

# Spatial distribution and source of potential toxic elements (PTEs) in urban soils of Guangzhou, China

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**Abstract** Potential toxic elements (PTEs) in urban soils are of great environmental concern because of their potential long-term effects on human health. A systematic soil geochemical survey was performed across central urban districts of Guangzhou, the largest city in southern China. Surface soil samples (0–10 cm) were collected from 426 sites in order to evaluate the environmental quality of this urban area. Geostatistical and multivariate analysis (principal component, clustering, and correlation) were applied to generate spatial distribution maps of PTEs concentrations as well as identify possible sources of metals. The results showed that PTEs ranged widely in value; Arsenic, Hg, Pb, Cu Zn, Cd, Ni, and Mn ranged from 1.4 to 144, 0.01 to 12.2, 18.5 to 4903, 5.0 to 417, 10.1 to 1795, 0.03 to 2.41, 2.5 to 77.6, and 21.2 to 1286 mg/kg, respectively. Iron ranged from 6.1 to 61.8 g/kg. Soils were enriched with Cd, Cu, Hg, Mn, Pb and Zn as compared with soil background values of Guangzhou. Spatial distribution maps indicated similar distribution patterns of Cd, Cu, Pb and Zn. Urbanization history and industrial activities affected the accumulation of PTEs. Relatively higher concentrations of As, Cd, Cu, Hg, Pb and Zn were found in

districts with a longer history of urbanization and industrial activities, such as the Liwan district along the Pearl River in western Guangzhou. This area was the most highly contaminated, whereas the Tianhe, a district with a limited time of development, was the least contaminated. Multivariate statistical analysis showed distinctly different associations among the studied metals; suggesting that Fe, Ni and Mn were predominantly derived from a natural (geological) source; As, Cu, Hg, Pb and Zn from anthropogenic sources; and Cd from both sources. Present PTEs levels were also compared with those reported from other urban areas around world, and results indicate that further studies on assessing both the human and ecosystem risks associated with urban contaminated soils will be necessary.

**Keywords** Multivariate analysis · Geostatistical analysis · Potential toxic elements (PTEs) · Spatial distribution maps · Source identification · Urban soil

## Introduction

Urban soil is an important component of urban environment and minimizing potential toxic element (PTE) content and bioavailability in urban soils is essential to the health of inhabitants in densely populated urban areas (Lu 2000; Lu et al. 2003; Ajmone-Marsan and Biasioli 2010). The transfer of PTEs from the soil to humans can be direct, such as soil consumption, or indirect through human consumption of plants or animals. Soil ingestion and inhalation, and dermal contact absorption had been recognized as important exposure routes of contaminants to humans in urban environment, especially for children up to the age of six (Ljung et al. 2006; Lu et al. 2011; Luo et al. 2011; Mielke et al. 1999; Poggio et al. 2009). For example, a

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robust nonlinear association has been identified between the blood Pb levels of children and the soil Pb levels in urban environments (Mielke et al. 2007).

Evaluation of the environmental impact of contaminants in soils starts with a determination of their concentration and spatial distribution. This is especially important in urban areas considering the complex, spatially heterogeneous soil features (Bityukova et al. 2000; Zhang et al. 2005). Environmental and health concerns have resulted in a large number of studies on PTEs in the urban soils of many cities around the world (Andersson et al. 2010; Calace et al. 2012; Imperato et al. 2003; Iqbal et al. 2012; Lu et al. 2003; Manta et al. 2002; Ruiz-Cortés et al. 2005; Wong et al. 2006; Zhang 2006). These studies show that urban soils are generally more contaminated than their rural soils due to extensive anthropogenic activities.

Understanding spatial distribution and sources of metals in soils is an initial step to implement mitigation strategies for reduction of concentrations that will minimize human exposure and protect populations at risk (Davis et al. 2009; Johnson and Demetriades 2011). Mapping based on geographical information systems (GIS) and geostatistical methods are useful approaches to describe these spatial distributions. The main benefit of geostatistics is the unbiased estimation of variables for spatial objects at unsampled locations (Maas et al. 2010). GIS-based geostatistical techniques, such as kriging, have been widely used to describe the spatial distribution and hotspots of elevated concentrations of heavy metals in urban soils (Cattle et al. 2002; Davis et al. 2009; Guagliardi et al. 2012; Hamzeh et al. 2011; Lee et al. 2006; Li et al. 2004, 2013; Malik et al. 2010; Rodríguez-Salazar et al. 2011; Zhang 2006). Multivariate statistical techniques, such as principal component analysis (PCA) and cluster analysis (CA) enable the pollutant composition in different samples to be compared and also provides a fingerprint for identifying the origins of the pollutant metal. This technique has also been applied widely to identify the sources of heavy metals in urban soils (Chen et al. 2012; Davis et al. 2009; Guagliardi et al. 2012; Iqbal et al. 2012; Manta et al. 2002; Malik et al. 2010; Li and Feng 2012; Sun et al. 2010; Wang et al. 2012; Yang et al. 2011; Zhang 2006).

The urban environment in China has been strongly modified by human activities, especially during the rapid urbanization and industrial growth in the past few decades. Numerous investigations on PTEs in Chinese urban soils have been reported in recent years (Chen et al. 2010, 2012; Cui et al. 2011; Lee et al. 2006; Li and Feng 2012; Li et al. 2004, 2013; Lu and Bai 2010; Lu et al. 2003; Luo et al. 2008; Shi et al. 2008; Sun et al. 2010; Wang et al. 2012; Yang et al. 2011; Zhao et al. 2014). There have also been a few reports on urban soils

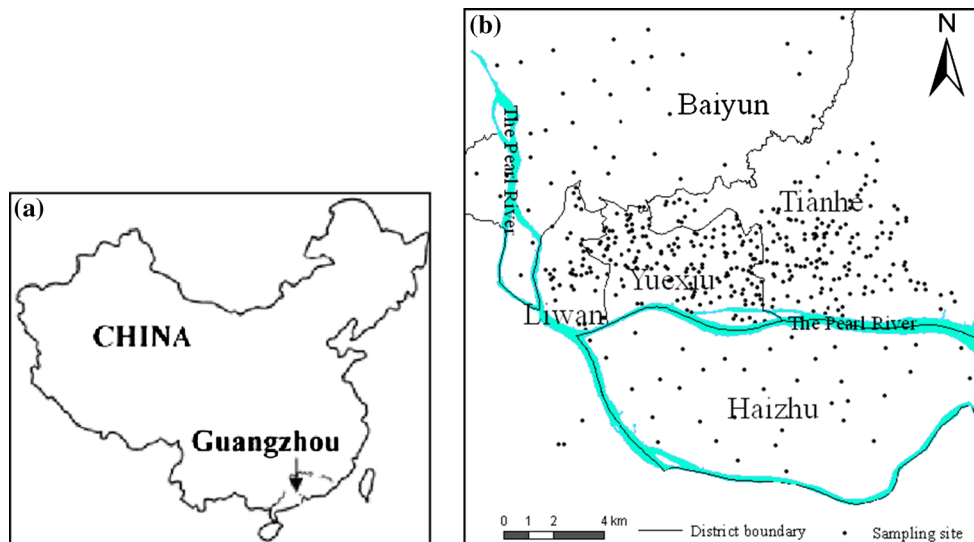
in Guangzhou, Lu et al. (2007, 2011) studied chemical fractionation of Cd, Cu, Ni, Pb, Zn, Fe and Mn, and evaluated bioaccessibility and exposure risk of As and Pb. Bi et al. (2013) and Cai et al. (2013) investigated the metal pollutions in soil, dust and tree leaves in different urban functional zones.

However, no comprehensive study has been performed on the metal content of soils across Guangzhou and no published systematic geochemical maps of these urban soils exist. In order to identify problem areas and the sources of metals in these soils, a large-scale field survey of trace elements was conducted and evaluated with geostatistical and multivariate statistical analysis. Four hundred and twenty six sites across five administrative districts were sampled and analysed for selected trace metals (As, Cd, Cu, Fe, Hg, Mn, Ni, Pb, Zn). The objectives of this research were to (1) determine the concentration of selected trace metals in the central urban areas of Guangzhou, (2) assess the variability and spatial distribution patterns of these elements, and (3) to identify metals whose concentrations may be influenced by anthropogenic activities and identify possible sources.

## Materials and methods

### Soil sampling

The study area is Guangzhou, the capital city of Guangdong province, located in southern China (Fig. 1). More details on the location were described Lu et al. (2007). Several parent materials were identified in the study area, including granite, sandstone and Pearl River alluvium. Urban soils in this city are generally human-altered and/or human-transported and classified as Udufts and Udepts (Soil Survey Staff 2014). These soils were generally modified for construction and greening purposes, with modification of the natural surface layer including cut, fill, and mixing of soil materials derived from other sources. A total of 426 sampling sites were selected in several centre administrative districts (Tianhe, Yuexiu, Liwan, Baiyun and Haizhu) of Guangzhou. Land uses included urban parks, residential areas, industrial areas, schoolyards etc. (Fig. 1). Sampling sites were selected using the grid methods. During the field sampling, the concrete sampling density and sites were adjusted under actual field conditions. Composite soil samples (collected from 0 to 10 cm) were obtained by mixing subsamples from five random points within 2 m<sup>2</sup> in each sampling site, and samples subsequently stored in polyethylene bags. The exact location (longitudes and latitudes) of each sample site was measured by GPS instrument.



