Relationship Between Heavy Metals and Soil Minerals (Subject Editor: Stefan Norra)

Multivariate Geostatistical Analysis of Heavy Metals in Topsoils from Beijing, China*

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Abstract

Background. Regional soil environmental quality is a hotspot and difficulty in the environmental sciences for the spatial variability of pollutants and the relationship between them. Beijing, the capital of China, has been undergoing a rapid economical development during the past three decades, and thus might encounter the same issues as the developed countries. However, there is little information about the soil environmental quality of Beijing, especially at the regional scale. The real soil environmental situation of heavy metals remains unknown, even less the sources of possible pollutants.

Objectives. The main objectives were to identify the spatial variability and main sources of heavy metals in Beijing soils by conducting multivariate statistical analyses, including geostatistical analysis assisted with GIS tools. These results will contribute to the establishment of the soil quality baseline and the management of regional environment.

Materials and Methods. Seven hundred and seventy-three samples of topsoils (0–20 cm) were collected from all over Beijing, China. The samples were digested with HNO_3 and H_2O_2. The concentrations of Cr, Cu, Ni, Pb and Zn were analyzed with a FL-AAS and those of Cd with a GF-AAS. The concentrations of As were determined with AFS-2202. Principal component analysis (PCA) and partial correlation analysis (CA) were used and geostatistics was conducted for the data processing.

Results. Concentrations of topsoil As, Cd, Cr, Cu, Ni, Pb and Zn in the Beijing area were measured and contour maps were constructed to describe the metals' spatial distribution. Except for the background effect of the soils, anthropogenic factors made the soil heavy metal concentrations increase, especially in the center of the city. Combined with the PCA results, it was found that vehicle exhaust and smelters were the main sources of soil heavy metals. Pedogenic factors were also controlling the spatial features of metals.

Discussion. Combined with the results of PCA, 7 heavy metals could be divided into 4 factors. F1 was the metals, i.e., Cu, Pb, Zn, mainly controlled by the human activities. Cr and Ni was in F2, Cd in F3 and As in F4. These 3 factors might be controlled by the soil parent materials. Concentrations of 7 heavy metals were comparable with the first level of environmental quality standard for soils of China and much lower than the second level of national standard for soils.

Conclusion. The heavy metal concentrations in the topsoil of Beijing are mostly comparable with the background values, especially for As, Cr and Ni. In the city center of Beijing, Cu, Pb and Zn had a high concentration of distribution. The spatial features of As, Cr and Ni are mainly controlled by pedogenic factors, whereas Cd, Cu, Pb and Zn are controlled by anthropogenic and parent factors. Traffic and smelting contribute greatly to the increase of Pb, Zn and Cu in the soil, especially in the center of the city. Landfill may have also affected the soil quality around it.

Recommendation. Different factors were controlled by parent materials, which might be related to the different soil minerals. Further research should be conducted in Beijing to elucidate the relationship between heavy metals and soil minerals.

Keywords: Beijing; China; geostatistics; heavy metals; multivariate statistics; soil minerals; soil pollution; topsoils

Introduction

Regional soil environmental quality is a hotspot in the environmental sciences for the need of establishment of soil environmental standard. National investigation of soil heavy metals have been conducted in China (CNEMC 1990), USA (Holmgren et al. 1993), Denmark (Bak et al. 1997) and Norway (Steinnes et al. 1997) for the purposes of background information. Differences caused by soil texture, geological origin and anthropogenic sources of heavy metals results in spatial variability (Bak et al. 1997), which increases the difficulty of this research and makes it necessary to conduct the surveys in different areas. However, since soil samples were distinct, it is essential to illustrate the data and assess potential environmental hazard in the form of raster maps depicting the regional geochemical distribution of pollutants by spatial interpolation (Li et al. 2006, Hanesch 2001). Geostatistics provides a set of statistical tools for incorporating spatial coordinates of observations in data processing (Tao 1995, Goovaerts 1999, Norra et al. 2001).

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Heavy metals in soils from industrialized countries, especially in agricultural soils, have increased due to the expanded use of fertilizers, including chemical fertilizers, livestock manures or sewage sludge (Sharma et al. 2000, Nicholson et al. 2003), and elevated atmospheric deposition (Nriagu 1989, Nriagu and Pacyna 1988). How to deal with the contaminated soils was drawn up in most industrialized countries (Belotti 1998, Urzelai 2000, Cattle et al. 2002, Manta et al. 2002). Beijing, the capital of China, has been undergoing a rapid development of economy during the past three decades. Along with the progress of agriculture and industry, some soil environmental problems also emerged gradually in local areas (Wang 1998). Beijing might be encountered by the same issues as the developed countries. However, the situations of soil heavy metals remain unknown on a city wide scale of Beijing. Therefore, a preliminary investigation of soil contamination at a regional scale was conducted in the Beijing municipal area. The main objectives were to identify the spatial variability and main sources of heavy metals in Beijing soils by conducting multivariate statistical analysis, including geostatistical analysis assisted with GIS tools. These results contribute to the establishment of the soil quality baseline and the management of the regional environment.

