

Assessing heavy-metal contamination and sources by GIS-based approach and multivariate analysis of urban–rural topsoils in Wuhan, central China

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Abstract Nine potentially harmful heavy metals (Cd, Co, Cr, Cu, Hg, Mn, Pb, Ni, and Zn) were measured in 477 topsoil samples collected from urban–rural areas in the city of Wuhan in order to identify their concentrations and possible sources,

and characterize their spatial variability for risk assessment. Results showed that in most rural areas heavy-metal concentrations in soil were similar to their natural background values, but Cd, Cu, Hg, Pb, and Zn concentrations were relatively higher in densely populated districts and around industrial facilities. Multivariate analyses (correlation matrix, principal component analysis, and cluster analysis) indicated that Cd, Cu, Hg, Pb, and Zn were mainly derived from anthropogenic inputs, and Co, Cr, and Mn were controlled by natural source, whereas Ni appeared to be affected by both anthropogenic and natural sources. The result of risk assessment indicated that nearly 48% of the study area suffered from moderate to severe contamination.

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Introduction

Soil contamination by heavy metals is a global problem due to the wide use of metals in all aspects of human life. Heavy metals do not decay with time, unlike many organisms and radionuclides, because of their nonbiodegradable nature and long biological half-life in bodies (Raghunath et al. 1999; Gallego et al. 2002; Cui et al. 2005). Once soil is polluted,

metals can be transferred from soil to other environmental media, such as underground water or crops, and pose a threat to human health as a consequence of inhalation or ingestion through the water supply and food chain (Culbard et al. 1988; Folinsbee 1993; Sánchez-Camazano et al. 1994). In addition, direct oral intake of soil particles by humans, particularly children, also poses a health hazard. Previous studies have found that direct oral ingestion of contaminated soils and dust by children is the principal cause of lead absorption (Healy et al. 1982; Xintaras 1992; USEPA 1994).

In the last three decades the geochemistry of soil contaminants (particularly heavy metals) in a number of cities has been studied, such as Minneapolis, USA (Mielke et al. 1984); Aberdeen, Scotland (Paterson et al. 1996); Birmingham, England (Wang et al. 1997); Berlin, Germany (Birke and Rauch 2000); Tallinn, Estonia (Bityukova et al. 2000); Seville, Spain (Madrid et al. 2004); Gainesville and Miami, Florida, USA (Chirenje et al. 2003); Montana, USA (Burt et al. 2003); Gibraltar (Mesilio et al. 2003); Japan (Takeda et al. 2003); Wolverhampton, England (Hooker and Nathanail 2006); and Ibadan, Nigeria (Odewande and Abimbola 2008). In recent years, China has also conducted such investigations; for example, Chen et al. (2005) reported the Cu, Ni, Pb, and Zn contamination status in urban park soils in Beijing. Lee et al. (2006) conducted an extensive survey in Hong Kong Island, and found that surface soils in urban and suburban areas were enriched with heavy metals, such as Cu, Pb, and Zn. Chen et al. (2008) investigated the urban–rural transitional area of Hangzhou, and showed that only 30% of the study soil did not suffer from moderate or severe pollution of heavy metals. Huang et al. (2007) reported the concentration levels of Hg, Cd, Pb, Zn, Cu, As, Ni, and Cr in soils and crops from Yangzhou.

Wuhan, the largest inland city and the most important industrial base in central China, has undergone accelerated industrialization and urbanization in recent years. This involved many different industries that produced a variety of wastes and pollutants, especially heavy metals. However, heavy-metal contamination in this important city has not been fully investigated; only a few studies have reported several metal concentrations in the specific region of this city (Xiong 1998; Yang and Dong 2004; Wang et al. 2005; Liu et al. 2008).

In unpolluted soils, metals are mainly derived from parent materials (bed rocks), while in urban–rural area, anthropogenic inputs, such as industry and agriculture emissions, may become predominant sources of metals in soils (Micó et al. 2006). Multivariate analysis [principal component analysis (PCA) and cluster analysis (CA)] has been widely used to distinguish between geogenic and anthropogenic sources of metals in soils. Pollution maps, which are produced by interpolating measured concentrations of pollutants, may also provide information on the relative contributions of different sources affecting soil composition (Yay et al. 2008).

This study of Wuhan district provides information that will be valuable for making strategic sustainable agriculture in Wuhan and other rapidly developing regions of China in the future. Thus the objectives of this study were to (1) determine concentrations of nine potentially harmful heavy metals (Cd, Co, Cr, Cu, Mn, Ni, Hg, Pb, and Zn) in topsoils of Wuhan city, (2) delineate their main sources by GIS-based approach and multivariate analysis, and (3) characterize their spatial variability for risk assessment.

Materials and methods

Site characteristics and sampling

Wuhan, the capital of Hubei Province, is located in the middle reaches of the Yangtze River (29°58′–31°22′N, 113°41′–115°05′E). It has a population of approximately 7.5 million, about 4.3 million of them residing in nine urban core districts within an area of 201 sq km. Its climate represents a typical subtropical humid monsoon with average annual temperature of 15.9°C and average annual rainfall of 1,300 mm (Chen et al. 2007). Wuhan is one of the biggest hubs for land, water, and air transportation in China. The major industries in Wuhan include ferrous smelters, chemical plants, power plants, papermaking, and machinery plants.