**Fig. 1** Location map of Guangzhou (a) and soil sampling sites in Guangzhou (b)

**Soil analysis**

Bulk soil samples were air-dried and hand crushed to pass a 2-mm nylon sieve to remove debris, stones and pebbles. Sub-samples were then ground with an agate grinder to pass a 0.15 mm nylon sieve. Soil pH was measured in a suspension of 1:2.5 (w/v) ratio of soil to distilled water using a glass electrode. Soil organic matter (SOM) was determined by  $K_2Cr_2O_7$  oxidation method (Nelson and Sommers 1996).

Concentrations of Cd, Cu, Fe, Mn, Ni, Pb and Zn were determined by digesting the soil with a mixture of concentrated  $HNO_3$ , HF and  $HClO_4$ . Elemental analysis was performed using flame atomic absorption spectrometry (AAS) (Hitachi Z-5300) for Cu, Fe, Mn, Ni, Pb and Zn, and graphite furnace AAS (Hitachi Z-5700) for Cd. Soil As was measured by hydride generation atomic fluorescence spectrometry (HG-AFS 230, Beijing) following digestion with HCl and  $HNO_3$ . Soil Hg was measured by cold vapor atomic absorption (F732-V, Shanghai) following digestion of the soil sample with a mixture of  $H_2SO_4$ ,  $HNO_3$  and  $KMnO_4$ .

All glass and plastic-ware was soaked in 5 % (v/v) nitric acid overnight and rinsed thoroughly with deionized water before use. Quality assurance and quality control (QA/QC) was assured by means of duplicated samples (about 10 % of all samples) and the use of standard reference material (ESS-3, GSBZ50013-88) from the China National Environmental Monitoring Center (CNEMC). The relative standard deviations (RSD) were generally less than 10 %. Recoveries of the standard reference material (ESS-3) for all studied metals were between 92 and 105 %.

**Geostatistical analysis and mapping based on GIS**

A primary application of geostatistics to soil science has been successful for the estimation and mapping of soil attributes in unsampled areas (Goovaerts 1999). This method uses the semi-variogram to quantify the spatial variation of a regionalized variable. The semi-variogram,  $\gamma(h)$ , measures the mean variability between two points  $x$  and  $x + h$ , as a function of their distance  $h$ .

$$\gamma(h) = \frac{1}{2N(h)} \sum_{i=1}^{N(h)} [Z(x_i) - Z(x_i + h)]^2 \tag{1}$$

where  $Z(x_i)$  is the value of the variable  $Z$  at location  $x_i$ , and  $N(h)$  is the number of pairs of sample points separated by the lag distance  $h$ . Based on the fitted semivariogram models, the ordinary kriging provided by the software of ArcGIS® (version 9.0) for Windows was used to estimate concentrations of metals in unsampled sites and generate the spatial distribution maps of the As, Cd, Cu, Hg, Pb and Zn. Since the distribution of As, Cd, Cu, Hg, Pb, and Zn concentration data were heavily skewed, it was necessary to transform the data prior to analysis. The Box-Cox transformation was effective in drawing the data sets towards normality with small skewness values, and all transformed data sets passed the Kolmogorov–Smirnov test for normality ( $K-S p > 0.05$ ).

**Multivariate statistical analysis**

Basic statistics (minimum, maximum, mean, median, standard deviation (SD), coefficient of variation, skewness and kurtosis) and multivariate analysis were performed using a

statistical software package SPSS<sup>®</sup> version 13 for Windows (SPSS 13.0). Concentration range for each metal calculated proportionately (maximum value as a multiple of the minimum value). Principal component analysis (PCA) was interpreted in accordance with the hypothetical source of metals (lithogenic, 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. Cluster analysis (CA) has often been coupled to PCA to confirm results and provide grouping of variables (Lee et al. 2006). In our study, CA was performed according to the Ward's linkage method, and clustering results were shown in a dendrogram that provided a visual representation of the steps in the hierarchical clustering solution and values of the distances between clusters (correlation coefficient distance).

## Results and discussion

### Metals concentrations and other properties in urban soils

Soils in this study ranged widely in pH from 2.55 to 9.33 (median 7.12). Acid soils (pH < 6.5) accounted for about 28.4 % of the samples, while neutral soils (pH of 6.5–7.5) and alkaline soils (pH > 7.5) accounted for 44.4 and 27.2 %, respectively (Table 1). These data indicated urban soils in Guangzhou had a tendency to be more alkaline (less acidic) than natural soils in the area that are generally

acidic to strongly acidic (GDSGSO 1993). The SOM ranged from 2.56 to 199 g/kg, with a mean value of 25.4 g/kg, suggesting the organic matter varied greatly among urban soils due to influence of organic waste additions.

Trace elements in surface soils varied widely in concentration, reflecting the variety in lithological types as well as anthropogenic impacts like traffic-related emissions, industrial emission, waste disposal, soil excavation, transport and redistribution (Table 1). Arsenic, Hg, Pb, Cu, Zn, Cd, Ni, and Mn ranged from 1.4 to 144, 0.01 to 12.2, 18.5 to 4903, 5.0 to 417, 10.1 to 1795, 0.03 to 2.41, 2.5 to 77.6, and 21.2 to 1286 mg/kg, with mean values of 17.4, 0.61, 87.6, 35.8, 107, 0.32, 18.7, 218 mg/kg, respectively. Iron ranged from 6.1 to 61.8 g/kg with a mean of 27.9 g/kg. Based on mean concentrations, elements were arrayed in the following decreasing order: Fe > Mn > Zn > Pb > Cu > Ni > As > Hg > Cd. Concentration range showed that Hg had the largest range (1223), while Fe had the smallest range (10). Descriptive statistics of metal concentrations in these urban soils showed their distribution was skewed by a small number of samples with high concentration. Only Fe approached a normal distribution (skewness = 0.56), with other metals positively skewed towards the lower concentration, i.e. there are many sites that had a low concentration of the particular metal, for example, As, Cu, and Pb had skewness values of 4.17, 5.34 and 19.5, respectively. This trend was also confirmed by the fact that median concentrations of these metals were much lower than their means. Results indicated a strong anthropogenic influence on metal concentrations.

**Table 1** Summary of element concentration with basic statistic parameters for the urban soil in Guangzhou ( $n = 426$ )

	As (mg/kg)	Cd (mg/kg)	Cu (mg/kg)	Fe (g/kg)	Hg (mg/kg)	Mn (mg/kg)	Ni (mg/kg)	Pb (mg/kg)	Zn (mg/kg)	pH	SOM (mg/kg)
Minimum	1.4	0.03	5.0	6.1	0.01	21.2	2.5	18.5	10.1	2.55	2.6
Maximum	14.4	2.41	417	61.8	12.2	1286	77.6	4903	1795	9.33	199.5
Mean	17.4	0.32	35.8	27.9	0.61	218	18.7	87.6	107		25.4
Standard deviation (SD)	15.0	0.29	41.4	7.9	1.0	136	10.3	238	116		18.9
Coefficient of variation (CV)	0.87	0.91	1.16	0.28	1.64	0.63	0.55	2.72	1.09		0.74
Median	14.1	0.23	25.3	27.0	0.34	185	16.2	63.8	78.8	7.12	21.8
Skewness	4.17	3.27	5.34	0.56	5.53	2.18	2.03	19.5	8.18		
Kurtosis	25.9	15.2	37.1	0.61	47.2	10.4	6.92	395	108		
SBV <sup>a</sup> <sub>I</sub>	17.4	0.083	13.6	29.0	0.157	158.6	22.03	42.88	58.1		
SGV <sup>b</sup>	20	30	–	–	15	–	75	450	–		
SQV <sup>c</sup>	12	10	63	–	6.6	–	50	140	200		
SG <sup>d</sup>	55	12	190	–	10	–	210	530	720		

<sup>a</sup> Soil Background Value in Guangzhou (CRGSBV 1982)

<sup>b</sup> UK soil guideline values for residential without plant uptake (Environment Agency 2002)

<sup>c</sup> Canadian Soil Quality Guidelines for Residential/Parkland (CCME 2007)

<sup>d</sup> Dutch Soil Guidelines for Intervention value (VROM 2000)

Soils sampled from the five administrative districts (Baiyun, Haizhu, Liwan, Tianhe, and Yuexiu), composing the core of Guangzhou were studied (Table 2). Results showed that metal enrichment in Guangzhou urban soils reflected their urbanization history and degree of industrial development. The Liwan district had the highest level of As, Cd, Cu, and Ni. This area has a long history (more than 2000 years), and is a well-developed industrial and commercial area located in the western part of Guangzhou along the northeast bank of the Pearl River. Haizhu, the island district in south central Guangzhou, had the highest mean Pb (202 mg/kg) and Mn (291 mg/kg) concentrations and lesser, but statistically similar amounts of Cd and Cu compared to the Liwan district. Yuexiu district, the commercial and cultural centre of Guangzhou, had the highest mean Hg and As (0.93 and 22.4 mg/kg, respectively). The Baiyun district lies to the north and is regarded as the northern suburbs, while the Tianhe district is on the east side of the city and became a district in 1980. These two districts had the lowest metal concentrations, a likely consequence of their lower degree and time of urbanization.

