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Source identification and ecological risk assessment of heavy metals in topsoil using environmental geochemical mapping: Typical urban renewal area in Beijing, China

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ABSTRACT

Environmental geochemical mapping with high-density soil sampling was conducted to determine the spatial distribution, possible sources and potential ecological risk of heavy metals at a former chemical industry area in Beijing. A total of 550 surface soil samples were collected and the concentrations of heavy metals, such as Ni, Cr, V, As, Cu, Pb, Cd, Zn and Hg, were analyzed. The spatial distribution characteristics of these metals were demonstrated by environmental geochemical mapping. Enrichment factors show that the soil concentrations of Cu, Pb, Cd, Zn and especially Hg were higher than the background values. Multivariate geostatistical analyses suggested that Cu, Pb, Cd, Zn and Hg in the topsoil were strongly influenced by anthropogenic or chemical industry activities while Ni, As, V and Cr mainly originated from the natural parent materials of the soils. The potential ecological risk was quantitatively estimated for each site and the risk map was plotted for assessment. Among the metals, Cd and Hg showed a higher potential ecological risk than the others.

1. Introduction

In recent years, there has been significant concern regarding urban soil contamination due to rapid industrialization and urbanization, especially contamination due to various heavy metals (Chen et al., 2010; Manta et al., 2002; Sun et al., 2010). Heavy metal pollutants can be discharged in many ways, such as via vehicle emission and industrial wastes (Cui et al., 2004). The accumulation of heavy metals in soils is of increasing concern due to its potential health risks and detrimental effects on soil ecosystems (Cui et al., 2004; McLaughlin et al., 1999). Pollution of urban soil with heavy metals has recently become a subject of many studies because of the serious risk it represents for the environment and human health (Albanese and Cicchella, 2012; Filippelli et al., 2012; Giaccio et al., 2012; Luo et al., 2011; Zhang et al., 2011). For an urban renewal area at a former industrial area, there should be concern about the soil pollution and potential health risks because the rate of urbanization is very fast in developing countries, especially in China.

As the capital of China and one of the biggest urban cities in the world, Beijing has become contaminated with chemicals in some areas (Luo et al., 2008). Recently, some papers have reported heavy metal pollution in Beijing, including soil pollution at former industrial sites (Luo et al., 2008, 2009a, 2009b). However, few of these papers (Hu et al., 2008; Wang et al., 2012) focused on such a typical chemical industry area: the southeastern chemical industry area of Beijing located in the Chaoyang District. A large number of factories were established in this location in the 20th century, including chemical, coking and glass. In preparation for the 2008 Olympic Games, most of the factories or plants were closed or moved. The industrial production activities resulted in contamination of the local urban soil, including pollution with heavy metals. So far, few reports have focused on the pollution of heavy metals in such a specific area.

The study of the spatial distribution and source identification of heavy metals in urban soils is very important in order to identify pollution hot-spots and assess the potential sources of pollutants (Acosta et al., 2011; Afshin et al., 2009; Carr et al., 2008; Cicchella et al., 2005; Imperato et al., 2003; Lee et al., 2006; Madrid et al., 2002). Usually, the identification of pollutant sources is conducted with the aid of multivariate statistical analyses, such as correlation analysis, PCA, and CA. Some authors have used multivariate statistical methods to identify the factors of lithogenic and anthropogenic origin responsible for the heavy metal pollution of urban soils (Facchinelli et al., 2001; Franco-Uría et al., 2009; Sollitto et al., 2010). Furthermore, geostatistical analysis and GIS-based spatial mapping have been used to study spatial distribution patterns and possible hot-spots of elevated concentrations of heavy metal contamination in an urban environment (Carr et al., 2008; Facchinelli et al., 2001; Lee et al., 2006; Li et al., 2004; Zhang, 2006).

The method of measuring the potential ecological risk index (Hakanson, 1980) has been widely used. Compared with other methods, such as the geoaccumulation index, the pollution load index, and the excess after regression analysis (Farkas et al., 2007; Ray et al., 2006), the potential ecological risk index benefits from the inclusion of a toxic response factor for a given substance. Thus, this method can be used to evaluate the combined pollution risk of multiple types of heavy metals to the ecological system.

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The present study focuses on determining the concentrations of heavy metals in the study area, mapping the spatial distribution of heavy metals through geostatistical analysis and GIS for the purpose of identifying their spatial patterns and possible hot spots of the concentrations of heavy metals, identifying the potential sources or influencing factors of heavy metals in the soils using correlation analysis, PCA and CA. The potential ecological risk of heavy metals in the topsoil was also assessed.

2. Materials and methods

2.1. Study area and sampling

The chemical plant area is located in the southeastern suburbs of Beijing between 4th Ring Road and 5th Ring Road. The chemical industry area was founded in the 1950s, and dozens of chemical factories and plants were located in this area, where they manufactured chemical products from chemical raw materials. There were two main plant areas: the Beijing Coking Plant area and the Second Chemical Plant area. In preparation for the 2008 Olympic Games, most of the factories or plants were closed or moved. With the urbanization of Beijing, the former southeast chemical industry area is now an urban renewal area surrounded by residential and commercial districts (Fig. 1).

During the summer of 2011, 550 soil samples from the top layer (0–20 cm) were collected using a 0.25 × 0.25 km grid (Fig. 1). To minimize sampling errors, each sample was composed of five sub-samples weighing ca. 1.0 kg, taken from the center and end points of a 2 m wide area using a stainless drill, and the samples were stored in polyethylene bags. To assure sampling quality, the ratio of duplicate sampling was 8%.