1 Samples and Methods

1.1 Study area and sampling

Beijing is located in northern China, comprising a total area of 16,808 km², including 11,337 km² agricultural land (MOLR 2002). Sixty-two percent of the total area is accounted for by mountains and 38% by plains. The land in the plain area is heavily industrialized and cultivated. Main soil types are fluvo-aquic soil (Calcaric Cambisol) and cinnamon soil (Anthrosol). There are 18 administrative districts (counties) over the city, among which 8 districts constitute the center of the city (**Fig. 1**) and account for about 40% of the traffic burden. The capital iron and steel company, the most important industrial factory of Beijing, is located in Shijingshan (SJS) District, one of the center districts.

Seven hundred and seventy-three topsoil samples (0~20 cm) were collected from the city (see Fig. 1). At each sampling site, 5 sub-samples were taken from the 4 vertexes and the center of a square block (10 m * 10 m) and mixed thoroughly to select 1 kg soil as the representative sample of the site. All samples came from urban or rural areas of different land use, covering all of the plain and mountain areas. Soil samples were distributed evenly in the research area with a lower density in mountains and higher density in plains.

1.2 Soil analyses

The samples were air-dried, ground, passed through a 0.149-mm nylon sieve, and digested with HNO_3 and H_2O_2 using Method 3050B (USEPA 1996). The concentrations of Cr, Cu, Ni, Pb and Zn were analyzed with a flame atomic absorption spectrometer and those of Cd with a graphite furnace atomic absorption spectrometer (Vario 6, Jena Co. Ltd., Germany).

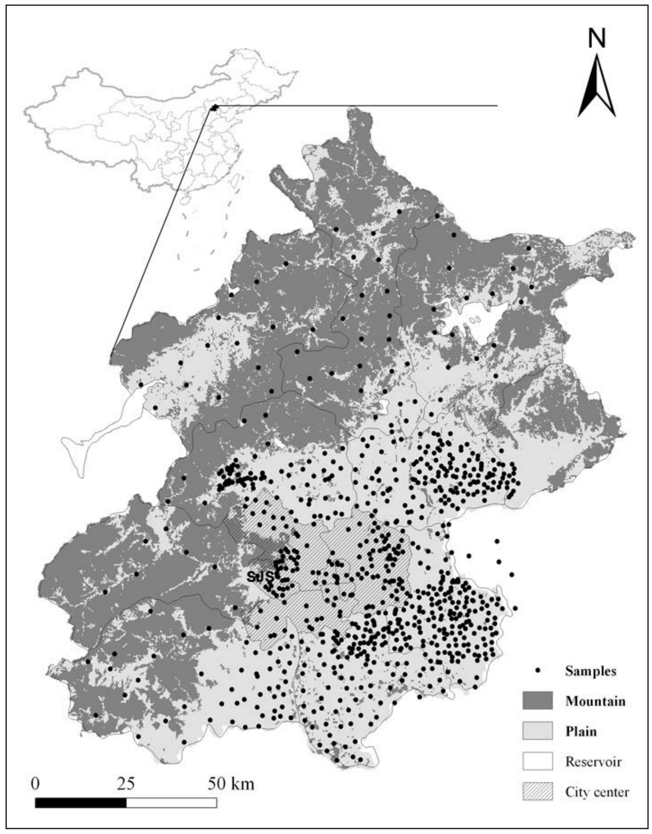

Fig. 1: Soil samples' location of heavy metal survey in Beijing, China

The concentrations of As were determined with an atomic fluorescence spectrometer (2202, Haiguang Co., Beijing, China). A standard reference material, GSS-1 soil, obtained from Center for National Standard Reference Material of China, was inserted for quality assurance/control.

1.3 Data processing

A Shapiro-Wilk test was employed for the distribution test of soil heavy metals. It was found that As concentrations were in normal distribution and the concentrations of Cd, Cr, Cu, Ni, Pb and Zn were also in normal distribution after log-transformation ($P<0.05$). A Grub's test method (Tao 1994) was used to eliminate the outliers. All statistical analyses were thus made based on the data in normal distribution. Principal component analysis (PCA) and partial correlation analysis (CA) were used to interpret the relations between heavy metals in geochemical processes. Since the original variables showed ambiguities in the component matrix, varimax rotation was made to clarify the loadings of 7 heavy metals in the components being extracted. The statistical analyses were performed using SPSS software. Geostatistics was used to describe the spatial characteristics of 7 heavy metals at the regional scale. The process of semivariogram model fitting was conducted using Surfer software and the spatial distribution using ordinary kriging was fulfilled with an Arc/GIS desktop. In the distribution map, the concentrations were divided into 5 classes by the quantiles of each heavy metal.

2 Results

2.1 Heavy metal concentrations in the soils

Table 1 shows the statistical results for the 7 heavy metal concentrations in the topsoil of Beijing. There were different sample numbers due to the process of outlier elimination. Geometric means were calculated and used to describe the central trend according to the log-normal distribution type of 6 heavy metals except As (Chen et al. 1999). Compared with their respective background values in Beijing area, As, Cr, Cu, Pb and Zn exhibited higher concentrations, and Cd, Ni had comparable concentrations. However, there were some samples attributed with almost ten times higher concentrations than the background values.