Soil samples were collected from an area of 1,908 sq km, including all inhabited and industrial parts of Wuhan, but also extending to nonurbanized areas around the city. The study area was divided into 2 × 2 km cells and 477 topsoil samples (0–20 cm depth) were collected from every grid intersection from garden or agricultural fields. In these cells 46

deep-layer soil samples were also taken from soil pits at depth of about 100 cm. At each sampling point, five subsamples were randomly taken and then mixed into a composite sample. The sample locations, distribution of population, and important industrial facilities are shown in Fig. 1.

In this paper, we also conducted a primary study on crops grow in contaminated soils. For this purpose, rice samples and most common vegetable samples were collected from croplands nearby one of the biggest ferrous smelter in the city. A total of 14 crop samples, consisting of 5 rice, 4 radish, 3 cabbage, and 2 lettuce samples, were collected by hand-picking using vinyl gloves and carefully packed into polyethylene bags and weighed in situ. Each sample consisted of 20–30 subsamples from an area of about 100 × 50 m. Samples were cleaned (soil removed) using a dry precleaned vinyl brush. The rice samples were threshed, weighed, washed with distilled water to eliminate airborne pollutants, dried in an oven to constant weight at 45°C, reweighed to determine the water content, and ground into power for analysis.

Chemical analysis

Soil samples were analyzed for pH and heavy metals, including copper (Cu), cobalt (Co), cadmium (Cd), chromium (Cr), mercury (Hg), manganese (Mn),

nickel (Ni), lead (Pb), and zinc (Zn). Soil pH was measured in a 1:5 soil-to-water suspension after stirring for 2 h.

Soil samples were air-dried at room temperature (25°C), stones or other debris were removed, and then the samples were sieved by 2-mm polyethylene sieve. Portions of soil samples (about 50 g) were ground in an agate grinder and sieved through 0.149 mm mesh. About 0.5 g of the prepared soil samples were digested in Teflon beakers with a mixture of nitric acid (HNO₃) and perchloric acid (HClO₄) using hot plane (Agricultural Chemistry Committee of China 1983). Total concentrations of Cd, Co, Cu, Cr, Mn, Ni, Pb, and Zn in the digested solution were measured by inductively coupled plasma mass spectrometry (X7 ICP-MS, TMO, USA) at the Hubei Geological Analytical Center in Wuhan. In addition, the contents of Hg in the digested solution were determined by atomic fluorescence spectrophotometry (AFS). One gram of plant sample was digested by 15 ml HCl and 5 ml H₂SO₄ (Huang et al. 2007). Cd, Pb, and Zn concentrations were measured by atomic absorption spectrometry (AA800, PE, USA) coupled with a graphite furnace at Key Laboratory of Biogeology and Environmental Geology in Wuhan. For quality assurance and quality control (QA/QC), we analyzed duplicates, method blanks, and standard reference materials (GBW 07404 and GBW 07602).

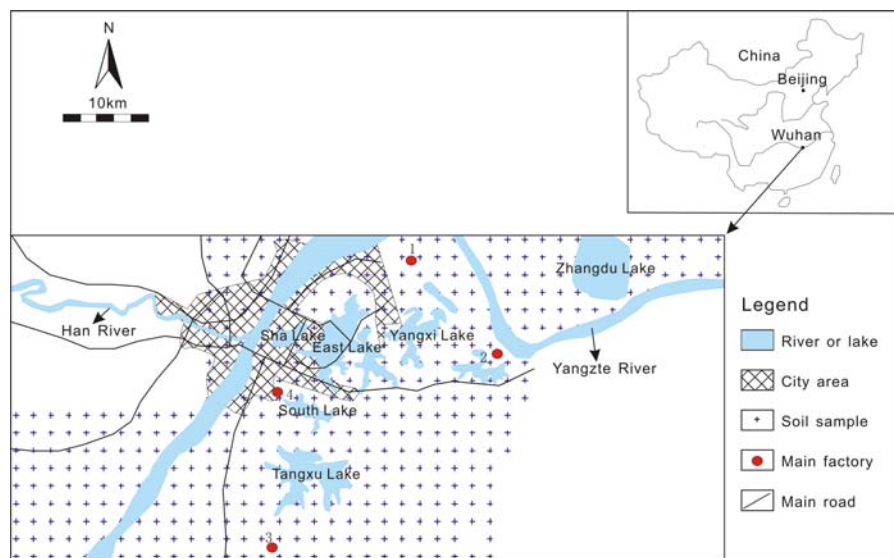


Fig. 1 Location of the study area and sampling sites. 1 ferrous smelter, 2 chemical plant, 3 papermaking plant, 4 machinery plant

Statistical analysis

In multivariate statistics a normal distribution for the variables under study was desirable (Chen et al. 2008). To avoid result distortions and low levels of significance, data transformation was performed on all measured values. In our study, the log transformation was used to make the data more normal and less skewed (Webster and Oliver 2001). After data transformation, it was possible to apply multivariate statistical methods such as correlation matrix (CM), principal component analysis (PCA), and cluster analysis (CA). Multivariate analysis was performed using SPSS 12.0 for Windows. CM was used to identify the relationship (Pearson correlation) between heavy-metal contents and soil properties. PCA was interpreted in accordance with the hypothetical source of heavy metals (geogenic, anthropogenic or mixed). Varimax rotation was applied because orthogonal rotation minimizes the number of variables with a high loading on each component and facilitates the interpretation of results. CA was applied to identify different geochemical groups, clustering the samples with similar heavy-metal content. Results are shown in a dendrogram where steps in the hierarchical clustering solution and values of the distances (correlation coefficient distance) between clusters are represented.

