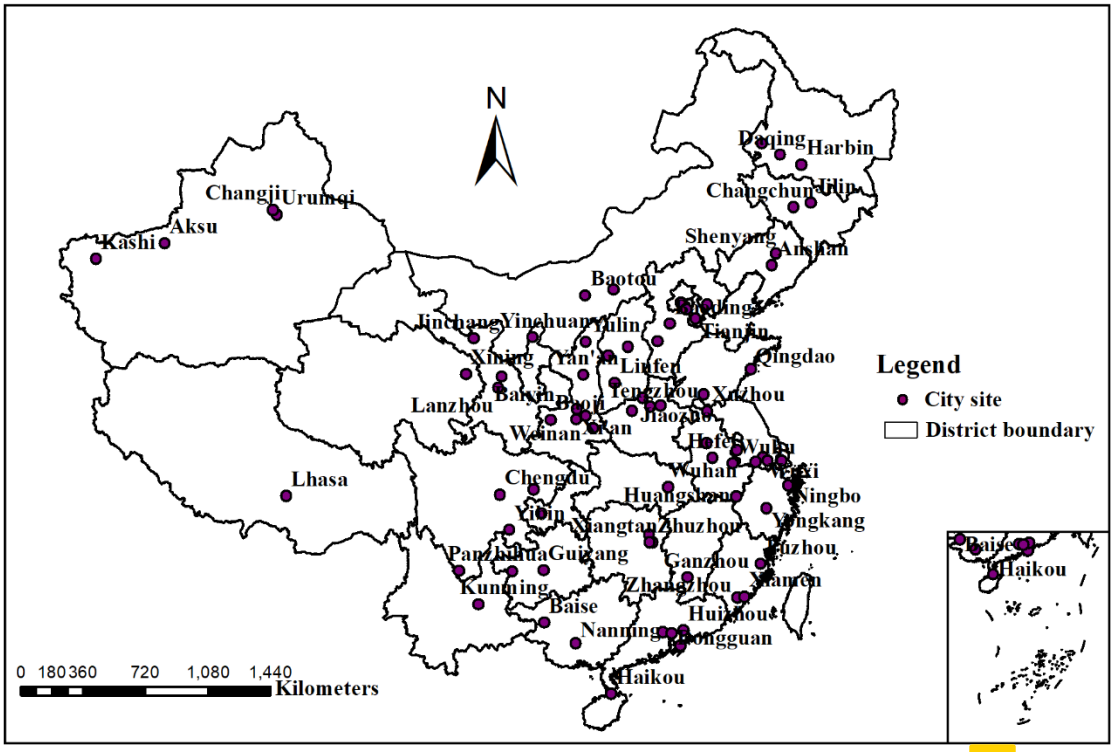


Figure 2. Distribution of city sites reviewed in this study around China.

Table 2. Parameter for the exposure risks calculation of heavy metals.

Parameter	implication		Children	Adult	Unit
C	concentration of the contaminant				mg kg^{-1}
IngR[a]	ingestion rate of soil		200	100	mg d^{-1}
InhR[b]	inhalation rate of soil		5	20	m^3 d^{-1}
CF[a]	conversion factor		1×10^{-6}	1×10^{-6}	kg mg^{-1}
EF[b]	exposure frequency		350	350	d a^{-1}
ED[a]	exposure duration		6	24	y
BW[b]	average body weight		15	55.9	kg
AT[a]	average time	for non-carcinogens	365×ED	365×ED	d
		for carcinogens	365×70	365×70	d
SA[b]	exposure skin surface area		1600	4350	cm^2
SL[b]	skin adherence factor		1	1	mg cm^{-2}
ABS[b]	dermal absorption factor		0.001	0.001	unitless
PEF[b]	particle emission factor		1.32×10^9	1.32×10^9	m^3 kg^{-1}

[a]USEPA 2001, [b]Environmental site assessment guideline in China, [c]USEPA 1989

Table 3. Reference doses for noncarcinogenic metals (mg kg^{-1} d^{-1}) and slope factors for carcinogenic metals (kg d mg^{-1}) [15, 17, 47].

metals	RfD_{ing}	RfD_{inh}	RfD_{derm}	SF_{ing}	SF_{inh}	SF_{derm}
As	3.00E-04	3.10E-04	1.20E-04	1.50	1.51	3.66
Cd	1.00E-03	1.00E-03	1.00E-05			
Cr	3.00E-03	2.86E-05	6.00E-05	0.50	4.20	2.00
Hg	3.00E-04	8.57E-05	2.10E-05			
Pb	3.50E-03	3.52E-03	5.30E-04			
Cu	4.00E-02	4.02E-02	1.20E-02			
Zn	3.00E-01	3.00E-01	6.00E-02			
Ni	2.00E-02	2.06E-02	5.40E-04	1.70	0.90	4.25

2.2.4. Statistical analysis

Spatial distributions of heavy metals were presented using the Kriging interpolation method performed by the geostatistical analysis GIS software (ArcGIS 10.1). Box-plots of geoaccumulation index(*Igeo*), pollution index (PI), integrated pollution index (IPI), ecological risk (E_r^i) and potential ecological risk index (PRI) of heavy metals were performed by software package SPSS 25.0 , the distribution of integrated pollution index (IPI) , potential ecological risk index (PRI) and carcinogenic risks(CR) of heavy metals were carried out by the ArcGIS 10.1 software.

3. . Results and discussion

3.1. Heavy metals concentrations and spatial distributions

The minimum, maximum，mean, median, standard deviation and coefficient of variation of statistical characteristics and spatial distributions of eight heavy metals in 76 urban soils in national scale of China were presented in Table s1 and Figure 3,respectively.As was shown in Table s1, the concentrations of heavy metals manifested significant variation among the cities, as for As, Cd, Cr, Hg, Pb, Cu, Zn and Ni, the ranges varied between 0.28 and 57.85, 0.07 and 13.31, 3.92 and 378.86,0.07 and 1.10, 0.13 and 409.20,0.32 and 430.00,0.21 and 374.47,and 0.26 and 361.00mg/kg, respectively, with the mean values of 11.89, 0.82, 75.41, 0.32, 58.10, 46.25, 122.94 and 36.32mg/kg, respectively, all of which exceeded the soil background values of China, in particular, Cd and Hg were 8.45,4.92 times higher than the national background, respectively, indicating the influence of urbanization and industrialization on urban soil pollution and the pollutant influence on the soil environment is serious [26, 28].There indicated the fact that the median concentrations of all the elements were

slightly less than their mean concentrations. In addition, the CV of heavy metals in urban soils decreased in the following order: Cd(160%)> Ni(149%)> Pb(115%) >Cu(114%)> Cr(78%) >Hg(77%) > As(74%)>Zn(57%),all of which manifested a high degree of variability and much stronger nonhomogeneous distribution of concentrations due to anthropogenically emitted heavy metals with the increasing of CV values, especially for the Cu, Ni and Cd[6, 15, 46].