2.2 PCA and CA

In multivariate statistical analysis, PCA can be used to identify the sources of contamination (Facchinelli et al. 2001). According to the results of PCA (**Table 2**), the original variables could be reduced to 4 factors (F1 ~ F4), which accounted for 85.3% of the total variances. As shown in Table 2, As had the main loadings in F4, Cd was mainly distributed in F3, Cr and Ni were in F2, and Cu, Pb, Zn were in F1. However, not all heavy metals could be distributed in one factor, for example, Cd partially in F1, Cu and Zn partially in F3. These suggested that Cd, Cu and Zn, etc. might be controlled by more factors.

Relationships between soil heavy metal concentrations were analyzed (**Table 3**). Cu, Pb and Zn were not significantly correlated with As. The same phenomena were also observed between Cu and Cr, Zn and Cr, Pb and Cd, Zn and Ni. There were strong negative correlations between Cd and Ni, and Cr and Pb. Except for the relations listed above, positive correlations existed between each other of 7 heavy metals.

Table 3: Correlation matrix of soil heavy metals in Beijing [a]

	As	Cd	Cr	Cu	Ni	Pb	Zn
As	1.000	0.086*	0.078*	0.015	0.093*	0.059	0.028
Cd		1.000	0.142**	0.243**	-0.143**	0.027	0.205**
Cr			1.000	0.005	0.527**	-0.150**	0.070
Cu				1.000	0.119**	0.180**	0.481**
Ni					1.000	0.158**	0.026
Pb						1.000	0.363**
Zn							1.000

[a] Partial correlation analyses were used. *P<0.05; **P<0.01

Table 1: Descriptive statistics of soil heavy metals in Beijing [a]

Metal	Nos. of samples	Concentrations: mg/kg					Background value In Beijing area [b]	Environmental Standard [c]	
		Range	Mean	S.D.	G. Mean	G. S.D.		Class 1	Class 2
As	650	0.10~25.26	8.35	2.70	7.83	1.513	7.81 ± 3.22	15	25
Cd	772	0.007~0.971	0.148	0.111	0.122	1.821	0.119 ± 0.112	0.2	1.0
Cr	772	7.00~228.2	35.6	13.9	33.6	1.399	29.8 ± 9.29	90	250
Cu	771	2.00~282.2	23.7	17.1	21.2	1.510	18.7 ± 6.33	35	100
Ni	772	2.80~168.9	27.8	8.70	26.7	1.330	26.8 ± 7.90	40	60
Pb	771	5.00~116.6	28.6	10.3	27.1	1.393	24.6 ± 5.08	35	350
Zn	771	22.0~399.7	65.6	29.8	61.6	1.386	57.5 ± 16.3	100	300

[a] Concentrations of 7 heavy metals are in log-normal distribution. Geometric means were used to describe the central trend of data. S.D. means standard deviation. G. means geometric.
[b] Chen et al. 2004. Mean ± S.D.
[c] SEPA 1995. Class 1 is the natural background level; class 2 is for the need of agricultural production and human health.

Table 2: Total variance explained and component matrixes for soil heavy metals in Beijing

Total Variance Explained			
Component	Rotation Sums of Squared Loadings [a]		
	Total	% of Variance	Cumulative %
1	2.207	31.53	31.53
2	1.575	22.51	54.04
3	1.184	16.91	70.95
4	1.006	14.38	85.32

Component Matrixes

Metals	Rotated Component Matrix				Communalities
	1	2	3	4	
As	0.115	0.124	0.086	**0.981**	0.999
Cd	0.309	0.072	**0.889**	0.093	0.900
Cr	–0.011	**0.887**	0.254	0.074	0.857
Cu	**0.751**	0.187	0.408	0.057	0.768
Ni	0.322	**0.837**	–0.124	0.104	0.831
Pb	**0.895**	0.062	0.013	0.101	0.816
Zn	**0.794**	0.168	0.372	0.071	0.802

[a] Rotation method: Varimax with Kaiser normalization

2.3 Spatial structure

Semivariogram calculation was conducted and experimental semivariogram of soil heavy metal concentrations could be fitted with a spherical model (for Cd, Cr, Cu, Pb and Zn) or exponential model (As and Ni). Parameters are presented in **Table 4**, including nugget value (C_0), sill (C_0+C), range (±) and coefficients of determination (R). The values of R were significant at the 0.05 level, which shows that the semivariogram models gave good descriptions of spatial structure of soil heavy metals.

The ratio of nugget to sill (RNS) can be used to express the extent of spatial autocorrelations of environmental factors (Cambardella et al. 1994), for example soil heavy metal concentrations in this study. A low RNS indicates the strong spatial autocorrelations of soil heavy metal concentrations while a high RNS indicates that random effects play an important role in spatial heterogeneity of heavy metals. The RNS of 7 heavy metals varied from 0.22 to 0.69, showing obvious interaction of spatial randomness and autocorrelation, especially for As, Cd, Cr and Ni. The spatial correlation of Pb was strong considering the 0.22 of RNS.

