Journal of Soils and Sediments (2019) 19:148–158
https://doi.org/10.1007/s11368-018-2011-6

SOILS, SEC 2 • GLOBAL CHANGE, ENVIRON RISK ASSESS, SUSTAINABLE LAND USE • RESEARCH ARTICLE

Impacts of urbanization and landscape patterns on the accumulation of heavy metals in soils in residential areas in Beijing

Tian Xie[1,2] · Meie Wang[1] · Weiping Chen[1] · Herman Uwizeyimana[1,2]

Received: 29 September 2017 / Accepted: 23 April 2018 / Published online: 2 June 2018

Abstract

Purpose In metropolitan cities, residential land use is most closely related to inhabitants' daily life among all land use types. The aim of this study is to determine the influence of urbanization and landscape attributes on heavy metal accumulation in urban residential areas.

Materials and methods Soil samples under different vegetative cover types were collected from 115 residential areas of Beijing. Samples were digested using a four-acid mixture (HCl, HNO_3, HF, and $HClO_4$). We analyzed contents of nine elements, including Cd, Co, Cr, Cu, Mn, Ni, Pb, V, and Zn. Meanwhile, urbanization and landscape information, including age of residential community, distance to the city center, population density, distance to the nearest building, height of the building, and green space area, were recorded at each sampling site. Statistical analytic tools and geospatial analysis techniques were employed to further examine the relationship between urbanization and landscape indicators and accumulation of heavy metals in urban residential soils.

Results and discussion Our results revealed that Cu, Cd, Pb, and Zn were the most accumulated heavy metals in the study area. Their mean concentrations were 23.5, 0.139, 27.3, and 96.2 mg/kg, respectively. The spatial distribution of heavy metal accumulation was also analyzed. Urbanization indicators, including age of residential community, distance to the city center, population density, and distance from sampling point to the nearest residential building, were found significantly correlated with the contents of Cu, Cd, Pb, and Zn in residential soils. However, height of the residential building and green space area had little impact on intercepting air pollutants and lowering the heavy metal concentration in residential soils. Moreover, different vegetative types were found to have significant influence on the heavy metal accumulation. Arbor was more efficient than other types in capturing atmospheric suspended particulates which contain heavy metals.

Conclusions In this study, we identified Cu, Cd, Pb, and Zn as the most accumulated heavy metals, illustrated the spatial distribution characteristics of heavy metal accumulation, and further elaborated the influence of urbanization and landscape patterns, as well as the vegetative cover types on the heavy metal accumulation. The accumulations of Cu, Pb, and Zn in urban residential soils were probably dependent on atmospheric deposition.

Keywords Heavy metal · Residential areas · Spatial patterns · Urbanization · Vegetation

1 Introduction

Heavy metal emissions triggered by urbanization and industrialization processes have become an irreversible process in the global biogeochemical cycling of chemical elements. Due to rapid urbanization and industrialization, heavy metal pollution in urban soils has been a serious environmental concern in many cities of developing countries. Risks of environmental pollution in urban settings have been associated with the urbanization process, especially in metropolitan areas (Kaye et al. 2006). Unlike agricultural and forest counterparts, urban

---

Responsible editor: Maxine J. Levin

Electronic supplementary material The online version of this article (https://doi.org/10.1007/s11368-018-2011-6) contains supplementary material, which is available to authorized users.

✉ Weiping Chen
wpchen@rcees.ac.cn

[1] State Key Laboratory for Urban and Regional Ecology, Research Center for Eco-Environmental Sciences, Chinese Academy of Sciences, Beijing, China

[2] University of Chinese Academy of Sciences, Huairou, China

soils have different functions (Grimm et al. 2008; Pickett et al. 2011; Ajmone-Marsan et al. 2016). Numerous studies have demonstrated that green space in urban areas is an indispensable resource for promoting public health by restoring mental fatigue, providing location for recreational and physical activities, serving as esthetic appreciation, and releasing people from high pressures (Maas et al. 2006; Schipperijn et al. 2010). Thus, urban soils in green space have more direct and indirect effects on inhabitants' health due to the detrimental environmental impact of heavy metal contamination (Miguel et al. 1997; Madrid et al. 2002; Chen et al. 2005). Therefore, it is imperative to understand heavy metal contamination in urban residential soils as well as its relationship to urbanization.

A great number of studies have shown a direct temporal and spatial relationship between urbanization and soil heavy metal contamination (Wang et al. 2012a; Peng et al. 2013). Urban soils have been experiencing different levels of urbanization stress. The accumulation of heavy metals in the urban soils can be highly affected by the urban artificial landscape (e.g., building, tree, and road) (Schwarz et al. 2012; Castanheiro et al. 2016). It has also been proved that vegetation plays a significant role in hampering heavy metals from accessing the urban soils. More research has been carried out to prove that vegetation serves as a natural surface for depositing, absorbing, and immobilizing the airborne particles (Weathers et al. 1995; Weathers et al. 2000; Weathers et al. 2006; Castanheiro et al. 2016).

In metropolitan areas, compared with other kinds of land use types, residential land use is the most intimately related to inhabitants' daily life. However, it has been reported that more and more residential soils have suffered serious heavy metal pollution (Schwarz et al. 2012; Aelion et al. 2014). Anthropogenic emissions on residential soils may originate from domestic activities, such as coal combustion and disposal of electric equipment, which proved to be a critical source of heavy metal pollution (Harrison et al. 1981; Wong et al. 2006; Lincoln et al. 2007; Christoforidis and Stamatis 2009).

It has been acknowledged that different urban land use types can affect heavy metal accumulation in urban soils (Wang et al. 2012b; Liu et al. 2016). However, most previous research on individual land use has focused on heavy metal concentration in soils of urban parks, farmland, and industrial zones (Madrid et al. 2002; Chen et al. 2005; Gu et al. 2016). Systemic investigations related to the effect of urbanization factors on heavy metal accumulation in urban residential soils are few. Therefore, we investigate trace elements from Beijing residential soils with the primary objectives being: (1) to identify the main pollutants and determine the state of the environment quality of residential soils, (2) to analyze the spatial distribution characteristics of heavy metal accumulations in residential areas, (3) to explore the relationship between urbanization and landscape parameters and the heavy metal contents, and (4) to discover the impact of vegetative cover types on the heavy metal accumulations in residential areas.

