Environ Monit Assess (2013) 185:1095–1106
DOI 10.1007/s10661-012-2617-x

Heavy metal contamination of urban soils and dusts in Guangzhou, South China

Quan-Ying Cai · Ce-Hui Mo · Hai-Qin Li · Huixiong Lü · Qiao-Yun Zeng · Yan-Wen Li · Xiao-Lian Wu

Received: 26 December 2011 / Accepted: 2 April 2012 / Published online: 17 May 2012

Abstract The heavy metal concentrations of soil and dust samples from roadside, residential areas, parks, campus sport grounds, and commercial sites were studied in Guangzhou, South China. Heavy metals in samples were determined by inductively coupled plasma atomic emission spectrophotometer following acidic digestion with $HClO_4$ + HF + HNO_3. High concentrations, especially of Cd, Pb, and Zn, were found with mean concentrations of Cd, Cr, Cu, Ni, Pb, and Zn in the urban dusts being 4.22±1.21, 62.2±27.1, 116±30, 31.9±12.6, 72.6±17.9, and 504±191 mg/kg dry weight, respectively. The respective levels in urban soils (0.23±0.19, 22.4±13.8, 41.6±29.4, 11.1±5.3, 65.4±40.2, and 277±214 mg/kg dry weight, respectively), were significantly lower. The integrated pollution index of six metals varied from 0.25 to 3.4 and from 2.5 to 8.4 in urban soils and dusts, respectively, with 61 % of urban soil samples being classified as moderately to highly polluted and all dust samples being classified as highly polluted. The statistical analysis results for the urban dust showed good agreement between principal component analysis and cluster analysis, but distinctly different elemental associations and clustering patterns were observed among heavy metals in the urban soils. The results of multivariate statistic analysis indicated that Cr and Ni concentrations were mainly of natural origin, while Cd, Cu, Pb, and Zn were derived from anthropogenic activities.

Keywords Heavy metals · Guangzhou · Multivariate statistic · Pollution index · Urban dust · Urban soil

Q.-Y. Cai · H.-Q. Li · H. Lü · Q.-Y. Zeng
Key Laboratory of Soil Environment and Waste Reuse in Agriculture of Guangdong Higher Education Institutions, College of Natural Resources and Environment, South China Agricultural University, Guangzhou 510642, China

C.-H. Mo (✉) · Y.-W. Li · X.-L. Wu
Key Laboratory of Water/soil Toxic Pollutants Control and Bioremediation of Guangdong Higher Education Institutions, Department of Environmental Engineering, Jinan University, Guangzhou 510632, China
e-mail: tchmo@jnu.edu.cn

Introduction

Heavy metals (HMs) derived from vehicular exhausts, incinerators, industrial wastes, atmospheric deposition, and other activities have continuously contributed to the burden of contaminants in the environment (Banat et al. 2005; Li et al. 2001; Katsoyiannis and Katsoyiannis 2006; Wei and Yang 2010). Due to their adverse effects on humans and ecosystem, HM

contamination has attracted significant attention from governmental and regulatory bodies, who are seeking to prevent further environmental deterioration.

To date, nearly half of the world's population lives in urban agglomeration; in the European Union, it has reached about 80 % and is continuously increasing. Urban soils consequently are often sealed, compacted, and generally influenced by the human presence and activity. Urban soils could be in fact considered as the source and sink of various pollutants that can be accumulated over long period of time. Due to the nonbiodegradability of HMs and their long half-lives for elimination from the body (Zhuang et al. 2009), their accumulation in the urban soil has a harmful effect on environmental quality including the biota and human beings in the long term. Owing to environmental and health concerns, the extensive investigations of HM contamination in urban soils have been conducted in some countries and regions such as Hong Kong (Lee et al. 2006; Li et al. 2001, 2004; Wei and Yang 2010; Wong et al. 2006), Nanjing (Lu et al. 2003), Beijing (Chen et al. 2005; Wang et al. 2012; Xia et al. 2011), Shenyang (Sun et al. 2010), New Orleans (Mielke et al. 2004), Turin (Biasioli et al. 2006), Mexico City (Morton-Bermea et al. 2009), and Islamabad (Iqbal and Shah 2011). Elevated concentrations of HMs, especially lead (Pb), were found in urban soils (Guney et al. 2010; Mielke et al. 2004; Li et al. 2004; Lee et al. 2006; Wei and Yang 2010). Interest in the levels of HMs associated with urban dusts has also risen in the last decades, particularly in the concentrations and distribution of Pb and other elements, and their source identification (Li et al. 2001).

Guangzhou, the largest city in South China and a major political, industrial, and economic center of Guangdong Province, has an area of 7,434 km^2 and a population of over 10 millions. In Guangzhou, the major industries include electronic and communication equipment manufacturing, automobile manufacturing, and petrochemical industries. Other sectors such as the biomedicine industry, the logistics industry, and the new material industry have been developing rapidly in the past decades. With the rapid industrialization and urbanization in Guangzhou, the environmental quality has severely deteriorated. However, few information is available about HMs in urban soils and dusts in Guangzhou (Guan and Peart 2006; Lu et al. 2007). The present study aimed at investigating and assessing the HM contamination of the urban soils and dusts in Guangzhou, and attempted to identify their possible sources by multivariate statistics.

Materials and methods

Chemicals and materials

Multielement stock solution containing Cd, Cr, Cu, Ni, Pb, and Zn (1,000±2 mg/L in 5 % HNO_3) was obtained from Merck (Darmstadt, Germany). Fresh working standard solutions were prepared by dilution of a particular stock solution with deionized water. Suprapur grade acids and deionized water were used for the preparation of samples, extraction solutions, and standard solutions. All glassware was cleaned by soaking for 24 h in diluted nitric acid, followed by rinsing three times with deionized water to remove any adhered impurities.

