Heavy metals in urban soils with various types of land use in Beijing, China

Xinghui Xia*, Xi Chen, Ruimin Liu, Hong Liu

School of Environment, Beijing Normal University/State Key Laboratory of Water Environment Simulation, Beijing 100875, China

A R T I C L E   I N F O

Article history:
Received 20 April 2010
Received in revised form 16 July 2010
Accepted 22 December 2010
Available online 30 December 2010

Keywords:
Urban soils
Heavy metals
Land use
Beijing

A B S T R A C T

Heavy metal concentrations of Cd, Cr, Cu, Ni, Pb and Zn were investigated for 127 urban soil samples collected from business area (BA), classical garden (CG), culture and education area (CEA), public green space (PGS), residential area (RA) and roadside area (RSA) in Beijing. The distribution of Cd, Cu, Pb and Zn was mainly affected by anthropogenic sources, with their mean concentrations much higher than the background values of Beijing, while Cr and Ni were from natural sources. Among the 6 types of land use, the concentrations of Cd, Cu, Pb and Zn in CG were significantly higher than those in the other 5 types of land use (p < 0.05), which were due to their historical use such as pigments, wood preservation and brassware. For the other 5 types of land use except CG, the mean concentration of Cd in RSA was significantly higher than those in BA, CEA, PGS and RA (p < 0.05), suggesting Cd was mainly from traffic sources. The distribution maps revealed that the concentrations of Cu, Pb and Zn showed decreasing trends from the center to the suburb of Beijing, they increased with the age of the urban area.

© 2011 Elsevier B.V. All rights reserved.

1. Introduction

Urban soils have some specific characteristics such as unpredictable layering, poor structure, and high concentrations of trace elements [1,2]. Although urban soils are not used for farming, as pollutants in urban soils can be easily transferred into humans through ingestion, inhalation, or dermal routes, etc., they will pose a health risk to urban residents. Due to the high population density and intensive anthropogenic activities, urban soils have been severely disturbed. Consequently, a great number of environmental problems have emerged, among which the heavy metal pollution remains as a major issue. The pollutants can be released in many ways such as vehicle emission, chemical industry, coal combustion, municipal solid waste, the sedimentation of dust and suspended substances in the atmosphere [3]. The concentrations of Cu, Pb and Zn in general are considered to be affected by traffic sources [4–6], and Cd might be associated with industrial activities [7]. These emissions have continuously added heavy metals to urban soils and they will remain present for many years even after the pollution sources have been removed.

The heavy metals in urban soils have a direct influence on public health [8]. Previous studies have revealed that human exposure to metals such as As, Pb and Hg will lead to their accumulation in the fatty tissues and affect the central nervous system [9–11]. Furthermore, the high concentrations of heavy metals in urban soils have severely disturbed the natural geochemical cycling of the urban ecosystem [5]. Therefore, much attention has been paid to the issues relating to urban soil contamination with heavy metals during the past decades [12–14], and the researches on heavy metals in urban soils have mainly focused on the level investigation. However, the research on the heavy metal distribution in different types of land use is limited [15,16]. As the pollutants in soils with different types of land use may exert different impact on public health [17,18], the study on the heavy metal concentrations in different types of land use of urban soils is desired.

Beijing is the political, economic and cultural center of China, with a history of over 1000 years and the residents of more than 10 million. Several researches have investigated the heavy metal concentrations in the suburban soils [19,20] and urban park soils [21] of Beijing. These studies showed that contamination of some heavy metals has occurred in suburban soils, and the accumulation was readily apparent in the urban park soils, especially Cu and Pb. However, the heavy metal concentrations in urban soils and those in different types of land use in Beijing remain unknown. In addition, as there is currently no soil quality criteria of heavy metal concentrations in urban soils for different types of land use in China, the investigation on heavy metals in urban soils with various types of land use in Beijing will provide scientific data and basis in this regard.

In this study, the distribution of Cd, Cr, Cu, Ni, Pb and Zn in urban soils of Beijing and the differences of their concentrations in 6 types of land use, including business area (BA), classical garden (CG), culture and education area (CEA), public green space (PGS), residential area (RA) and roadside area (RSA), were investigated. The maps of the 6 observed heavy metals were made to identify their spatial pat-
terns in the region, and the possible sources of these heavy metals were identified through multivariate statistical analysis.