Mean concentrations of As, Fe and Ni were the similar or lower than the corresponding background value of soils in Guangzhou (CRGSBV 1982), whereas Cd, Cu, Hg, Pb and Zn were higher, clearly demonstrating an anthropogenic contribution for the elevated metals. The data collected in this study were evaluated with risk assessment guidelines from other countries. When the upper end of the range for each metal were examined, As, Cu, Hg, Ni, Pb, and Zn all exceed one or more guidelines. The mean of metals for Guangzhou as a whole is less than the UK Soil Guideline values for Residential without plant uptake (Environment Agency 2002), Canadian Soil Quality Guidelines for Residential/Parkland (with exception of As) (CCME 2007), and Dutch Soil Guidelines for Intervention value (VROM 2000). The mean As content in Liwan and Yuexiu districts exceeded the UK guidelines, as well as the mean Pb content of the Haizhu district exceeding the Canadian guidelines. Values imply that the environmental and human health risks posed by heavy metals in the urban soils of Guangzhou city may deserve further attention.

**Correlation analysis among metals and soil properties**

The Pearson correlation coefficients for metals in these soils indicated that SOM was significantly positively correlated with As, Cd, Cu, Hg, Mn, Ni, Pb and Zn concentration ( $p < 0.01$ ), while pH had little correlation to metal concentration (Table 3). These results suggest either the importance of SOM in the retention of these metals in surface soil horizons or possibly that the heavy metals had

**Table 2** Potential toxic element concentrations in urban soils for different administrative districts

<i>n</i>	As (mg/kg)	Cd (mg/kg)	Cu (mg/kg)	Fe (g/kg)	Hg (mg/kg)	Mn (mg/kg)	Ni (mg/kg)	Pb (mg/kg)	Zn (mg/kg)	
Baiyun	39	16.5 ± 9.6bc	0.35 ± 0.21b	39.5 ± 47.3b	26.0 ± 8.1a	0.33 ± 0.40b	214 ± 107bc	13.5 ± 7.07d	65.9 ± 35.3b	156 ± 104a
Haizhu	37	13.7 ± 9.0c	0.42 ± 0.33ab	47.4 ± 72.2ab	25.9 ± 9.8a	0.31 ± 0.27b	291 ± 172a	15.2 ± 8.13cd	202 ± 795.6a	194 ± 282a
Liwan	44	21.3 ± 11.5ab	0.49 ± 0.44a	59.1 ± 68.4a	28.1 ± 7.3a	0.64 ± 0.52ab	253 ± 110ab	24.5 ± 15.2a	97.8 ± 58.7b	159 ± 131a
Tianhe	154	12.3 ± 6.8c	0.22 ± 0.21c	22.9 ± 12.4c	28.8 ± 7.4a	0.44 ± 0.69b	192 ± 148c	17.5 ± 8.15bc	66.9 ± 42.6b	61.5 ± 34.1c
Yuexiu	152	22.4 ± 21.2a	0.34 ± 0.27b	38.4 ± 33.4b	27.8 ± 7.74a	0.93 ± 1.43a	217 ± 118bc	20.3 ± 10.5b	83.4 ± 43.6b	103 ± 67.0b

Mean ± SD with different letters indicate the means are significantly different at  $p = 0.05$  probability level (Duncan's multiple range test) within each column



anthropogenic origins in the soil through waste organic materials.

The correlation among metals may provide some information on source and pathways of the metals, while high correlation coefficients between metals could indicate similar sources (Manta et al. 2002; Yang et al. 2011). Significant correlation of Fe with As, Cd, Cu, Mn, Ni, Pb and Zn ( $p < 0.01$ ) confirms that Fe oxyhydroxide coatings on soil particles are efficient adsorbents (Wilson et al. 2012). A significantly positive correlation at  $p < 0.01$  was found among Cd, Cu, Pb and Zn, suggesting similar factors influencing retention and/or common natural or anthropogenic origins. For example, the positive correlation between Hg and As reflects similar influential factors and common origins. Lead, on the other hand, showed poorer correlations with Hg and As. This suggests a difference in factors impacting retention and/or different sources for Pb.

### Spatial distribution pattern of metals

Mapping of soil geochemical distribution allows understanding of the spatial distribution and enables identification of areas that may contain hazardous concentrations (hotspots). Knowledge of spatial distribution of a contaminant is essential for site assessment and any subsequent risk assessment (Guagliardi et al. 2012; Johnson and Demetriades 2011; Li et al. 2013). Metal concentrations were first interpolated with the ordinary kriging method. The variogram surface was used to check the directional features of each metal prior to fitting the semivariogram models. As expected, clear directional features (the variogram values increase differently at different directions) were observed for all selected metals. Experimental semivariograms suggested that the theoretical Gaussian model was in reasonable agreement with the data for As, Cu, Pb

and Zn, whereas Hg and Cd data were best fitted to Spherical and Exponential models, respectively. The range of these elements shows that Hg had shorter effective range than As, Cu, Zn, Cd and Pb, indicating that this element had poorer spatial structure and more variation caused by extrinsic factors.

The city has a long-history of coal combustion by urban inhabitants as well as industrial production and the spatial distribution map of heavy metal concentrations reflected urban history and human activity intensity (Fig. 2). The maps showed a similar spatial distribution for Cu, Zn, Pb and Cd and these elements had highest concentrations in the western part of Guangzhou (Liwan, Yuexiu, and Haizhu districts). These maps provided a spatial refinement and reconfirmation of the statistical analysis, in which strong association were found among these metals (Table 3). Other elements were also highest in the western part of the city. For example, both As and Hg had isolated hot spots in western Yuexiu district, likely reflecting the industrial and commercial history of that district. The most polluted hotspot in the study area was located in Liwan and Yuexiu districts, part of the old city center established about 2000 years ago. A former coal-burning power plant, steel and iron plant, chemical and manufacturing factories, etc. were distributed in these areas, and former municipal waste dumping area was also located at the surrounding area of these districts. Thus, the urban environment was most seriously modified in these areas by industrial and human activities.

### Principal component analysis (PCA) and cluster analysis (CA)

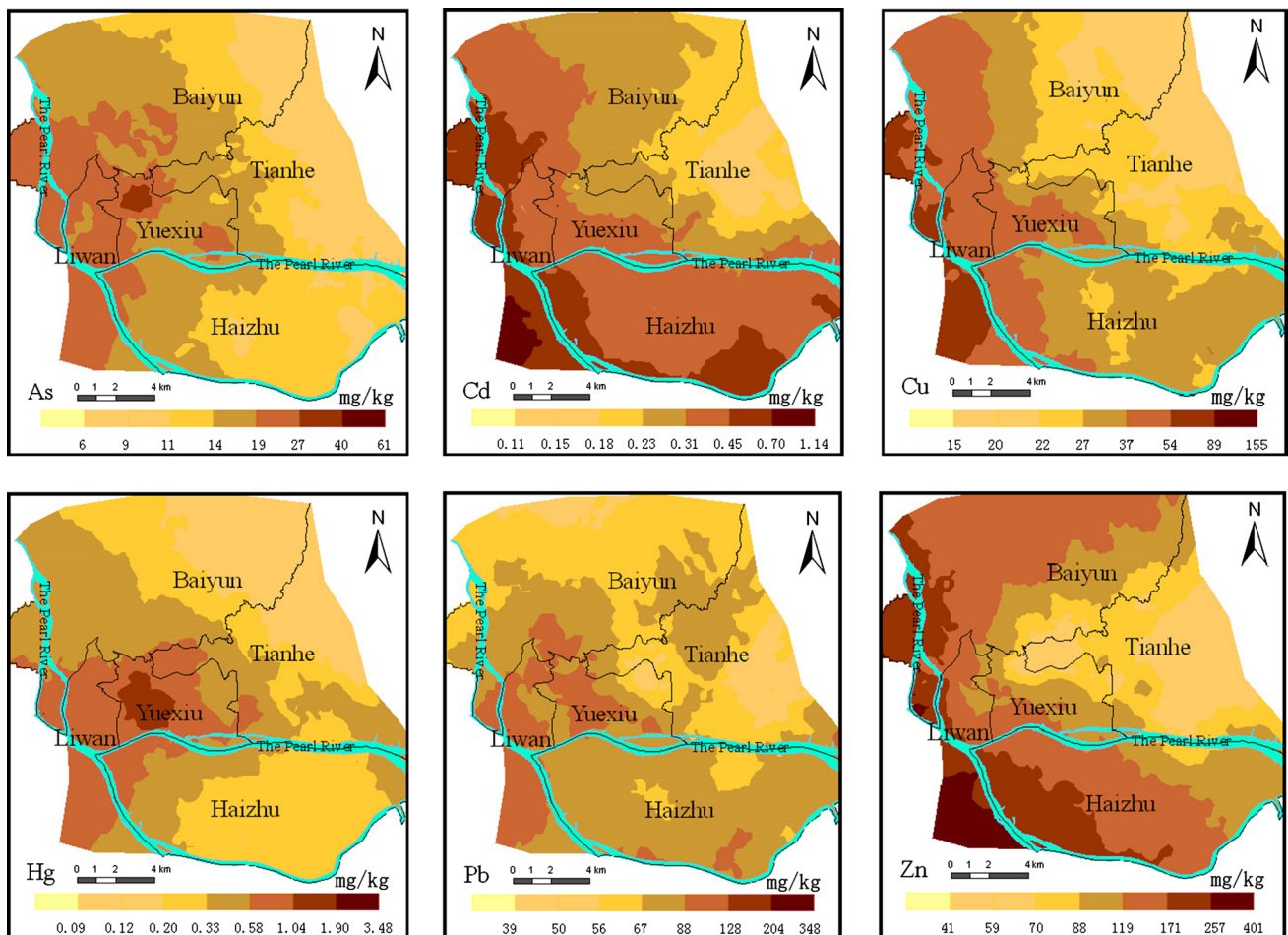
Principal component analysis has frequently been used to identify underlying dimensions or factors that may describe