Soil and dust sampling

Urban soil samples (n=78, 0–20 cm depth) were collected from different districts including urban parks, roadsides, residential areas, and campus sport grounds within the urban area according to their locations, functions, history, road section, and traffic density (Fig. 1). In the sampling program, each soil sample consisted of five subsamples obtained within 2 m^2 in each sampling site, and then stored in polyethylene bags for transport and storage. The soil samples were air-dried and then sieved through a 1.0-mm polyethylene sieve. Portions of the soil samples (approximately 20 g) were further ground to pass through a 100-mesh polyethylene sieve. The prepared soil samples were then stored in polyethylene bags in a desiccator.

Urban dust samples (n=18) in the different districts of Guangzhou were selected according to their locations and functions (Fig. 1). Each dust sample was collected from different sites within an 8-m^2 area. Urban dusts were collected using polyethylene brush, tray, and containers and were stored in polyethylene containers.

Analysis of heavy metals

The modified method presented by Tessier et al. (1979) was applied to measure the total concentrations

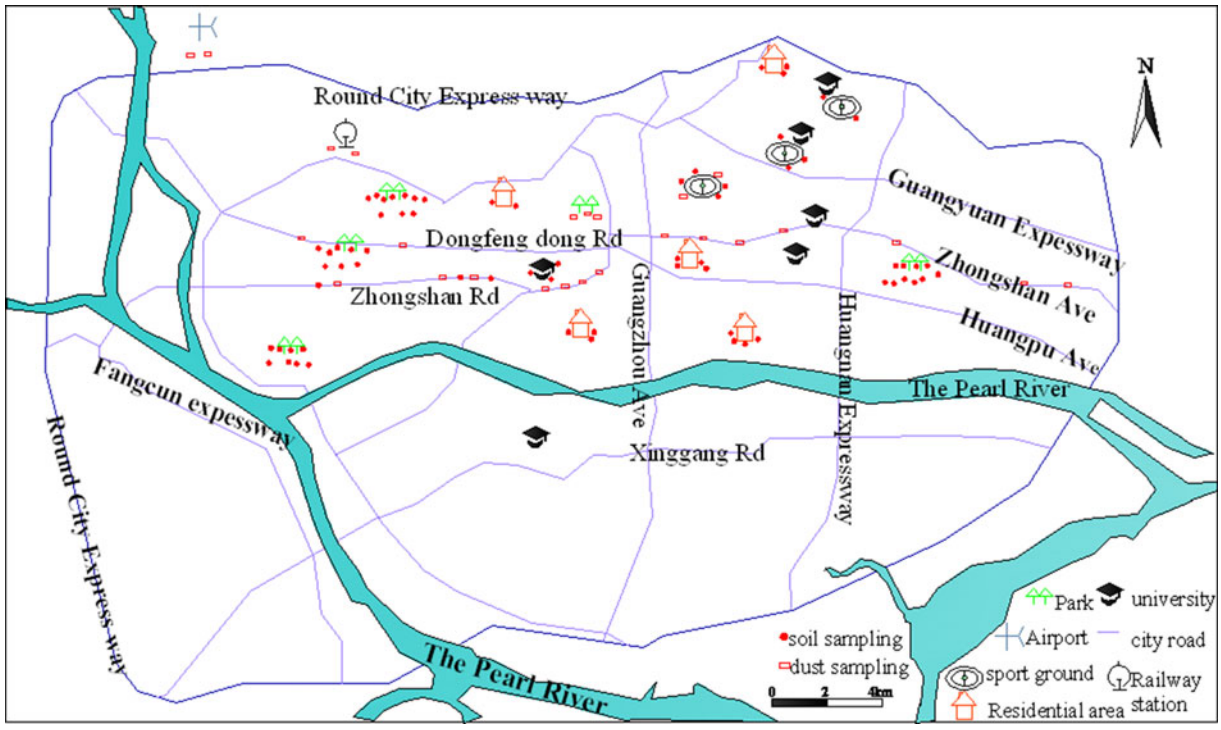

Fig. 1 Sampling locations of urban soils and dusts in Guangzhou

of HMs (Cd, Cr, Cu, Ni, Pb, and Zn) in the urban soil and dust samples. Approximately 0.20 g (100 mesh) of each sample was digested twice with a mixture (1:5, *v*/*v*) of 2 mL concentrated $HClO_4$ (Guangzhou Chemical Co.) and 10 mL HF (Guangzhou Chemical Co.; the mixtures were evaporated to near dryness each time). Finally, $HClO_4$ (1 mL) alone was added and the mixtures were evaporated until the appearance of white fumes. The residue obtained was dissolved with 0.1 mol/L HNO_3, transferred into polyethylene volumetric flask (25 mL) through 0.45-μm filters, and then diluted to the mark.

The concentrations of Cr, Cu, Ni, Pb, and Zn in the extracts were measured by inductively coupled plasma atomic emission spectrophotometer and that of Cd by graphite furnace atomic absorption spectrometry under optimized measurement conditions. The calibration curves were established with these most dilute solutions. For quality control, reagent blanks and replicates were analyzed to detect contamination and to assess precision and bias. The analytical results showed no signs of contamination and that the precision and bias of the analysis were generally <10 %.

Statistical analysis

Experimental results were expressed on a dry weight basis. Statistical analysis including principal components analysis (PCA) and cluster analysis (CA) were performed using SPSS 10.0 for Windows. Arithmetic means were used for the average concentrations of HMs.

To assess the soil and dust environment quality, a pollution index (PI) of each metal and an integrated pollution index (IPI) of the six metals analyzed were attributed to each sampling site. The PI is defined as the ratio of the HM concentrations in this study to the natural background values of soils in China (Chen et al. 2005). The PI of each metal was calculated and classified as either low ($PI \leq 1$), middle ($1 < PI \leq 3$), or high ($PI > 3$). The IPI of the six metals for urban soils and dusts was defined as the mean value of the metal's PI (Chen et al. 2005), and then was classified as low ($IPI \leq 1$), middle ($1 < IPI \leq 2$), or high ($IPI > 2$).