In order to identify the spatial distribution of the heavy metals concentrations in reviewed urban soils across China, ordinary kriging interpolation method was used to obtain the spatial distribution patterns of elements performed by the GIS software(ArcGIS 10.1)(Fig 2). It should be mentioned that any interpolation methods involve uncertainty and the results from specific sites should be taken as the expected possible values but not the true values[49].As was shown in Fig 2, the element of As presented high concentrations in southwest region and low concentrations in north and northeast region, the hot-spots locations concentrated in several cities including Liupanshui, Guiyang, Zhuzhou, Changsha and Lanzhou. The high concentrations of Cd mainly distributed in southcentral region consisting of Hubei, Hunan and Jiangxi provinces, which shared some distribution regions with As, the hotspots located in Wuhan and Changsha cities. For Cr, the high concentrations mainly concentrated in southcentral, north and northwest regions including Ganzhou, Changsha, Jiaozuo, Luoyang, Xining and Yinchuan hot-spot cities. The high concentrations of Hg mainly distributed in southwest and southeast coast regions, the hotspot located in Guangzhou, Huangshan, Zhangzhou, Ningbo, Fuzhou, Suzhou and Liupanshui cities. The element of Pb presented high concentrations in southeast and northwest regions, with the hot-spot cities locating in HongKong, Dongguan, Guangzhou, Ganzhou, Baoji, Tongchuan and Shangluo. There manifested the similar distribution pattern in Cu and Ni, both of which with hotspot situated in Kunming, Panzhihua, Guiyang and Jinchang cities. As to Zn, the high concentrations centralized in southwest and northwest regions, with the hot-spot cities of Kunming, Yinbin, Panzhihua, Chengdu, Guiyang, Ganzhou, Changsha, Baiyin, Shangluo, Baoji, Lanzhou, Kashi and Urumqi, in addition, the high concentrations of Zn also scattered in Zhuzhou, Xiangtan, Nanjing, Xuzhou, Fuzhou and Shanghai cities.

On the whole, the hot-spot cities of heavy metals in urban soils mainly concentrated in the southwest, southcentral, southeast coast, northcentral and northwest regions of China, which should be labeled as priority controlling contamination regions for heavy metals. And there indicated the southern part were relatively higher contaminated than the northern, which may be associated to the high geochemical background in southwest regions and the long-term industrial activities, such as Yunnan Gejiu Tin capital and Lanping Znic capital, Sichuan Panzhihua V-Ti magnetite, Guizhou Liupanshui coal mine, Gansu Jinchang Nickel capital, Hunan Shizhuyuan polymetallic mine, Guangxi Dachang Sb polymetallic mine and Guangdong Dabaoshan polymetallic mine, Fujian Youxi Pb-Zn mine are all located in the high-contaminated regions, which could generate other accompanying heavy metals such as Cd and Cr[50].Furthermore, the increasing urban population and manufacturing industries activities may also be the significant contributions to the pollutant [27, 46, 51]. In addition, due to the datas collected in Xizang, Xinjiang and Gansu provinces were fewer in published literatures and several abnormal values were eliminated in Qingdao and Jilin, therefore the authentic contaminated level of those regions might not well embody.