2. Materials and methods

2.1. Study area

Beijing, the capital of China, is situated at the northern tip of the roughly triangular North China Plain, with its center located at 39.9N and 116.4E. As one of the four municipalities in China, it consists of 18 administrative districts (counties), among which 8 districts constitute the urban area. The urban area of Beijing is situated in the south-central part of the municipality and occupies an expanding part of the municipality's area. It spreads out of the concentric ring roads, of which the 5th Ring Road passes through several satellite towns. The city has a typical monsoon-influenced climate, characterized by hot, humid summers due to the East Asian monsoon, and generally cold, windy, dry winters due to the vast Siberian anticyclone. Its annual temperature is about 11.5 °C and the annual precipitation is about 600 mm. In the past three decades, Beijing has been undergoing a fast economic development and urban construction in China, during which the urban population has reached over 15 million.

2.2. Sample collection

Some studies have focused on heavy metal distributions in garden, park, roadside soil, residential area, and commercial area in urban areas [15,16,18]. In addition, soil quality criteria of heavy metal concentrations have been established for different types of land use including residential area, commercial area, industry area and agriculture area in UK [22] and Canada [23]. For Beijing city, there are many CEAs and PGSs in urban area. Therefore, according to the previous studies and the practical situation of Beijing, 6 types of land use including BA, CG, CEA, PGS, RA and RSA were selected in this study based on their different functions. Although CEA, RA and BA are all built up areas, human activities and the pollutant sources may be different from each other.

Each type of land use contained at least 8 sampling sites, with each site having a consistent land use. We assure all the sampling sites were distributed as evenly as possible in the urban area of Beijing. A total of 127 topsoil samples (0–20 cm) were collected during April to May 2008 with a stainless steel shovel. The coordinates of the sample location were recorded with a GPS, and the sampling location is shown in Fig. 1. A total of 8 samples were collected in BA, 9 samples were collected in CG, 9 samples were collected in CEA, 12 samples were collected in PGS, and 12 samples were collected in RA. In RSA, 77 samples were collected from both sides of 10 roads, which were expressed by double lines in Fig. 1. The numbers of sub-samples (more than 5) were determined based on the area of sampling site. The larger the area was, the more the sub-samples were collected, and the sub-samples were fairly well-distributed on each site. Each road contained 4–12 sampling sites according to the in situ situation, which were within 30 m distant from the road. For the other 5 types of land use, the soil samples were collected far away from the road (far greater than 30 m). All the samples collected were kept in sealed kraft packages respectively to avoid contamination and transported to the laboratory immediately.

2.3. Sample preparation and analysis

The soil samples were dried indoors at room temperature, the impurities such as stones and tree leaves were removed from them; the samples were then ground to pass through a 0.15 mm nylon sieve for analysis. A small portion of each sample (0.25 g) was transferred into a Teflon beaker (50 ml) containing concentrated HNO3 (5.0 ml), HF (10.0 ml), and HClO4 (2.0 ml). The solution was heated for 3 min at 200 °C; the beaker was then removed from the heat and allowed to cool. Concentrated HNO3 (5.0 ml), HF (10.0 ml), and HClO4 (2.0 ml) were added to the beaker again, and the solution was heated at 200 °C for 10 min. After that, the beaker was covered and allowed to stand for 12 h, and then heated until the fume of HClO4 disappeared. Immediately 8 ml aqua regia was added to the beaker, the solution was heated until the residual volume was 2–3 ml, and the wall of the beaker was washed with 10 ml Milli-Q water. The solution was then transferred from the beaker to a volumetric polypropylene tube (25 ml) and the solution was made up

![Fig. 1. Sample location of urban soils in Beijing.](image_url)
to the mark with dilute nitric acid. The concentrations of Cd, Cr, Cu, Ni and Pb were determined with ICP-MS (X Series II, Thermo Fisher Scientific), and the concentration of Zn was determined with ICP-OES (IRIS Intrepid II, Thermo Fisher Scientific).