2 Materials and methods

2.1 Study area

The metropolitan built-up areas of Beijing, which is centered by the Forbidden City, are enclosed by the 5th ring road and fully urbanized. Serving as the oldest and most developed section of the city, the urban built-up areas include six administrative districts: Dongcheng, Xicheng, Chaoyang, Fengtai, Shijingshan, and parts of the Haidian Districts. Based on the official statistics of local government (http://www.bjstats.gov.cn/tjsj/cysj/201511/t20151109_311727.html), the population of Beijing has exceeded 21.7 million and was still growing up until 2015. Open green space sporadically scatters the city in terms of public parks, roadside trees and greenbelts, residential and school attached green land, urban wood, and other green fields. The total green area has covered 48.4% of the urban surface up until 2015 (http://www.bjyl.gov.cn/zwgk/tjxx/201604/t20160401_178532.html).

2.2 Soil sampling and chemical analysis

According to the development characteristics of Beijing, the study area is divided by major ring roads into four different sections, including Section 1 (the region between the 4th and the 5th ring roads), Section 2 (between the 3rd and the 4th), Section 3 (between the 2nd and the 3rd), and Section 4 (inside the 2nd ring road). According to the location and size, the four sections are further divided into 39 sub-sections, including 15 sub-sections from Section 1, 12 from Section 2, 8 from Section 3, and 4 from Section 4. Based on the construction age of residential communities in each sub-section, 2–5 residential communities with their representative landscapes were finally selected in Fig. 1.

The selected soil sample locations were divided into six vegetative cover categories as (a) arbor, (b) shrub, (c) herb, (d) arbor-herb, (e) shrub-herb, and (f) arbor-shrub-herb compound land, representing all the vegetative cover types in residential areas of Beijing (Fig. S1, Electronic Supplementrary Material). Vegetative cover types were geographically distributed in the study area (Fig. 1). Soil sampling sites within each vegetative cover types were selected as follows: The arbor vegetative cover type made up of 23 sampling points, and samples were collected under deciduous species as far as possible if allowed; the shrub vegetative cover type made up of 12 sampling points, stood for low woody perennial plant located beside the lanes and promenades in the residential communities; the herb type made up of 19 sampling points, represented

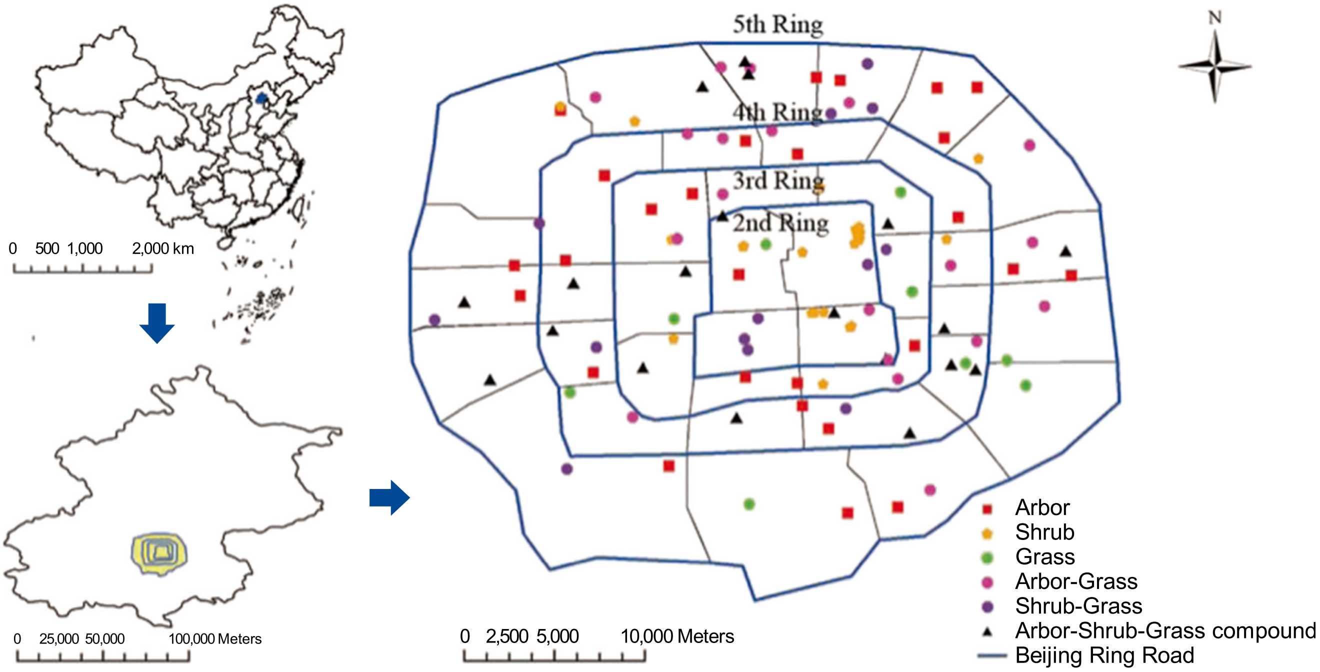

Fig. 1 Study area and residential sample locations with different vegetative cover types

the green space with lawn of grass covers; the arbor-herb type with 14 sampling points, included the sites where trees stand with grass understory; the shrub-herb vegetative type with 19 sampling points, was made up of shrubs accompanied with herbaceous plants tiled; and arbor-shrub-herb compound land with 28 sampling points, consisted of trees, low woody perennial plants, and grassland with multilayer structure. In each sampling site, a representative composite was achieved by mixing five sub-samples of surface soil (0–10 cm depth). Altogether, 115 samples were collected.

The soil samples were air-dried, ground, and passed through a 0.149 mm × 0.149 mm meshed sieve to remove roots and other debris. The 0.25 g of soil aliquots were kept in Teflon pots containing 10 mL HCl overnight and then were digested in the acid solution of HNO_3 (5 mL), HF (5 mL), and $HClO_4$ (3 mL). The final digested extracts were dissolved by 2 mL of 1:1 HCl and then terminated by the dilution with ultrapure water to 50 mL for detection of Cr, Co, Cu, Mn, Ni, and V using ICP-OES and to 250 mL for determination of Cd, Pb, and Zn using ICP-MS.