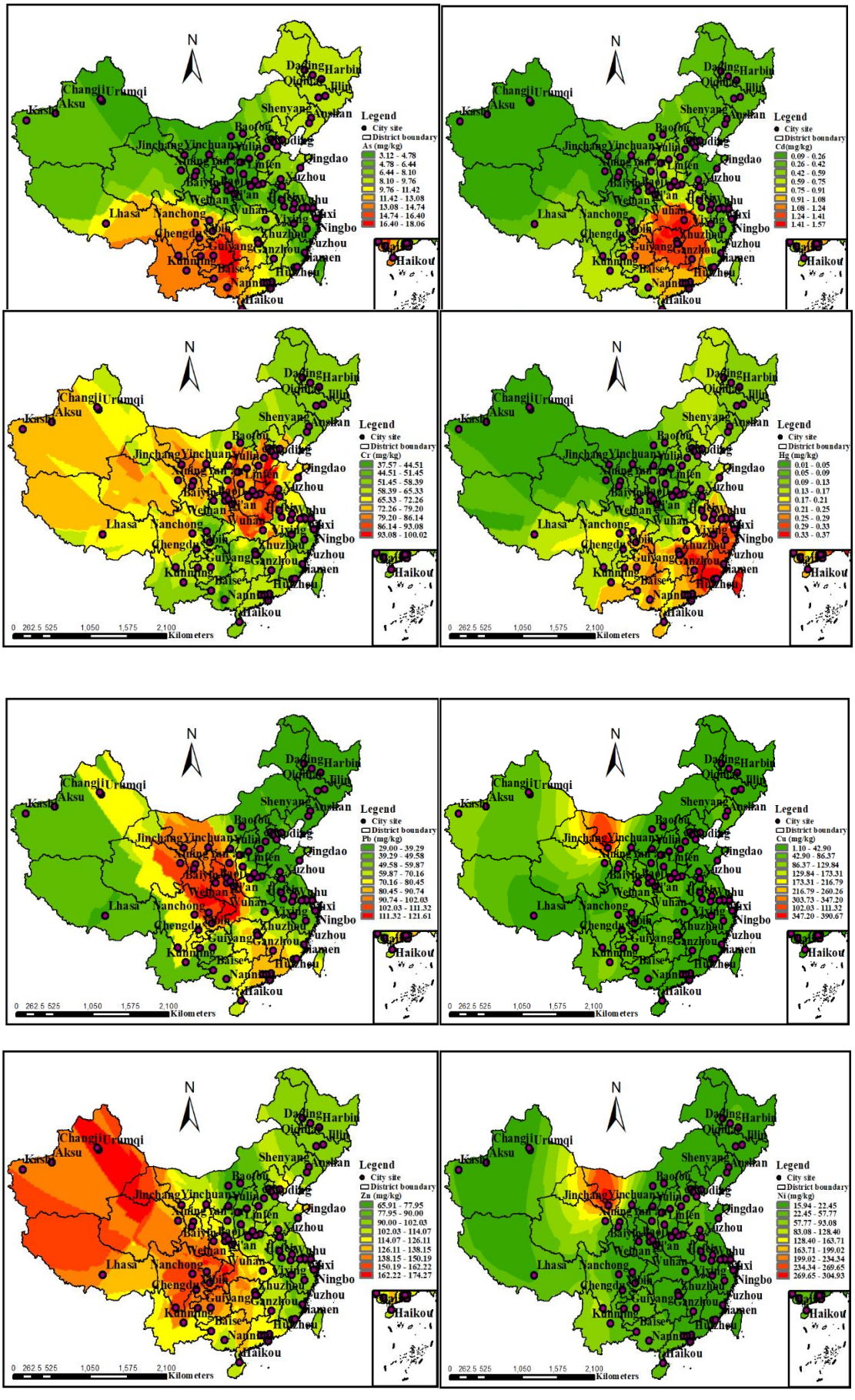


Figure 3. Spatial distribution of heavy metals content in urban soils around China.

Table S1. Concentrations of heavy metals in urban soils around China(mg/kg).

City	n	As	Cd	Cr	Hg	Pb	Cu	Zn	Ni	Reference
Beijing	550	8.55	0.17	60.30	0. 32	33.70	31.30	83.80	23.30	[52]
Kaifeng	99	6.31	1.05	53.11	—	36.71	36.4	164.03	23.87	[53]
Guiyang	62	20.53	0.32	35.71	0.19	22.17	64.87	217.9	48.65	[54]
Shijiazhuang	220	9.42	0.28	71.85	0.11	31	27.39	104.48	28.2	[55]
Chongqing	48	8.02	0.98	26.58	0.31	32.61	24.63	96.77	25.64	[56]
Luoyang	215	—	1.71	71.42		65.92	85.4	215.75	—	[57]
Jilin	136	10.5	—	3.93	—	6.62	7.29	1.58	—	[58]
Tangshan	63	6.79	0.1	46.2	0.07	25.08	20.97	63.38	17.33	[59]
Guangzhou	426	17.4	0.32	—	0.61	87.60	35.8	107	18.7	[60]
Changchun	352	12.5	0.13	66	0.12	35.4	29.4	90	—	[61]
Huhhot	62	6.4	—	54.75	—	11.63	30.07	89.93	16.47	[62]
Xi'an	62	12.2	—	69.8	—	36.9	32.4	101.3	30.7	[63]
Yongkang	181	6		121		40	24	95	23	[64]
Shanghai	273	—	0.52	107.9	—	70.69	59.25	301.4	31.14	[65]
Zhengzhou	90	—	—	—	—	39.63	59.11	91.67	—	[66]
Wuhan	467	—	3.22	41.85	—	28.16	18.82	88.07	—	[67]
Chengdu	35	11	0.36	60	0.31	76.9	42	224	—	[68]
Huangshan	49	0.78	1.5		1.1	0.9	0.75	0.77	0.58	[69]
Shenyang	93	22.69	1.1	67.9	0.39	116.76	92.45	234.8	—	[24]
HongKong	152	—	0.62	23.1	—	94.6	23.3	125	12.4	[29]
Baotou	88	—	0.29	35.6	—	39.82	27.76	79.45	—	[70]
Qingdao	83	7.71	0.11	55.83	—	27.11	17.95	49.66	—	[71]
Baiyin	132	5.91	0.29	52.62	0.27	64.59	57.33	197.06	17.3	[72]
Taiyuan	80	10.96	0.21	73.69	0.12	26.29	28.87	86.08	29.76	[73]
Changsha	110	32.8	6.9	121	0.41	89.4	51.4	276	—	[74]
Baoji	50	8.75	—	98.08	—	409.20	107.19	374.47	—	[75]
Urumqi	85	—	—	69.24	—	28.74	47.9	263.24	—	[76]
Xuzhou	172	17.1	0.4	219.4	0.05	35.5	43.8	163.8	42.9	[77]
Nanjing	150	—	—	84.7	—	107.63	66.1	162.6	—	[78]
Wuxi	1957	9.77	0.17	—	0.38	41.76	34.73	86.95	—	[79]
Zhuzhou	60	20.68	0.61	91	0.21	86	37.4	141	—	[80]
Daqing	—	5.7	1	98.1	—	26.2	—	39.93	42.08	[81]
Suzhou	167	15.51	0.33	75.6	0.52	40.26	—	—	—	[82]
Hefei	151	10.8	0.2	—	0.18	37	38.6	108.8	27.3	[83]
Xiangtan	54	18.72	0.46	84	0.24	65	37.5	127	—	[84]
Zhangzhou	108	6.86	0.35	29.7	0.47	75.9	32.6	106.7	12.8	[85]
Kunming	204	13.23	1.32	109.94	0.24	60.28	111.25	150.63	50.13	[86]
Lanzhou	117	20.63	—	93.96	—	42.72	52.41	184.22	38.22	[87]
Xining	155	7.65	—	182.54	—	32.57	19.73	45.13	25.21	[88]
Lhasa	—	9.66	0.26	19.69	—	16.22	13.55	102.84	14.83	[89]
Haikou	70	3.82	0.25	92.4	0.07	29.1	26.7	84.1	52.5	[90]
Panzhihua	17	9.67	0.3	234.04		30.01	62.86	158.22	125.1	[91]
Ningbo	114	6.68	0.22		0.47	47.54	48.58	122.57	6.68	[92]
Qiqihar	55	7.87	—	34.85	-1.03	13.37	—	62.08	—	[93]
Jinchang	74	—	0.3	—	—	32.2	430	116	361	[94]
Harbin	307	8.87	0.17	61.28	0.08	26.74	22.33	72.03	25.73	[95]
Yinchuan	96	—	—	109.1	—	25	16.8	26	25.3	[96]
Wuhu	153	—	1.2	78.3	—	29.1	35	96.8	26.3	[97]
Jiaozuo	44	—	0.33	378.86	—	20.23	36.26	—	—	[98]
Huizhou	104	0.28	0.18	0.11	0.42	0.13	0.32	0.21	0.26	[99]
Anshan	115	—	0.86	69.9	—	45.1	52.3	213	33.5	[100]
Tianjin	70	11	0.18	51	0.43	45	33	148	39	[28]
Huainan	36	12.54	0.19	49.39	0.21	24.21	21.74	—	—	[15]
Yan'an	40	—	0.1	66.22	—	20.18	23.65	71.2	37.56	[101]
Fuzhou	179	8.28	0.3	40.11	0.77	89.83	39.41	158.65	16.04	[102]
Linfen	217	16.59	—	41.12	—	33.91	16.6	101.32	36.11	[103]
Baise	36	8.68	0.16	67.19	—	20.74	29.04	86.01	24.04	[104]
Dongguan	170	13.33	0.25	74.9	0.152	160.27	66.64	150.8	44.45	[105]
Yixing	47	—	0.11	65.23	—	31.39	23.57	68.62	26.4	[106]
Xiamen	146	5.82	—	41.77	—	37.35	23.26	—	—	[14]