BC content in soil samples was determined with the chemo-thermal oxidation method [24]. The soil samples were acidified in the silver capsules with 1 M HCl (stop adding until gas evolution was no longer observed) to remove inorganic carbon and dried overnight at 40 °C, the organic carbon was then removed during a thermal oxidation procedure at 375 °C in a tube furnace for 24 h in the presence of excess oxygen. Finally, BC content in soil samples was determined by an elemental analyzer (Vario El, Elementar Analysensysteme GmbH, Germany).

The quality assurance and quality control (QA/QC) procedures were conducted by using standard reference materials; GSS-1, GSS-2, GSS-3 and GSS-8 (Geochemical Standard Soil). Recoveries of the 6 observed heavy metals were between 95–103% for Cd, 94–107% for Cr, 92–106% for Cu, 97–102% for Ni, 95–105% for Pb and 96–108% for Zn, respectively. Duplicated samples were performed simultaneously for 20% of the soil samples, the standard deviation ranged within 5%, and blank samples were also performed throughout all the experiments.

2.4. Statistical analysis and spatial distribution maps

Descriptive data analysis, principal component analysis (PCA) and cluster analysis (CA) were carried out with EXCEL 2003 (Microsoft Inc., Redmond, USA) and SPSS v.16.0 (SPSS Inc., Chicago, USA). In the PCA, the principal components were calculated based on the correlation matrix, the eigen values more than 1 were observed, and VARIMAX normalized rotation was also applied. In CA, the data were standardized to Z score and then classified using the Ward’s method, and the distance measure used in CA was the Squared Euclidean distance. Nonparametric tests were conducted with KOLMOGOROV–SMIRNOV test for normality (K–S p > 0.05), and their mean concentrations were comparable to the soil background values of Beijing and China. As shown in Table 1, the mean and geometric mean of each heavy metal were lower than the guideline values of China and Canada [23,27]. Only 7.1% of Cd concentrations, 2.3% of Cu concentrations and 1.6% of Zn concentrations exceeded their corresponding guideline values of China, and all the Pb concentrations were lower than the guideline values of China and Canada [23,27]. Only 7.1% of Cd concentrations, 2.3% of Cu concentrations and 1.6% of Zn concentrations exceeded their corresponding guideline values of China, and all the Pb concentrations were lower than the guideline values of China. In addition, no Cd concentration of the urban soil samples exceeded the soil guideline value of UK (1.8 mg/kg) [22].

Compared with heavy metal concentrations in other cities around the world (Table 2), the concentrations of Cd, Cu, Pb and Zn in urban soils of Beijing were relatively low. The mean concentration of Cr was higher than most of the reported values, which may be due to the high background value of Cr in Beijing (60.84 mg/kg).

### Table 1

<table>
<thead>
<tr>
<th>City</th>
<th>Cd</th>
<th>Cr</th>
<th>Cu</th>
<th>Ni</th>
<th>Pb</th>
<th>Zn</th>
</tr>
</thead>
<tbody>
<tr>
<td>Naples, Italy</td>
<td>0.11</td>
<td>74</td>
<td>-</td>
<td>262</td>
<td>251</td>
<td></td>
</tr>
<tr>
<td>Palermo, Italy</td>
<td>0.68</td>
<td>34</td>
<td>63</td>
<td>17.8</td>
<td>202</td>
<td>138</td>
</tr>
<tr>
<td>Bangkok, Thiland</td>
<td>0.29</td>
<td>26.4</td>
<td>61.7</td>
<td>24.8</td>
<td>47.8</td>
<td>118</td>
</tr>
<tr>
<td>Seville, Spain</td>
<td>0.39</td>
<td>39</td>
<td>68</td>
<td>22</td>
<td>137</td>
<td>145</td>
</tr>
<tr>
<td>Madrid, Spain</td>
<td>0.75</td>
<td>72</td>
<td>14</td>
<td>161</td>
<td>210</td>
<td></td>
</tr>
<tr>
<td>Seoul, Korea</td>
<td>0.51</td>
<td>84</td>
<td>-</td>
<td>240</td>
<td>271</td>
<td></td>
</tr>
<tr>
<td>Turbo, Finland</td>
<td>0.20</td>
<td>17.9</td>
<td>19.15</td>
<td>12.45</td>
<td>20</td>
<td>72.5</td>
</tr>
<tr>
<td>Damascus, Syria</td>
<td>0.51</td>
<td>30</td>
<td>35</td>
<td>10</td>
<td>84</td>
<td></td>
</tr>
<tr>
<td>Hong Kong, China</td>
<td>0.62</td>
<td>23.1</td>
<td>23.3</td>
<td>12.4</td>
<td>94.6</td>
<td>125</td>
</tr>
<tr>
<td>Shenyang, China</td>
<td>0.42</td>
<td>51.26</td>
<td>-</td>
<td>75.29</td>
<td>137.99</td>
<td></td>
</tr>
<tr>
<td>Shanghai, China</td>
<td>0.52</td>
<td>107.9</td>
<td>59.25</td>
<td>31.14</td>
<td>70.69</td>
<td>301.4</td>
</tr>
<tr>
<td>Beijing, China</td>
<td>0.192</td>
<td>60.27</td>
<td>34.43</td>
<td>25.87</td>
<td>39.50</td>
<td>89.63</td>
</tr>
</tbody>
</table>