Results and discussion

HM concentrations in urban soils and dusts

Descriptive statistics of HM concentrations in the urban soils and dusts of Guangzhou, as well as background values of Guangzhou soils are summarized in Table 1. The concentrations of Cd (0.010–0.88 mg/kg), Cr (3.3–68 mg/kg), Cu (1.5–150 mg/kg), Ni (1.8–24 mg/kg), Pb (10–190 mg/kg), and Zn (14–1,000 mg/kg) in urban soils of Guangzhou were varied greatly. The mean concentrations of Cu, Cr, and Ni in the urban soils were lower than the natural background values of soils in China, whereas those of Zn and Pb in all urban soil samples and Cd in park and roadside soil samples were considerably higher than the natural background value of soils in China, especially Zn, showing about two- and fivefold higher levels. Thus, it was evident that Zn and Pb pollution existed in some urban soil samples. Moreover, mean concentrations of Zn in Guangzhou urban soils also exceeded existing limits for soils in public and private green and residential areas in Canada and Italy (CCME 1999; Gazzetta Ufficiale 1999). The mean concentrations of Cu, Zn, and Pb were remarkably higher, while those of Cd, Ni, and Cr were found to be slightly lower than average HM concentration in the

Table 1 Heavy metal concentrations in the urban soils and dusts of Guangzhou (mg/kg, dry weight)

Location		Cd	Cr	Cu	Ni	Pb	Zn
Park (n=36)	Min	0.01	3.3	1.5	3.7	12.2	14.4
	Max	0.87	68.2	37.2	23.7	194	834
	Mean	0.26	22.8	12.9	11.0	65.5	266
	SD	0.22	15.7	7.7	5.0	46.1	215
Roadside (n=14)	Min	0.09	8.2	31.1	7.2	44.8	94
	Max	0.88	49.3	150	21.3	106	1,014
	Mean	0.25	23.1	77.4	12.1	68.6	422
	SD	0.20	12.3	29.8	3.6	18.8	269
Residential area (n=16)	Min	0.03	3.6	8.1	1.8	10.1	17.8
	Max	0.33	48.0	20.9	17.3	75.4	538
	Mean	0.13	20.5	15.2	8.7	43.9	212
	SD	0.10	13.6	3.4	4.2	24.9	160
Sport grounds (n=12)	Min	0.06	10.3	25.3	4.9	57.3	112
	Max	0.41	23.5	80.0	14.0	161	483
	Mean	0.17	15.3	60.9	8.7	83.4	231
	SD	0.10	4.8	18.5	3.0	36.1	117
Urban soils (n=78)	Min	0.01	3.3	1.5	1.8	10.2	14.4
	Max	0.88	68.1	150	24.4	194	1,014
	Mean	0.23	22.4	41.6	11.1	65.4	277
	SD	0.19	13.8	29.4	5.3	40.2	214
Dusts (n=18)	Min	1.00	28.3	52.7	17.5	39.2	245
	Max	7.44	121	261	56.0	123	1,007
	Mean	4.22	62.2	116.3	31.9	72.6	504
	SD	1.21	27.1	30.3	12.6	17.9	191
China background[a]		0.20	90	35	40	10	35
Soil quality guidelines of Canada[b]		10	63	64	200	–	140
Limits for contaminated soils in Italy[c]		–	120	150	150	120	100

[a] Background values in soil of China (National Environmental Protection Agency of China 1995)

[b] For residential area and park soil (CCME 1999)

[c] Limits of soils in public and private green and residential areas (Gazzetta Ufficiale 1999)

natural soils of the Pearl River Delta (Wong et al. 2002). The concentrations of HMs in soils were found to depend on land utilization and spatial location to some extent. The highest concentrations of Cd, Cu, and Zn were detected in roadside soil while Cr, Ni, and Pb in park soil, respectively (Table 1). Moreover, among roadside soil samples (n=14), the highest mean HM concentrations (except to Cr) were found in the sampling site that was very close to the city center and the old railway station. Among soil samples from five parks, the highest mean concentrations were observed in the park located at the city center with higher population and traffic density, which were far higher than those in the park which is located at the new district and built in 1996.

The concentrations and fractionation of heavy metals in park and roadside soils in Guangzhou have been reported in previous studies (Lu et al. 2007). The current results were comparable with previous study, however exhibited a wider range. Compared to other urban soils from different cities in China, the concentration distribution patterns of HMs in this study were similar to the values found in the Pearl River Delta including Hong Kong (Lee et al. 2006; Li et al. 2001; Wong et al. 2002), but the mean concentration of Zn in this study was markedly higher than the respective values reported in the other urban soils (Chen et al. 2005; Lee et al. 2006; Li et al. 2001; Lu et al. 2003; Wong et al. 2002; Wei and Yang 2010). Compared to urban soils from other places, the value of Pb (65.9± 37.7 mg/kg) in Guangzhou urban soils was similar to those measured in smaller cities such as Fuhis in Jordan (Banat et al. 2005) and Galway in Ireland (Zhang et al. 2006), but was much lower than those reported from some large and/or industrialized cities such as Turin, Italy (with a mean of 149 mg/kg, Biasioli et al. 2006), Madrid, Spain (with a mean of 161 mg/kg, De Miguel et al. 1998), and New Orleans (ranging from 163 to 10,300 mg/kg, Mielke et al. 2004). Concentrations of Cu and Zn were similar to those in Turin, while values of Cr and Ni were far lower than those in Turin (Biasioli et al. 2006).

Concerning urban dusts, the mean concentrations of HMs analyzed (except to Ni) were significantly higher than the natural background values of soils in China, particularly for Cd and Zn (Table 1). The mean concentrations of HMs decreased in order of Zn > Cu > Pb > Cr > Ni > Cd. Similarly, the concentration distribution profiles of HMs in this study were consistent with those in Hong Kong and other cities (Li et al. 2001; Tokalıoğlu and Kartal 2006; Wei and Yang 2010), and the concentration ranges of HMs were comparable with those in street dusts of Hong Kong (Li et al. 2001). Urban dusts could indicate the short-term contamination released from vehicle exhaust emission and other anthropogenic activities taking place in urban environments. Moreover, Harrison et al. (1985) estimated that the dust collected in the gutters represented about 10 % of the total output from motor vehicles with concentrations increasing towards the center of the road. Special attention, therefore, should be given to the HMs in urban dusts.