Liupanshui	36	57.85	1.98	—	0.87	—	71.41	—	—	[107]
Kashi	—	—	6.34	29.33	—	81.39	103.54	140.7	15.95	[108]
Aksu	50	—	—	25.56	—	75.98	97.26	120.33	8.41	[109]
Yibin	47	8.7	—	—	—	65.2	61.5	135.4	—	[110]
Nanchong	—	—	0.82	15.32	—	85.99	50.29	106.83	—	[111]
Shangluo	15	—	0.55	—	0.58	127.99	59.31	155.08	—	[112]
Tongchuan	26	—	—	93.48	—	357.47	66.48	116.17	—	[113]
Yulin	25	—	0.73	72.98	—	—	27.31	—	—	[114]
Lvliang	—	—	2.74	—	—	70.7	18.71	47.95	18.95	[115]
Tengzhou	355	7.83	0.14	60.37	0.05	25.1	27.02	66.09	26.95	[116]
Ganzhou	50	—	1.74	173.17	—	216.99	32.03	146.61	—	[117]
Langfang	—	30	7.58	0.16	63.3	0.04	27.1	20.1	—	[118]
Baoding	48	9.75	0.18	66.30	0.21	38.99	29.1	122.36	28.05	[119]
Weinan	38	8.49	—	96.99	—	46.71	20.88	71.56	25.43	[120]
Changji	35	—	—	52.18	—	7.52	65.99	221.48	—	[121]
Nanning	46	23.2	0.77	20.94	—	65.56	45.56	105.41	37.04	[122]
Min		0.28	0.07	3.92	0.07	0.13	0.32	0.21	0.26	
Max		57.85	13.31	378.86	1.10	409.20	430.00	374.47	361.00	
Median		9.54	0.32	66.22	0.26	37.18	34.73	106.77	26.30	
Mean ±SD		11.89 ±8.84	0.82 ± 1.30	75.41 ±5 9.13	0.32 ± 0.25	58.10 ±6 6.71	46.25 ±5 2.52	122.94 ± 70.23	36.32 ±54. 18	
CV(%)		74	160	78	77	115	114	57	149	
BGV of China		11.2	0.097	61	0.065	26	22.6	74.2	26.9	[123]

3.2. Assessment of heavy metals pollution in urban soils using geochemical indicators

The Box-plots of geoaccumulation index (*Igeo*), pollution index (PI), integrated pollution index (IPI) , ecological risk(E_r^i) and potential ecological risk index (*PRI*) of heavy metals in urban soil around China was presented in Fig[illegible]s was shown in Figure 4, the *Igeo*, PI , IPI , E_r^i *PRI* values of heavy metals varied significantly in different sites. The *Igeo* values of As, Cd, Cr, Hg, Pb, Cu, Zn and Ni ranged from -7.29 to 0.95,-1.63 to 5.69,-9.43 to 1.99,-0.19 to 4.47,-8.70 to 3.67,-7.35 to 3.57,-8.77 to 1.85 and -6.38 to 2.77, respectively, with the mean values decreased in the following order: Hg(1.47) >Cd(1.40) > Pb(0.03) > Cu(2.40E-4) > Zn(-0.15) > Cr(-0.72) > As(-0.73) > Ni(-0.83).The mean pollution levels of Hg and Cd ranked moderately contaminated levels, and the other six metals ranked uncontaminated levels based on the *Igeo* classification criterion. As was shown in Figure 4, As manifested uncontaminated and uncontaminated to moderately contaminated levels in 82.00% and 18.00% of sites, respectively. Cd manifested the most serious contamination in the study area, with uncontaminated, uncontaminated to moderately contaminated, moderately contaminated, moderately to heavily contaminated, heavily contaminated, heavily to extremely contaminated and extremely contaminated levels in 16.07%,23.21%,32.14%,12.51%,8.92%,1.79% and 5.36% of sites, respectively, and the *Igeo* values of As in the cities of Wuhan, Changsha, Kashi reached 5.68,5.19 and 5.14, respectively, all of which ranked extremely contaminated levels. For Cr and Zn, the ranks of uncontaminated, uncontaminated to moderately contaminated and moderately contaminated levels presented 80.65%,14.52%,4.83% and 46.15%,40.00%,13.85% of sites, respectively. Hg manifested uncontaminated, uncontaminated to moderately contaminated, moderately contaminated, moderately to heavily contaminated , heavily contaminated levels and heavily contaminated to extremely contaminated levels in 2.94%,32.35%,38.24%,17.65% , 5.88% and 2.94% of sites, respectively, and the higher *Igeo* values for Hg were located in Huangshan(4.47), Shangluo(3.69) and Baiyin(3.17) cities, both of which reached the heavily contaminated levels. Pb and Cu manifested similar contaminated condition, with uncontaminated, uncontaminated to moderately contaminated, moderately contaminated, moderately to heavily contaminated and heavily contaminated levels in 47.22%, 36.11%, 13.00%,1.39%,2.78% and 45.07%, 39.43%, 12.68%, 1.41%, 1.41% of sites, respectively. For Pb, Baoji and Tongchuan cities ranked heavily contaminated levels, the *Igeo* values of which reached 3.67 and 3.48, respectively. For Cu, the most serious contamination was located in Jinchang which ranked heavily contaminated levels with the *Igeo* values reached 3.57. Ni presented the most uncontaminated levels, with the uncontaminated, uncontaminated to moderately contaminated,

moderately contaminated, moderately to heavily contaminated levels in 90.00%,2.50%,2.50% and 5.00% of sites, respectively.