### Table 2

The descriptive statistics of heavy metal concentrations in urban soils of Beijing are summarized in Table 2. The skewness values of Cd, Cu, Pb and Zn were 2.24, 3.80, 2.39 and 2.57, respectively, revealing the strongly positively skewed distribution. After the log-arithmetic transformation was applied to the raw data of Cd, Cu and Zn, the skewness values reduced to 0.68, 1.49, 1.09 and 1.19, respectively. The log-transformed data of Cd, Cu, Pb and Zn passed the Kolmogorov–Smirnov test for normality (K–S p > 0.05), so they followed the log normal distributions. Due to the strongly skewed distribution, geometric means were used for Cd, Cu, Pb and Zn. The geometric means of Cd, Cu, Pb and Zn in urban soils of Beijing were much higher than the soil background values of Beijing [25] and China [26]. In contrast, Cr and Ni followed the normal distributions (K–S p > 0.05), and their mean concentrations were comparable to the soil background values of Beijing and China.

#### 3. Results and discussion

#### 3.1. Heavy metal concentrations in urban soils

The descriptive statistics of heavy metal concentrations in urban soils of Beijing are summarized in Table 2. The skewness values of Cd, Cu, Pb and Zn were 2.24, 3.80, 2.39 and 2.57, respectively, revealing the strongly positively skewed distribution. After the log-arithmetic transformation was applied to the raw data of Cd, Cu and Zn, the skewness values reduced to 0.68, 1.49, 1.09 and 1.19, respectively. The log-transformed data of Cd, Cu, Pb and Zn passed the Kolmogorov–Smirnov test for normality (K–S p > 0.05), so they followed the log normal distributions. Due to the strongly skewed distribution, geometric means were used for Cd, Cu, Pb and Zn. The geometric means of Cd, Cu, Pb and Zn in urban soils of Beijing were much higher than the soil background values of Beijing [25] and China [26]. In contrast, Cr and Ni followed the normal distributions (K–S p > 0.05), and their mean concentrations were comparable to the soil background values of Beijing and China. As shown in Table 1, the mean and geometric mean of each heavy metal were lower than the guideline values of China and Canada [23,27]. Only 7.1% of Cd concentrations, 2.3% of Cu concentrations and 1.6% of Zn concentrations exceeded their corresponding guideline values of China, and all the Pb concentrations were lower than the guideline values of China. In addition, no Cd concentration of the urban soil samples exceeded the soil guideline value of UK (1.8 mg/kg) [22].

Compared with heavy metal concentrations in other cities around the world (Table 2), the concentrations of Cd, Cu, Pb and Zn in urban soils of Beijing were relatively low. The mean concentration of Cr was higher than most of the reported values, which may be due to the high background value of Cr in Beijing (60.84 mg/kg).
Detailed information of physicochemical properties of the soil samples, such as particle size distribution, pH, TOC and CEC (cation exchange capacity), can be found elsewhere [28]. In addition, the BC contents in urban soils in Beijing varied from 0.03 to 1.50%, with the mean of 0.39%. Being produced by incomplete combustion of biomass and/or fossil fuel, BC has been found in urban soils, it can reflect the pollution history of a city during urbanization [29,30]. In this study, Pearson’s correlation analysis indicated that the concentrations of Cd, Cu, Pb and Zn were significantly positively correlated with BC ($p < 0.01$). This was in agreement with the research results reported by He and Zhang [31], who also found significant correlations of BC with the concentrations of Cu, Pb and Zn in Nanjing. The correlations of BC with Cd, Cu, Pb and Zn may be due to the coexistence of BC with Cd, Cu, Pb and Zn as a result of mechanical abrasion and fuel burning of vehicles as well as the adsorption of heavy metals on BC in soils, and further research needs to be conducted. In contrast, no significant correlation of BC with Cr and Ni was found.