With comparison to urban soils of Guangzhou, the urban dusts exhibited relatively higher mean concentrations of the six metals, especially Cd, displaying more than 15-fold higher levels. Similarly, Li et al. (2001) reported the concentrations of HMs in urban dusts were significantly higher than in urban soils. Ericson and Gonzalez (2003) observed the increased trend of mean soil Pb levels as follows: background → schools and parks→ residential soil and residential dust → point sources. In this study, mean Pb levels in urban soils and dusts increased in order of residential area < park < roadside < dust < sport grounds, implying the relatively low risk for residents and tourists but the high one for players.

Environmental quality assessment of the urban soils and dusts

The PI, calculated according to the natural background values of HMs in soils of China, varied considerably across the different metals (Table 2). Ni and Cr in urban soils showed lower values, ranging from 0.05 to 0.59 and 0.04 to 0.76, respectively, and all of the samples had low PIs (Table 2 and Fig. 2), showing that the concentrations of Ni and Cr in the urban soil samples were comparable with the natural background values of HMs in soils in China and there was no obvious pollution of Ni and Cr. Cu showed low PIs in park and residential area soils, and middle PIs in roadside and sport ground soils. The PI of Cd varied from 0.07 to 4.4, and 80 % of residential area soil samples and 82 % of sport ground soil samples had low level PIs, while for both park and roadside soil about 50 and 35 % of samples were classified as low PIs and moderately polluted, respectively. The PIs of Zn were markedly higher, varying from 0.14 to 8.3; around 71 % of roadside soil samples and 30 % of

Table 2 Statistical results of pollution index (PI) and integrated pollution index (IPI) of HMs in the urban soils and dusts of Guangzhou

Location		Cd	Cu	Zn	Ni	Cr	Pb	IPI
Park (n=36)	Min	0.07	0.04	0.14	0.09	0.04	0.35	0.25
	Max	4.3	1.1	8.3	0.59	0.76	5.5	2.7
	Mean	1.3	0.37	2.7	0.28	0.25	1.9	1.1
	SD	1.1	0.18	2.2	0.10	0.21	1.3	0.7
Roadside (n=14)	Min	0.43	0.89	0.94	0.18	0.09	1.3	0.97
	Max	4.4	4.3	10	0.53	0.55	3.0	3.4
	Mean	1.3	2.2	4.2	0.30	0.26	2.0	1.7
	SD	1.0	0.8	2.7	0.1	0.1	0.5	0.7
Residential area (n=16)	Min	0.17	0.23	0.18	0.05	0.04	0.29	0.30
	Max	1.7	0.60	5.4	0.43	0.53	2.2	1.6
	Mean	0.65	0.43	2.1	0.22	0.23	1.3	0.82
	SD	0.5	0.1	1.6	0.1	0.2	0.7	0.5
Sport grounds (n=12)	Min	0.28	0.72	1.1	0.12	0.11	1.6	0.86
	Max	2.1	2.3	4.8	0.35	0.26	4.6	2.0
	Mean	0.83	1.7	2.3	0.22	0.17	2.4	1.3
	SD	0.5	0.5	1.2	0.1	0.1	1.0	0.3
Dusts (n=18)	Min	5.0	1.5	2.5	0.44	0.30	1.1	2.5
	Max	37.2	7.5	10.1	1.4	1.3	3.5	8.4
	Mean	21.1	3.3	5.1	0.80	0.69	2.1	5.5
	SD	8.4	1.3	1.9	0.28	0.26	0.6	1.6

other urban soil samples were classified as highly polluted (high PIs). The results demonstrated that Zn pollution was widespread in urban soils in Guangzhou. The PI for Pb varied between 0.29 and 5.5 with a mean of 1.9, and 41 % of park soil samples and 47 % of residential area soil samples were classified as low–middle PI, but all roadside and sport ground soil samples were classified as moderately–highly polluted. Thus, it was likely that many of the roadside and sport ground soils in Guangzhou were highly polluted by Pb.

The IPIs of six elements in urban soil samples varied from 0.25 to 3.4 with an average of 1.2 (Table 2). It was obvious that the high IPI in most of samples was accounted for mainly by the Pb and Zn values. Concerning the different soil types, 79 % of residential area soil samples and 52 % of park soil samples had low IPI, indicating that park and residential area soils in this study were slightly contaminated by HMs and also less polluted compared to Beijing park soils (Chen et al. 2005). Around 91 % of sport ground and 86 % of roadside soils exhibited moderate IPI. Thus urban soil quality in Guangzhou has clearly been impacted, particularly roadside and sport ground soils.

Regarding urban dusts, mean PIs of HMs were significantly higher than those of the urban soils (Table 2). Cd showed the highest PI, ranging from 5.0 to 37, indicating that urban dusts were seriously contaminated by Cd. The PIs of Cu, Zn and Pb were all >1.0, and 61 and 89 % of urban dust samples were classified as highly polluted according to the PIs of Cu and Zn (Fig. 2e), respectively. Ni and Cr PIs varied from 0.44 to 1.4 and from 0.30 to 1.3, with 78 and 89 % of urban dust sample being classified as low PI, respectively. The IPIs of urban dust samples ranged from 2.5 to 8.4 with a mean of 5.5 (Table 2), indicating that all dust samples were classified as highly polluted.

On the other hand, Pb is known to be one of the less mobile elements in soils, which could explain the high values found in the urban soils and dusts. Moreover, among HMs investigated in this study, it is one of the most toxic for humans. Contaminated urban soils and dusts have been identified by several authors as a significant source of Pb exposure

