Identification of heavy metal pollutants using multivariate analysis and effects of land uses on their accumulation in urban soils in Beijing, China

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Abstracts In order to evaluate the current state of the environmental quality of soils in Beijing, we investigated contents of 14 metals in Beijing urban soils inside the 5th ring road by even grids sampling. Statistic analyses were conducted to identify possible heavy metal pollutants, as well as the effects of land uses on their accumulation. Our results revealed that the urban soils in Beijing were contaminated by Cd, Pb, Cu, and Zn. Land uses and urbanization ages affected the accumulation of the four heavy metals in soils significantly. Soils in industrial areas have the highest average Cu and Zn contents, while Pb contents in park areas and Cd in agricultural areas are the highest. The accumulations of Pb and Zn in urban soils increase significantly with sampling plots approaching the city center. And Pb, Cd, and Zn contents in soils in traffic areas also tend to increase in the city center. However, residential areas have the lowest contents of all the four heavy metals.

Keywords Heavy metal pollution · Urban soils · Land use · Urbanization age

Introduction

Urban soil is an important component of urban ecosystems. One of the main characteristic of urban soil is that it is often contaminated by various kinds of pollutants such as heavy metals. Due to proximity to humans, accumulation of harmful substances in urban soils is of great concern (Manta et al. 2002; Maas et al. 2010). Strong accumulation of heavy metals such as Cu, Cd, Zn, Pb, and Hg in urban soils has been reported by many researchers (Mellor 2001; Madrid et al. 2002; Morton-Bermea et al. 2009). Heavy metals may be transferred to human bodies by way of ingestion, inhalation, and dermal contact, or through the food chain (Biasioli et al. 2006; Vrscaj et al. 2008).

Heavy metal contamination of Beijing urban soils has been widely reported at different scales. Early works in the 1970s and 1980s investigated the soil environmental quality, the distribution of heavy metals in soils in the west suburban areas and the wastewater irrigation areas in the east–south suburban, and the background values of agricultural soils in mountain and plain areas in Beijing (Fu et al. 2006). Since 2000, many investigations have been done on the heavy metal pollution in the wastewater irrigation areas in the southeastern suburbs of Beijing (Fu et al. 2006; Hu et al. 2006; Liu et al. 2005; Zhu 2001) and

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the newly developed city districts (Chen et al. 2005a; Zheng et al. 2003; 2005a, b, c, d). However, few works have been focused on the heavy metal pollution of soils in Beijing inner city. Chen et al. (2005b) investigated the pollution of Pb, Zn, and Cu in 30 urban parks in Beijing. Xia et al. (2011) investigated contents of Cd, Pb, Cu, Zn, Cr, and Ni in surface soils inside the 5th road in Beijing with six land use types, which included business area, classical garden, cultural and education area, public green space, residential area, and roadside area.

Zhang (2006) suggested that three criteria could be considered to identify pollutants: (1) relatively high contents, (2) different multivariate relationships from elements of natural origins, and (3) spatial patterns related to pollution sources. The comparison of the values measured with corresponding background values or existing guidelines published by environmental protection administrations is a way to assess the exceed contents of heavy metals. And multivariate analysis based on different classification criteria such as factor analysis, cluster analysis, and multidimensional scaling may classify elements into groups with close relationships. Morton-Bermea et al. (2009) pointed out that the use of geostatistical techniques in extensive urban areas has to be done with caution because urban contamination could be modified by multiple anthropogenic factors. Alternatively, statistical methods such as ANOVA and multiple comparisons were used in this study to assess the potential heavy metal pollutant (Bai et al. 2011).

The present study focused on the area inside the 5th ring road of Beijing by even grids sampling. With the rapid development of Beijing during recent decades, the land uses inside the 5th ring road in Beijing have been modified greatly. The purposes of this work were to investigate the current state of the environmental quality of soils in Beijing and to identify possible heavy metal pollutants using statistical analysis. And potential heavy metal pollution sources were also deduced.