**Table 3** Pearson correlation coefficients among potential toxic elements and soil properties in urban soils ( $n = 426$ )

	SOM	pH	As	Cd	Cu	Fe	Hg	Mn	Ni	Pb	Zn
SOM	1	-0.083	0.327**	0.427**	0.456**	0.081	0.354**	0.182**	0.371**	0.154**	0.398**
pH		1	-0.154**	0.032	-0.004	-0.058	-0.051	0.085	-0.013	0.012	0.064
As			1	0.237**	0.143**	0.203**	0.190**	0.107*	0.286**	0.061	0.134**
Cd				1	0.530**	0.258**	0.192**	0.401**	0.607**	0.256**	0.603**
Cu					1	0.156**	0.218**	0.233**	0.471**	0.321**	0.616**
Fe						1	0.009	0.315**	0.499**	0.260**	0.223**
Hg							1	0.074	0.173**	0.064	0.160**
Mn								1	0.485**	0.236**	0.348**
Ni									1	0.117*	0.344**
Pb										1	0.763**
Zn											1

\*\* Correlation is significant at the 0.01 level (2-tailed)

\* Correlation is significant at the 0.05 level (2-tailed)



**Fig. 2** The distribution maps of As, Cd, Cu, Hg, Pb, and Zn concentrations in urban soils

relationships among sets of interrelated variables. Results of PCA can give an indication to the origin of various elements based on known relationships between relative elemental concentrations and mineralogy of geological material. Unusual combinations of elements can indicate anthropogenic sources. Principal component analysis linearly transforms an original set of variables into a substantially smaller set of uncorrelated new variables that represent most of the information of the original data set (Lewis-Beck 1994). A small set of uncorrelated variables is much easier to understand and use in further analysis than a larger set of correlated variables (Lewis-Beck 1994). A CA was performed on chemical parameters of both data sets, using the weighted-pair group average based on correlation coefficients (Pearson coefficient). This method is the most appropriate to determine correlation between variables. The distance axis represents the degree of association between groups of variables, i.e. the lower the value on the axis, the more significant the association. In general, the results of CA agreed very well with those of PCA, and CA can be used as an alternative method to confirm results.

The PCA loadings of metals as well as cumulative percentage of variance in urban soils are shown in Table 4, the three-dimensional relationships among metals based on the three principal components are illustrated in Fig. 3, and the corresponding CA (as a dendrogram or cluster tree) is shown in Fig. 4. Results showed that the three extracted components had eigenvalues larger than 1 before and after the matrix rotation. As a consequence, metals were grouped into a three-component model that accounted for about 66 % of total variance. In the rotated component matrix, the first principal component (PC1) explained 26.03 % of the total variance and exhibited a high positive factor loading on Cu, Zn, Pb and Cd. The second principal component (PC2) had 23.39 % of the total variance and exhibited a high positive factor loading on Ni, Fe, Mn and Cd. The third principal component (PC3) (16.29 % of the total variance) showed a high positive factor loading on Hg and As.

The strong relationship in PC1 among Zn, Pb, and Cu may reflect anthropogenic contamination of urban soils, including vehicle emission and industrial activities (Calace

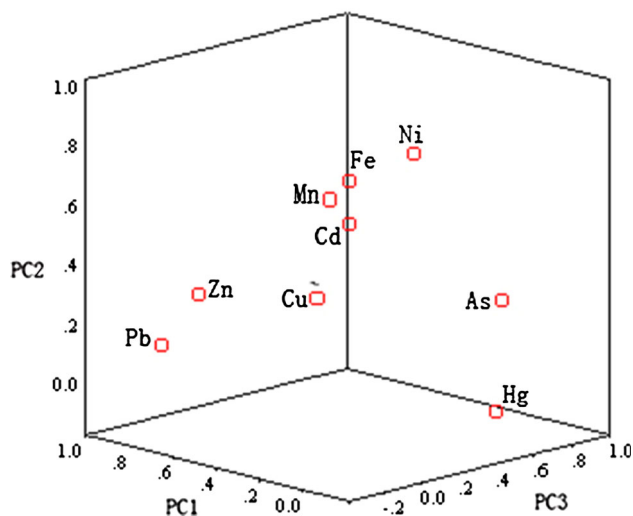
**Table 4** Total variance explained and component matrix for the heavy metals

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 (%)
PC1	3.50	38.88	38.88	3.50	38.88	38.88	2.34	26.03	26.03
PC2	1.30	14.49	53.37	1.30	14.49	53.37	2.11	23.39	49.42
PC 3	1.11	12.34	65.71	1.11	12.34	65.71	1.47	16.29	65.71
PC 4	0.88	9.80	75.51						
PC 5	0.75	8.32	83.84						
PC 6	0.65	7.18	91.01						
PC 7	0.42	4.69	95.71						
PC 8	0.27	2.94	98.70						
PC 9	0.12	1.30	100.00						

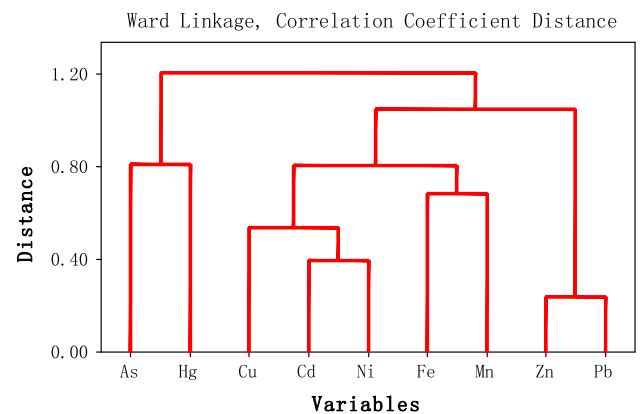
  

Metals	Component matrix			Rotated component matrix		
	PC1	PC2	PC3	PC1	PC2	PC3
As	0.347	0.456	0.308	-0.077	0.304	0.570
Hg	0.287	0.135	0.745	0.135	-0.151	0.784
Cu	0.715	-0.181	0.259	0.635	0.204	0.407
Zn	0.812	-0.506	0.032	0.926	0.208	0.121
Pb	0.581	-0.634	-0.155	0.851	0.093	-0.172
Cd	0.790	0.082	0.102	0.489	0.484	0.410
Ni	0.742	0.468	-0.101	0.167	0.781	0.378
Fe	0.512	0.349	-0.484	0.076	0.779	-0.075
Mn	0.593	0.202	-0.337	0.246	0.667	0.018

Extraction method: PCA; rotation method: Varimax with Kaiser normalization

**Fig. 3** Principal component analysis loading plot for the three rotated components

et al. 2012; Li et al. 2004; Tahmasbian et al. 2014). These elements are not generally concentrated in geologic materials and were obviously higher than the soil background

**Fig. 4** Dendrogram of the cluster analysis of urban soils based on their element concentrations ( $n = 426$ )

values in Guangzhou (Table 1). These metals were therefore related to the impact of urbanization and industrialization and had anthropogenic sources. The association of Zn, Pb and Cu suggested the presence of vehicle emissions resulting from gasoline combustion and traffic-related sources. Vehicle emissions have been considered to be a



principal source of Pb in soil in urban environments (Calace et al. 2012; Dao et al. 2014; Hamzeh et al. 2011; Li et al. 2004; Wilcke et al. 1998; Yang et al. 2011). Higher concentration of Zn can be attributed to the wear and tear of tires and brake linings; vehicular tires have about 1 % Zn (Councell et al. 2004). The Zn, Pb, Cu concentrations were higher in soils sampled from old city center. Some urban parks in Guangzhou were former landfill sites for both municipal and industrial wastes. The result of CA was in total agreement with the PCA results. Thus, the elements in PC1 could be generally concluded to be from anthropogenic sources.

The PC2 was dominated by Ni, Fe and Mn along with a strong cluster in CA. These three metals represent a natural geochemical association of major rock-forming elements in soil and may reflect natural sources from parent materials (Ljung et al. 2006; Lu 2000; Wilcke et al. 1998). This may be derived from the fact that Fe in soils of this study was near the background Guangzhou value and its concentration in soils had normal distribution (Table 1). Therefore, PC2 suggests that these metals were mainly contributed by the geological source.

The PC3 loaded by Hg and As also constituted a strong cluster and likely had anthropogenic origins. These two elements are common products coal combustion and waste incineration (Yang et al. 2011). Atmospheric Hg can accumulate in surface soil by wet and dry deposition. Also, Hg has been used in many industrial and domestic products, and historical use of Hg also plays an important role for the accumulation of Hg in soils (Chen et al. 2010).

Cadmium had relatively high loadings in both PC1 and PC2. It is probable that this element resulted from both geologic and anthropogenic origins as this element may have many environmental pathways such as rock weathering, wind blown dust, agriculture and traffic. In fact, industrial discharges may contribute significantly to the accumulation of Cd in urban soils and the application of fertilizer can caused accumulation of Cd (Li et al. 2004; Lee et al. 2006).