Table 4: Parameters of fitted semivariogram models for seven heavy metals in Beijing [a]

	Model	C_0	C	$C_0/(C_0+C)$	α (km)	R^2 [b]
As	Exponential	5.145	7.473	0.688	14	0.586
Cd	Spherical	0.052	0.023	0.691	97	0.829
Cr	Spherical	0.014	0.009	0.609	70	0.940
Cu	Spherical	0.022	0.035	0.386	25	0.854
Ni	Exponential	0.007	0.007	0.500	15	0.869
Pb	Spherical	0.007	0.025	0.219	34	0.895
Zn	Spherical	0.014	0.025	0.359	25	0.819

[a] In table, C_0 means nugget value. C_0+C means sill. α means range of spatial correlation

[b] Coefficients of determination (R) passed F test method at 0.05 significance level.

2.4 Spatial distribution

From **Fig.** 1 and **4**, it can be found that the distribution of Cr had two parts with a clear boundary almost along the northwest mountain area. The highest concentration zone was located in the northeast part, which almost coincided with the location of the highest concentration of Ni. Cu, Pb and Zn had their higher concentration areas in the central part of the city.

Figs. 2, 3 5–8 show the spatial distribution of 7 heavy metals. Only a very small area was attributed with a high concentration of As. Soil As concentrations were still comparable with the background values of Beijing. There was a zone with a high contour of Cd at the north and west of the city.

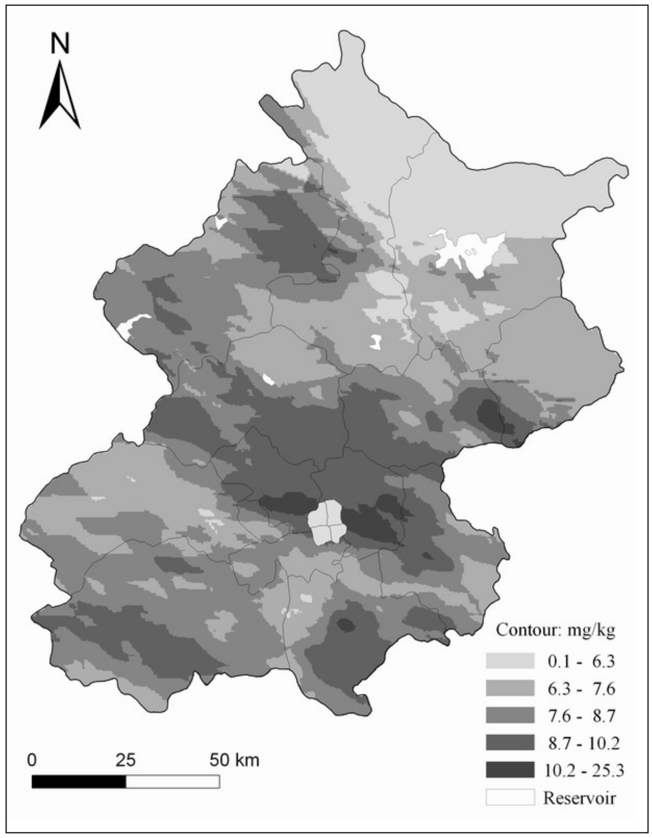

Fig. 2: Spatial distribution of As in the topsoil of Beijing

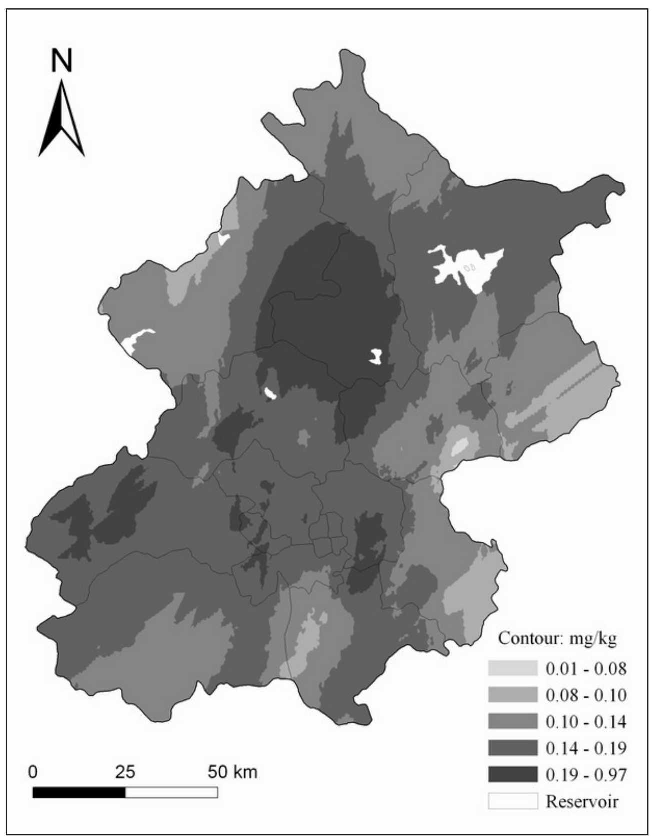

Fig. 3: Spatial distribution of Cd in the topsoil of Beijing

3 Discussion

3.1 The analysis of spatial feature

From the spatial distributions of 7 heavy metals, it could be found that the parent materials and anthropogenic factors played important roles in soil heavy metal concentrations of Beijing, and the effects of these two factors varied with the heavy metals.