Soil pH was measured in distilled water at a dry soil with a weigh to volume ratio of 1:2.5. Soil organic matter (SOM) was determined using HCl treatment and dry combustion method by an elemental analyzer (Soon and Abboud 1991).

2.3 Quality assurance and quality control

Geochemical Standard soil, GSS-1 was referred as quality assurance and quality control (QA/QC) procedures. Reagent blank was also brought along with every batch of the chemical analyses. The recoveries in the standards were 93–110% for Cd, 79–92% for Co, 80–116% for Cr, 79–92% for Cu, 90–110% for Mn, 86–97% for Ni, 80–101% for Pb, 81–87% for V, and 92–111% for Zn. Duplicates of 10% soil samples and reagent blanks were included in each array of samples. The analysis would be rejected if outcomes of duplicates exceeded ± 10% of one another.

2.4 Urban spatial parameters collection and statistics analysis

To examine the relationship between heavy metal accumulation in residential soils and urbanization indicators, information of the residential areas was collected. The age of residential communities, distance from sampling point to the nearest building, and height of the building were investigated, measured, and recorded at each sampling site. The population data on each block was collected from the statistics of 2010 national census. The data of distances to the city center, population density, and green space area of sampling residential communities were visualized, delineated, and calculated from the interpreted remote sensing of IKONOS satellite imagery of Beijing built-up areas of 2014 using ArcGIS 10.0. The spatial distributions of the main heavy metals, as covariates of population density and age of the residential community, were predicted according to the Cokriging interpolation method using ArcGIS 10.0 (Peng et al. 2016).

Statistics analysis was carried out by SPSS 20.0. The nonparametric Kolmogorov-Smirnov (K-S) test ($p > 0.05$) was employed for examining the statistical distribution of the data. Principal component analysis (PCA) was applied to determine the residential contamination as well as cluster analysis (CA). Spearman and Partial correlation analysis was carried out to calculate correlation between the heavy metal contents and the urbanization parameters. OriginPro 8 was employed for regression analysis between the heavy metal contents and the urbanization parameters. Besides, variance analysis (ANOVA) was conducted to investigate heavy metal accumulation affected by vegetative cover types. The least significant difference (LSD) and post hoc Tamhane's T2 were applied in multiple comparison tests for variables with homogeneity and non-homogeneity of variance, respectively.

3 Results and discussion

3.1 Descriptive statistics

A statistical description of elemental concentrations of residential soils in Beijing is summarized in Table 1. When we compared measured concentrations to corresponding background values, only the mean of Cd was greater than its background value. The means of the rest elements were either lower than (Co, Cr, Mn, Ni, V, and Zn) or similar to (Cu and Pb) their background values. Most of the measured maximum values were also below (Co, Cr, Mn, Ni, V) or similar to (Cd and Cu) their corresponding background values. However, Pb and Zn had maximum concentrations more than twice their corresponding backgrounds. It indicated the external accumulation of the two elements in the surface soils. The coefficients of variation (CV) of the elements in this study ranged from 10.0% to 69.2%. The CVs of Cu, Pb, and Zn were rather greater. While the remaining elements, especially Co, Mn, and Ni were obviously weaker, indicating that their contents were quite constant.

3.2 Pollution identification

PCA and CA were carried out to classify elements from similar sources and identify the main pollutants in residential soils. Results of PCA analysis are shown in Table 2. All the metals were explained by three principal components taking more than 82% of the total variance. Factor 1 was primarily loaded with Cu, Cd, Pb, and Zn, explaining 32% of total variance. Factor 2 was mainly loaded with Cr, Mn, and V and factor 3 was represented by Co and Ni. The same groups as those by PCA were classified by CA: group 1 for Cu, Cd, Pb, and Zn; group 2 for Cr, Mn, and V; and group 3 for Co, and Ni (Fig. 2). It could be deduced from PCA and CA that the emission sources of Cu, Cd, Pb, and Zn were probably similar, same as the elements of Cr, Mn and V, and Co and Ni. Comparison with the backgrounds, we could conclude that Cu, Cd, Pb, and Zn were the dominating heavy metals accumulated in residential areas of Beijing. Thus, the emphasis of this study will further shift to the investigation of patterns of the dominating elements.

Comparing the means of the main heavy metals in residential areas to those in other land use types and the whole city from previous studies (Chen et al. 2005, 2010; Sun et al. 2011; Wang et al. 2012b), the means of Cu, Cd, and Pb in residential areas in Beijing were mostly less than those in other land use types in Beijing (Table 3). Mean concentration of Pb in residential soils was greater than those of agricultural soil and the whole city, while mean value of Zn was larger than that in other land use types.

3.3 Spatial distribution pattern

The spatial distribution of the four elements identified as the most accumulated heavy metals was illustrated in Fig. 3. The concentration of each heavy metal was categorized into three intervals based on its range. The spots or regions with the highest or lowest concentration intervals of each metal are highlighted. In general, all heavy metals were distributed unevenly in Beijing residential areas. The highest concentration almost accumulated in the center, particularly within the 3rd ring road of Beijing. Heavy metal contents in residential areas within the inner rings were higher than those located in outer ones. Most heavy metals had their lowest values at the northwest quadrant in the study area.

Specifically, for the concentrations of Cu (Fig. 3a), Pb (Fig. 3b), and Zn (Fig. 3c), apart from the high contaminated region within the 2nd ring road, other highly contaminated spots were separated at northeast, northwest, and southeast quadrants within/or near 3rd ring roads. In contrast, the relevant concentrations in residential soils between the 4th and 5th ring roads, especially in the west part and southeast quadrant of Beijing, were relatively low. The similar distributions of the metals in the corresponding figures suggested that they might probably have similar emission resources (Fig. 3).

For Cd, its distribution in residential soils was generally higher in the southeast, while the lower Cd concentration was found in the northwest part of Beijing (Fig. 3b). The Cd content was not obviously accumulated in the center. High Cd concentration spots were distributed sporadically in different directions.