### 3.2. Comparison of heavy metal concentrations of the 6 types of land use

As shown in Table 3, the mean concentrations of Cd, Cu, Pb and Zn were the highest in CG. Two independent samples

<table>
<thead>
<tr>
<th></th>
<th>Cd</th>
<th>Cr</th>
<th>Cu</th>
<th>Ni</th>
<th>Pb</th>
<th>Zn</th>
</tr>
</thead>
<tbody>
<tr>
<td>BA</td>
<td>0.162</td>
<td>58.78</td>
<td>36.43</td>
<td>25.08</td>
<td>39.70</td>
<td>80.77</td>
</tr>
<tr>
<td>CG</td>
<td>0.237</td>
<td>58.99</td>
<td>50.06</td>
<td>25.73</td>
<td>73.63</td>
<td>117.96</td>
</tr>
<tr>
<td>CEA</td>
<td>0.156</td>
<td>59.11</td>
<td>30.80</td>
<td>24.98</td>
<td>34.76</td>
<td>82.92</td>
</tr>
<tr>
<td>PGS</td>
<td>0.143</td>
<td>60.07</td>
<td>27.69</td>
<td>24.63</td>
<td>29.89</td>
<td>77.79</td>
</tr>
<tr>
<td>RA</td>
<td>0.183</td>
<td>58.96</td>
<td>36.15</td>
<td>24.49</td>
<td>38.39</td>
<td>100.45</td>
</tr>
<tr>
<td>RSA</td>
<td>0.199</td>
<td>59.85</td>
<td>28.96</td>
<td>23.89</td>
<td>33.25</td>
<td>83.66</td>
</tr>
</tbody>
</table>

Fig. 2. Maps of heavy metal distributions in urban soils in Beijing.
test (Mann–Whitney U) showed that the concentrations of Cd, Cu, Pb and Zn in CG were statistically significant higher than those in the other 5 types of land use ($p < 0.05$). For example, the mean concentration of Pb in CG (73.63 mg/kg) was almost twice than those in the other 5 types of land use (29.98–39.70 mg/kg).

For the other 5 types of land use, test for several independent samples (Kruskal–Wallis H) was conducted to determine whether the heavy metal concentrations differed in BA, CEA, PGS, RA and RSA. The $p$ value for Cd was 0.024, lower than 0.05. Therefore the difference of Cd concentrations in BA, CEA, PGS, RA and RSA was statistical significant ($p < 0.05$), which suggested that land uses had significant effects on the distribution of Cd in urban soils. The Cd concentration with different types of land use followed the sequence: RSA > RA > BA > CEA > PGS, the mean concentration of Cd in RSA (0.199 mg/kg) was significantly higher than that in PGS (0.143 mg/kg) ($p < 0.05$), indicating an obvious accumulation of Cd in RSA. The $p$ values for Cu, Pb and Zn were larger than 0.05, therefore there were no significant difference of Cu, Pb and Zn concentrations in BA, CEA, PGS, RA and RSA ($p > 0.05$), which inferred that these 5 types of land use had similar effects on the distributions of Cu, Pb and Zn.

The mean concentrations of Cr in the 6 types of land use varied from 58.78 to 60.07 mg/kg, and those of Ni varied from 24.49 to 25.89 mg/kg. There was no significant difference of Cr and Ni concentrations in the 6 types of land use ($p > 0.05$), indicating that land uses had no significant effects on the distribution of Cr and Ni in urban soils.