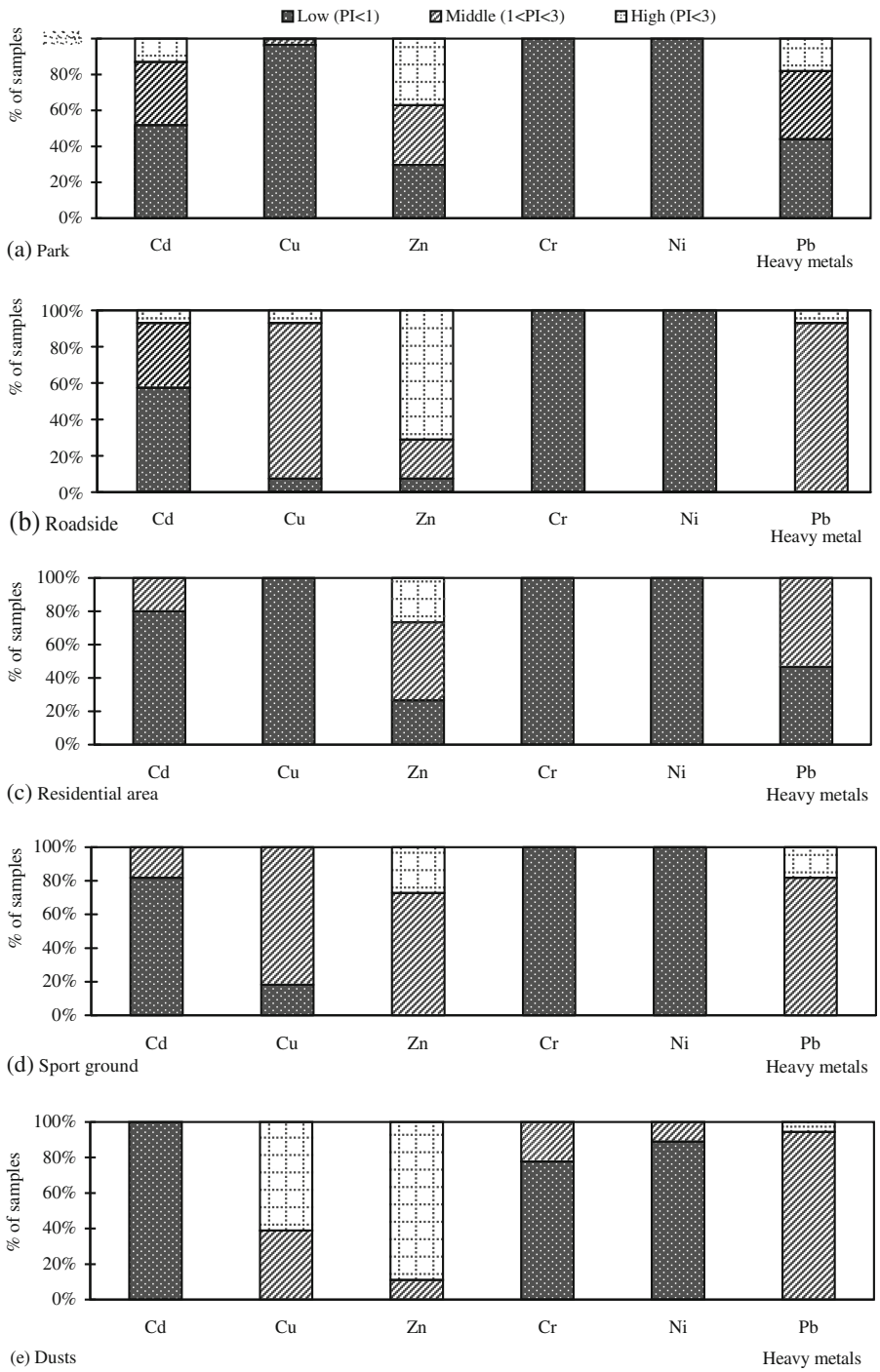

Fig. 2 Pollution characteristics of heavy metals in the urban soils and dust of Guangzhou (**a**) Park, (**b**) roadside, (**c**) Residential area, (**d**) Sport ground, (**e**) Dusts

to children (Ericson and Gonzalez 2003; Mielke et al. 1999). Some researchers have reported a significant association between blood Pb levels and soil Pb levels (Ericson and Gonzalez 2003; Mielke et al. 1999). Given that a safe Pb soil level for most children (≤6 years) is around 80 mg/kg (Mielke et al. 1999), 35 % of soils and 52 % of dust samples in this study exceeded this limit, and thereby, special attention should be paid at the risk of high Pb levels in urban soils and dusts.

Multivariate analysis and possible pollution sources

Principal components analysis

The PCA results indicate that HM concentrations could be considered as four principal components (PCs), which accounted for 88.4 and 90.8 % of the total variances in the urban soils and dusts, respectively (Table 3). In the urban soils, elements such as Cd, Cr, Ni, Pb, and Zn were closely associated in the first principal component (PC1), which explained 47.4 % of the total variance. The component matrix indicated that Cu was mainly associated in the second principal component (PC2). In urban soils, metal accumulation originated from different sources, especially anthropogenic input (Lee et al. 2006). The PC1 accounted for most of the variability, and each succeeding component accounted for a decreased percentage of the remaining variability. This implied that anthropogenic activities might be the dominant influence on some metals in the urban soils.

Concerning the urban dusts, the elements associated with the PC1, PC2, and PC3 were considerably different from those in the urban soils. In the urban dusts, Cu and Pb were closely associated in the PC1, accounting for 32.5 % of the total variance (Table 3). Cd and Zn were associated in the PC2 which accounted for 30.2 % of the total variance. The unique moderate association of Cr and Ni with PC1 and PC3 probably indicated that Cr and Ni in the urban dusts of Guangzhou might be governed by more than one factor.

Hierarchical cluster analysis

Hierarchical cluster analysis (HCA) was performed on the concentrations of HMs in the urban soils and dusts. The results were illustrated in Fig. 3. The distance cluster represented the degree of association between elements. The lower the value on the distance cluster, the more significant was the association.

A criterion for the distance cluster of between 5 and 10 was used in this study. Based on the HCA results, the six elements both in the urban soils and dusts were classified into two clusters.

Cluster I: Contained Cd, Cu, Pb and Zn. These elements probably came from anthropogenic sources in the urban environment.
Cluster II: Contained Cr and Ni. The two elements might mainly originate from the natural parent materials.