3.4 Related influencing factors

General description of related influencing factors is shown in Table S1 (Electronic Supplementrary Material). Ages of the residential communities in this work ranged from 4 to 36 years, averaged 18.5 years. Distances to the city center were from 1.4 to 12.8 km with an average of 7 km. Population densities in investigated residential communities ranged from 4.6 to 77.1 thousand persons/km^2, with a mean value of 20.1 thousand persons/km^2. Distances from sampling points to the nearest buildings ranged from 1 to 40 m, averaged 8.2 m. Heights of

Table 1 Descriptive statistics of heavy metal concentrations of residential soils in Beijing (mg/kg)

	Mean	Minimum	Maximum	Median	S.D.	CV(%)
Cd						
This study	0.139	0.071	0.358	0.130	0.045	32.3
Background value[a]	0.074	0.005	0.339	0.073	0.058	78.4
Relative variation	0.878	13.200	0.056	0.781		
Co						
This study	6.66	5.10	8.72	6.666	0.67	10.0
Background value[a]	15.6	10.4	28.0	14.2	4.45	28.5
Relative variation	− 0.573	− 0.510	− 0.689	− 0.531		
Cr						
This study	48.3	13.6	86.5	45.2	17.6	36.4
Background value[a]	68.1	50.6	163	64.4	15.9	23.3
Relative variation	− 0.291	− 0.731	− 0.469	− 0.298		
Cu						
This study	23.5	8.20	103	18.6	15.2	64.7
Background value[a]	23.6	15.0	101	23.7	4.68	19.8
Relative variation	− 0.004	− 0.453	0.020	− 0.215		
Mn						
This study	509	259	736	528	106	20.8
Background value[a]	685	206	1370	705	254	37.2
Relative variation	− 0.257	0.257	− 0.463	− 0.221		
Ni						
This study	16.1	11.9	32.6	16.0	2.2	13.8
Background value[a]	29.0	17	48.9	27.4	29.0	100
Relative variation	− 0.445	− 0.300	− 0.333	− 0.416		
Pb						
This study	27.3	11.7	101	21.2	15.6	57.3
Background value[a]	25.4	10	46	24.1	6.29	24.8
Relative variation	0.075	0.170	1.196	− 0.120		
V						
This study	63.8	26.1	99.5	61.1	19.5	30.1
Background value[a]	79.2	57.7	134	75.7	17.8	22.5
Relative variation	− 0.194	− 0.548	− 0.257	− 0.416		
Zn						
This study	96.2	25.0	521	76.5	66.6	69.2
Background value[a]	103	48.2	226	97.5	35.4	34.5
Relative variation	− 0.066	− 0.481	1.305	0.032		

[a] CNEMC (China National Environmental Monitoring Center) 1990

the residential buildings ranged from 3 to 90 m, and averaged 28.3 m. And, the green space areas in residential communities were from 5.7 to 7009.8 m^2, with an average of 784.7 m^2.

3.4.1 Urbanization factors

Results of Spearman correlation analysis showed that Cu, Cd, Pb, and Zn in residential soils followed similar trends regarding to each residential urbanization indicator in Table 4. Heavy metal concentrations were significantly positively correlated with construction age and population density of residential community but negatively correlated with distance to the city center and distance to the nearest building (Table 4). Besides, linear regressions between the logarithm of concentrations of Cu, Cd, Pb, and Zn, and the logarithm of urbanization indicators were further explored in Fig. S2 (Electronic Supplementrary Material).

Spearman correlation and linear regression analyses between heavy metals and population density of residential community in Table 4 and Fig. S2c (Electronic Supplementrary Material) indicated the impacts of the resident activities. Additionally, heavy metal accumulations in residential soils were significantly influenced by the distance to the nearest

Table 2 Total variance explained and rotated component matrix for the elements of residential soil in Beijing (significant principle component loadings are italicized)

Element	Rotated component		
	1	2	3
Cd	*0.693*	− 0.004	0.312
Co	0.186	0.026	*0.937*
Cr	0.082	*0.948*	0.005
Cu	*0.940*	0.026	0.028
Pb	*0.828*	0.063	0.082
Mn	0.154	*0.861*	0.171
Ni	− 0.002	0.058	*0.937*
V	0.027	*0.965*	− 0.063
Zn	*0.874*	0.255	− 0.091
Percentage of variance	32.00	29.38	21.15
Cumulative percent	32.00	61.38	82.53

Extraction method: principle component analysis. Rotation method: Varimax with Kaiser normalization

building (Table 4 and Fig. S2d, Electronic Supplementrary Material). Previously, Schwarz et al. (2012) have examined the correlation between concentration of Pb in soil and distance to the nearest building, and speculated that the significant correlation between Pb concentration in soil and distance to the nearest building was due to the Pb-based paint source at the sampling buildings in residential areas. In our study, the same pattern was also applied to Cu, Cd, and Zn. Specifically, Cd and Pb widely originated from the painting and pigment in old buildings before the prohibition of lead-based painting. Besides, Cu, Cd, Pb, and Zn might commonly exist in the backer of PVC windows. Cu and Zn are important elements serving as the stabilizers for soldering. For security reasons, the windows of the apartments living in lower floors were widely equipped with soldered burglary-resisting bars, which were enriched with alloyed metal including Cu, Cd, Pb, and Zn.

Spatial distribution of heavy metals (Cu, Cd, Pb, and Zn) with respect to spatial urbanization patterns, including age of residential community, distance to the city center, population density, and distance to the nearest building, is displayed in Fig. 3 as well as Figs S3, S4, and S5 (Electronic Supplementrary Material). Spots with older residential communities, shorter distances to the city centers, denser population districts, and closer distance to the residential buildings were always located at higher concentration accumulated regions. Thus, statistically significant correlations between the heavy metal concentrations and the relevant urbanization factors could be presented in terms of spatial data. Result of the spatial correlations between the concentrations and urbanization indicators also justified the previous analyses.

3.4.2 Landscape factors

The residential buildings and residential green space may serve as barriers against atmospheric deposition of pollutants on residential soils. Statistical analysis showed that there was significant Spearman correlation between the heavy metal contents and building height and green space area ($P < 0.01$).