The PI values of As, Cd, Cr, Hg, Pb, Cu, Zn and Ni ranged from 0.01 to 2.58,0.49 to 77.38,0.004 to 5.94,1.31 to 33.33,0.004 to 19.12,0.01 to 17.84,0.003 to 5.40 and 0.02 to 10.26, respectively, with the mean values decreased in the following order: Cd(7.10)> Hg(5.80)> Pb(2.37)> Cu(2.02)> Zn(1.83)> Ni(1.36)> Cr(1.22)> As(1.08) (Figure 3).The mean values of Cd and Hg reached high contamination levels, and the mean values of Pb, Cu, Zn, Ni, Cr and As reached moderate contamination levels based on the PI classification criterion. The PI values of Cd in Wuhan (77.38), Changsha (54.76) and Kashi (52.83) manifested the most contamination levels among all the cities, for Hg, the most contamination levels located in Huangshan, Shangluo, Baiyin and Shenyang cities with the PI values reached 33.33, 19.33, 13.50 and 10.54, respectively. For Pb, the most contamination levels were located in Tongchuang and Baoji cities with the PI values reached 19.12 and 16.70, respectively. The most contamination levels of Cu and Ni were located in Jinchang city with the PI values reached 17.84 and 10.26, respectively. For Zn and As, the most contamination sites were located in Baoji, Jiaozuo and Shenyang cities, respectively, and the PI values of which reached 5.40,5.94 and 2.58, respectively. All the high PI values cities of every metals mentioned in the former reached high contamination levels, with the exception of the PI value of As in Shenyang reached moderate contamination levels.

The IPI values ranged between 0.03 to 16.20 among all the cities with the mean value reached 2.76(Figure 4), which illuminated that the mean contamination of all the urban soils in the study areas ranked high contamination level based on the IPI classification criterion. As was shown in Fig5, the percentages of IPI distribution in low contamination, moderate contamination, high contamination and extremely high contamination levels of heavy metals in urban soils around China were 10.39%,36.37%,37.66% and 15.58%, respectively. The low contamination levels mainly distributed in the northern, the high contamination and extremely high contamination levels mainly distributed in the northwest, north center, southwest, south center, east and east coast of China. The extremely high contamination levels of the cities were mainly located in Wuhan, Kashi, Changsha, Shangluo, Tongchuan , Lvliang，Jinchang, Luoyang, Baoji and Ganzhou, and the IPI values of which were 16.20,10.69,9.99,7.23,7.16 and 7.06, 6.81,6.48,6.37 and 6.06,respectively.

The E_r^i values of As, Cd, Cr, Hg, Pb, Cu, Zn and Ni ranged from 0.10 to 28.93,14.57 to 1642.90,0.004 to 11.88,44.44 to 1333.33,0.02 to 95.61,0.09 to 89.21,0.005 to 5.40 and 0.09 to 51.28, respectively, the mean values of which decreased in the following order: Hg(232.11)> Cd(213.07)> Pb(11.84)> As(10.84) > Cu(10.14) > Ni(6.81) > Cr(2.39)>Zn(1.83). Based on the E_r^i classification criterion, the mean E_r^i values of Cd and Hg reached high ecological risk and considerable ecological risk degree, respectively, the mean E_r^i values of other six metals were below 40,all of which ranked low ecological risk degree. As was shown in Fig4,the percentages of ecological risk degree of As, Cr and Zn were low ecological risk degree in 100% of sites; Pb ,Cu and Ni manifested low ecological risk degree in the percentages of 97.33%,98.63 and 95.45% of sites, respectively; for Cd, the low, moderate, considerable, high and very high ecological risk degree presented in the percentages of 15.25%,22.04%,30.51%,15.25% and 16.95% of sites, respectively; Hg manifested moderate, considerable, high and very high ecological risk degree in the percentages of 22.22%,22.22%,44.45% and 11.11% of sites, respectively. Therefore, it could be induced that Cd and Hg served as the predominant ecological risk factors of the eight metals, which contributed most to the ecological risk degree of urban soils among all the study cities.

The *PRI* values ranged between16.60 to 1835.91 among all the cities with the mean value reached 299.69(Figure 4), which demonstrated that the mean ecological risk of all the urban soils in the study areas ranked moderate ecological risk degree based on the *PRI* classification criterion. As was shown in Figure 5, the percentages of the ecological risk distribution in low, moderate, considerable, and high ecological risk degree among the sites around China were 36.36%,25.97%,27.28% and 10.39%, respectively. The low ecological risk degree and moderate ecological risk degree mainly distributed in the north of China, the considerable ecological risk degree and high ecological risk degree mainly distributed in the southwest, south center, north center, east and east coast of China, which presented the similar distribution with the IPI. The high ecological

risk degree were mainly located in Wuhan (2332.65), Changsha (1835.91), Huangshan(1798.58), Kashi (1631.60), Shangluo(994.86), Lvliang(913.44), Shenyang(809.63), Luoyang(724.53) and Baiyin(655.60).

On the whole, the *Igeo* ,PI and E_r^i values of Cd and Hg all presented higher than the other six metals, which manifested the most contamination levels and ecological risk degree among the eight metals, consequently, Cd and Hg should be labeled as the priority control metals in the urban soils around China. Furthermore, according to the IPI and *PRI* values(Figure 6), the high contamination and ecological risk regions mainly concentrated in the southwest, south center, north center ,east and east coast of China, the cities were mainly located in Huangshan, Wuhan, Kashi, Changsha, Shangluo, Tongchuan , Lvliang， Jinchang, Luoyang ,Baoji ,Ganzhou, Shenyang and Baiyin.