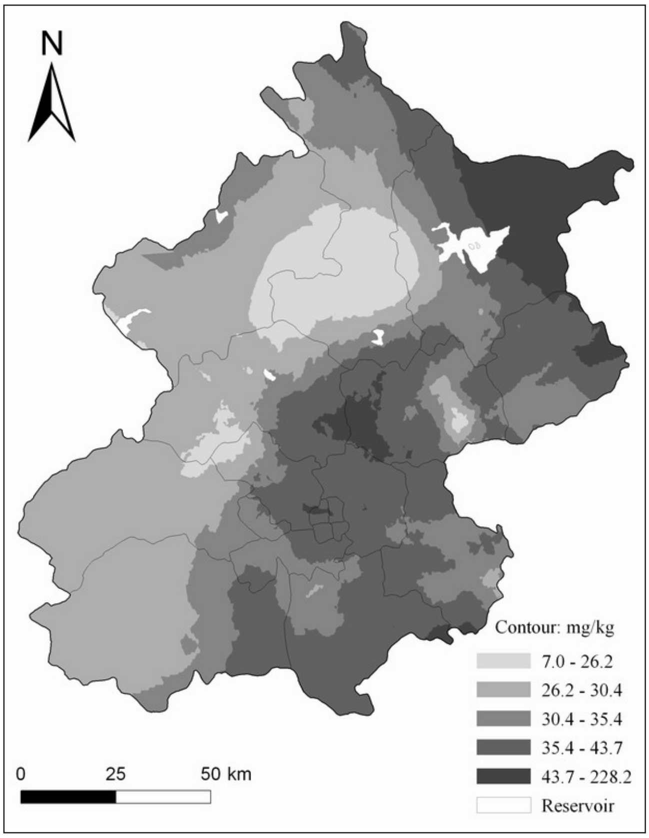

Fig. 4: Spatial distribution of Cr in the topsoil of Beijing

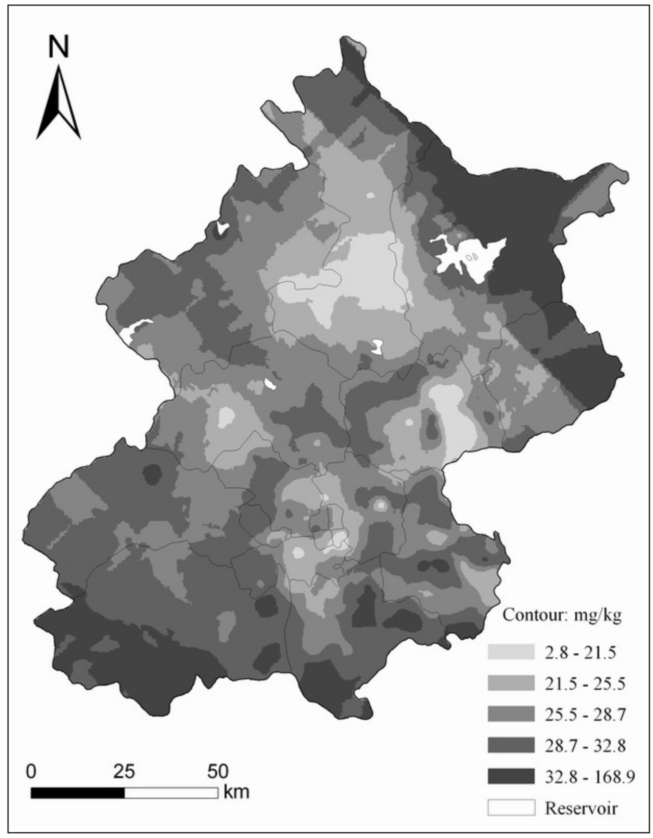

Fig. 6: Spatial distribution of Ni in the topsoil of Beijing

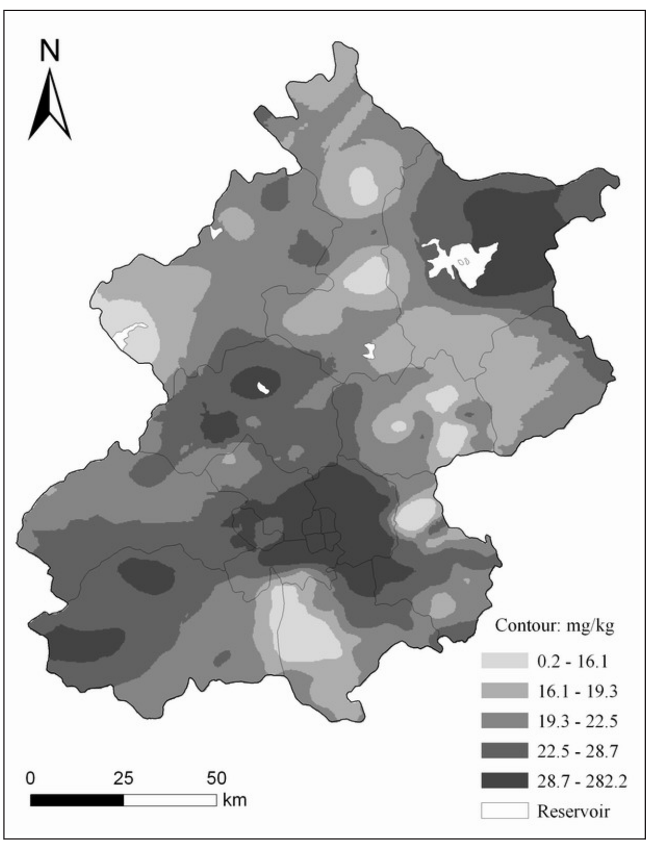

Fig. 5: Spatial distribution of Cu in the topsoil of Beijing

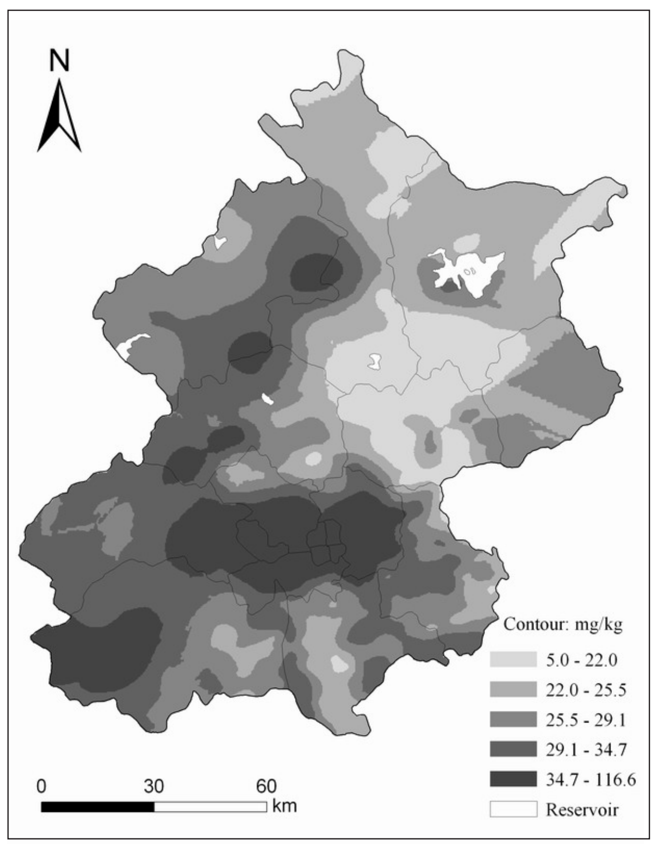

Fig. 7: Spatial distribution of Pb in the topsoil of Beijing

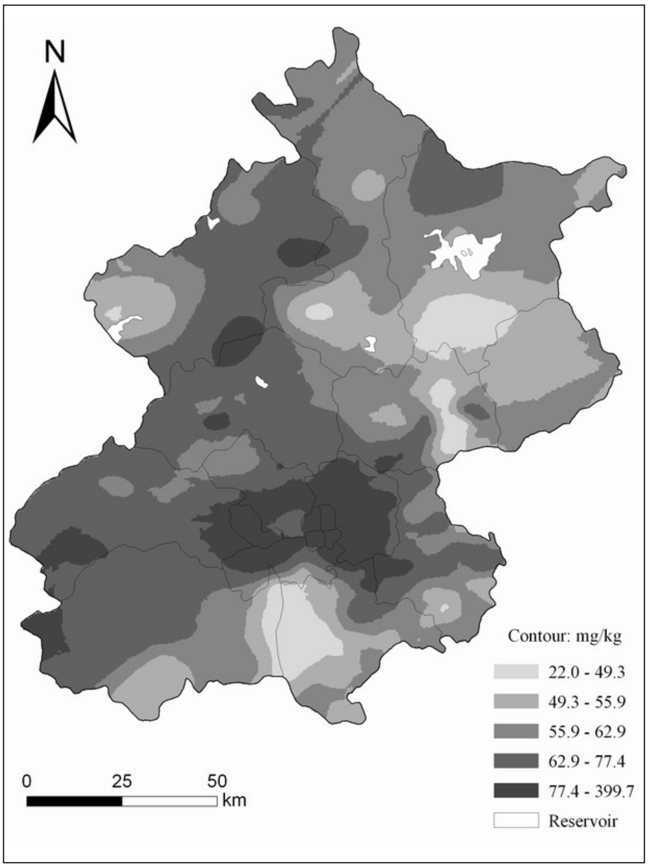

Fig. 8: Spatial distribution of Zn in the topsoil of Beijing

Arsenic had a very different distribution from other metals. This was consistent with the result of PCA that only As had high loadings in F4. Highest concentration area was found in the central and east part of the city. Since the RNS of As was high, there might be some factors remaining unknown at current research scale. The influences of these factors were exhibited as the random effects, i.e., the nugget effect, and would be discovered at a smaller scale.