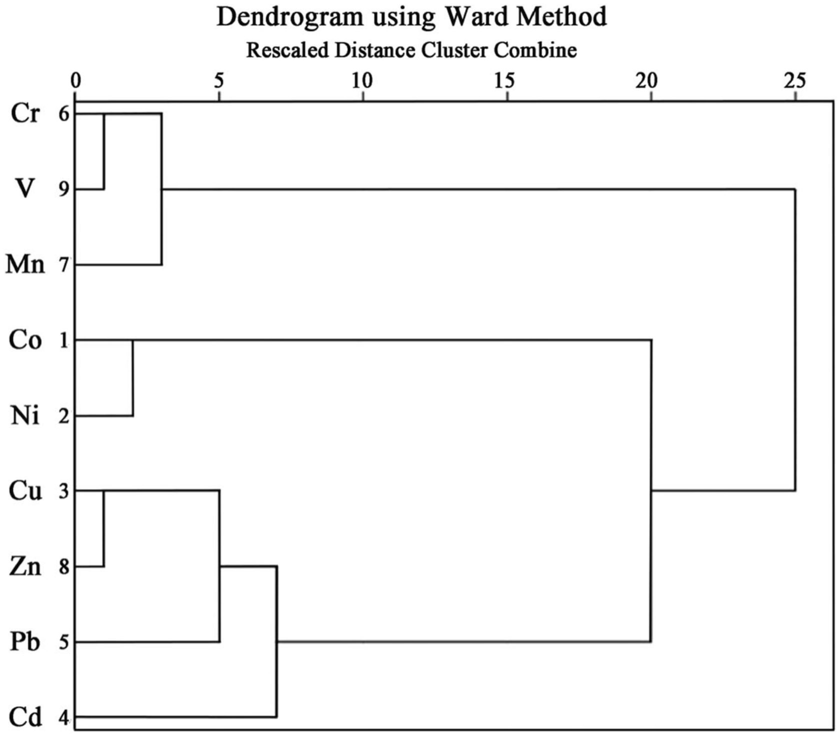

Fig. 2 Hierarchical dendogram for the elements obtained by Ward's method in residential soil in Beijing

Table 3 Comparison of the heavy metal concentrations between residential and other land use soils in Beijing

	Number	Cu	Cd	Pb	Zn
Mean values in this study (mg/kg)	115	23.5	0.139	27.3	96.2
General soil of Beijing (mg/kg) (Wang et al. 2012b)	233	31.7	0.13	23.3	92.9
Roadside soil of Beijing (mg/kg) (Chen et al. 2010)	80	29.7	0.215	35.4	92.1
Park soil of Beijing (mg/kg) (Chen et al. 2005)	30	71.2	–	66.2	87.6
Agricultural soil of Beijing (mg/kg) (Sun et al. 2011)	98	24.4	0.147	25.7	–

However, during the last several decades, the construction, development, and renewal of Beijing have expanded from inner ancient town outward the outer rings. Therefore, the younger residential communities usually construct taller buildings and own larger green land area.

To get rid of the disturbances of urbanization process, partial correlations were carried out by controlling the urbanization factor (Table 4). The results of partial correlation disagreed with Spearman. The partial correlations showed that the heavy metal accumulation has significant correlation neither with the height of the nearest building nor the green space area in residential areas in Beijing.

The result showed that both the residential building height and residential green space area actually provided little information on the cause of contamination abatement in urban environment. The reason behind higher soil contamination in the residential communities with shorter height buildings and less green space area might primarily be explained by the legacies of long-term human inhabitation and urbanization levels rather than the functions of residential building and green space area in residential communities. Additionally, surface soils in those newly built residential communities were more likely to be displaced by deep or alien soil in the course of construction. Hence, the results from partial correlations