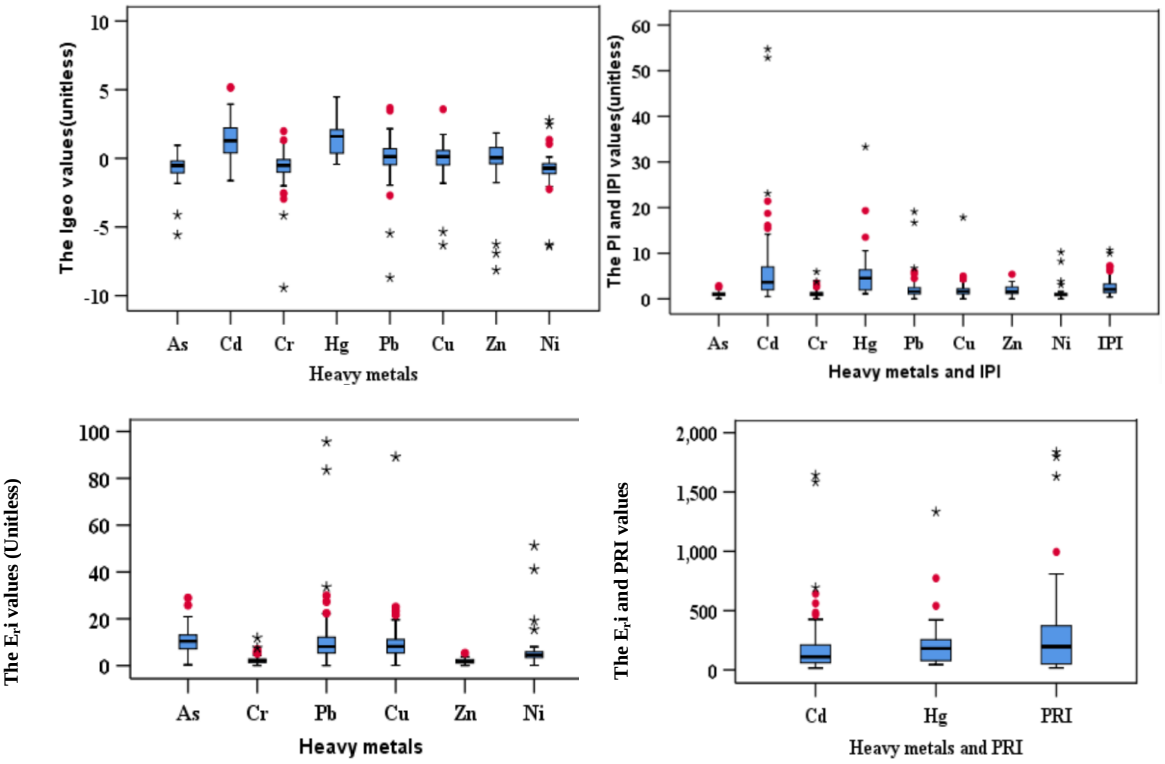


Figure 4. Box-plots of geoaccumulation index (*Igeo*), pollution index (PI), integrated pollution index (IPI), ecological risk (E_r^i) and potential ecological risk index (*PRI*) of heavy metals in urban soil around China. The top and bottom edges of the box represent 75th and 25th percentile respectively, the upper and lower limit of whiskers represent the maximum and minimum of the unoutliers, the black horizontal lines inside each box represent median values, the red dots represent mild outliers and the black stars represent extreme outliers.

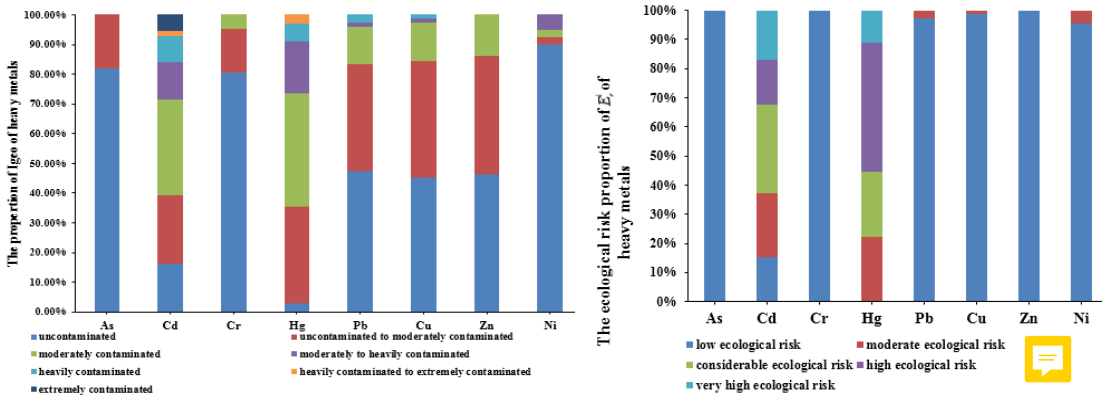


Figure 5. The proportion of geoaccumulation index (*Igeo*) and ecological risk (E_r^i)of heavy metals in urban soils around China.

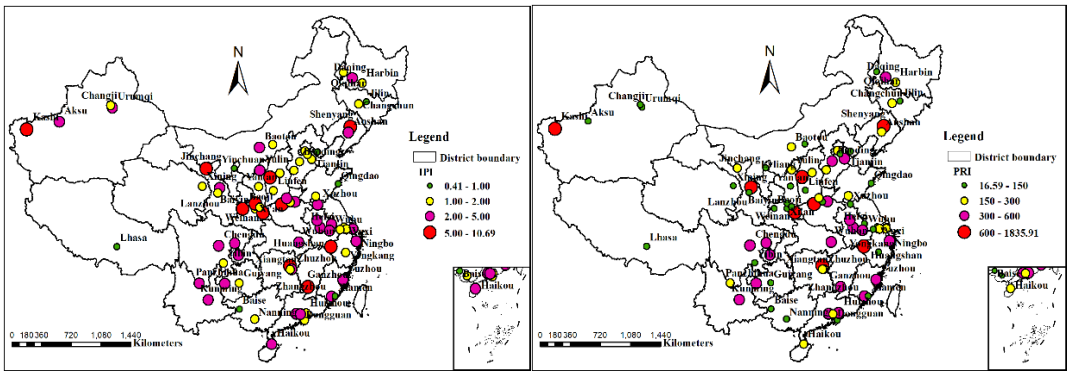


Figure 6. The distribution of integrated pollution index (IPI) and potential ecological risk index (*PRI*) of heavy metals in urban soils around China.