The distribution of Cr had a clear boundary along the northwest mountain area. According to the terrain of Beijing (see Fig. 1), the mountain area is located in the west and north of the city. The west mountain area belongs to the Mt. Taihang Ranges and rocks are mainly limestone. North mountain area belongs to the Mt. Yanshan Ranges and rocks are mainly granite and gneiss. Materials carried by the rivers originating from the north mountain were deposited in the flat area. Thus, the plain in the east part of Beijing arose based on these alluvial deposits (BMPC 1990). This geological condition could have determined the concentration and distribution of Cr in the soils. In this study, Cr and Ni were loaded in F2 of PCA and had significant correlations indicating that they may have similar sources. In some studies it was shown that Cr and Ni were associated mostly with the same soil minerals (Pierce et al. 1982, Chen et al. 1999). In this study, at the northeast part of the city, there was a zone with high concentrations of Cr and Ni showing almost no urbanization. Thus, the main source of Cr and Ni in Beijing soil should be pedogenic material.

Most PCA loadings of Cu, Pb and Zn were in F1 and the high concentration areas of them also had similar locations, which indicates that the three metals might have the same sources. Their RNS shows a good spatial correlation. Current research scale is appropriate for the exploration of factors affecting the distribution of three metals. For example, atmospheric deposition contributed greatly to the input of heavy metals to the soil, especially for Zn, followed by Pb and Cu (Nicholson et al. 2003). Traffic or vehicles might be the most important source for Cu, Pb and Zn in Beijing street sediments according to Kuang et al. (2004). It has been proved that leaded gasoline makes the Pb concentration increase in the environment. Although this application has ceased in Beijing, Pb could remain in topsoil (Martin 2001) and its effect could last a long time. Cu might also come from vehicle brake lining (Martin 2001), and Zn from the traffic emission, especially from the vehicle tires (Li et al. 2001). The areas with high metal concentrations were the center of the city, which bears the heavy traffic and a large population density. The normal vehicle exhaust along the road would release considerable heavy metals. Moreover, the capital iron and steel plant is located in the Shijingshan District and the high concentration areas of Cu, Pb and Zn partly overlap with this district. Kuang et al. (2004) also found that the plant could have polluted the street sediments locally. Thus, smelting activities obviously affect the soil heavy metal concentrations.

At the north part of the city, Cd had a zone with high concentrations. According to the map obtained from BMPC (1990), there were coal mines distributed around the area. Since there were not any other obvious human activities around the site, it was conferred that geological factors caused this unusual area. At the west part of the city, there was another zone with high concentrations of Cd, Cu and Pb (see Fig. 3, 5 and 7) around a landfill field. The solid waste disposal is an issue that needs attention.

3.2 Soil environmental quality of Beijing

Seven heavy metals in the topsoil of Beijing had different accumulation characteristics. The concentrations of Ni were close to the background values. It was evident that there was no Ni pollution in Beijing soil. Since Cr was similar with Ni in the source and there was no distribution of high concentrations in most areas of the city, the accumulation of Cr in the soil was minor. Similar phenomena were also found for As and Cd. Although there existed some areas with high concentrations caused by human activities, the soil quality was still under control for them (see Table 1). However, the accumulation of Cu, Pb and Zn should be paid some attention, especially in the central area of the city. In the urban planning, soil environmental quality should be taken into account to make the risks avoided reasonable.

3.3 Controlling factors of soil heavy metals

In this study, heavy metals in Beijing soils were controlled by pedogenic or anthropogenic factors. Cu, Pb and Zn, with PCA loadings in F1 were obviously disturbed by anthropogenic activities in some areas. Although Cr and Ni, As, Cd made different factors, their concentrations in most areas of Beijing were still under control and comparable with the respective background values, which indicates that they may be controlled mainly by parent material. Because of the close relationship between heavy metals and soil minerals (Chen et al. 1999, Manta et al. 2002), 4 metals were distributed in different PCA factors. Further research about relations between heavy metals and soil minerals should be conducted in Beijing. Multivariate statistical analysis, including geostatistical analysis, are a useful tool for the identification of spatial features and contaminant sources.

3.4 Comparison among different regions of the world

Beijing is a typical city of China with high developing speed. Consequently, it might encounter the environmental problems that happened in other cities or regions (**Table 5**). Since As, Cr and Ni were mainly controlled by pedogenic factors in Beijing soil, the differences between different regions were negligible. For Cu, Pb and Zn, the values of Beijing were higher than the values of rural soil and lower than the values of urban soil. Beijing had the lowest concentration of soil Cd.