De Miguel et al. (1997) suggested that HMs in the urban dust could be classified as “urban” elements (e.g., Cd, Cu, Pb, Zn) and elements of a mixed origin or which have undergone geochemical changes from their original sources (e.g., Cr, Ni). Moreover, many authors suggested that enrichment of Cu, Zn, and Pb in the urban soils deriving from main anthropogenic origin (Lee et al. 2006). This could be somehow substantiated by the Pearson’s correlation coefficients obtained for the six elements. Correlation matrices of HMs in the urban soils and dusts of Guangzhou were

Table 3 Matrix of the principal component analysis of heavy metals in the urban soils and dusts of Guangzhou

	Principal component							
	Urban soils (n=78)				Urban dusts (n=18)			
	PC1	PC2	PC3	PC4	PC1	PC2	PC3	PC4
Cd	*0.85*	−0.13	−0.21	−0.21	−0.11	*0.70*	0.56	−0.35
Cr	*0.70*	−0.47	0.11	0.40	0.52	0.40	−0.64	−0.27
Cu	0.42	*0.78*	0.37	0.20	*0.77*	−0.30	0.49	0.05
Ni	0.66	0.37	−0.57	0.30	0.62	0.41	0.65	0.06
Pb	*0.74*	−0.39	0.29	−0.13	*0.76*	0.32	−0.42	0.31
Zn	*0.76*	0.36	−0.08	−0.40	0.12	*0.90*	−0.02	−0.03
Initial eigenvalue	2.85	0.98	0.92	0.56	1.95	1.81	0.97	0.71
% of total variance	47.8	16.3	15.4	8.9	32.5	30.2	22.0	6.1
% of cumulative variance	47.8	64.2	79.5	88.4	32.5	62.7	84.7	90.8

The italicized numbers are the dominant elements in different PCs

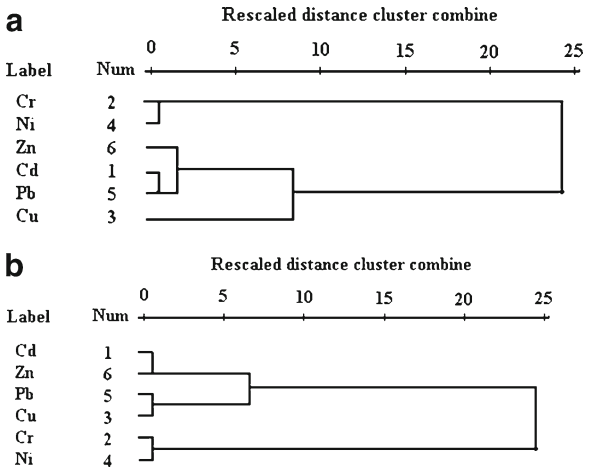

Fig. 3 Dendrogram of the cluster analysis of the urban soils and dusts based on the HM concentrations. **a** Urban soils (n=78). **b** Urban dusts (n=18)

presented in Table 4. Correlation coefficients between each metal in the urban soils indicate that there existed significant correlation between Zn and the other elements (except Ni), between Cd and Cu or Pb, and between Pb and Cu, while a weak relationship between Cr and the other elements (except Zn), and between Ni and the other elements. The highest mean values for Cr, Cu, Ni, and Zn were found in roadside soils, while the correlation coefficients between Ni and Cu, Cr and Zn, and Cr and Cu were not as high as that between Zn and Cu (Table 4), indicating that Zn and Cu might be from the same source such as the mechanical abrasion of vehicles (Jiries et al. 2001).

In the urban dusts, significant correlation was observed between Pb and the other HMs (except Cr and Ni), Cd and Cu, Cd and Zn, Cr and Ni, and Cu and Zn (Table 4). In this study, the results exhibited a weak correlation between Ni and the other elements (except Cr), and Cr and "urban" elements (Cd, Cu, Pb, and Zn), indicating that Cr or Ni had different sources from those of "urban" elements. In fact, compared to background values of Chinese soils, Cd, Zn, and Pb have extremely elevated concentrations in the urban dusts of Guangzhou, suggesting anthropogenic inputs of these elements, while Cr and Ni had mean concentrations approximating to their corresponding background values, indicating a relevant natural contribution.

In general, the concentrations of HMs in soils and dusts could be influenced by variation in soil, physicochemical properties, and physical transport or sorting, in addition to anthropogenic inputs (Banat et al. 2005). The accumulation of Cu, Zn, and Pb in the urban soils indicated that despite the natural high levels of these three elements in the Pearl River Delta (Wong et al. 2002), there was a considerable contribution from diffuse pollution sources and anthropogenic sources. Pb and Zn were significantly correlated, both in urban soils and dusts, as could be seen from their correlation coefficient (Table 4), indicating that there

Table 4 Correlation (Pearson) coefficient matrices between heavy metal concentrations in urban soils and dusts

	Cd	Cr	Cu	Ni	Pb	Zn
Urban soils (n=78)						
Cd	1					
Cr		1				
Cu	*0.318*		1			
Ni		*0.281*		1		
Pb	**0.574**		*0.348*		1	
Zn	**0.596**	*0.300*	*0.351*		**0.381**	1
Urban dusts (n=18)						
Cd	1					
Cr		1				
Cu	*0.328*		1			
Ni		*0.290*		1		
Pb	*0.305*		**0.651**		1	
Zn	**0.506**		*0.341*		**0.363**	1

Correlation coefficients significant at the 99 % are in bold phase. Correlation coefficients significant at the 95 % are italicized

might be a traffic source coupled with industrial sources. As shown in many reports, traffic activities were a significant contribution to Cu, Pb, and Zn of urban soils and dusts (Guney et al. 2010; Jiries et al. 2001; Lee et al. 2006; De Miguel et al. 1997; Mielke et al. 1999). In Guangzhou, there were 358,921 and 584,923 motor vehicles (including motorcycles) in 1991 and 1997, respectively, while the number reached 1,666,490 by 2004 (Tan et al. 2006). The rapid increase of motor vehicle number implied the increased emission of HMs. In particular, high Pb concentrations in urban soils and dusts also reflected the significant degree of historical Pb contamination and the long half-life of Pb as linked mainly to traffic activities (Guney et al. 2010; Li et al. 2001), although Pb had been banned in petrol for a number of years in Guangzhou. Additionally, the high concentrations of HMs such as Pb were observed in the soil samples of sport grounds, which might be attributed to the input of coal cinders containing HMs (He et al. 2006) in the past decades.