Materials and methods

Study sites and soil sampling

The metropolitan Beijing is organized into six concentric squares centered at the Forbidden City

and expanded outward. Each ring is bordered by a circular express road for automobiles. The investigation included essentially the entire area inside of the 5th ring road where population is dense and traffic density is high. The study area covers six separate administrative districts of Beijing, including Dongcheng and Xicheng, located inside the 2nd ring road, and Chaoyang, Haidian, Fengtai, and Shijingshan, located between the 2nd and the 5th ring road (Fig. 1).

The study area was divided into 285 cells based on the 1 min of latitude $\times$ 1 min of longitude grids (approximately 1.9 $\times$ 1.0 km). One composite surface soil sample (0–10 cm) was obtained inside each grid by mixing five subsamples uniformly distributed within a representative 10 $\times$ 10-m open space inside the grid in 2008. All sampling sites were vegetated with lawn and weed except for agricultural areas. In total, 233 soil samples were collected due to restricted accessibility at some sites. Of the 233 samples, 25 represented public parks, 58 represented traffic areas in which ring roads have monthly average daily traffic more than 100 thousand and average traffic in all the roads is more than 5 thousand per hour, 38 represented schools and public areas, 28 represented agricultural areas within 2 km² of downtown, 15 represented industrial areas (due to the policy of relocating existing factories and most of these 15 factories are located in the downwind southwest quadrant of the city close to the downtown area), and 69 represented residential areas in which the average population density is about two thousand per square kilometer (Fig. 1).

Chemical analysis

Soil samples were air-dried and ground to pass through a 2-mm sieve. A quarter of the 2-mm sieved samples was further ground to pass through a 0.1-mm sieve. Soil samples (0.25 g, 0.1-mm-mesh sieve) were digested using a four-acid digestion: 10 ml HCl, 5 ml HNO₃, 5 ml HF, and 3 ml HClO₄. Addition digestion processes with the last three acids were needed according to the digested degree. Digested extracts were dissolved in 1:1 aqua regia and made up to 50 ml for ICP-AES analysis of Cu, Zn, Cr, Ni, Fe, Al, Mn, Co, Na, K, Mg, and Ca and 250 ml for ICP-MS analysis of Cd and Pb.

Fig. 1 The simplified urban map of Beijing with soil sampling locations

Quality assurance and quality control

Quality assurance and quality control procedures were conducted using the standard reference materials Geochemical Standard Soil (GSS-1). Recoveries of the six heavy metals were 89–103% for Cu, 93–110% for Zn, 90–111% for Cr, 88–101% for Ni, 95–101% for Cd, and 98–110% for Pb, respectively, and 95–119% for other eight elements. Duplicated samples were performed simultaneously for 10% of the soil samples in each array of assay, the standard deviation was ranged within 5%, and blank samples were also performed in each array of assay.

Statistic analysis

Contents of 14 metal elements were compiled to form a multi-element database using SPSS. Statistical analysis including factor analysis, cluster analysis, multidimensional scaling, ANOVA, multiple comparison, Pearson correlation analysis were performed using SPSS 17.0.

In the factor analysis, principle components with eigenvalues over 1 were extracted. Cluster analysis was

performed among 14 elements using between-group linkage method with Pearson correlation as the interval. Factor analysis classified elements based on the close relationships between them, while multidimensional scaling and cluster analysis were used to distinguish visually the similarities or the differences in-between elements by a derived stimulus configuration and a cluster tree, respectively. Derived stimulus configuration was obtained using Euclidean distance model, while a cluster tree was obtained based on Pearson's correlation coefficient.

ANOVA was used to assess the significant impacts of land uses on the accumulation of heavy metals in Beijing urban soil. Multiple comparisons were used to reveal significant differences of heavy metal contents in-between soils of land uses, while Pearson correlation analysis was used to suggest the close linear relationships between the accumulation of elements and between the accumulation of heavy metals and the distance from the city center.

Before factor analysis and cluster analysis, the raw data were standardized by Box–Cox transformation to the normality using Minitab 15. The data were also standardized to the Z score and then classified with

multidimensional scaling using Euclidean distance model.