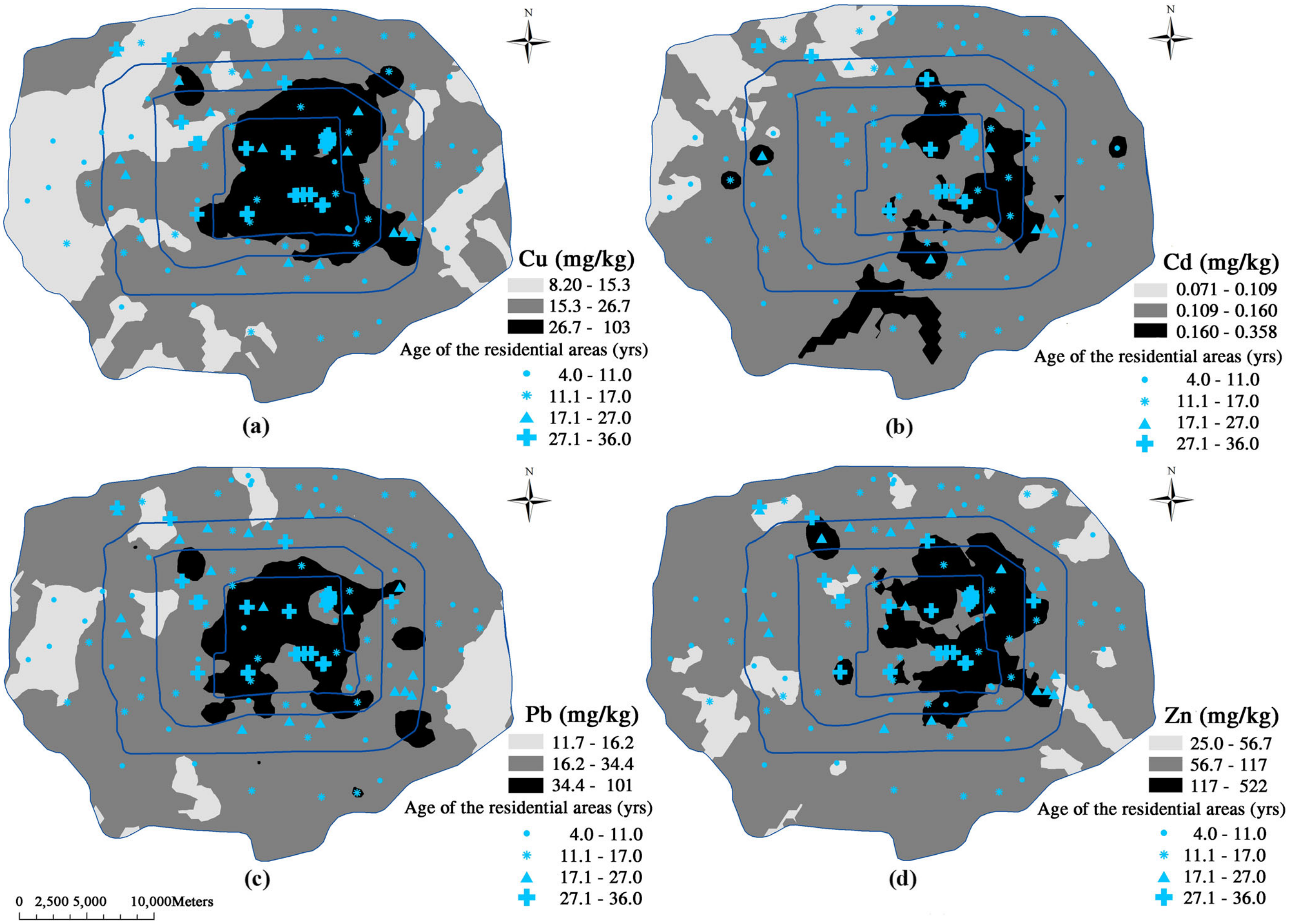

Fig. 3 Geochemical maps correlating the spatial distribution of heavy metals with the spatial patterns of urbanization factor (age of residential community)

Table 4 Correlations and partial correlations between heavy metals and urbanization indicators

		Cu	Cd	Pb	Zn
AR	Spearman's rho	0.462**	0.329**	0.517**	0.394**
DC		− 0.603**	− 0.359**	− 0.580**	− 0.527**
PD		0.354**	0.196*	0.366**	0.356**
DB		− 0.515**	− 0.394**	− 0.527**	− 0.420**
pH		− 0.350**	− 0.340**	− 0.318**	− 0.249**
SOC		0.724**	0.632**	0.751**	0.589**
HB	Spearman's rho	− 0.389**	− 0.325**	− 0.467**	− 0.375**
	Partial correlation	− 0.046	− 0.194	− 0.139	− 0.101
GA	Spearman's rho	− 0.383**	− 0.313**	− .429**	− .340**
	Partial correlation	− 0.113	− 0.184	− 0.188	− 0.092

AR age of residential community, *DC* distance to the city center, *PD* population density of residential community, *DB* distance from sampling point to the nearest residential building, *SOM* soil organic matter, *HB* height of the nearest residential building, *GA* green space area

*Correlation is significant at the 0.05 level

**Correlation is significant at the 0.01 level

were more reliable than those from Spearman ones. The two landscape factors, height of the nearest building and green space area, did not contribute to the interception of heavy metal contamination, at least they were not the main factors. Though various urban parameters were discussed in previous studies (Mielke 1999; Mielke et al. 2004; Yesilonis et al. 2008), some important landscape indicators in residential communities, e.g., height of the nearest building and green space area, were often ignored. The result in this section could be served as an important complementary evidence for heavy metal accumulation patterns in urban context.

3.4.3 Soil environmental factors

The ranges of pH and soil organic matter (SOM) in residential soils were from 7.98 to 8.84 and from 0.500 to 5.200, with coefficients of variance of 1.87 and 28.4%, respectively, suggesting that pH was evenly distributed in the study area, while SOM concentrations were more variable. Besides, the results of Spearman correlation analysis between heavy metals and soil environmental factors are displayed in Table 4. The results showed that all the elements were significantly negatively correlated with soil pH. Although it has been known that the metals could become immobile in alkaline soil environment (McBride 1981; Tiller et al. 1979; Kabata-Pendias 2001), the range of soil pH in this study was narrow. It has also been documented that the residential soils in Northern China are generally alkaline (Xi 1998; Liu et al. 2016). Therefore, pH would not strongly fluctuate the solubility of heavy metals, and the trend from Spearman analysis might not be reliable.

Meanwhile, the results also indicated that SOM had a positive correlation with heavy metal contents. It has been reported that mobilized Cu could be captured by SOM and the Pb content of surficial soil would be primarily ascribed to the organic matter in the earth surface (Fleming et al. 1968; Kabata-Pendias 2001). Besides, SOM was also capable of bonding Cd and Zn in stable forms (John 1972; Kabata-Pendias 2001). Therefore, organic matter should be considered as an important sink of the relevant elements.

3.4.4 Impact of vegetative cover types

The algebra mean values and variances of soil heavy metal accumulation under different vegetative cover types are summarized in Table 5.

Table 5 Multiple comparison of soil heavy metal accumulation under different vegetation cover types

	Cu (mg/kg)	Cd (mg/kg)	Pb (mg/kg)	Zn (mg/kg)
Arbor	37.2 a	0.154 ab	39.4 a	142.2 a
Shrub	24.3 b	0.147 abc	22.5 b	93.1 b
Herb	28.6 b	0.122 bc	22.5 b	81.0 b
Arbor-herb	27.6 b	0.119 c	30.1 ab	76.4 b
Shrub-herb	27.0 b	0.124 bc	20.8 b	82.5 b
Arbor-shrub-herb compound	23.2 b	0.162 a	26.1 b	94.0 b

Means followed by different letters indicate significant difference according to ANOVA ($P < 0.05$)

The mean contents of Cu, Pb, and Zn in soil under arbor cover were significantly higher than those under most of the rest vegetative cover types, respectively ($P < 0.05$). The concentration of Cu in soil under arbor cover (37.2 mg/kg) was significantly greater than those under other cover types ($P < 0.05$). None of Cu concentration under other types exceeded 30 mg/kg. The mean Pb concentration under arbor cover type was 39.4 mg/kg, while the Pb concentrations under most of the other vegetative cover types were around 20 mg/kg. Also, the mean Zn concentration under arbor type reached 142.2 mg/kg, and Zn concentrations under other vegetative cover types were below 100 mg/kg.

The arbor type has a relatively high profile to capture atmospheric suspended particulates containing heavy metals (Peng et al. 2012). Heavy metals in atmospheric deposition would be rinsed during precipitation and directly accumulate in soil. Therefore, arbor cover type was more efficient to capture atmospheric contaminations than other types. Moreover, more attention has been paid to the planted landscape in residential areas of Beijing leading to regular and productive management of grass and shrub by property rangers. On the contrary, less care has been taken of the soil under arbors compared with other types. For instance, leaves, litter material, and trash under arbors might be left unattended. As a result, soils under arbor vegetation were easier to accumulate some heavy metals. Besides, several investigations on the balances of Cu, Pb, and Zn in different ecosystem have also demonstrated that the atmospheric input of the metals greatly exceed their output including leaching and biomass production (Kabata-Pendias 2001). Thus, it indicates that the accumulation of Cu, Pb, and Zn may be highly dependent on the atmospheric deposition in residential areas of Beijing.