Risk evaluation

To quantify the pollution risk and obtain the potential contaminated region, the Nemeru synthesis index evaluation method was performed, which has been widely used in recent years (Li et al. 2003; Chen et al. 2008). The synthesis index can be computed by Eq. 1:

$$P = \sqrt{\frac{\left(\frac{C_i}{S_i}\right)_{\max}^2 + \left(\frac{C_i}{S_i}\right)_{\text{avg}}^2}{2}}, \quad (1)$$

where P is the synthesis evaluation score corresponding to each sample, C_i is the measured value of a certain element at each sample point, i is any element, and S_i is the evaluation criterion of the i th element. In this study, the evaluation criterion is based on the natural soil background value of China. The evaluation process was performed according to the following procedure. Firstly, the synthesis index

of each sample was evaluated based on Eq. 1. Secondly, kriging was performed on the synthesis scores of all samples to obtain an integrated pollution distribution by using MapGIS 7.0. Finally, the pollution distribution was graded into five categories based on Chinese soil environmental quality assessment standard for green-food production area (State Development Center for Green-Food of China 2000).

Results and discussion

Descriptive statistics

A description of metal (Cd, Co, Cr, Cu, Hg, Mn, Pb, Ni, and Zn) concentrations and pH value of topsoil and deep-layer soils is listed in Table 1, including the geometric mean and geometric standard deviation. Mean values were used when the concentration had normal distribution and geometric mean values were used when the concentration had log-normal distributions. In order to stabilize variances in all subsequent statistical analysis, the values of metal concentrations were transformed to their common logarithms (Fig. 2).

The mean concentrations of Cd, Co, Cr, Cu, Hg, Mn, Pb, Ni, and Zn in topsoils were 0.20, 16, 85, 34, 0.11, 630, 33, 34, and 85 mg kg⁻¹, respectively. Most of these concentrations were comparable to those in the deep-layer soil, but Cd, Hg, and Pb concentrations were notable higher than those in the deep-layer soils, suggesting the anthropogenic input of these metals to topsoil. In comparison with local background soil data (Wei et al. 1990), most metals in the topsoils had similar concentrations to their corresponding background values, indicating that during the recent decades from the early 1990s heavy metal in the topsoils in Wuhan city had no obvious increase.

Compared with concentrations of heavy metals in urban soils in the world (Table 2), metal concentrations in soils from Wuhan were comparable to those reported in cities in China (i.e., Yangzhou, Hangzhou, Beijing), but Cd, Cu, Hg, Pb, and Zn concentrations were much lower than those from some developed and industrialized cities (i.e., Madrid, London, Hong Kong, Rome, Malina), while Cr, Co, Mn, and Ni showed higher concentrations compared with these cities.

Table 1 Summary statistics for heavy-metal concentration (mg kg⁻¹) in topsoils

Elements (<i>N</i> = 477)	Min.	Max.	AM	ASD	CV (%)	GM	GSD	Distribution type	Subsoils (<i>N</i> = 46)	Background value ^a
Cd	0.07	0.80	0.23	0.13	55	0.20	0.21	Log-normal	0.13	0.17
Co	6	23	16	2.5	16	16	0.07	Normal	17	15.4
Cr	23	320	85	18	220	83	0.08	Normal	85	86.0
Cu	11	94	35	10	28	34	0.11	Log-normal	30	30.7
Hg	0.03	1.4	0.15	0.18	120	0.11	0.29	Log-normal	0.03	0.08
Mn	190	1,270	630	200	33	590	0.15	Normal	770	712
Pb	17	130	38	11	30	33	0.10	Log-normal	25	26.7
Ni	10	57	34	8	23	37	0.10	Normal	38	37.3
Zn	39	250	90	30	34	85	0.13	Log-normal	77	83.6
pH	4.9	8.9	6.9	1.0	14	6.9	0.06	Log-normal	7.7	6.5

Min minimum value, *Max* maximum value, *AM* arithmetic mean, *ASD* arithmetic standard deviation, *GM* geometric mean, *GSD* geometric standard deviation, *CV* coefficients of variation

^a Natural background value in Hubei (Wei et al. 1990)