Data transformation

In order to identify the potential heavy metal pollutants in Beijing urban soil, further analysis using multivariate statistics would be applied. However, the probability features of the data sets must be checked prior to performing further analysis (Zhang 2006). The shape parameters and results of the Kolmogorov–Smirnov (K–S) test for normality after Lilliefors significance correction for all the raw data, logarithmically transformed, and Box–Cox-transformed data were shown in Table 1. Of the raw data, only one element, Ca, can pass the K–S test for normality ($p > 0.05$). Log transformation and Box–Cox transformation improved the normality of the raw data. After log transformation and Box–Cox transformation, there were four (Cd, Zn, Mg, and Ni) and eight (Cu, Zn, Cr, Fe, Mg, Ca, Mn, and Ni) passing the K–S test for normality, respectively. For those elements (K, Na, Al, Co, and Pb) that could not pass the K–S test, the skewness values of the data sets were significantly reduced after the Box–Cox transformation.

Results and discussion

Heavy metal contents in Beijing urban areas

Table 2 summarized the statistical attributes of soil heavy metal contents in Beijing urban soil and corresponding background values. Except for Ni and Cr, the maximum values and SD of the other four elements are higher than the background, which suggested contamination of Cd, Pb, Cu, and Zn has occurred for at least some plots sampled in this study. The data were also compared with the first and second criteria of the Chinese Environmental Quality Standard for Soils (GB 15618–1995) (SEPAC 1995) (Table 3), in which class I criteria were suitable to keep natural background values, while class II could be used to the threshold values for protecting human health (Bai et al. 2011). The results showed that there was pollution of Cd, Pb, Cu, Zn, and Cr in Beijing urban soils. The Cu and Zn contents exceeded the first criterion of the environmental quality standards in 20% and 32.17% of the plots and exceeded the second criterion in 2.17% and 0.43% of the plots, respectively. For Cd, 7.30% of them exceeded the first criterion, while 0.86% of them exceeded the second criterion. For Pb and Cr, 9.87% and 0.87% of

Table 1 Shape parameters and results of Kolmogorov–Smirnov test after Lilliefors significance correction (K–S p) for element concentrations in soils

	Raw data			Log-transformed data			Box–Cox-transformed data		
	Skewness	Kurtosis	K–S p	Skewness	Kurtosis	K–S p	Skewness	Kurtosis	K–S p
Cu	5.26	31.88	0.00	1.83	5.94	0.00	0.09	0.12	0.09*
Cd	3.43	12.27	0.00	1.41	3.25	0.09*	0.42	3.52	0.01
Zn	1.87	6.16	0.00	0.39	0.43	0.2*	0.23	0.46	0.2*
Cr	2.10	8.21	0.00	1.19	2.88	0.00	−0.05	0.27	0.2*
K	2.27	15.28	0.00	0.93	8.80	0.00	0.24	6.90	0.00
Na	1.81	7.53	0.00	1.00	3.94	0.00	0.41	3.32	0.00
Fe	1.1	3.77	0.00	0.47	2.49	0.02	0.172	2.70	0.08*
Mg	0.46	0.96	0.04	−0.128	0.99	0.2*	−0.128	0.99	0.2*
Ca	0.28	0.57	0.2*	−0.64	0.62	0.00	−0.186	0.25	0.2*
Al	1.71	10.48	0.00	0.64	6.16	0.00	0.29	5.03	0.00
Mn	−3.06	19.42	0.00	−7.34	67.86	0.00	−0.08	1.17	0.2*
Ni	0.98	2.66	0.01	0.38	1.00	0.2*	0.12	0.43	0.2*
Co	−0.63	3.15	0.04	−2.26	12.06	0.00	0.32	1.58	0.04
Pb	5.33	42.84	0.00	0.92	3.77	0.00	0.15	3.88	0.01

* refers to significance at 0.05 level

Table 2 The statistical attributes of soil heavy metal concentrations in Beijing urban soil