3.3. Health risk assessment of heavy metals contamination in urban soils

The assessment results of the mean values of non-carcinogenic and carcinogenic risks of each element through three exposure pathways in urban soils are shown in Table4. The mean HQ values of eight metals for children and adults via ingestion (HQ_{ing}) , inhalation (HQ_{inh}) and dermal contact (HQ_{dermal}) all descended in the trend HQ_{ing} > HQ_{dermal} > HQ_{inh}, manifesting that ingestion was the predominant exposure pathway to pose adverse effects on human health, which was consistent with the previous research[15, 19].In addition, the HQ_{ing} and HQ_{dermal} values for children were higher than adults, while as for the HQ_{inh} values were opposite. The mean HI values of As ,Cd ,Cr ,Hg ,Pb ,Cu ,Zn and Ni for children were 5.24E-01,1.89E-02,4.55E-01,1.55E-02,2.26E-01,1.54E-02,5.52E-03 and 3.04E-02, for adults were 7.63E-02,7.51E-03,1.38E-01,3.02E-03,3.71E-02,2.30E-03,8.66E-04 and 8.18E-03, respectively, all of which were less than 1, illustrating unlikely adverse effects on human health, in addition, they followed the decreasing trend Cr >As > Pb > Cd > Ni > Cu > Hg > Zn. The mean pollution levels of Hg and Cd ranked moderately contaminated levels, Cr and As ranked uncontaminated levels based on the *Igeo* classification criterion, however, Cr and As contribute most to the HI while Hg and Cd posed less, illustrating that the uncontaminated metals should also be paid attention. the In term of the individual urban site, the HI values of eight metals for adults were all less than 1, however, some of the risks values for children exceeded 1,for example, the HI values of As in Changsha(1.45) and Nanning(1.02),Cr in Jiaozuo(2.29) ,Xining(1.10) and Ganzhou(1.04), Pb in Baoji(1.60) and Tongchuan(1.39), which demonstrated that heavy metals posed unlikely adverse effects on adults, while there may occur adverse health effects on children. Furthermore, the HI values of children were higher than those of adults, indicating that children exposed more serious non-carcinogenic health threaten compared with adults, which might be induced by the physiological behaviors in children such as the direct finger or hand sucking and higher exposure per unit of body weight[15, 124]. It has been reported that the mean IQ (Intelligence Quotient) of children aged between 3 and 4 years with significantly higher blood Pb levels in the exposure area was significantly lower than that of children of the same age in the control area[31, 125].

The carcinogenic risk (CR) for As, Cr and Ni were assessed (Table3) and Cd, Hg, Pb, Cu and Zn were excluded owing to the lack of carcinogenic slope factors. The values of CR_{ing}, CR_{inh} and CR_{derm} presented in the descended order of CR_{ing} > CR_{dermal} > CR_{inh}, indicating that ingestion was the main exposure pathway to pose carcinogenic risk on human health, which was consistent with the non-carcinogenic risk. The values of CR_{ing} for children exceeded those of adults, while for CR_{inh} and CR_{derm}, the values of adults were higher than children. The mean CR values of As, Cr and Ni for children and adults all lied in the ranges of greater than 10^{-6} and less than 10^{-4}, indicating an acceptable carcinogenic risk to human beings. Nevertheless, due to the cumulativity of the heavy metals, the carcinogenic risk of those metals can't be neglected especially for children. The CR values for children surpassed the adults, which were similar to the HI values. The CR values of the three metals emerged in the trend of Ni >Cr >As for both adults and children， which was consistent with the previous research in 32 urban soils in China conducted by Pan[31].

In terms of the single urban site, the carcinogenic risk of the three assessed metals for adults were all at an negligible or acceptable risk levels, however, for children, the risks values in several sites surpassed 1×10^{-4}. The distribution of CR for children in urban soils in China were mapped (Figure 7). According to Fig 6, all the CR of As for children were at an negligible or acceptable risk levels, however, some values were close to the threshold value 1×10^{-4},illustrating that carcinogenic risk of As should also be brought to forefront. With regard to Cr and Ni, the majority of the urban sites were at an negligible or acceptable risk levels for children, with the exception of several sites reaching the high risk of developing cancer levels. For Cr, the high risk of developing cancer for children were located in Xining(1.03E-4) and Jiaozuo(2.14E-4), for Ni, the sites were distributed in Jinchang(6.86E-4) and Panzhihua(2.38E-4), all the CR values of the aforementioned sites exceeded the threshold value 1×10^{-4}, suggesting the pollution sources should be quantitively identified and the precautionary measures should be taken in these cities to reduce the cancer risks. Additionally, children's living behaviors should be also properly guided, such as washing hands regularly and reducing the outdoor activities frequency.

Table 4. The mean values of human health risks for children and adults of each element and exposure pathways.

		As	Cd	Cr	Hg	Pb	Cu	Zn	Ni
HQ_{ing}	children	5.14E-01	1.06E-02	3.26E-01	1.39E-02	2.15E-01	1.50E-02	5.31E-03	2.35E-02
	adults	6.89E-02	1.42E-03	4.37E-02	1.87E-03	2.89E-02	2.01E-03	7.13E-04	3.16E-03
HQ_{inh}	children	9.29E-06	1.98E-07	6.38E-04	9.11E-07	4.00E-06	2.79E-07	9.92E-08	4.27E-07
	adults	9.97E-06	2.12E-07	6.85E-04	9.78E-07	4.29E-06	2.99E-07	1.07E-07	4.58E-07
HQ_{derm}	children	1.01E-02	8.35E-03	1.29E-01	1.57E-03	1.12E-02	3.94E-04	2.10E-04	6.88E-03
	adults	7.40E-03	6.09E-03	9.38E-02	1.15E-03	8.18E-03	2.88E-04	1.53E-04	5.02E=03
HI	children	5.24E-01	1.89E-02	4.55E-01	1.55E-02	2.26E-01	1.54E-02	5.52E-03	3.04E-02
	adults	7.63E-02	7.51E-03	1.38E-01	3.02E-03	3.71E-02	2.30E-03	8.66E-04	8.18E-03
CR_{ing}	children	1.95E-05		4.13E-05					6.77E-05
	adults	1.05E-05		2.22E-05					3.63E-05
CR_{inh}	children	3.73E-10		6.57E-09					6.79E-10
	adults	1.60E-09		2.82E-08					2.91E-09
CR_{derm}	children	3.82E-07		1.32E-06					1.35E-06
	adults	1.11E-06		3.86E-06					3.95E-06
CR	children	1.997E-05		4.27E-05					6.90E-05
	adults	1.16E-05		2.61E-05					4.03E-05