However, the comparison between different regions over the world is difficult owing to the great differences of the parent materials. Certainly, the digestion methods have obvious effects on the analysis results. From this aspect it is very important and necessary to establish the soil quality benchmark based on the geochemical process, which could be used to assess the extent of soil heavy metal accumulation. Furthermore, a research limited in single scale was deficient in the soil quality assessment. Pollutants would show different spatial features at different spatial scale. Further research should be developed at multiple scales for the monitoring and assessment of soil environmental quality.

4 Conclusions

The heavy metal concentrations in the topsoil of Beijing are mostly comparable with the background values, especially for As, Cr and Ni. In most areas of Beijing, soil environmental quality is under control and suitable for agriculture use.

The spatial features of As, Cr and Ni are mainly controlled by pedogenic factors, while Cd, Cu, Pb and Zn are controlled by anthropogenic and parent factors. Traffic and smelting contribute greatly to the increase of Pb, Zn and Cu in the soil, especially in the center of the city. Landfill will obviously also affect the soil quality around it.

Results combined the principal component analyses and the spatial distribution pattern based on the GIS tools indicate that multivariate statistical analyses are useful in the assessment of regional soil quality and the results would be credible in this study.

According to the RNS, As, Cd, Cr and Ni had large random effects at the current scale. Further research can be conducted at a smaller scale. In addition, the relations of heavy metals, such as As, Cd and Cr, and soil minerals, is an issue contributing to a better understanding of soil environmental sciences in Beijing.

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Table 5: Average heavy metal concentrations (mg/kg) in topsoil from different areas of the world

Location	Land use	As	Cd	Cr	Cu	Ni	Pb	Zn	Reference
Nanjing	Urban soil	–	–	84.7	66.1	–	107.3	162.6	Lu et al. 2003
	Rural soil	–	–	41.9	25.4	–	17.5	75.2	
Hong Kong	Urban soil	10.7	0.74	–	9.1	–	89.9	58.8	Chen et al. 1997
	Rural soil	16.5	0.94	–	16.1	–	40.6	51.0	
Pearl River	Paddy soil	–	0.34	57.1	20.7	17.0	35.1	61.1	Wong et al. 2002
Delta	Crop soil	–	0.58	71.4	33.0	21.2	40.0	84.7	
Palermo	Urban soil	–	0.68	34.0	63.0	17.8	202	138	Manta et al. 2002
Warsaw	Complex	–	1.0	12.9	24.8	–	–	139.6	Pichtel et al. 1997
Piemonte	Complex	–	–	46.2	58.3	83.2	16.1	62.7	Facchinelli et al. 2001
Denmark	Complex	4.1	0.18	12.3	7.7	6.3	12.2	19.5	Bak et al. 1997
Florida	Complex	2.4	0.22	5.1	4.7	6.7	5.4	12.0	Ma et al. 1997

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Mapping of Trace Metals in Urban Soils

The Example of Mühlburg/Karlsruhe, Germany

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Abstract. Spatial distribution maps depicting the concentrations of antimony, lead, tin, copper and zinc, and the presence of land-use units were generated for Mühlburg, a district of the City of Karlsruhe, Germany. The influence of the spatial land-use structure on the distributions of the element concentrations is statistically evaluated and discussed. The variography for Mühlburg shows an average range of 200–400 m for the spatial correlations of Sb, Pb, Sn and Zn. The variograms of Pb and Zn are characterised by hole effects at 300 m distances, i.e. the result of repeated stronger spatial correlations for certain distances between the sample sites. Most probably, this is an effect of the typical urban structure of streets, buildings, green spaces, and industry. Kriging method was used for the interpolation of Sb, Pb, Sn and Zn concentrations. Only Cu does not show a spatial correlation. In this case, the interpolation was carried out with a smoothed triangulation routine. Pollution plumes of point sources such as lead works, a bell foundry and a coal-fired thermal power station superimpose the more diffuse pollution from traffic, household heating processes, waste material disposal, etc. The trace element concentrations in soils of housing areas increase with the age of the developed area. Industrial areas show the highest level of pollution, followed by housing areas developed before 1920, traffic areas, allotments, housing areas developed between 1920 and 1980, parks and sports areas, cemetery and housing areas developed after 1980.

It is demonstrated that spatial distribution maps of element concentrations indicate potential emission sources of harmful substances, even if the emission itself or the direct surrounding soil have not been analysed. The analytical tools presented enable town planners to discern areas of higher soil pollution. Detailed investigations can be focussed on these areas to evaluate the possibilities of soil usage and transfer. These methods enable one to manage urban soil in an adequate manner. For these reasons, the methods demonstrated support an urban environmental impact assessment and are a part of a sustainable urban soil management.

Keywords: Environmental chemistry; environmental impact assessment; geographic information system (GIS); geostatistics;Germany; GIS; Karlsruhe; mapping; research articles; soils; spatial variability; sustainable development; trace elements; urban development; urban land-use; urban soil management