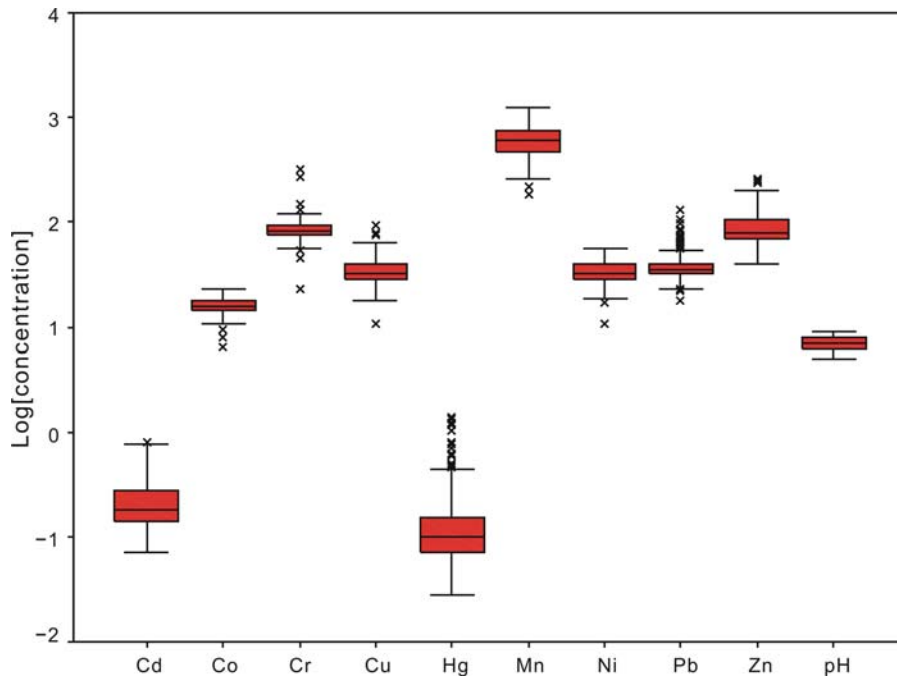


Fig. 2 Box-and-whisker plots for Cd, Co, Cr, Cu, Hg, Mn, Pb, Ni, Zn, and pH; outliers are also indicated

Spatial distribution of pollution

Distribution patterns of nine metals were prepared by interpolating data from 477 sampling points, using MapGIS 7.0 (Fig. 3). Cd, Cu, Pb, and Zn showed similar spatial distribution patterns with relatively higher concentrations in heavily populated districts of the city. This suggested that human activities such as

household heating and vehicle traffic played a dominant role in the enrichment of these metals in surface soil, especially for Pb and Zn (Xiong 1998; Huang et al. 2007).

In addition, it is worth highlighting that Hg was significantly enriched in the old city zone, as shown in Fig. 3, which was quite different from other metals. One possible pollution source of Hg in this

Table 2 Average heavy-metal concentrations (mg kg⁻¹) in urban soils from different cities in the world

City	Cd	Co	Cr	Cu	Hg	Mn	Pb	Ni	Zn	Reference
Wuhan	0.20	16	85	34	0.11	630	33	34	85	This paper
Hangzhou	0.26	9.25	62.23	36.57	0.69	415.27	46.15	20.04	116.07	Chen et al. (2008)
Yangzhou	0.3		77.2	33.9	0.2		35.7	38.5	98.1	Huang et al. (2007)
Hong Kong	0.36	3.55	17.8	16.2			88.1	4.08	103	Lee et al. (2006)
Beijing				59.6			55.8	22.2	82.5	Chen et al. (2005)
Hong Kong	1			73			294		183	Li et al. (2001)
Ibadan	8.4		64.4	46.8		1,097.9	95.1	20.2	228.6	Odewande and Abimbola (2008)
Seville			39	68		471	137	22	145	Madrid et al. (2004)
Tallinn		5.2	39.9	45		384	75.3	16	156.1	Bitjukova et al. (2000)
Berlin	0.5	2.5	18.1	18.5	0.06		40.6		101	Birke and Rauch (2000)
Madrid		6.42	74.7	71.7		340	161	14.1	210	De Miguel et al. (1998)
Birmingham							360			Wang et al. (1997)
Aberdeen		6.4	23.9	27.0		286	94.4	14.9	58.4	Paterson et al. (1996)
Rome	0.31						330.8			Angelone et al. (1995)
London	1			73			294		183	Thornton (1991)
Manila	0.57			98.7			213.6	20.9	440	Pfeiffer et al. (1988)

area is emissions from the fossil fuel consumed (especially coal burning) and subsequent atmosphere deposition (Nakagawa and Hiromoto 1997; Wang et al. 2003; Kuo et al. 2006). Using of cinnabar in Chinese traditional medicine in the center city was another important factor (Yang and Dong 2004). Another area located at the upper right of the map (Fig. 3), close to an organic chemical plant (OCP), also had enriched Hg in the soils. This finding was in agreement with previous study which reported that emissions from the OCP were the primary reason for Hg contamination in this area (Wang et al. 2005).

Co, Cr, and Mn showed similar distribution characteristics with no obvious enrichment in the studied area, suggesting geogenic origin. The distribution of Ni, between the two patterns observed for Cd, Cu, Pb, Zn and Co, Cr, Mn, may be understood as a combination of geogenic and anthropogenic factors. These findings are consistent with previous studies (Manta et al. 2002; Li et al. 2003; Chen et al. 2008; Huang et al. 2007).

Multivariate analysis approaches

Correlation matrix

Correlation analysis was carried out to determine the extent of the relationship between the metals

investigated. As shown in Table 3, there were significant correlations existing between many metals, especially anthropogenic elements such as Cd, Cu, Pb, and Zn ($r^2 = 0.59\text{--}0.85$, $P < 0.01$). The strongest correlations were found between Cu and Zn ($r^2 = 0.85$, $P < 0.01$) and between Zn and Pb ($r^2 = 0.74$, $P < 0.01$), similar to those of Nan et al. (2002) of 0.88 between Zn and Cu and 0.80 between Zn and Pb.