### Comparison of metal concentrations with other urban soil studies

The range and mean/median of metal concentrations in surface horizons from Guangzhou were compared with similar data from other 49 cities around the world in order to evaluate the soil quality of our study area (Table 5). In general, Cu, Pb and Zn were the most frequently investigated as potential toxic elements in these other studies; arsenic and Hg were the least investigated. Metal concentrations had wide ranges in these studies and Guangzhou topsoils were intermediate in concentration compared with other cities around world. The mean/median concentration

of As in Guangzhou urban soils was similar to or higher than soils in most cities with the exception of Shengyang (China), Xuzhou (China) and Athen (Greece). The surface soil in Xuzhou (China) had the highest mean As concentration. The mean/median concentration of Cd in this study was comparable with or lower than soils in most cities except for Beijing (China), Changchun (China), Tianjin (China), Trondheim (Norway), Murcia (Spain) and Pensacola (USA). The mean/median concentration of Cu in Guangzhou soils was lower than or similar to other cities with the exception of Ottawa (Canada), Hong Kong (China), Weinan (China), Jakobstad (Finland), Turku (Finland), Novi Sad (Serbian), Murcia (Spain) and Pensacola (USA). The mean/median Hg concentration was similar to or higher than soils in other cities except for Palermo (Italy). The mean/median Ni concentration was lower than soils in other most cities, and soil in Torino (Italy) had the highest Ni concentration up to 790 mg/kg. The mean/median Zn concentration was similar to or lower than those in other most cities with the exception of Annaba (Algeria), Murcia (Spain) and Pensacola (USA).

It should be noted that comparisons between studies are relative and reported means and ranges are all based on methodology of the particular study. The diversity of soil sampling locations (including industrial area, urban park, roadsides, commercial area, playground, residential area, etc.), number of samples (ranging from 21 to 2182), sampling depth (0–5, 0–10, 0–15, or 0–20 cm) and extraction method used for soil analysis (including aqua regia (HCl/HNO<sub>3</sub>, 3:1), concentrated HF, HNO<sub>3</sub> and HClO<sub>4</sub>, concentrated HNO<sub>3</sub> and HClO<sub>4</sub>, HNO<sub>3</sub> and H<sub>2</sub>O<sub>2</sub> and HNO<sub>3</sub> in various concentrations) in the literature can be a serious constraint in the comparison of published data. In fact, although the term “total” is often used in these studies, data can be assumed to have a 20–30 % of variation from the others due to the different extraction techniques adopted (Ajmone-Marsan and Biasioli 2010). In view of the high value of the urban soil as an environmental resource and the threat to human health it poses, it is highly desirable that an effort towards harmonization of methodologies is made so that the issue of urban soil contamination can be tackled at the global level (Ajmone-Marsan and Biasioli 2010).

### Conclusions

A comprehensive soil survey was conducted to investigate PTEs in soils of Guangzhou urban areas, the usefulness of geostatistical approach and multivariate analysis for mapping their spatial distributions and identifying possible sources were evaluated. These soils showed a wide range and diverse correlations of PTE concentrations, and human

**Table 5** A summary of metal concentrations in topsoil of different cities (range, mean/median)

City/country	As (mg/kg)	Cd (mg/kg)	Cu (mg/kg)	Fe (g/kg)	Hg (mg/kg)	Mn (mg/kg)	Ni (mg/kg)	Pb (mg/kg)	Zn (mg/kg)	References
Annaba/Algeria	NA	0.01–14.15 (0.44/0.3)	0.2–132.1 (39/23.8)	7.11–47.5 (24.3/ 25.2)	NA	33.7–636.2 (355/405)	NA	3.1–823.7 (53.1/42.3)	4.7–258.8 (67.5/64.7)	Maas et al. (2010)
Lithgow/Australia	NA	NA	11–682 (31.8/ 28)	NA	NA	NA	NA	<5–3200 (20.8/27)	34–4950 (109/97)	Rouillon et al. (2013)
Ottawa/Canada	1.7–9.9 (3/ 2.8)	0.11–0.75 (0.3/0.27)	6.27–42.46 (13.19/ 12.1)	15.3–33.2 (21.5/ 20.7)	0.018–2.01 (0.11/0.05)	320–873 (525/532)	10.5–27.9 (16.3/15.8)	15.6–547.4 (64.69/ 33.78)	50.4–380.4 (114/100)	Rasmussen et al. (2001)
Beijing/China	5.7–23 (9.9/ NA)	0.003–0.98 (0.13/0.11)	13.4–208 (31.7/26.1)	NA– (0.30/0.26)	0.022–9.4 (0.30/0.26)	NA	17.8–39 (24.0/–23.8)	4.02–174.4 (23.3/19.3)	29.4–322 (92.9/84.5)	Chen et al. (2010), Luo et al. (2008), Wang et al. (2012)
Changchun/China	6.1–67.7 (12.5/NA)	0.028–11.04 (0.13/NA)	15.9–437 (29.4/NA)	NA	0.025–1.43 (0.12/NA)	399–3933 (743/NA)	NA	19.7–377.5 (35.4/NA)	44.8–1106.8 (90/NA)	Yang et al. (2011)
Hangzhou/China	NA	0.65–4.57 (1.2/1.12)	7.4–177.3 (52/44.8)	4.19–71.92 (NA)	NA	NA	NA	15–492 (88.2/ 65.8)	19–1249 (207/180)	Lu and Bai (2010)
Hong Kong/China	NA	0.11–1.36 (0.36/0.33)	1.30–277 (16.2/10.4)	NA	NA	NA	0.24–19.9 (4.08/3.65)	7.53–496 (88.1/70.6)	23.0–930 (103/78.1)	Lee et al. (2006)
Nanjing/China	NA	NA	13.6–869 (66.1/NA)	29.4–57.3 (39.7/NA)	NA	474–1325 (799/NA)	30.1–68 (41.4/ NA)	36.3–472 (107/NA)	57.7–852 (163/NA)	Lu (2000), Lu et al. (2003)
Shanghai/China	NA	0.19–3.66 (0.52/N)	23.1–151.7 (59.25/NA)	NA	NA	NA	4.95–65.7 (31.1/NA)	13.72–192.4 (70.69/NA)	102.5–1025 (301/NA)	Shi et al. (2008)
Shenyang/China	7.5–137.7 (22.7/ 17.6)	0.01–9.64 (1.10/0.54)	7.6–430 (92.4/71.1)	NA	0.06–1.34 (0.39/0.33)	132–1030 (636/657)	NA	1.9–940 (117/ 70.1)	25–1140 (235/182)	Li et al. (2013)
Tianjin/China	5.4–18 (11/ NA)	0.01–2.1 (0.18/NA)	13–79 (33/ NA)	NA	0.03–6.2 (0.43/NA)	NA	25–49 (39/ NA)	3.9–120 (45/ NA)	58–387 (148/NA)	Zhao et al. (2014)
Weinan/China	2.6–11.5 (8.49/NA)	NA	14.6–34.7 (20.9/NA)	NA	NA	431–654 (538.5/ NA)	20.8–35.8 (25.4/NA)	19.0–89.5 (46.7/NA)	44.5–196.8 (71.6/NA)	Li and Feng (2012)
Xi'an/China	NA	NA	27.2–792 (54.3/39.4)	NA	NA	519–780 (672/672)	23.7–39.1 (34.5/34.7)	26–506.5 (59.7/45.4)	68.6–4965 (186/104)	Chen et al. (2012)
Xuzhou/China	8.7–577 (39.8/13)	0.11–2.9 (0.54/0.42)	17–80 (38.2/ 32)	26.6–41.5 (33.7/ 32.9)	0.02–1.3 (0.29/0.18)	430–902 (543/508)	23–104 (34.3/ 30)	16–120 (43.3/ 36)	53–380 (144/102)	Wang and Qin (2007)
Zhangzhou/China	NA	0.02–7.88 (0.53/0.11)	3–128.1 (36.8/28.6)	10.3–90.3 (54.9/ 56.8)	0.03–2.89 (0.57/0.36)	NA	4.5–26.2 (12.6/12.8)	29.8–1173.8 (103/54.3)	18.6–144 (85.5/72.6)	Cui et al. (2011)
Las Tunas/Cuba	NA	NA	56–160 (94/92)	28–79 (52/49)	NA	NA	8–143 (36/25)	5–140 (42/35)	96–409 (199/170)	Rizo et al. (2013)
Tallinn/Estonia	NA	NA	7–621 (45/ 35)	NA	NA	76–1750 (384/320)	4.3–65 (16/15)	5.7–602 (75.3/ 50)	11.4–1560 (156/114)	Bityukova et al. (2000)