On the other hand, atmospheric HMs impacted the soil or dust HM content. Atmospheric emissions of HMs represent a major intermediate path of anthropogenic HM inputs into the surface environment (Wong et al. 2003). Soil or dust could as well contribute to the HM concentrations in the atmosphere (Chen et al. 1997). Lee et al. (2007) observed the elevated concentrations of metals, especially Cd, Pb, and Zn, in the aerosols of urban and suburban areas within Guangzhou. In the Pearl River Delta (including Guangzhou and Hong Kong), the most abundant HM in atmospheric deposition was Zn among HMs investigated, followed by Cu and Pb, and the lowest one was Cd (Lee et al. 2007; Wong et al. 2003), which was in good agreement with the HM distribution patterns in the urban soils and dusts. Moreover, the atmospheric deposition of HMs in the Pearl River Delta was significantly elevated compared to other regions (Wong et al. 2003). Local sources of pollution around the city of Guangzhou, automobile exhausts and industry, were dominant in the atmosphere compared to the long-range transport of HMs from the northern inland areas of China (Lee et al. 2007).

Generally, the results of CA agreed well with that of the PCA, in the urban dusts of this study for example. However, there was a difference between the CA and PCA in the urban soils of this study. Similarly, Lee et al. (2006) reported the differences between two analyses for the urban soils and country park soils. This might be related to the anthropogenic inputs in the urban environment which caused significant enrichments of HMs, such as Cu, Pb, and Zn in the soils. Therefore, the original associations of these elements with major elements derived from their natural sources were altered, exhibiting a different clustering pattern in urban soils. De Miguel et al. (1999) pointed out that in many cases, because of the complexity of urban environments, it was impossible to distinguish the influence of single source of trace elements or characterize single cycle. The pollution pattern of HMs in the urban soils and dusts in Guangzhou might be affected by multiple factors, which needed further investigation.

Conclusion

Elevated HM concentrations were found in urban soils and dusts in Guangzhou, especially for Cd, Pb, and Zn. Mean HM concentrations in urban dusts were remarkably higher compared to those in urban soils. Individual HMs behaved in a different way in roadsides, residential areas, parks, and sport grounds. Eighty-nine percent of park soil and all residential area soils were classified as lowly–moderately polluted; 86 % of roadside soils and 91 % of sport ground soils exhibited a moderate IPI, while all dusts were classified as highly polluted. More than 70 and 53 % of soil samples had middle–high PIs of Zn and Pb, respectively. Such middle–high PIs or IPI imply potential health threat to local residents. The results of PCA were in good agreement with that of the CA in the urban dusts, but they provided with distinctly different elemental associations and clustering patterns among metals in the urban soil. With respect to the high HM concentrations and PI or IPI, further work is considered necessary not only to investigate the speciation distribution and bioavailability of HMs in urban soil of Guangzhou but also to identify and quantify their sources.

Acknowledgments This work was supported by the Natural Science Foundation of China (Nos. 30800708, 41001328, 41071211, 41173101), the Natural Science Foundation of Guangdong Province (Nos.2011020003196, 2011010001083), the High-level Talents Program of Guangdong Universities, the Program of Guangdong Science & Technology Department (No. 2010B020311006), and the Program of Guangzhou Science & Technology Department (No.2010A82070466).

References

Banat, K. M., Howari, F. M., & Al-Hamad, A. A. (2005). Heavy metals in urban soils of central Jordan: Should we worry about their environmental risks? *Environmental Research, 97*, 258–273.

Biasioli, M., Barberis, R., & Ajmone-Marsan, F. (2006). The influence of a large city on some soil properties and metals content. *Science of Total Environment, 356*, 154–164.

CCME (1999). Contaminated sites cleanup criteria—Recommended Canadian soil quality guidelines. Winnipeg, Manitoba, Canada. P.D.: PPD97-01.

Chen, T. B., Wong, J. W. C., Zhou, H. Y., & Wong, M. H. (1997). Assessment of trace metal distribution and contamination in surface soils of Hong Kong. *Environmental Pollution, 96*, 61–68.

Chen, T. B., Zheng, Y. M., Lei, M., Huang, Z. C., Wu, H. T., Chen, H., et al. (2005). Assessment of heavy metal pollution in surface soils of urban parks in Beijing, China. *Chemosphere, 60*, 542–551.

De Miguel, E., Llmas, J. F., Chacón, E., Berg, T., Larssen, S., Røyset, O., et al. (1997). Origin and patterns of distribution of trace elements in street dust: Unleaded petrol and urban lead. *Atmospheric Environment, 31*, 2733–2740.

De Miguel, E., Jiménez de Grado, M., Llamas, J. F., Martín-Dorado, A., & Mazadiego, L. F. (1998). The overlooked contribution of compost application to the trace element load in the urban soil of Madrid (Spain). *Science of Total Environment, 215*, 113–122.

De Miguel, E., Llamas, J. F., Chacón, E., & Mazadiego, L. F. (1999). Sources and pathways of trace elements in urban environments: A multi-elemental qualitative approach. *Science of Total Environment, 235*, 355–357.

Ericson, J. E., & Gonzalez, E. J. (2003). Hierarchical sampling of multiple strata: An innovative technique in exposure characterization. *Environmental Research, 92*, 221–231.

Gazzetta Ufficiale (1999). Gazzetta Ufficiale delle Repubblica Italiana. Regolamento recante criteri, procedure e modalità per la messa in sicurezza e il ripristino ambientale dei siti inquinati, ai sensi dell'articolo 17 del decreto legislativo 5/2/1997, no. 22, e successive modificazioni e integrazioni 471:67.

Guan, D. S., & Peart, M. R. (2006). Heavy metal concentrations in plants and soils at roadside locations and parks of urban Guangzhou. *Journal of Environmental Science, 18*, 495–502.

Guney, M., Onay, T. T., & Copty, N. K. (2010). Impact of overland traffic on heavy metal levels in highway dust and soils of Istanbul, Turkey. *Environmental Monitoring and Assessment, 164*, 101–110.