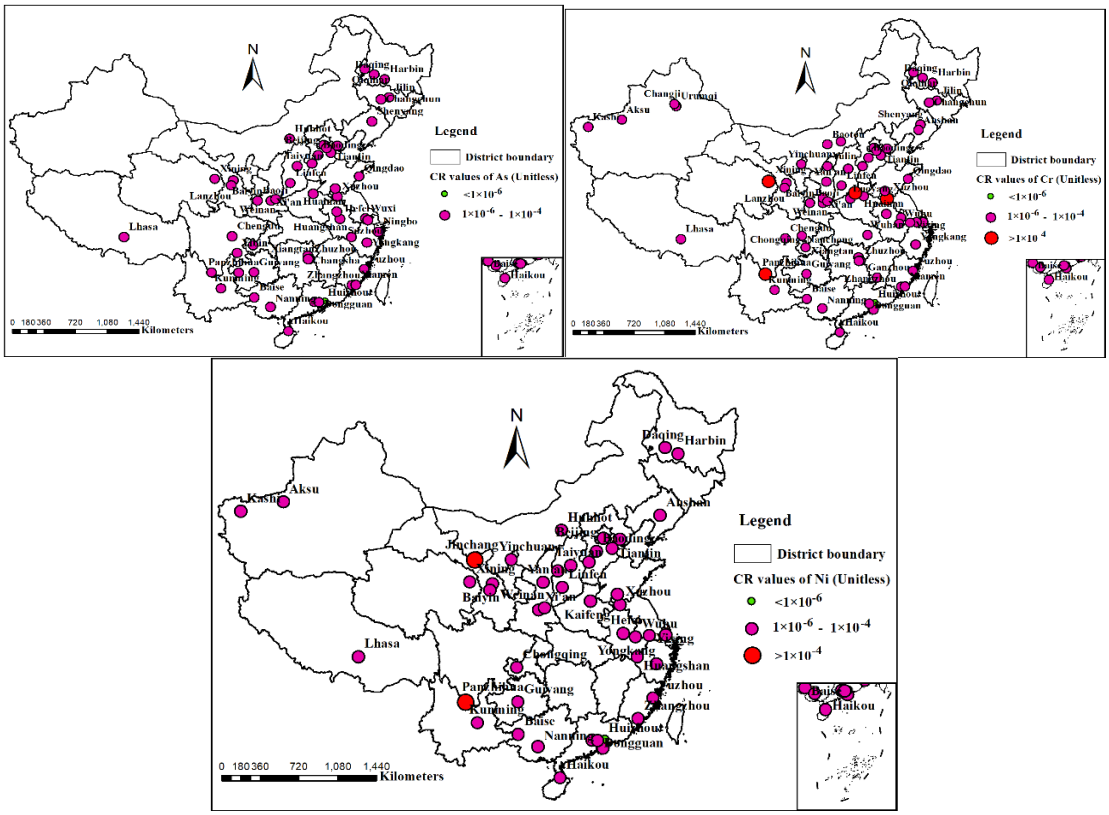


Figure 7. The distribution of carcinogenic risks(CR) of As, Cr and Ni for children in urban soils around China.

4. Conclusions

The mean values of eight heavy metals all exceeded the soil background values of China, in particular, Cd and Hg were 8.45, 4.92 times higher than the national background. All the CV of metals manifested a high degree of variability and strong influence of human activities. The hot-spot cities of heavy metals in urban soils mainly concentrated in the southwest, southcentral, southeast coast, northcentral and northwest regions of China based on the ordinary kriging interpolation method. The mean pollution levels of Hg and Cd ranked moderately contaminated levels, and the other six metals ranked uncontaminated levels based on the Igeo classification criterion. According to the PI classification criterion, Cd and Hg reached high contamination levels, and the other metals reached moderate contamination levels. The integral urban soils in the study areas ranked high contamination level and moderate ecological risk degree, respectively. Cd and Hg posed as the dominant ecological risk factors among the eight metals, which should be labeled as the priority control metals in the urban soils around China. The high contamination and ecological risk regions mainly concentrated in the southwest ,south center ,north center ,east and east coast of China, the cities were mainly located in Wuhan, Kashi, Changsha , Shangluo, Tongchuan , Lvliang， Jinchang, Luoyang ,Baoji ,Ganzhou, Shenyang and Baiyin. According to the HQ values, ingestion was the dominated exposure pathway to pose adverse effects on human health. Although the mean HI values of eight heavy metals all presented unlikely adverse effects on human health, and the mean CR values of As, Cr and Ni for children and adults all suggested an acceptable carcinogenic risk to human beings, the risks in some of the single sites should be paid attention. Children exposed more serious non-carcinogenic and carcinogenic health threaten compared with adults, indicating that children's behaviors should be adopted reasonable guidance and paid more attention in comparison with adults.

Limits and future work

Due to the online datas of heavy metals in urban soil in western areas of China are less and the lack of data especially the small cities in some provinces, this study may not fully reflect the situation

of heavy metal pollution in urban soil all over the China. With the action plan on The Belt and Road proposed by Chinese goverment and the number of tourists into the western part increasing year by year, it will inevitably bring heavy metals pollution to the urban soil, so it is in need of comprehensive further research in urban soil of the western part.

The bioavailability is related to the morphology of the heavy metals, thus the human risks assessment may overestimate only taking into account the total concentrations. For lack in the parameters of Cd, Hg, Pb, Cu and Zn, the hazard of which were not assessed. In addition, the elderly and sensitivity human being should be estimated separately according to their body situation. Moreover, it has been reported that synergistic interactions generated by mixed metal can result in numerous adverse health effects on human, thus it should be furtherly evaluated the health risks posed by multiple heavy metals.

Finally, at present, large amounts of soil remediation projects have been carried out in mining areas and agricultural soils, however, there is still a lack of effective treatment in urban soils around China, therefore, soil assessment and remediation in densely populated urban areas should be extensively emphasized in the future. Additionally, the temporal and spatial variation and quantitative sources apportionment of the urban soil pollution should be furtherly studied base on the models.

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