**Table 5** continued

City/country	As (mg/kg)	Cd (mg/kg)	Cu (mg/kg)	Fe (g/kg)	Hg (mg/kg)	Mn (mg/kg)	Ni (mg/kg)	Pb (mg/kg)	Zn (mg/kg)	References
Jakobstad/ Finland	1.4–16.3 (NA/2.7)	0.06–2.52 (NA/0.25)	4.7–2612 (NA/22)	8.2–95.2 (NA/11.6)	0.011–2.31 (NA/0.093)	103–787 (NA/209)	4.5–386 (NA/ 7.9)	10.2–3439 (NA/59)	17–2368 (NA/82)	Peltola and Åström (2003)
Turku/ Finland	0.2–10.8 (NA/3.2)	0.03–2.50 (NA/0.2)	<1–495 (NA/ 19.15)	1.38–54.8 (NA/23.1)	NA	8–692 (NA/ 235)	<1–55.9 (NA/ 12.45)	6–264 (NA/ 20)	4–499 (NA/ 72.5)	Salonen and Korkka-Niemi (2007)
Berlin/ Germany	NA–126 (5.1/3.9)	NA–53 (0.92/0.35)	NA–12,300 (79.5/31.2)	NA	NA–71.2 (0.42/0.19)	NA	NA–769 (10.7/7.7)	NA–4710 (119/76.6)	NA–25210 (243/129)	Birke and Rauch (2000)
Athen/ Greece	6–204 (29/ 24)	0.1–3.5 (0.4/ 0.3)	11–4109 (48/ 39)	6–48 (24/ 24)	NA	168–2731 (587/554)	27–727 (111/ 102)	3–2764 (77/ 45)	18–1089 (122/98)	Argyriaki and Kelepertzis (2014)
Istafhan/Iran	NA	NA	20.8–144 (59.9/52)	NA	NA	NA	NA	17.4–215.4 (84.2/73.2)	38–652 (196.7/ 154.8)	Tahmasbian et al. (2014)
Kerman/ Iran	NA	0.28–0.46 (0.33/0.33)	38.9–204 (68.6/53.4)	23.4–37.4 (28.8/ 27.5)	NA	461–845 (611/576)	NA	48–233 (102/ 94.5)	42–152 (73/ 68)	Hamzeh et al. (2011)
Dublin/ Ireland	NA	NA	10–123 (31.2/ 25)	NA	NA	NA	NA	14–714 (80.5/ 39)	22–360 (107.4/94)	Dao et al. (2014)
Galway/ Ireland	<5–30 (8.6/8)	NA	9–271 (33.2/ 27)	4.4–56.1 (17/17)	NA	69–6302 (1214/ 539)	2–86 (20.7/22)	25–534 (78.4/ 58)	23–656 (99.3/85)	Zhang (2006)
Naples/Italy	NA	NA	6.2–286 (74/ 54)	NA	NA	NA	NA	4–3420 (262/ 184)	30–2550 (251/180)	Imperato et al. (2003)
Palermo/ Italy	NA	0.27–3.80 (NA/0.84)	10–344 (NA/ 77)	NA	0.04–56.0 (NA/1.85)	142–1259 (NA/566)	7.0–38.6 (NA/ 19.1)	57–2516 (NA/ 253)	52–433 (NA/ 151)	Manta et al. (2002)
Renda- Cosenza/ Italy	3–22 (7.48/ 7)	0.13–2.44 (0.4/0.3)	11.6–250 (44.4/30.4)	31–105.8 (54.7/ 51.3)	0.09–0.45 (0.19/0.18)	500–5400 (130/100)	18–82 (34.7/ 33)	8–708 (63.7/ 31)	38–871 (166.7/ 127)	Guagliardi et al. (2012)
Torino/Italy	NA	NA	34–283 (90/ 76)	NA	0.21–0.90 (0.48/0.47)	NA	103–790 (209/ 175)	31–870 (149/ 117)	78–545 (183/149)	Biasioli et al. (2006), Rodrigues et al. (2006)
Tuscany/ Italy	NA	NA	27.5–305 (85.0/62.5)	NA	NA	NA	27.5–112 (59.0/55.2)	30.2–1025 (219/122)	45.1–337 (128/107)	Bretzel and Calderisi (2006)
Mexico/ Mexico	NA	NA	26–461 (93/ NA)	NA	NA	NA	29–151 (49/ NA)	15–693 (116/ NA)	95–1890 (447/NA)	Rodríguez-Salazar, et al. (2011)
Oslo/ Norway	<3–69.6 (5.48/ 4.50)	0.06–3.10 (0.41/0.34)	4.76–437 (31.7/23.5)	2.2–50.2 (21.8/ 21.1)	0.01–2.30 (0.13/0.06)	71.4–2230 (486/438)	2.23–232 (28.4/24.1)	<5–1000 (55.6/33.9)	22.9–1150 (160/130)	Tijhuis et al. (2002)
Trondheim/ Norway	0.32–23 (4.0/3.3)	0.002–5.5 (0.19/0.12)	5.4–383 (39/ 32)	NA	0.02–2.2 (0.15/0.09)	NA	17–153 (45/ 43)	16–10,125 (81/32)	4.3–1056 (112/80)	Andersson et al. (2010)
Sialkot/ Pakistan	NA	21.1–51.8 (36.8/ 45.68)	7.1–347 (26.85/ 18.9)	7.97–30.1 (18/17.8)	NA	MA	62.6–206 (85.5/83.4)	95–186 (121.4/ 121.5)	52.9–363 (94.2/78.1)	Malik et al. (2010)

**Table 5** continued

City/country	As (mg/kg)	Cd (mg/kg)	Cu (mg/kg)	Fe (g/kg)	Hg (mg/kg)	Mn (mg/kg)	Ni (mg/kg)	Pb (mg/kg)	Zn (mg/kg)	References
Novi Sad/ Serbian	NA	0.75–2.09 (1.59/1.69)	8.36–45.7 (21.9/19.7)	6.64–19.0 (10.7/ 10.3)	0.16–0.55 (0.30/0.27)	286–836 (424/387)	16.6–27.4 (23.2/23.3)	17.5–55.9 (28.8/25.8)	63.3–400 (111/85.6)	Škrbić and Đurišić-Mladenović (2013)
Ljubljana/ Slovenia	NA	NA	15–123 (39/ 32)	NA	0.15–0.86 (0.41/0.38)	NA	14–38 (26/26)	11–387 (87/ 68)	63–446 (148/122)	Biasioli et al. (2007), Rodrigues et al. (2006)
Avilés/ Spain	4.5–1117 (20.9/NA)	0.80–7.80 (2.16/NA)	19–1040 (62.5/NA)	16.7–98.3 (35.6/NA)	0.17–2.41 (0.57/NA)	185–4261 (690/NA)	5.00–48.0 (16.7/NA)	54.0–1160 (149/NA)	110–1959 (376/NA)	Ordóñez et al. (2003)
Gibraltar/ Spain	0.4–1351 (9.6/NA)	0.2–3.18 (0.8/ NA)	0.02–12.500 (40.2/NA)	0–43.5 (17.6/NA)	NA	0.1–1220 (314/NA)	0.2–648 (40.5/ NA)	0.75–26.500 (137.6/NA)	0.42–44.900 (178/NA)	Mesilio et al. (2003)
Murcia/ Spain	NA	0.03–0.74 (NA/0.13)	2.4–16.9 (NA/8.9)	NA	NA	34.1–206 (NA/135)	3.6–16.7 (NA/ 11.1)	4.8–150 (NA/ 21.9)	1.9–54.1 (NA/16.6)	Acosta et al. (2011)
Seville/ Spain	NA	0.18–4.85 (2.89/NA)	10.7–198 (54.5/NA)	8.7–29.2 (16.4/NA)	0.11–1.30 (0.42/0.3)	187–781 (391/NA)	11.1–46.7 (21.2/NA)	23.0–725 (156/NA)	38.8–326 (120/NA)	Ruiz-Cortés et al. (2005), Rodrigues et al. (2006)
Stockholm/ Sweden	1.5–37.3 (6.1/NA)	0.06–1.11 (0.40/NA)	7.3–1315 (71/ NA)	NA	0.01–6.52 (0.59/NA)	NA	5.6–31.0 (12.8/NA)	4.6–1279 (101/NA)	20–965 (171/NA)	Linde et al. (2001)
Uppsala/ Sweden	1.41–15.0 (NA/3.46)	0.08–0.71 (NA/0.21)	10.9–110 (NA/25.4)	1.56–3.79 (NA/2.49)	0–3.66 (NA/ 0.139)	199–833 (NA/494)	7.22–39.1 (NA/18.5)	8.53–358 (NA/25.5)	44.8–149 (NA/84.0)	Ljung et al. (2006)
Damascus/ Syria	NA	NA	16–97 (34/ 30)	NA	NA	NA	24–58 (39/35)	<5–108 (17/ 10)	46–293 (103/84)	Möller et al. (2005)
Bankok/ Thailand	NA	0.05–2.53 (0.29/0.15)	5.1–283 (41.7/26.6)	3.9–26.7 (16.1/ 18.4)	NA	50–810 (340/290)	4.1–52.1 (24.8/23.0)	12.1–269.3 (47.8/28.9)	3–814 (118/ 38)	Wilcke et al. (1998)
Newcastle/ UK	5–279 (20/ 15)	0.01–6.95 (0.65/0.28)	20–12,107 (233/77)	NA	0.03–4.99 (0.50/0.32)	NA	11–165 (30/ 26)	40–4134 (350/ 233)	75–4625 (419/274)	Rimmer et al. (2006)
Sheffield/ UK	NA	NA	NA	NA	NA	NA	8–473 (40/32)	19–4300 (244/ 164)	NA	Rawlins et al. (2005)
Baltimore/ USA	NA	0.0003–3.1 (1.06/0.89)	5–336 (45/ 35)	6.34–2.58 (23.5/ 22.3)	NA	6–2125 (472/422)	5–336 (27/18)	4–5652 (231/ 89)	6–1109 (141/81)	Pouyat et al. (2007)
New York/ USA	1–46 (15/ 13)	0.1–3 (0.4/ 0.4)	14–138 (50/ 46)	NA	0.1–1 (0.5/ 0.3)	19–3117 (491/406)	8–97 (32/29)	40–730 (221/ 178)	19–300 (96/ 81)	Burt et al. (2014)
Pensacola/ USA	0.13–14 (1.87/1.4)	0.02–1.8 (0.13/0.04)	0.27–54 (6.26/4.4)	0.59–18 (4.91/3.9)	0.005–0.38 (0.03/0.02)	NA	0.17–8 (2.48/ 1.95)	0.82–325 (23.98/11.5)	0.53–289 (33.22/17)	Liebens et al. (2012)
Guangzhou/ China	1.4–144 (17.4/ 14.1)	0.03–2.41 (0.32/0.23)	5.0–417 (35.8/25.3)	6.1–61.8 (27.9/ 27.0)	0.01–12.2 (0.61/0.34)	21.2–1286 (218/185)	2.5–77.6 (18.7/16.2)	18.5–4903 (87.6/63.8)	10.1–1795 (107/78.8)	Present study

NA not available

activities have led to high accumulation of metals. Spatial distribution maps of As, Cd, Cu, Hg, Pb, and Zn displayed several hotspots of metal pollution that may pose potential risks to residents. Multivariate analysis revealed Fe, Ni and Mn were predominantly derived from natural sources; As, Cu, Hg, Pb and Zn from anthropogenic sources; and Cd from mixed sources. Compared with other studies around the world, present metal concentrations in Guangzhou soils can be considered at an intermediate level.