	Number	Min	Median	Max	Mean	Geometric mean	SD
Cu	230	13.4	26.1	207.9	31.7	27.4	24.9
Background (1995)	<i>40</i>	<i>15</i>	<i>23.7</i>	<i>101.0</i>	<i>23.6</i>	<i>23.1</i>	<i>4.68</i>
Cd	233	0.003	0.11	0.98	0.13	0.11	0.09
Background (1995)	<i>40</i>	<i>0.005</i>	<i>0.073</i>	<i>0.339</i>	<i>0.074</i>	<i>0.0534</i>	<i>0.058</i>
Zn	230	29.4	84.5	322.3	92.9	86.6	38.2
Background (1995)	<i>40</i>	<i>48.2</i>	<i>97.5</i>	<i>226.0</i>	<i>102.6</i>	<i>97.2</i>	<i>35.37</i>
Cr	230	44.6	60.0	121.5	61.0	60.3	9.82
Background (1995)	<i>40</i>	<i>50.6</i>	<i>64.1</i>	<i>163.0</i>	<i>68.1</i>	<i>66.7</i>	<i>15.94</i>
Ni	230	17.8	23.8	39.0	24.0	23.4	3.19
Background (1995)	<i>40</i>	<i>17.0</i>	<i>27.4</i>	<i>48.9</i>	<i>29.0</i>	<i>28.2</i>	<i>7.45</i>
Pb	233	4.02	19.3	174.4	23.3	20.8	15.5
Background (1995)	<i>40</i>	<i>10.0</i>	<i>24.1</i>	<i>46.0</i>	<i>25.4</i>	<i>24.7</i>	<i>6.29</i>

Italicized letters refer to respective background

them exceeded the first criterion, respectively, but no plot exceeded the second criterion. For Ni, there was no plot showing excess of the first criterion.

A comparison was performed among studies of soil heavy metal investigation in the urban, suburban, rural, wastewater irrigation fields, and urban parks of Beijing in recent years (Hu et al. 2006; Chen et al. 2005a, b; Zheng et al. 2005a, b, c, d, 2006; Zhu 2001) (Table 4). The heavy metal contents observed in different works varied greatly, which may be attributed to the number of sample sites and methods of sampling and detection. It was suggested that the suburban and the wastewater irrigation fields of Beijing had higher average content of Cd, urban parks have higher average contents of Pb and Cu, while urban soil of Beijing has higher average content of Zn. As for the content of Cr, the average content in soils of Beijing at a province scale (Zheng et al. 2005c, 2006) was the lowest compared with areas in smaller scale such as urban and suburban areas.

Correlations among 14 metals in Beijing urban soils

The factor analysis was performed to investigate the relationship among the 14 metals analyzed. The principle components with eigenvalues larger than 1 were extracted with the loadings rotated for the maximum variance. A total of four factors were extracted, accounting for 72.8% of the total variance (Table 5). Factor 1 included four elements Cu, Zn, Cd, and Pb and accounted for about 21.0% of the total variance. Positive loadings of factor 1 corresponded to Cu and Zn, while Cd and Pb were negatively related to factor 1. Four elements (Fe, Al, K, and Na) and two elements (Ca and Mg) were positively related to factor 2 (19.0%) and factor 4 (18.4%), respectively. Factor 3, accounting for 14.2% of the variance, positively corresponded to Cr and Ni, while it negatively corresponded to Co and Mn.

Figure 2 illustrates the dendrogram (cluster tree) using cluster analysis for the elements. The 14 elements can be classified into two large groups:

Table 3 The first and second criteria of Chinese Environmental Quality Standard for Soils (GB 15618–1995) (SEPAC 1995)

	Cu	Cr	Ni	Zn	Pb	Cd
1st standard (mg/kg)	35	90	40	100	35	0.2
2nd standard (mg/kg) pH>7.5	100	250	60	300	350	0.6
$n \geq 1$ st standard (%)	20	0.87	0	32.17	9.87	7.30
$n \geq 2$ nd standard (%)	2.17	0	0	0.43	0	0.86