The soil samples were air-dried, mixed thoroughly, and passed through a 0.2-mm sieve. Portions (approximately 50 g) of the soil samples were ground in an agate grinder, sieved through a 0.15-mm sieve, and stored in brown bottles at 4 °C for chemical analysis.

2.2. Analytic methods and quality control

Chemical analyses were carried out by the National Research Center for Geoanalysis (China) according to national standard soil environmental quality standards (GB 15618-2008). Cr, Ni, V, Pb, Cu and Zn contents were analyzed using X-ray fluorescence spectrometry (RS-1818, HORNGJAAN). Cd content was analyzed using a graphite atomic absorption spectrophotometer (AA6810 SONGPU). Hg and As contents were analyzed using an atomic fluorescence spectrophotometer (XGY-1011A). Standard reference materials, GSS-1 and GSS-4, obtained from the Center of National Standard Reference Material of China, were analyzed as part of the quality assurance and quality control (QA/QC) procedures. Good agreement was achieved between the data obtained from the present work and the certified values, with recoveries between 92 and 108%. Analysis of the samples, including soil samples and blanks, was performed in triplicate, and the standard deviation was within 5%. Also, 8% blind duplicates were analyzed to check the quality of the analysis.

2.3. Statistical analysis and geochemical mapping

Multivariate statistical techniques, such as principal component analysis (PCA), cluster analysis (CA), and geostatistical analysis are powerful tools to segregate sources contributing to observed pollution (Li and Feng, 2012; Lu et al., 2012). These techniques have been used both to differentiate between different natural sources that cause variations in soil composition and to identify pollution sources affecting the metal content of soil. A correlation matrix and PCA were used to evaluate heavy metal-waste properties relations. PCA was used to study the correlations among heavy metals and properties and their grouping into a few factors. After grouping, the metals and properties within each factor are more highly correlated with metals and properties in that factor than with metals and properties in other factors. Varimax rotation and CA were applied because they minimize the number of metals and properties with a high loading on each component and facilitates the interpretation of results (Micó et al., 2006).

Kaiser–Meyer–Olkin (KMO) measure of sampling adequacy is used to compare the magnitudes of the observed correlation coefficients in relation to the magnitudes of the partial correlation coefficients. Large KMO (0–1) values are good because correlations between pairs of variables can be explained by the other variables. Bartlett's test of sphericity is used to test the hypothesis that the correlation matrix is an identity matrix with suitable significance ($p < 0.05$). In this case, the result of the KMO (0.832) and Bartlett's test ($p < 0.001$) suggested that PCA was suitable for analysis of the data set. Prior to Pearson correlation analysis

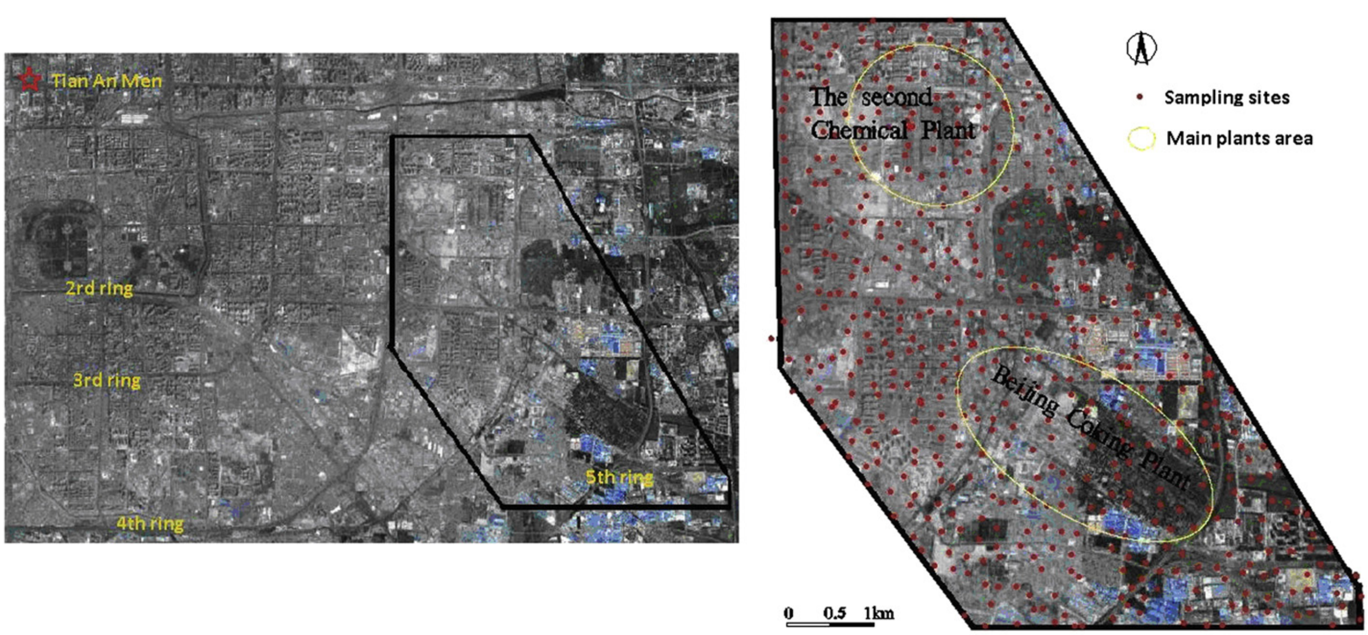

Fig. 1. Location of the sampling sites.