The soil under compound vegetative cover type should have had a significant effect in intercepting the heavy metal contamination from atmospheric deposition. However, none of the soil under the multi-layers with different compound vegetative cover accumulated quite high heavy metal contents except for Cd (Table 5), probably because the understory plants with the soils under multiple layers were carefully attended. The grass clippings, defoliation, and litters would be removed before the heavy metals migrated into the soil with the decomposition of detritus (Peng et al. 2012). Additionally, the soil under compound vegetative cover type might receive more intensive anthropogenic disturbance than that under arbor type. Thus, the compound type with multiple layers did not exhibit any superior in intercepting heavy metals to the other vegetation cover types in residential areas in this study.

In contrast, the mean concentration of Cd in soil under arbor-shrub-herb compound type (0.162 mg/kg) was discovered to be greater than that in herb (0.122 mg/kg), arbor-herb (0.119 mg/kg), and shrub-herb (0.124 mg/kg) at $P < 0.05$. However, the concentration of Cd in arbor type did not prevail over other vegetation cover types. The fact that Cd did not show the same trends as other metals did suggests that only a little proportion of accumulation of Cd in residential areas might originate from atmospheric deposition. The local contamination might contribute more to the accumulation of Cd, such as wastewater discharge or residential waste dumping. Besides, though Cd is a non-essential element for metabolic process, it could be effectively absorbed by the root and leaf system of plants (Kabata-Pendias 2001). Therefore, the Cd in local soil might also be disturbed by the absorption of the type and biomass of the plants.

The impact of vegetative cover types on heavy metal accumulation in this study presented detailed evidence of heavy metal accumulation features in urban areas. Other studies have proven that leaves of common species are able to accumulate atmospheric heavy metals (Tomašević et al. 2004; Rodríguez et al. 2007). The effect of arbor species on removal of atmospheric particulates has also been demonstrated (Paul et al. 2000; Tallis et al. 2011; Nowak et al. 2013). Arbor plants could thus be served as indicators of heavy metal pollutions in urban regions (Miguel et al. 1997; Rodríguez Martín et al. 2015). Schwarz et al. (2012) found no significant difference between different vegetative categories, which is contradictory to the present study. The concentrations of heavy metals in the previous study remained extremely high compared to those in this study. The ability of capturing particles by trees was thus prone to be hidden even swamped by the elevated concentrations. In this study, the landscape features including vegetative cover types could be considered to influence the heavy metal accumulation in urban areas.

4 Conclusions

This study investigated soil heavy metals from 115 sampling sites in urban residential areas of Beijing. The results revealed the potential influence of urbanization factors and green space patterns on the accumulation of heavy metal in urban residential soils. The main findings are as follows:

1. Cu, Cd, Pb, and Zn were identified as the most accumulated heavy metals in residential soils in Beijing. In general, their concentrations were lower than those in other urban land use types.
2. Spatial distribution of heavy metal accumulation in residential soils was described. Severe heavy metal accumulated areas were mostly located within the 3rd ring road especially in the center of Beijing. While the outer rings suffered less contamination.
3. Urbanization indicators, including age of the residential community, distance to the city center, population density, and distance from sampling point to the nearest residential building, were found significantly correlated with the contents of Cu, Cd, Pb, and Zn.

4. The height of buildings and green space area generally had little to do with contamination interception in residential soils, which at least are not the main factors.
5. We also found that the concentrations of Cu, Cd, Pb, and Zn had significant differences among various vegetative cover types in the residential areas. The contents of Cu, Pb, and Zn in residential soils probably originated from atmospheric deposition. While the Cd content might be less atmospheric deposition dependent.

Acknowledgements We acknowledge the financial support of the Natural key R&D Program of China (2017YFC0505702), the Natural Science Foundation of China (41601556), and the Chinese Academy of Sciences (QYZDB-SSW-DQC034).

References

Aelion CM, Davis HT, Lawson AB, Cai B, McDermott S (2014) Temporal and spatial variation in residential soil metal concentrations: implications for exposure assessments. Environ Pollut 185: 365–368

Ajmone-Marsan F, Certini G, Scalenghe R (2016) Describing urban soils through a faceted system ensures more informed decision-making. Land Use Policy 51:109–119

Castanheiro A, Samson R, De Wael K (2016) Magnetic- and particle-based techniques to investigate metal deposition on urban green. Sci Total Environ 571:594–602

Chen TB, Zheng YM, Lei M, Huang ZC, Wu HT, Chen H, Fan K-K, Yu K, Wu X, Tian Q-Z (2005) Assessment of heavy metal pollution in surface soils of urban parks in Beijing, China. Chemosphere 60: 542–551

Chen X, Xia X, Zhao Y, Zhang P (2010) Heavy metal concentrations in roadside soils and correlation with urban traffic in Beijing, China. J Hazard Mater 181:640–646

Christoforidis A, Stamatis N (2009) Heavy metal contamination in street dust and roadside soil along the major national road in Kavala's region, Greece. Geoderma 151:257–263

CNEMC China National Environmental Monitoring Center (1990) Background values of elements in soils of China (in Chinese)

Fleming GA, Walsh T, Ryan P (1968) Some factors influencing the content and profile distribution of trace elements in Irish soils. Proc 9th Int Congr Soil Sci 2:341

Grimm NB, Faeth SH, Golubiewski NE, Redman CL, Wu J, Bai X, Briggs JM (2008) Global change and the ecology of cities. Science 319:756–760

Gu Y-G, Gao Y-P, Lin Q (2016) Contamination, bioaccessibility and human health risk of heavy metals in exposed-lawn soils from 28 urban parks in southern China's largest city, Guangzhou. Appl Geochem 67:52–58

Harrison RM, Laxen DPH, Wilson SJ (1981) Chemical associations of lead, cadmium, copper, and zinc in street dusts and roadside soils. Environ Sci Technol 15:1378–1383

John MK (1972) Cadmium adsorption maxima of soils as measured by the langmuir isother. Can J Soil Sci 52:343–350