### 3.3 Maps of heavy metal concentrations

Our previous study [32] found that the concentrations of Cu, Pb and Zn showed decreasing trends with increasing distance from the road, and we also found that the concentration of Pb in roadside soils was significantly positively correlated with traffic density ($p < 0.05$), which were in agreement with the research results reported by Nabulo et al. [33]. Besides the traffic emission, there were some other sources of heavy metals (see Section 3.4) in the urban area of Beijing. In this study we analyzed the spatial distributions of heavy metals in the whole urban area of Beijing. As shown in Fig. 2, the spatial distribution patterns of Cu, Pb and Zn were generally similar, with decreasing concentrations from the center of the city to the suburb. The high concentrations or hotspots for the 3 heavy metals mainly existed within...
the 2nd Ring Road. The concentrations of Cu, Pb and Zn in other parts of the city were relatively low. In addition, as shown in Table 4, when the urban area was divided into several concentric parts based on the distance from the center of the city, whether the data from RSA was included or not, Cu, Pb and Zn concentrations showed decreasing trends from the center of the city to the suburb. This may result from the development process of Beijing. The district inside the 2nd Ring Road is an old urban area with long history, the present layout of which was formed in the Ming Dynasty over 500 years ago. The urban area of Beijing was formerly within the confines of the 2nd Ring Road, and it did not make a big change until the middle of the 20th century. With 30 years rapid development since the economic reforms in 1978, the urban area of Beijing has expanded to the newly constructed 5th Ring Road. As shown in Fig. 2, Cu, Pb and Zn concentrations in newly built urban area, especially the area around the 5th Ring Road, were much lower than those inside the 2nd Ring Road. It inferred that the longer history the urban area was, the higher the concentration was. This was due to the fact that the older urban area had longer time for heavy metals from all kinds of pollution sources to accumulate in the soils. Furthermore, we also found Hg concentration showed a decreasing trend from the center to

<table>
<thead>
<tr>
<th>Data source</th>
<th>Element</th>
<th>Area Inside 2nd Ring Road</th>
<th>Between 2nd and 4th Ring Road</th>
<th>Outside 4th Ring Road</th>
</tr>
</thead>
<tbody>
<tr>
<td>Including all the 6 types of land use</td>
<td>Cu</td>
<td>53.94</td>
<td>31.72</td>
<td>28.57</td>
</tr>
<tr>
<td></td>
<td>Pb</td>
<td>63.96</td>
<td>36.88</td>
<td>31.68</td>
</tr>
<tr>
<td></td>
<td>Zn</td>
<td>113.74</td>
<td>88.72</td>
<td>80.53</td>
</tr>
<tr>
<td>Including 5 types of land use except RSA</td>
<td>Cu</td>
<td>76.22</td>
<td>34.07</td>
<td>26.85</td>
</tr>
<tr>
<td></td>
<td>Pb</td>
<td>78.50</td>
<td>43.04</td>
<td>27.86</td>
</tr>
<tr>
<td></td>
<td>Zn</td>
<td>128.90</td>
<td>90.25</td>
<td>73.70</td>
</tr>
</tbody>
</table>

Table 4
Comparison of mean concentrations of Cd, Cu, Pb and Zn among different areas with and without the data from RSA (mg/kg).
the suburb of Beijing, it increased with the age of the urban area [28].

Cd had different distribution patterns from Cu, Pb, and Zn. Although the greatest value existed within the 2nd Ring Road, several relatively high concentrations or hotspots of Cd existed near the main roads and the road intersection in the northern part, western part, and eastern part of the city. This implied that Cd has different sources from Cu, Pb, and Zn. Cr and Ni displayed different overall distribution patterns from Cu, Pb, and Cd, and they had no decreasing trend from the center of the city to the suburb.

3.4. Source identification

In multivariate statistical analysis, PCA and CA can be used to identify the sources of contamination [10, 20, 34]. For PCA analysis, the factor loadings with a VARIMAX rotation as well as cumulative percentage of variance are displayed in Table 5. All the heavy metals were well represented by the first two principal components, which accounted for over 70% of the total variance. Factor 1 was dominated by Cd, Cu, Pb, and Zn, accounting for 49.58% of the total variance. Cr and Ni were highly loaded in Factor 2 which explained 23.94% of the total variance. The result of CA analysis is illustrated in the dendrogram (Fig. 3), two distinct clusters can be identified. Cluster I contained Cd, Cu, Pb, and Zn, while the long distance between Cd and the other 3 heavy metals may suggest that this cluster can be further divided into two sub-clusters. Cluster II contained Cr and Ni. The results of PCA agreed well with that of the CA. As mentioned in Section 3.1, the concentrations of Cd, Cu, Pb, and Zn in Beijing were obviously higher than the background values of Beijing and China, and concentrations of Cr and Ni were comparable to the background values. Therefore, the distribution of Cd, Cu, Pb, and Zn in urban soils of Beijing was mainly affected by anthropogenic sources, while Cr and Ni were mainly from natural sources. This is also in agreement with the variation of heavy metals in the 6 types of land use and the spatial distribution of heavy metals in the urban soils of Beijing as mentioned in Sections 3.2 and 3.3.