Values of the first criterion are equal to natural backgrounds

Table 4 Heavy metal means of data of Beijing reprinted in the literature

Author	Sample site	Number	Extraction solution	Cd	Pb	Cu	Zn	Cr	Ni
This study	Urban area	233	Aqua regia, HClO ₄ , HF	0.13	23.3	31.7	92.9	61.0	24.0
Hu et al. (2006)	Urban–rural transition zone of southern Beijing	70	Aqua regia, HClO ₄ , HF	0.24	18.8	26.1	61.2	67.8	24
Xia et al. (2011)	Urban area	127	Aqua regia, HClO ₄ , HF	0.192	39.5	34.4	89.3	60.3	25.9
Chen et al. (2005b)	Urban park	30	HNO ₃ , H ₂ O ₂		66.2	71.2	87.6		22.2
Zheng et al. (2005a, b, c, d; 2006) (geomatic mean)	Farmland, orchard, greenbelt, and nature soils	609	HNO ₃ , H ₂ O ₂	0.12	26.6	20.9	63.7	33.9	26.8
Zhu (2001)	Wastewater irrigation area in the suburban area of east–south Beijing	40		0.171	43.8	34.6	121	61.1	26.0
Chen et al. (2005a)	Beijing suburban (around 4th ring road)	220		0.168	38.3				

from Ca to Cd and from Al to Ni. However, the relationships of elements in each of the two groups were hard to explain, and the associations among elements were complicated. So the elements were further classified into four groups using a criteria value of rescaled distance between 15 and 20 (Fig. 2): group 1: Ca and Mg; group 2: Co, Mn, and Cd; group 3: Al, K, Fe, and Na; and group 4: Cu, Pb, Zn, Cr, and Ni. The metal classification from cluster analysis was consistent with the results from factor analysis in the following two groups: group 1 from cluster analysis

Table 5 Principal component loadings after rotation for the maximum variance

Elements	Factor 1	Factor 2	Factor 3	Factor 4
Ca	−0.129	−0.016	0.081	0.943
Cd	−0.766	−0.018	−0.080	−0.046
Co	−0.379	0.056	−0.564	0.020
Cr	0.110	0.085	0.793	0.091
Cu	0.791	−0.108	0.167	−0.157
Fe	0.015	0.723	0.445	−0.241
Mg	0.020	−0.364	−0.150	0.865
Mn	−0.073	−0.038	−0.844	0.176
Ni	0.373	−0.080	0.678	0.062
Pb	0.881	−0.084	0.141	−0.041
Zn	0.707	0.034	0.311	−0.058
Al	0.128	0.749	−0.012	−0.469
K	−0.020	0.877	0.029	−0.033
Na	−0.336	0.805	−0.297	0.040
Eigenvalue	2.935	2.672	2.587	1.994
% of variance	20.965	19.085	18.475	14.240

and factor 4 from factor analysis, group 3, and factor 2. However, groups 2 and 4 from cluster analysis were different from factors 1 and 3 from factor analysis in classifying the metals Co, Mn, Cd, Cu, Pb, Zn, Cr, and Ni.

Multidimensional scaling (ALSCAL) using Euclidean distance model was applied to further verify the classifying results above (Fig. 3). The analysis of scatter plot of linear fit suggested the multidimensional scaling in this study was quite valid. The multidimensional scaling showed that two groups, the group of Cu, Cd, Pb, and Zn and the group of Ni, Co, Cr, and Mn, could be perfectly classified, which was consistent with the results of factor analysis.

Results of comparison, factor analysis, and multidimensional scaling suggested that Cd, Pb, Cu, and

Fig. 2 Cluster tree of elements using cluster analysis based on Pearson's correlation coefficient

Fig. 3 Derived stimulus configuration of elements and its scatter plot of linear fit for elements

Zn were the main anthropogenic contaminants in Beijing urban soil. But results from cluster analysis showed those four heavy metals were in different groups. Researches indicate that Cr and Ni come from the same mineral, and they always associate with each other (Zheng et al. 2003, 2005c). A more detailed observation to the cluster analysis suggested that the difference in rescaled distance from Co and Mn to Cd and from Cu, Pb, and Zn to Cr and Ni was almost 5 (Fig. 3). So it is more reasonable that Cd belongs to the group of Cu, Pb, and Zn from factor analysis, while Cr and Ni belong to the group of Co and Mn.