Kabata-Pendias A (2001) Trace elements in soils and plants, 3rd edn. CRC Press, Boca Raton

Kaye JP, Groffman PM, Grimm NB, Baker LA, Rv. P (2006) A distinct urban biogeochemistry? Trends Ecol Evol 21:192–199

Lincoln JD, Ogunseitan OA, Shapiro AA, Saphores J-DM (2007) Leaching assessments of hazardous materials in cellular telephones. Environ Sci Technol 41:2572–2578

Liu R, Wang M, Chen W, Peng C (2016) Spatial pattern of heavy metals accumulation risk in urban soils of Beijing and its influencing factors. Environ Pollut 210:174–181

Maas J, Verheij RA, Groenewegen PP, de Vries S, Spreeuwenberg P (2006) Green space, urbanity, and health: how strong is the relation? J Epidemiol Commun Health 60:587–592

Madrid L, Díaz-Barrientos E, Madrid F (2002) Distribution of heavy metal contents of urban soils in parks of Seville. Chemosphere 49: 1301–1308

McBride MB (1981) Forms and distribution of copper in solid and solution phases of soil. In: Loeragan JF, Robson AD, Graham RD (eds) Copper in soils and plants. Academic Press, New York, p 25

Mielke H (1999) Lead in the inner cities. Am Sci 87:62

Mielke HW, Wang G, Gonzales CR, Powell ET, Le B, Quach VN (2004) PAHs and metals in the soils of inner-city and suburban New Orleans, Louisiana, USA. Environ Toxicol Pharmacol 18:243–247

Miguel ED, Llamas JF, Chacón E, Berg T, Larssen S, Røyset O, Vadset M (1997) Origin and patterns of distribution of trace elements in street dust: unleaded petrol and urban lead. Atmos Environ 31:2733–2740

Nowak DJ, Hirabayashi S, Bodine A, Hoehn R (2013) Modeled PM2.5 removal by trees in ten U.S. cities and associated health effects. Environ Pollut 178:395–402

Paul BK, Freer-Smith PH, Gail T (2000) Particulate pollution capture by urban trees: effect of species and windspeed. Glob Chang Biol 995–1003

Peng C, Ouyang Z, Wang M, Chen W, Jiao W (2012) Vegetative cover and PAHs accumulation in soils of urban green space. Environ Pollut 161:36–42

Peng C, Ouyang Z, Wang M, Chen W, Li X, Crittenden JC (2013) Assessing the combined risks of PAHs and metals in urban soils by urbanization indicators. Environ Pollut 178:426–432

Peng C, Wang M, Chen W (2016) Spatial analysis of PAHs in soils along an urban–suburban–rural gradient: scale effect, distribution patterns, diffusion and influencing factors. Sci Rep_UK 6:37185

Pickett STA, Cadenasso ML, Grove JM, Boone CG, Groffman PM, Irwin E, Kaushal SS, Marshall V, McGrath BP, Nilon CH, Pouyat RV, Szlavecz K, Troy A, Warren P (2011) Urban ecological systems: scientific foundations and a decade of progress. J Environ Manag 92:331–362

Rodríguez Martín JA, De AC, Ramosmiras JJ, Gil C, Boluda R (2015) Impact of 70 years urban growth associated with heavy metal pollution. Environ Pollut 196:156–163

Rodríguez N, Amils R, Jiménez-Ballesta R, Rufo L, Fuente V (2007) Heavy metal content in *Erica andevalensis*: an endemic plant from the extreme acidic environment of Tinto River and its soils. Arid Land Res Manag 21:51–65

Schipperijn J, Stigsdotter UK, Randrup TB, Troelsen J (2010) Influences on the use of urban green space—a case study in Odense, Denmark. Urban For Urban Green 9:25–32

Schwarz K, Pickett STA, Lathrop RG, Weathers KC, Pouyat RV, Cadenasso ML (2012) The effects of the urban built environment on the spatial distribution of lead in residential soils. Environ Pollut 163:32–39

Soon YK, Abboud S (1991) A comparison of some methods for soil organic carbon determination. Commun Soil Sci Plan 22:943–954

Sun J, Zhang G, Dong W, Han P, Lu A (2011) Annual variability analysis and evaluation of heavy metals in Beijing agricultural soil, China. J Agro-Environ Sci 30:899–903 (in Chinese)

Tallis M, Taylor G, Sinnett D, Freer-Smith P (2011) Estimating the removal of atmospheric particulate pollution by the urban tree canopy of London, under current and future environments. Landscape Urban Plan 103:129–138

Tiller KG, Nayyar VK, Clayton PM (1979) Specific and non-specific sorption of cadmium by soil clays as influenced by zinc and calcium. Soil Res 17:17–28

Tomašević M, Rajšić S, Đorđević D, Tasić M, Krstić J, Novaković V (2004) Heavy metals accumulation in tree leaves from urban areas. Environ Chem Lett 2:151–154

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

Wang M, Markert B, Chen W, Peng C, Ouyang Z (2012b) 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

Weathers KC, Lovett GM, Likens GE (1995) Cloud deposition to a spruce forest edge. Atmos Environ 29:665–672

Weathers KC, Lovett GM, Likens GE, Lathrop R (2000) The effect of landscape features on deposition to Hunter Mountain, Catskill Montains, New York. Ecol Appl 10:528–540

Weathers KC, Simkin SM, Lovett GM, Lindberg SE (2006) Empirical modeling of atmospheric deposition in mountainous landscapes. Ecol Appl 16:1590–1607

Wong CSC, Li X, Thornton I (2006) Urban environmental geochemistry of trace metals. Environ Pollut 142:1–16

Xi CF (1998) Chinese soils. Chinese Agriculture Press, Beijing, pp 24–288 (In Chinese)

Yesilonis ID, Pouyat RV, Neerchal NK (2008) Spatial distribution of metals in soils in Baltimore, Maryland: role of native parent material, proximity to major roads, housing age and screening guidelines. Environ Pollut 156:723–731

http://www.bjstats.gov.cn/tjsj/cysj/201511/t20151109_311727.html, Accessed Sep 13, 2017

http://www.bjyl.gov.cn/zwgk/tjxx/201604/t20160401_178532.html, Accessed Sep 13, 2017