The concentrations of Cd, Cu, Pb, and Zn in urban soils of Beijing were the highest in CG, which may be due to the historical use of heavy metals. Beijing was the capital of many dynasties in ancient China, 7 of 9 classical gardens selected in this study have a history of over 200 years, with lots of historical wood buildings, brassware, and silver ornaments in them. Cd and Pb were used historically as red and yellow pigments [35], which were the main colors in Chinese historical buildings. Cu compounds in liquid form were used as a wood preservative, particularly in treating original portion of structures during restoration of damage due to dry rot [36]. Alloying of Cu with Zn to make brass was practiced soon after the discovery of Cu itself. For example, brass was used for musical instruments and timpani [37], which were widely used as palace musical instruments in ancient China. With the time passing by, Cd, Cu, Pb, and Zn used for pigments, wood preservation and brassware in CG would slowly transfer into the soils around through physicochemical reaction and erosion by rain and wind. In addition, our previous study also found much higher Hg concentration in CG [28], which was due to the historical use of Hg. Therefore, the high concentrations of Cd, Cu, Pb, and Zn in CG were due to their accumulation for several hundreds of years.

For the other 5 types of land use, including BA, CEA, PGS, and RA, the concentration of Cd in RSA was much higher than those in BA, CEA, PGS, and RA, indicating the traffic sources of Cd. This could be explained mainly by the use of Cd in vehicle tyres and the emission from burning vehicle fuels [38]. The concentrations of Cu, Pb, and Zn in RSA were similar to those in CEA and PGS, but lower than those in BA and RA. Domestic waste, street markets, paintings, construction activities and handling of bulk goods [39] may be the main contributors to the high values of Cu, Pb, and Zn in BA and RA.

The sources of Cd, Cu, Pb, and Zn in urban soils of Beijing are extremely complicated. Anthropogenic sources such as vehicle exhaust, household waste and construction activities have made the heavy metal concentrations higher than their background values. Besides, as Beijing is a city with a long history, and the historical buildings such as palaces and temples are all well-preserved, the historical use of heavy metals in pigments, wood preservation and brassware would also play an important role for their accumulation in urban soils around.

4. Conclusion

This investigation in different types of land use in Beijing revealed an obvious accumulation of Cd, Cu, Pb, and Zn; their concentrations were much higher than the background values of Beijing. The concentrations of Cr and Ni in urban soils of Beijing were comparable to the background values. Pearson’s correlation analysis showed that Cd, Cu, Pb, and Zn concentrations were significantly positively correlated with BC at the 0.01 level.

The concentrations of Cd, Cu, Pb, and Zn in CG were much higher than those in the other 5 types of land use, and the concentration of Cd in RSA was much higher than those in BA, CEA, PGS, and RA (p < 0.05). The spatial distribution patterns of Cu, Pb, and Zn were generally similar, with decreasing concentrations from the center of the city to the suburb; the longer history the urban area was, the
higher the concentration was. Cd had several high concentrations or hotspots near the main roads and the road intersection in the northern part, western part and eastern part of the city. Cr and Ni had no decreasing trend from the center of the city to the suburb.

Source identification inferred that the distribution of Cd, Cu, Pb and Zn in urban soils of Beijing was mainly affected by anthropogenic sources, while Cr and Ni were mainly from natural sources. Historical use of Cd, Cu, Pb and Zn for pigments, wood preservation and brassware was the main reason for their highest values in CG. For the other 5 types of land use, Cu, Pb and Zn mainly originated from intensive and complicated anthropogenic activities. Cd in urban soils was mainly from traffic sources.

Acknowledgements

The study was supported by the Major State Basic Research Development Program (No. 2010CB951104) and the Scientific Research Foundation of Beijing Normal University (No. 2009SB-8).

References