Relationship between soil metal contents and distance from city center

There were significant negative relationships between factor 1 scores (corresponding to Cu, Cd, Pb, and Zn) and the distance from the city center (Table 6). Among the four metals, soil Pb and Zn contents significantly correlate to the distance from the city center ($p < 0.01$), indicating the content of these two heavy metals in surface soil increased with the

samples approaching city center. It was reported in several literatures that contents of Cd, Pb, Cu, and Zn in soils tended to increase as plots were sampled closer to the older inner city (Li et al. 2001; Mellor 2001; Madrid et al. 2002; Li et al. 2004; Zhang 2006; Yesilonis et al. 2008). Chen et al. (2005b) studied Pb and Cu contents in soils of 30 Beijing parks and revealed there were significant correlations between the locations (older historic center and newer districts) and contents of Pb and Cu.

Further analysis based on different land use types showed that Pb contents in residential areas, traffic areas, and schools were also significantly correlated with the distance from city center, while Cd and Zn contents in traffic areas and Cu content in parks related to the distance from city center. One of the pollution characteristics in urban soils is that ages of soils exposed to anthropogenic pollution such as traffic emissions and traffic burdens increase when approaching the city center. Our results suggested that the accumulation of Pb, Cd, and Zn in surface soils of Beijing was related to the traffic emission in some way.

Table 6 Person correlation coefficient of factor 1 and its related metal concentrations (milligrams per kilogram) to the distance from city center

	Whole	Resident	Traffic	Parks	Schools
Cd	-0.065	-0.110	-0.422**	-0.076	-0.015
Pb	-0.355**	-0.182*	-0.295*	-0.380	-0.441**
Cu	-0.123	-0.123	-0.045	-0.627**	-0.182
Zn	-0.216**	-0.138	-0.284*	-0.250	-0.277
Factor 1	0.318**				

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

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

Effects of land uses on the accumulation of heavy metals in Beijing urban soils

Table 6 summarized variations in the amounts of Cu, Pb, Zn, and Cd in Beijing urban soil under different land use pattern. The results of ANOVA showed that land use had significant impacts on the accumulation of heavy metals in Beijing urban soil. Cu and Zn had the highest average contents in industrial areas, while Pb contents in park areas were significantly higher compared with the other six land use types. Cd had the highest contents in agricultural areas. Residential

areas had the significantly lowest average contents of these four heavy metals.

The contamination of Cd, Cu, Pb, and Zn in urban soil usually came from gasoline, car components, oil lubricants, and industrial and incinerator emissions (Li et al. 2001). Although the ban of Pb-containing gasoline in Beijing has been more than 10 years, its impact on the content of Pb in urban soil may last for the coming years (Chen et al. 2005b). Elevated Pb content was detected in Beijing urban parks (Table 7), which was consistent with the report by Chen et al. (2005b), who found that most of the Beijing urban parks had Pb content in soil above corresponding background levels, and serious soil pollution of Pb in some Beijing urban parks was observed. Most of the urban parks of Beijing are located in areas of high-density population and traffic. Pb accumulation in urban parks from traffic pollution seemed inevitable and reasonable. In addition, most of the urban parks of Beijing have histories of hundreds of years and experienced many times of repair. The Pb contamination in urban soil may come from the deposition of house decoration waste such as paint (Chen et al. 2005b).

Cadmium has specific geochemistry property and pollution sources. The sources of Cd in soil may be from industrial and traffic emission by fuel and coal combustion, deposition of solid wastes such as plastics, and application of Cd-containing phosphate fertilizers (Yesilonis et al. 2008; Cao et al. 2009). It was reported that Cd contamination in agricultural soils of the southern urban–rural zone of Beijing and in the vegetable fields may come from the irrigation of the river water polluted by electroplating plants and the application of plastic sheets in farmland (Hu et al. 2006; Zheng 2005d). The application of Cd-containing phosphate fertilizer also might be a source of soil Cd

accumulation in urban parks and agricultural soil (Li et al. 2001; Bai et al. 2010). As shown in Table 7, Cd content in agricultural soil was the highest. Besides, parks and industrial areas of Beijing also had higher contents of Cd in soil (Table 7). Industrial emission and application of Cd-containing agricultural materials may be the major contribution sources.