Although this study was clearly limited in its analyses of the processes and factors influencing metal concentrations in urban soils, it contributed to the very limited database available on metals in urban soils of Guangzhou, provided a basis for hazard assessment, and established a baseline for future monitoring and management of these metals in this area.

Furthermore, the work also highlights the need for further studies on assessing both the human and ecosystem risks associated with urban contaminated soils, setting up Chinese soil guideline values for urban environments, and taking measures to remediated contaminated urban soils.

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## References

- Acosta JA, Faz A, Martínez-Martínez S, Arocena JM (2011) Enrichment of metals in soils subjected to different land uses in a typical Mediterranean environment (Murcia City, southeast Spain). *Appl Geochem* 26:405–414
- Ajmone-Marsan F, Biasioli M (2010) Trace elements in soils of urban areas. *Water Air Soil Pollut* 213:121–143
- Andersson M, Ottesen RT, Langedal M (2010) Geochemistry of urban surface soils—monitoring in Trondheim, Norway. *Geoderma* 156:112–118
- Argyaki A, Kelepertzis E (2014) Urban soil geochemistry in Athens, Greece: the importance of local geology in controlling the distribution of potentially harmful trace elements. *Sci Total Environ* 482–483:366–377
- Bi XY, Liang SY, Li XD (2013) Trace metals in soil, dust, and tree leaves of the urban environment, Guangzhou, China. *Chin Sci Bull* 58:222–230
- Biasioli M, Barberis R, Ajmone-Marsan F (2006) The influence of a large city on some soil properties and metals content. *Sci Total Environ* 356:154–164
- Biasioli M, Grčman H, Kralj T, Madrid F, Díaz-Barrientos E, Ajmone-Marsan F (2007) Potentially toxic elements contamination in urban soils: a comparison of three European cities. *J Environ Qual* 36:70–79
- Birke M, Rauch U (2000) Urban geochemistry: investigations in the Berlin metropolitan area. *Environ Geochem Health* 22:233–248
- Bitjukova L, Shogenova A, Birke M (2000) Urban geochemistry: a study of element distributions in the soils of Tallinn (Estonia). *Environ Geochem Health* 22:173–193
- Bretzel F, Calderisi M (2006) Metal contamination in urban soils of Coastal Tuscany (Italy). *Environ Monit Assess* 118:319–335
- Burt R, Hernandez L, Shaw R, Tunstead R, Ferguson R, Peaslee S (2014) Trace element concentration and speciation in selected urban soils in New York City. *Environ Monit Assess* 186:195–215
- Cai QY, Mo CH, Li HQ, LüH X, Zeng QY, Li YW, Wu XL (2013) Heavy metal contamination of urban soils and dusts in Guangzhou, South China. *Environ Monit Assess* 185:1095–1106
- Calace N, Caliandro L, Petronio BM, Pietrantonio M, Pietroletti M, Trancalini V (2012) Distribution of Pb, Cu, Ni and Zn in urban soils in Rome city (Italy): effect of vehicles. *Environ Chem* 9:69–76
- Cattle JA, McBratney AB, Minasny B (2002) Kriging method evaluation for assessing the spatial distribution of urban soil lead contamination. *J Environ Qual* 31:1576–1588
- CCME (Canadian Council of Ministers of the Environment) (2007) Canadian soil quality guidelines for the protection of environmental and human health. Canadian Council of Ministers of the Environment, Winnipeg
- Chen X, Xia XH, Wu S, Wang F, Guo XJ (2010) Mercury in urban soils with various types of land use in Beijing, China. *Environ Pollut* 158:48–54
- Chen X, Lu X, Yang G (2012) Sources identification of heavy metals in urban topsoil from inside the Xi'an Second Ringroad, NW China using multivariate statistical methods. *Catena* 98:73–78
- Councill TB, Duckenfield KU, Landa ER, Callender E (2004) Tire-wear particles as a source of zinc to the environment. *Environ Sci Technol* 38:4206–4214
- CRGSBV (Cooperative Research Group on Soil Background Value, Chinese Academy of Sciences) (1982) Guangzhou Environmental Monitoring Station, Department of Geography, Sun Yat-sen University. Study on soil background values in Guangzhou. In: Editorial Board of Environmental Science (ed) Element background values in environment and their research methods. Science Press, Beijing, pp 27–34 (in Chinese)
- Cui ZA, Qiao SY, Bao ZY, Wu NY (2011) Contamination and distribution of heavy metals in urban and suburban soils in Zhangzhou City, Fujian, China. *Environ Earth Sci* 64:1607–1615
- Dao L, Morrison L, Zhang H, Zhang C (2014) Influences of traffic on Pb, Cu and Zn concentrations in roadside soils of an urban park in Dublin, Ireland. *Environ Geochem Health* 36:333–343
- Davis HT, Marjorie Aelion C, McDermott S, Lawson AB (2009) Identifying natural and anthropogenic sources of metals in urban and rural soils using GIS-based data, PCA, and spatial interpolation. *Environ Pollut* 157:2378–2385
- Environment Agency (2002) Soil guideline values for inorganic mercury contamination, Department for Environment, Food and Rural Affairs; Environment Agency, Rio House, Waterside Drive, Aztec West, Almondsbury, Bristol, BS32 4UD
- GDSGSO (Guangdong Soil General Survey Office) (1993) Soils of Guangdong. Science Press, Beijing
- Goovaerts P (1999) Geostatistics for natural resources evaluation. Oxford University Press, Oxford
- Guagliardi I, Cicchella D, De Rosa R (2012) A geostatistical approach to assess concentration and spatial distribution of heavy metals in urban soils. *Water Air Soil Pollut* 223:5983–5998
- Hamzeh MA, Aftabi A, Mirzaee M (2011) Assessing geochemical influence of traffic and other vehicle-related activities on heavy metal contamination in urban soils of Kerman city, using a GIS-based approach. *Environ Geochem Health* 33:577–594
- Imperato M, Adamo P, Naimo D, Arienzo M, Stanzione D, Violante P (2003) Spatial distribution of heavy metals in urban soils of Naples city (Italy). *Environ Pollut* 124:247–256
- Iqbal S, Wasim M, Tufail M, Arif M, Chaudhry MM (2012) Elemental contamination in urban parks of Rawalpindi/Islamabad—a source identification and pollution level assessment study. *Environ Monit Assess* 184:5497–5510