Another strong relationship was found between Cr, Co, Mn, and Ni ($r^2 = 0.48\text{--}0.68$, $P < 0.01$), indicating their common origin. This result was in agreement with previous studies (Facchinelli et al. 2001; De Temmerman et al. 2003; Chen et al. 2008). Meanwhile, Ni also showed a strong correlation with Cu ($r^2 = 0.73$) and Zn ($r^2 = 0.69$), suggesting that Ni could be controlled by mixed sources.

Comparatively, the correlations between Hg and other metals were less significant, probably indicating distinct origin.

Principal component analysis

Because the correlation matrix (Table 3) showed the existence of a strong relationship between certain variables, the data were submitted to PCA to study interrelated correlation patterns. The obtained factors were rotated using a varimax normalized algorithm,

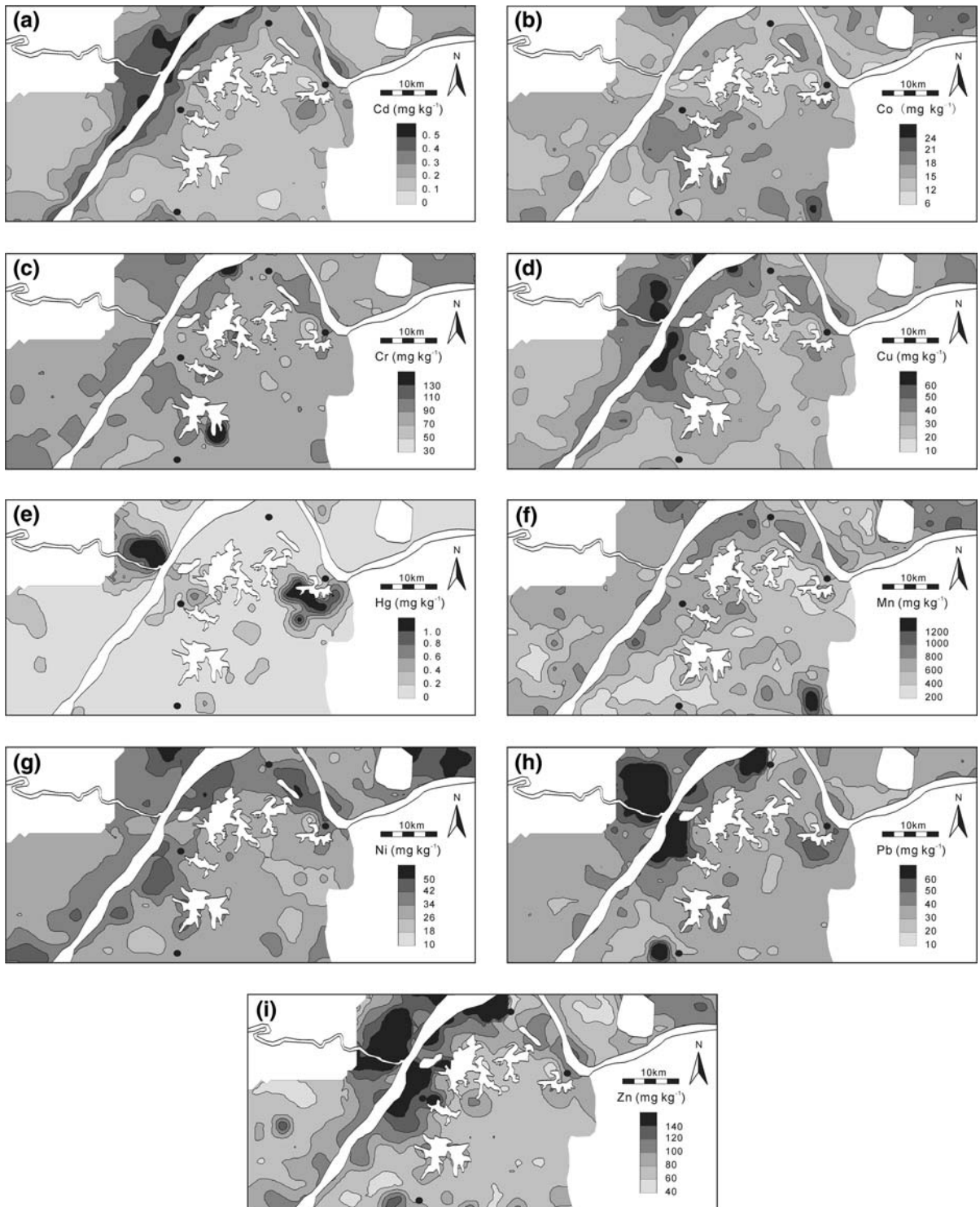


Fig. 3 Spatial distribution of heavy-metal contents in topsoils in Wuhan district

Table 3 Pearson correlation matrix for total soil metals ($N = 477$)