The industrial areas had the highest average content of Zn in soils compared with other land use types. The results indicated that there are point pollution sources of Zn in Beijing soils.

In residential areas, heavy metal contents were generally lower than other land use types (Table 7). The results indicated the soil environmental quality for residential areas was good in the Beijing urban area. However, the heavy metal contents were relatively higher in city center areas with high density of human activity, suggesting that there are potential health risks from heavy metal contamination to people in Beijing.

Conclusion

Based on the systemic investigation inside the 5th ring road in Beijing and the following statistical analysis, we concluded:

1. The urban soils in Beijing were contaminated by Cd, Pb, Cu, and Zn, and the accumulation of these metals in soil was significantly affected by land uses and urbanization ages.
2. The accumulation of Pb and Zn increases with sampling plots approaching the city center, and Pb, Cd, and Zn contents in soils in traffic areas also tend to increase in the city center.

Table 7 Concentrations and multiple comparisons of heavy metals of different land use (milligrams per kilogram)

Element	Traffic	Resident	Park	Industrial	Schools	Wasteland	Agricultural
Pb Means $\pm$ SD	23.0 $\pm$ 14.9	19.6 $\pm$ 6.99	39.6 $\pm$ 25.2	26.3 $\pm$ 8.97	22.9 $\pm$ 7.19	23.8 $\pm$ 10.0	19.2 $\pm$ 6.68
Multiple comparisons	b	b	a	b	b	b	b
Zn Means $\pm$ SD	93.8 $\pm$ 42.0	88.7 $\pm$ 37.0	94.9 $\pm$ 53.8	113.4 $\pm$ 46.9	91.5 $\pm$ 37.2	89.0 $\pm$ 30.0	89.2 $\pm$ 33.1
Multiple comparisons	ab	b	ab	a	ab	ab	ab
Cd Means $\pm$ SD	0.116 $\pm$ 0.058	0.106 $\pm$ 0.038	0.155 $\pm$ 0.158	0.153 $\pm$ 0.103	0.129 $\pm$ 0.049	0.153 $\pm$ 0.057	0.167 $\pm$ 0.204
Multiple comparisons	bc	c	ab	abc	abc	abc	a
Cu Means $\pm$ SD	31.4 $\pm$ 24.4	26.0 $\pm$ 10.0	34.11 $\pm$ 12.7	51.1 $\pm$ 52.34	38.05 $\pm$ 41.0	33.1 $\pm$ 7.38	25.7 $\pm$ 11.5
Multiple comparisons	bc	c	abc	a	ab	abc	bc

3. Soils in park areas have high Pb contents. And Cd accumulation in agricultural areas was the highest. Residential areas have the lowest contents of all the four heavy metals.