- Johnson CC, Demetriades A (2011) Urban geochemical mapping: a review of case studies in this volume. Chapter 2. In: Johnson CC, Demetriades A, Locutura J, Ottesen RT (eds) Mapping the chemical environment of urban areas. Wiley, Chichester, pp 7–27
- Lee CS, Li X, Shi W, Cheung SC, Thornton I (2006) Metal contamination in urban, suburban, and country park soils of Hong Kong: a study based on GIS and multivariate statistics. *Sci Total Environ* 356:45–61
- Lewis-Beck MS (1994) Factor analysis and related techniques. SAGE, Jurong
- Li X, Feng L (2012) Multivariate and geostatistical analyzes of metals in urban soil of Weinan industrial areas, Northwest of China. *Atmos Environ* 47:58–65
- Li XD, Lee SL, Wong SC, Shi WZ, Thornton I (2004) The study of metal contamination in urban soils of Hong Kong using a GIS-based approach. *Environ Pollut* 129:113–124
- Li XY, Liu LJ, Wang YG, Luo GP, Chen X, Yang XL, Hall MHP, Guo RC, Wang HJ, Cui JH, He XY (2013) Heavy metal contamination of urban soil in an old industrial city (Shenyang) in Northeast China. *Geoderma* 192:50–58
- Liebens J, Mohrerr CJ, Rao KR (2012) Trace metal assessment in soils in a small city and its rural surroundings, Pensacola, FL, USA. *Environ Earth Sci* 65:1781–1793
- Linde M, Bengtsson H, Öborn I (2001) Concentrations and pools of heavy metals in urban soils in Stockholm, Sweden. *Water Air Soil Pollut Focus* 1(3–4):83–101
- Ljung K, Otabbong E, Selinus O (2006) Natural and anthropogenic metal inputs to soils in urban Uppsala, Sweden. *Environ Geochem Health* 28:353–364
- Lu Y (2000) Characteristics of urban soils in Nanjing and their environmental significance. Ph D dissertation submitted to Institute of Soil Science, Chinese Academy of Sciences Nanjing (in Chinese with English abstract)
- Lu SG, Bai SQ (2010) Contamination and potential mobility assessment of heavy metals in urban soils of Hangzhou, China: relationship with different land uses. *Environ Earth Sci* 60:1481–1490
- Lu Y, Gong ZT, Zhang GL, Burghardt W (2003) Concentrations and chemical speciations of Cu, Zn, Pb and Cr of urban soils in Nanjing, China. *Geoderma* 115(1/2):101–111
- Lu Y, Zhu F, Chen J, Gan H, Guo Y (2007) Chemical fractionation of heavy metals in urban soils of Guangzhou, China. *Environ Monit Assess* 134:429–439
- Lu Y, Yin W, Huang LB, Zhang GL, Zhao YG (2011) Assessment of bioaccessibility and exposure risk of arsenic and lead in urban soils of Guangzhou City, China. *Environ Geochem Health* 33(2):93–102
- Luo W, Lu Y, Wang G, Shi Y, Wang T, Giesy JP (2008) Distribution and availability of arsenic in soils from the industrialized urban area of Beijing, China. *Chemosphere* 72:797–802
- Luo XS, Yu X, Li XD (2011) Distribution, availability, and sources of trace metals in different particle size fractions of urban soils in Hong Kong: Implications for assessing the risk to human health. *Environ Pollut* 159:1317–1326
- Maas S, Scheifler R, Benslama M, Crini N, Lucot E, Brahmis Z (2010) Spatial distribution of heavy metal concentrations in urban, suburban and agricultural soils in a Mediterranean city of Algeria. *Environ Pollut* 158:2294–2301
- Malik RN, Jadoon WA, Husain SZ (2010) Metal contamination of surface soils of industrial city Sialkot, Pakistan: a multivariate and GIS approach. *Environ Geochem Health* 32:179–191
- Manta DS, Angelone M, Bellanca A, Neri R, Sprovieria M (2002) Heavy metals in urban soils: a case study from the city of Palermo (Sicily), Italy. *Sci Total Environ* 300:229–243
- Mesilio L, Farago ME, Thornton I (2003) Reconnaissance soil geochemical survey of Gibraltar. *Environ Geochem Health* 25:1–8
- Mielke HW, Gonzales CR, Smith MK, Mielke PW (1999) The urban environment and children's health: soils as an integrator of lead, zinc, and cadmium in New Orleans, Louisiana, USA. *Environ Res (Sect A)* 81:117–129
- Mielke HW, Gonzales CR, Powell ET, Jartun M, Mielke PW (2007) Nonlinear association between soil lead and blood lead of children in metropolitan New Orleans, Louisiana: 2000–2005. *Sci Total Environ* 388:43–53
- Möller A, Müller HW, Abdullah A, Abdelgawad G, Utermann J (2005) Urban soil pollution in Damascus: concentrations and patterns of heavy metals in the soils of the Damascus Ghouta. *Geoderma* 124:63–71
- Nelson DW, Sommers LE (1996) Total carbon, organic carbon, and organic matter. In: Sparks DL (ed) Methods of soil analysis, part 3, SSSA Book Ser. 5. SSSA, Madison, pp 961–1010
- Ordóñez A, Loredó J, De Miguel E, Charlesworth S (2003) Distribution of heavy metals in the street dusts and soils of an industrial city in Northern Spain. *Arch Environ Contam Toxicol* 44:160–170
- Peltola P, Åström M (2003) Urban geochemistry: a multimedia and multielement survey of a small town in Northern Europe. *Environ Geochem Health* 25:397–419
- Poggio L, Vrščaj B, Schulin R, Hepperle E, Marsan FA (2009) Metals pollution and human bioaccessibility of topsoils in Grugliasco (Italy). *Environ Pollut* 157:680–689
- Pouyat RV, Yesilonis ID, Russell-Anelli J, Neerchal NK (2007) Soil chemical and physical properties that differentiate urban land-use and cover type. *Soil Sci Soc Am J* 71:1010–1019
- Rasmussen PE, Subramanian KS, Jessiman BJ (2001) A multi-element profile of house dust in relation to exterior dust and soils in the city of Ottawa, Canada. *Sci Total Environ* 267:125–140
- Rawlins BG, Lark RM, O'Donnell AM, Lister TR (2005) The assessment of point and diffuse metal pollution of soils from an urban geochemical survey of Sheffield, England. *Soil Use Manag* 21:353–362
- Rimmer DL, Vizard CG, Pless-Mullolob T, Singleton I, Air VS, Keatinge ZAF (2006) Metal contamination of urban soils in the vicinity of a municipal waste incinerator: one source among many. *Sci Total Environ* 356:207–216
- Rizo OD, Morell DF, Arado Lopez JO, Borrell Munoz JL, D'Alessandro Rodriguez K, Lopez Pino N (2013) Spatial distribution and contamination assessment of heavy metal in urban topsoils from Las Tunas City, Cuba. *Bull Environ Contam Toxicol* 91:29–35
- Rodrigues S, Pereira ME, Duarte AC, Ajmone-Marsan F, Davidson CM, Grčman H, Hossack I, Hursthouse AS, Ljung K, Martini C, Otabbong E, Reinoso R, Ruiz-Cortés E, Urquhart GJ, Vrščaj B (2006) Mercury in urban soils: a comparison of local spatial variability in six European cities. *Sci Total Environ* 368:926–936
- Rodríguez-Salazar MT, Morton-Bermea O, Hernández-Álvarez E, Lozano R, Tapia-Cruz V (2011) The study of metal contamination in urban topsoils of Mexico City using GIS. *Environ Earth Sci* 62:899–905
- Rouillon M, Gore DB, Taylor MP (2013) The nature and distribution of Cu, Zn, Hg, and Pb in urban soils of a regional city: Lithgow, Australia. *Appl Geochem* 36:83–91
- Ruiz-Cortés E, Reinoso R, Díaz-Barrientos E, Madrid L (2005) Concentrations of potentially toxic metals in urban soils of Seville: relationship with different land uses. *Environ Geochem Health* 27:465–474
- Salonen V, Korkka-Niemi K (2007) Influence of parent sediments on the concentration of heavy metals in urban and suburban soils in Turku, Finland. *Appl Geochem* 22:906–918

- Shi G, Chen Z, Xu S, Zhang J, Wang L, Bi C, Teng L (2008) Potentially toxic metal contamination of urban soils and roadside dust in Shanghai, China. *Environ Pollut* 156:251–260
- Škrbić B, Đurišić-Mladenović N (2013) Distribution of heavy elements in urban and rural surface soils: the Novi Sad city and the surrounding settlements, Serbia. *Environ Monit Assess* 185:457–471
- Soil Survey Staff (2014) Keys to soil taxonomy, 12th edn. USDA Natural Resource Conservation Service, Washington
- Sun Y, Zhou Q, Xie X, Liu R (2010) Spatial, source and risk assessment of heavy metals in urban soils in typical regions of Shenyang, China. *J Hazard Mater* 174:455–462
- Tahmasbian I, Nasrazadani A, Shoja H, Sinigani AAS (2014) The effects of human activities and different land use on trace element pollution in urban topsoil of Isfahan (Iran). *Environ Earth Sci* 71:1551–1560
- Tijhuis L, Brattli B, Sæther OM (2002) A geochemical survey of topsoil in the city of Oslo, Norway. *Environ Geochem Health* 24:67–94
- VROM (2000) Circular on target values and intervention values for soil remediation: DBO/1999226863, Ministry of Housing, Spatial Planning and Environment, Directorate-General for Environmental Protection, Department of Soil Protection, Netherlands Government Gazette, No. 39
- Wang XS, Qin Y (2007) Some characteristics of the distribution of heavy metals in urban topsoil of Xuzhou, China. *Environ Geochem Health* 29:11–19
- Wang M, Markert B, Chen W, Peng C, Ouyang Z (2012) Identification of heavy metal pollutants using multivariate analysis and effects of land uses on their accumulation in urban soils in Beijing, China. *Environ Monit Assess* 184:5889–5897
- Wilcke W, Müller S, Kanchanakool N, Zech W (1998) Urban soil contamination in Bangkok: heavy metal and aluminum partitioning in topsoils. *Geoderma* 86:211–228
- Wilson MA, Young AV, Knapp BD, Hoover DR, Swenson HK (2012) Geochemistry of alluvial soils composed of metal-enriched sediments, main stem of the Coeur d'Alene River, Idaho. *Soil Sci Soc Am J* 76:1462–1477
- Wong CSC, Li XD, Thornton I (2006) Urban environmental geochemistry of trace metals. *Environ Pollut* 142:1–16
- Yang Z, Lu W, Long Y, Bao X, Yang Q (2011) Assessment of heavy metals contamination in urban topsoil from Changchun City, China. *J Geochem Explor* 108:27–38
- Zhang C (2006) Using multivariate analyses and GIS to identify pollutants and their spatial patterns in urban soils in Galway, Ireland. *Environ Pollut* 142:501–511
- Zhang GL, Yang FG, Zhao YG, Zhao WJ, Yang JL, Gong ZT (2005) Historical change of heavy metals in urban soils of Nanjing, China during the past 20 centuries. *Environ Int* 31:913–919
- Zhao L, Xu Y, Hou H, Shanguan Y, Li F (2014) Source identification and health risk assessment of metals in urban soils around the Tanggu chemical industrial district, Tianjin, China. *Sci Total Environ* 468–469:654–662