	Cd	Co	Cr	Cu	Hg	Mn	Ni	Pb	Zn	pH
Cd	1									
Co	0.12**	1								
Cr	0.37**	0.57**	1							
Cu	0.72**	0.41**	0.57**	1**						
Hg	0.14**	-0.03**	-0.04	0.25**	1					
Mn	0.45**	0.57**	0.48**	0.54**	-0.26**	1				
Ni	0.56**	0.60**	0.65**	0.73**	-0.07	0.68**	1			
Pb	0.59**	0.27**	0.41**	0.73**	0.45**	0.33**	0.41**	1		
Zn	0.76**	0.31**	0.47**	0.85**	0.21**	0.57**	0.69**	0.74**	1	
pH	0.60**	0.09*	0.26**	0.50**	-0.11*	0.61**	0.51**	0.32**	0.54**	1

Correlation significant at * $P < 0.05$; ** $P < 0.01$

Table 4 Total variance explained for heavy-metal contents

Component	Initial eigenvalues			Extraction sums of squared loadings			Rotation sums of squared loadings		
	Total	% of variance	Cumulative %	Total	% of variance	Cumulative %	Total	% of variance	Cumulative %
1	4.9	54	54	4.9	54	54	3.5	39	39
2	1.7	18	72	1.7	18	72	2.6	29	67
3	0.9	10	82	0.9	10	82	1.4	15	82
4	0.5	5.4	88						
5	0.4	3.9	92						
6	0.3	2.8	95						
7	0.2	2.5	97						
8	0.1	1.6	99						
9	0.1	1.4	100						

Extraction method: principal component analysis

which allows an easier interpretation of the principal component loadings and the maximization of the variance explained by the extracted factors. Three principal components were extracted from the available dataset, explaining a total variance of approximately 82% (Table 4).

The first factor (F1), explaining 39% of the total variance, was strongly and positively related to Cd, Cu, Pb, and Zn (Table 5). The second factor (F2), explaining 29% of the total variance, showed high positive factor loadings on Co, Cr, Mn, and Ni. The third factor (F3), explaining 15% of the total variance, mostly condensed the information of Hg.

The plot of factor loadings (Fig. 4) showed the grouping of metals in factor 1 and factor 2. According to numerous studies (Brümelis et al. 2002; Manta et al. 2002; Micó et al. 2006; Yay et al. 2008; Chen

et al. 2008) the association of these metals with the factors clearly reflected anthropogenic influence or geogenic characteristics. Cobalt, Cr, Mn, and Ni were known to be geogenic influenced while Cd, Cu, Pb, Zn, and Hg were typically anthropogenic influenced (Bloemen et al. 1995). In our study, F1 loaded by Cd, Cu, Pb, and Zn can be identified as a tracer of anthropogenic pollution. F2 was dominated by Co, Ni, Cr, and Mn, suggesting that the distributions of these elements were mainly controlled by natural sources, so the second factor can be inferred to be a geogenic factor. Ni showed high values in F2, but it was also represented in F1 (0.59), which can be explained by the fact that Ni in topsoil from Wuhan was affected by both geogenic and anthropogenic sources. The third factor included only the element Hg, whose mean concentration exceeded the

Table 5 Component matrix and rotated component matrix for heavy-metal contents

Element	Component matrix			Rotated component matrix		
	PC1	PC2	PC3	PC1	PC2	PC3
Cd	0.91	0.19	-0.04	0.92	0.05	0.00
Cu	0.89	0.23	-0.20	0.89	0.29	0.13
Pb	0.85	-0.29	-0.02	0.81	0.42	0.20
Zn	0.76	0.28	-0.44	0.69	0.25	0.51
Co	0.74	0.48	0.11	0.02	0.93	0.04
Cr	0.72	-0.46	-0.16	0.32	0.76	0.02
Mn	0.71	-0.29	0.29	0.59	0.66	-0.16
Ni	0.59	-0.48	0.55	0.50	0.59	-0.39
Hg	0.14	0.80	0.49	0.13	-0.08	0.93

Extraction method: principal component analysis; rotation method: varimax normalization

background value by about 1.5 times (Table 1), and which could be regarded as a second anthropogenic source.

Cluster analysis

In order to discriminate distinct groups of heavy metals as tracers of natural or anthropogenic sources, cluster analysis was performed on the available dataset. The obtained results (Fig. 5) enabled the

identification of three groups by clustering at level of approximately 12: Cu, Cd, Pb, and Zn (group I); Co, Cr, Ni, and Mn (group II); and Hg (group III). This result was similar to the factor analysis results.

Group I was made up of those metals involved in F1 and group III involved in F3. These two groups of metals were mainly affected by some anthropogenic factors. Metals in Group II seemed to be controlled by natural factors due to their relatively low concentrations and coefficient of variation (Manta et al. 2002).

Based on multivariate analysis (CM, FA, and CA), it is reasonable to conclude that Cd, Cu, Hg, Pb, and Zn in topsoil of Wuhan are mainly controlled by anthropogenic inputs, Co, Cr, and Mn appear to be associated with natural source, whereas Ni is affected by both geogenic and anthropogenic sources.