Harrison, R., Johnston, W., Ralph, J., & Wisen, S. (1985). The budget of Pb, Cu and Cd for a major highway. *Science of the Total Environment, 46*, 137–145.

He, P. J., Xiao, Z., Shao, L. M., Yu, J. Y., & Lee, D. J. (2006). In situ distributions and characteristics of heavy metals in full-scale landfill layers. *Journal of Hazardous Materials, 137*, 1385–1394.

Iqbal, J., & Shah, M. H. (2011). Distribution, correlation and risk assessment of selected metals in urban soils from Islamabad, Pakistan. *Journal of Hazardous Materials, 192*, 887–898.

Jiries, A. G., Hussein, H. H., & Halash, Z. (2001). The quality of water and sediments of street runoff in Amman, Jordan. *Hydrological Processes, 15*, 815–824.

Katsoyiannis, I. A., & Katsoyiannis, A. (2006). Arsenic and other metal contamination of groundwaters in the industrial area of Thessaloniki, Northern Greece. *Environmental Monitoring and Assessment, 123*, 393–406.

Lee, C. S., Li, X., Shi, W., Cheung, S. C., & Thornton, I. (2006). Metal contamination in urban, suburban, and country park soils of Hong Kong: A study based on GIS and multivariate statistics. *Science of Total Environment, 356*, 45–61.

Lee, C. S. L., Li, X. D., Zhang, G., Li, J., Ding, A. J., & Wang, T. (2007). Heavy metals and Pb isotopic composition of aerosols in urban and suburban areas of Hong Kong and Guangzhou, South China—Evidence of the long-range transport of air contaminants. *Atmospheric Environment, 41*, 432–447.

Li, X., Poon, C., & Liu, P. S. (2001). Heavy metal contamination of urban soils and street dusts in Hong Kong. *Applied Geochemistry, 16*, 1361–1368.

Li, X., Lee, S., Wong, S., Shi, W., & Thornton, I. (2004). The study of metal contamination in urban soils of Hong Kong using a GIS-based approach. *Environmental Pollution, 129*, 113–124.

Lu, Y., Gong, Z., Zhang, G., & Burghardt, W. (2003). Concentrations and chemical speciations of Cu, Zn, Pb and Cr of urban soils in Nanjing. *China Geoderma, 115*, 101–111.

Lu, Y., Zhu, F., Chen, J., Gan, H., & Guo, B. (2007). Chemical fractionation of heavy metals in urban soils of Guangzhou, China. *Environmental Monitoring and Assessment, 134*, 429–439.

Mielke, H. W., Gonzales, C. R., Smith, M. K., & Mielke, P. W. (1999). The urban Environment and Children's Health: Soils as an integrator of lead, zinc, and cadmium in New Orleans, Louisiana, U.S.A. *Environmental Research, 81*, 117–129.

Mielke, H. W., Wang, G., Gonzales, C. R., Powell, E. T., Le, B., & Quach, V. N. (2004). PAHs and metals in the soils of inner-city and suburban New Orleans, Louisiana, USA. *Environmental Toxicology Pharmacology, 18*, 243–247.

Morton-Bermea, O., Hernández-Álvarez, E., González-Hernández, G., Romero, F., Lozano, R., & Beramendi-Orosco, L. E. (2009). Assessment of heavy metal pollution in urban topsoils from the metropolitan area of Mexico City. *Journal of Geochemical Exploration, 101*, 218–224.

National Environmental Protection Agency of China (1995). Environmental quality standard for soils (GB 15618–1995).

Sun, Y., Zhou, Q., Xie, X., & Liu, R. (2010). Spatial, sources and risk assessment of heavy metal contamination of urban soils in typical regions of Shenyang, China. *Journal of Hazardous Materials, 174*, 455–462.

Tan, J. H., Bi, X. H., Duan, J. C., Rahn, K. A., Sheng, G. Y., & Fu, J. M. (2006). Seasonal variation of particulate polycyclic aromatic hydrocarbons associated with PM10 in Guangzhou, China. *Atmospheric Research, 80*, 250–262.

Tessier, A., Campbell, P. G. C., & Bission, M. (1979). Sequential extraction procedure for the speciation of paniculate trace metals. *Analytical Chemistry, 51*, 844–858.

Tokalıoğlu, Ş., & Kartal, Ş. (2006). Multivariate analysis of the data and speciation of heavy metals in street dust samples

from the Organized Industrial District in Kayseri (Turkey). *Atmospheric Environment, 40*, 2797–2805.

Wang, M., Bai, Y., Chen, W., Markert, B., Peng, C., & Ouyang, Z. (2012). A GIS technology based potential eco-risk assessment of metals in urban soils in Beijing, China. *Environmental Pollution, 161*, 235–242.

Wei, B., & Yang, L. (2010). A review of heavy metal contaminations in urban soils, urban road dusts and agricultural soils from China. *Microchemical Journal, 94*, 99–107.

Wong, C. S. C., Li, X. D., Zhang, G., Qi, S. H., & Min, Y. S. (2002). Heavy metals in agricultural soils of the Pearl River Delta, South China. *Environmental Pollution, 119*, 33–44.

Wong, C. S. C., Li, X. D., Zhang, G., Qi, S. H., & Peng, X. Z. (2003). Atmospheric deposition of heavy metals in the Pearl River Delta, China. *Atmospheric Environment, 37*, 767–776.

Wong, C. S. C., Li, X., & Thornton, I. (2006). Urban environmental geochemistry of trace metals. *Environmental Pollution, 142*, 1–16.

Xia, X., Chen, X., Liu, R., & Liu, H. (2011). Heavy metals in urban soils with various types of land use in Beijing, China. *Journal of Hazardous Materials, 186*, 2043–2050.

Zhang, C. (2006). Using multivariate analyses and GIS to identify pollutants and their spatial patterns in urban soils in Galway, Ireland. *Environmental Pollution, 142*, 501–511.

Zhuang, P., Zou, H., & Shu, W. (2009). Biotransfer of heavy metals along a soil-plant-insect-chicken food chain: Field study. *Journal of Environmental Sciences, 21*, 849–853.