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References

- Bai, J. H., Xiao, R., Cui, B. S., Zhang, K. J., Wang, Q. G., Liu, X. H., et al. (2011). Assessment of heavy metal pollution in wetland soils from the young and old reclaimed regions in the Pearl River Estuary, South China. *Environmental Pollution*, 159, 817–824.
- Bai, J. H., Yang, Z. F., Cui, B. S., Gao, H. F., & Ding, Q. Y. (2010). Some heavy metals distribution in wetland soils under different land use types along a typical plateau lake, China. *Soil and Tillage*, 106, 344–348.
- Biasioli, M., Barberis, R., & Ajmone-Marsan, F. (2006). The influence of a large city on some soil properties and metals content. *Science of the Total Environment*, 356, 154–164.
- Cao, H. C., Luan, Z. Q., Wang, J. D., & Zhang, X. L. (2009). Potential ecological risk of cadmium, lead and arsenic in agricultural black soil in Jilin Province, China. *Stochastic Environment Research and Risk Assessment*, 23, 57–64.
- Chen, J. Z., Chen, J., Xie, X. J., Mao, J. G., & Zhang, X. L. (2005a). The distribution character of heavy metals in peri-urban area of Beijing. *Acta Pedologica Sinica*, 42(1), 149–152.
- Chen, T. B., Zheng, Y. M., Lei, M., Huang, Z. C., Wu, H. T., Chen, H., et al. (2005b). Assessment of heavy metal pollution in surface soils of urban parks in Beijing, China. *Chemosphere*, 60, 542–551.
- Fu, H., Wu, Y. H., & Wei, L. H. (2006). Distribution and evaluation of heavy metals in agricultural soil in southern area of Beijing. *Journal of Agro-Environment Science*, 25(1), 182–185.
- Hu, K. L., Zhang, F. R., Li, H., Huang, F., & Li, B. G. (2006). Spatial patterns of soil heavy metals in urban-rural transition zone of Beijing. *Pedosphere*, 16(6), 690–698.
- Li, X. D., Poon, C. S., & 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. *Environmental Pollution*, 129, 113–124.
- Liu, W. H., Zhao, J. Z., Ouyang, Z. Y., Soderlund, L., & Liu, G. H. (2005). Impacts of sewage irrigation on heavy metal distribution and contamination in Beijing, China. *Environment International*, 31, 805–812.
- Maas, S., Scheifler, R., Benslama, M., Crini, N., Lucot, E., Brahmia, Z., et al. (2010). Spatial distribution of heavy metal concentrations in urban, suburban and agricultural soils in a Mediterranean city of Algeria. *Environmental Pollution*, 158, 2294–2301.
- Madrid, L., Barrientos, E. D., & Madrid, F. (2002). Distribution of heavy metal contents of urban soils in parks of Seville. *Chemosphere*, 49, 1301–1308.
- Manta, D. S., Massimo, A., Bellanca, A., Neri, R., & Sprovieri, M. (2002). Heavy metals in urban soils: a case study from the city of Palermo (Sicily), Italy. *Science of the Total Environment*, 300, 229–243.
- Mellor, A. (2001). Lead and zinc in the Wallsend Burn, and urban catchment in Tyneside, UK. *Science of the Total Environment*, 269, 49–63.
- 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.
- SEPAC (State Environmental Protection Administration of China) (1995) Chinese environmental quality standard for soils (GB15618-1995)
- Vrscaj, B., Poggio, L., & Marsan, F. A. (2008). A method for soil environmental quality evaluation of management and planning in urban areas. *Landscape and Urban Planning*, 88, 81–94.
- 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, 2043–2052.
- Yesilonis, I. D., Pouyat, R. V., & Neerchal, N. K. (2008). Spatial distribution of metals in soils in Baltimore, Maryland: role of native parent material, proximity to major roads, housing age and screening guidelines. *Environmental Pollution*, 156, 723–731.
- 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.
- Zheng, Y. M., Chen, T. B., Zheng, G. D., Cheng, H., Lou, J. F., Wu, H. T., et al. (2005a). Soil copper accumulation under different land use types—the case of Beijing. *Journal of Natural Sources*, 20(5), 690–696.
- Zheng, Y. M., Cheng, T. B., Cheng, H., Zheng, G. D., & Lou, J. (2005b). Lead accumulation in soils under different land use types in Beijing city. *Acta Geographica Sinica*, 60(5), 791–797.
- Zheng, Y. M., Cheng, T. B., Zheng, G. D., Huang, Z. C., & Lou, J. F. (2005c). Chromium and nickel accumulations in soils under different land use in Beijing municipality. *Resources Science*, 27(6), 162–166.
- Zheng, Y. M., Lou, J. F., Chen, T. B., Chen, H., Zheng, G. D., Wu, H. T., et al. (2005d). Cadmium accumulation in soils for different land uses in Beijing. *Geographical Research*, 24(4), 542–548.
- Zheng, Y. M., Song, B., Cheng, T. B., Zheng, G. D., & Huang, Z. C. (2006). Zinc accumulation and pollution risk in soils under different land use types in Beijing. *Journal of Natural Resources*, 21(1), 64–72.
- Zheng, Y., Chen, H., Chen, T., Zheng, G., Wu, H., & Zhou, J. (2003). Spatial distribution patterns of Cr and Ni in soils of Beijing. *Quaternary Sciences*, 23(4), 436–445.
- Zhu, G. Z. (2001). Pollution of heavy metals on soils in east-south area of Beijing and its remediation. *Agro-environmental Protection*, 20(3), 164–166. 188.