Heavy metals in crops

In this study, we only collected crop samples from near a ferrous smelter. In the first stage of the study, we only analyzed Cd, Pb, and Zn concentrations in limited crop samples from this area. The concentrations of these three metals in vegetables and rice are given in Table 6. The levels of heavy-metal concentrations in analyzed crops were generally lower than

Fig. 4 Factor loading for the first two dominant factors

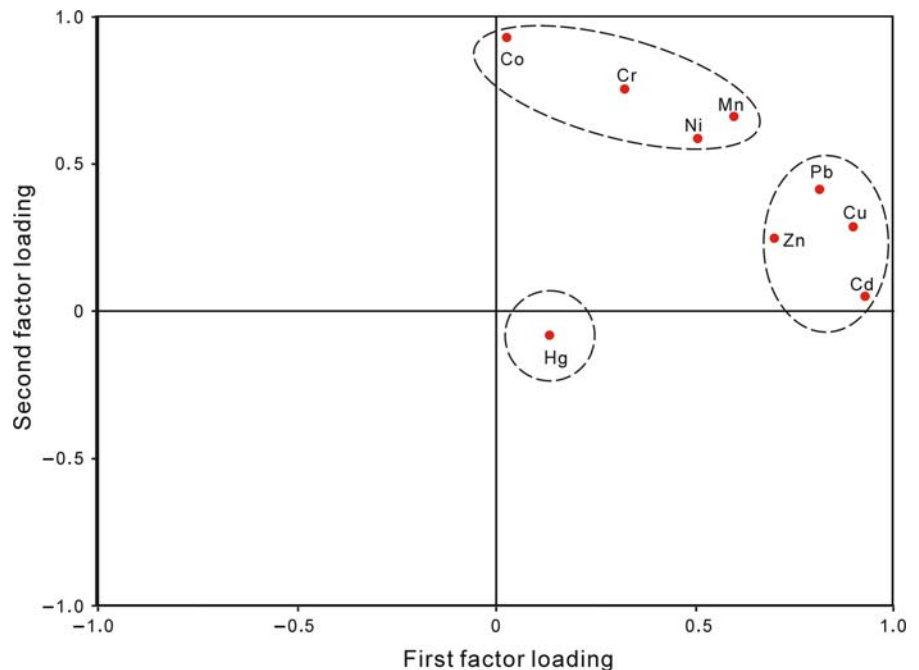
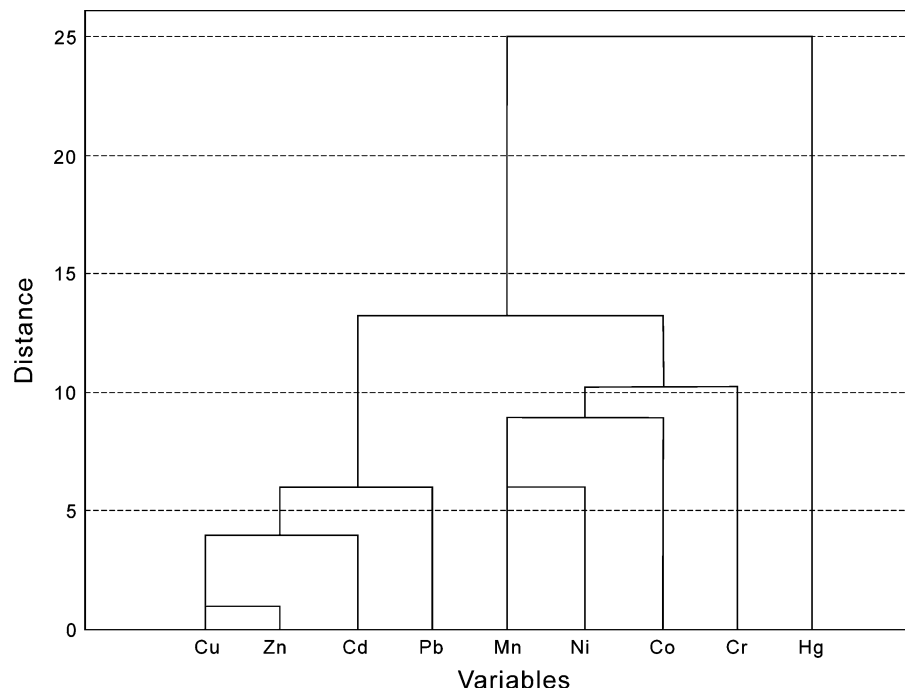


Fig. 5 Clustering results of the heavy-metal concentrations in topsoil samples from Wuhan city



the amounts recorded in the soils in which the crops were grown, except for Cd in cabbage, lettuce, and rice root, and Zn in rice root.

The average Cd, Pb, and Zn contents in rice root (0.55 , 19 , and 110 mg kg^{-1} , respectively) were much higher than those in stem and grain (Table 6), indicating that only limited quantities of metals were absorbed into the upper parts of the rice, probably because the roots acted as a barrier to translocation of metals within the plants (Davies and White 1981).

The mean Cd, Pb, and Zn concentrations in vegetables were observably higher than the threshold levels of the food quality standard (Ministry of Health of China 2005), especially Pb, which was about 45 times higher in cabbage. The mean Cd and Zn concentrations

in rice grain were slightly below the threshold levels, but Pb was much higher, by about 15 times.

In comparison, the bioconcentration factors (BCF; metal concentration in plant/metal concentration in soil) for Cd in plants were higher than those for Pb and Zn in this study. This indicated that Cd was more easily absorbed by plants than Pb and Zn. Xue et al. (2005) also reported that Cd had maximal BCF values among Cd, Zn, Cu, Pb, and Cr.

Risk assessment

After understanding the main sources of heavy metals in topsoils, risk evaluation was carried out to provide some advice for managers. During the processing of

Table 6 Concentrations of heavy metals in vegetables and rice, and their bioconcentration factors

Metal	Mean concentrations (mg kg^{-1})						Bioconcentration factors						*	**
	Rice ($N = 5$)			Radish ($N = 4$)	Cabbage ($N = 3$)	Lettuce ($N = 2$)	Rice ($N = 5$)			Radish ($N = 4$)	Cabbage ($N = 3$)	Lettuce ($N = 2$)		
	Root	Stem	Grain				Root	Stem	Grain					
Cd	0.55	0.19	0.18	0.19	0.27	0.30	2.4	0.83	0.78	0.83	1.2	1.3	0.2	0.2
Pb	19	6	6	7	9	7	0.49	0.16	0.16	0.19	0.24	0.19	0.3	0.2
Zn	110	40	44	55	40	48	1.2	0.45	0.49	0.62	0.44	0.53	20	50

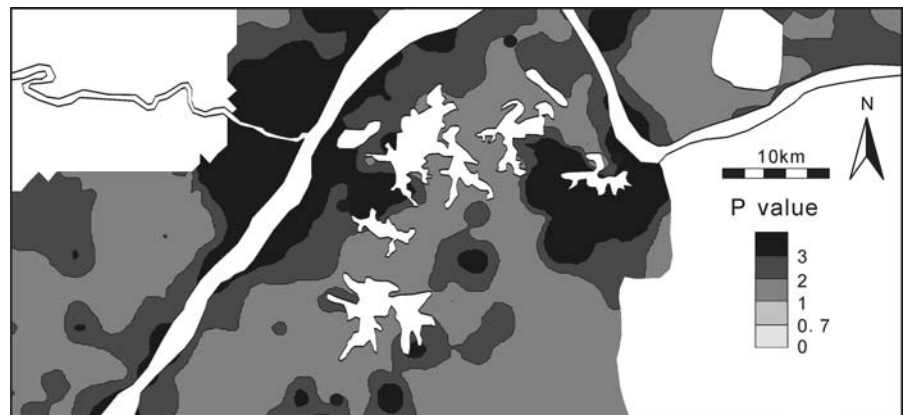
* National guidance limit for vegetables

** National guidance limit for rice grain (Ministry of Health of China 2005)

Table 7 The evaluation standard and results of soil heavy metals

Grade level	P^a	Pollution grade	Area (km ²)	Percent (%)
1	$P \leq 0.7$	Safety	0	0
2	$0.7 < P \leq 1$	Guard	12	1
3	$1 < P \leq 2$	Low pollution	968	51
4	$2 < P \leq 3$	Moderate pollution	556	29
5	$P > 3$	Severe pollution	372	19

^a Synthesis evaluation score, graded into five categories based on Chinese soil environmental quality assessment standard for green-food production area (State Development Center for Green-Food of China 2000)

Fig. 6 Evaluation map of contaminating elements in soils

evaluation, the Nemeró synthesis index evaluation method was adopted.

The evaluation results and evaluation map are shown in Table 7 and Fig. 6. It can be seen from the map that about 19% of the study area had severe pollution status, 29% moderate pollution, 51% low pollution, and only 1% of the study area had unpolluted status. From the evaluation map, it is clear that moderate to severe pollution areas were mainly distributed in the urban area and those areas close to the point sources of pollution. From the city policy-makers' point of view, development of flower planting or city parks in those areas appears to be more appropriate than cultivation of vegetables or field crops.

Conclusions

The results obtained in this work increase our knowledge of the heavy-metal concentrations and their possible sources in the topsoil of Wuhan, a representative city in central China.

Topsoil samples collected from Wuhan have high Cd, Cu, Hg, Pb, and Zn concentrations coupled with high coefficients of variation, indicating the dominance of anthropogenic sources, whereas Co, Cr, Mn, and Ni exhibited generally low coefficients of variation and quite homogeneous distributions across the study area, suggesting a major geogenic source.

Results of the distribution patterns of the heavy metals suggested that Cd, Cu, Pb, and Zn, which exhibited similar spatial distributions, were higher in heavily populated districts of the city and close to point sources of pollution, whereas the patterns of Co, Cr, and Mn seemed smoother and more regular. The distribution of Ni, between these two patterns, can be understood as an integrated factor. The particular spatial pattern of Hg was mainly attributed to human activity in the inner city and local organic chemical plants.

From multivariate analyses (CM, FA, and CA), it is reasonable to conclude that Cd, Cu, Hg, Pb, and Zn are mainly controlled by anthropogenic inputs, Co, Cr, and Mn appear to be associated with natural source, whereas Ni is affected by both geogenic and anthropogenic sources.

Heavy-metal concentration contrasts between soil and plant indicate that Cd is more easily absorbed by plants than Pb and Zn. The evaluation results show that about 48% of the study area suffers from moderate or severe pollution; the evaluation map could furthermore provide necessary information for policy-makers in terms of city management and land use.

The results have shown that multivariate analysis of a mass set of data together with GIS-based approach can provide valuable insight in the context of the sources of soil pollutants.

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