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Contamination characteristics and source apportionment of heavy metals in topsoil from an area in Xi'an city, China

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ABSTRACT

As soil-extractable elements potentially pose ecological and health risks, identifying their contamination characteristics and sources is crucial. Therefore, to understand topsoil trace elements in the urban ring zone from the Second Ring Road to the Third Ring of Xi'an city in China, we determined the concentrations of Zn, Co, V, As, Cu, Mn, Ba, Ni and Pb, and analyzed the sources of the contamination. The results showed that the individual pollution indices of Pb, Co, Cu, Zn, Ba, Ni, Mn, As, and V were 1.79, 1.48, 1.41, 1.33, 1.20, 1.07, 1.04, 0.99, and 0.99, respectively. Evaluation with the aid of the pollution load index (PLI) indicated slight soil contamination by these elements in the study area. Using the positive matrix factorization (PMF) method, we identified four sources of contamination, namely (1) a natural source, (2) traffic emission source, (3) industrial emission source, and (4) mixed source. PMF is an effective tool for source apportionment of heavy metals in topsoil. The contribution rates of the natural source, traffic source, mixed source, and industrial source to the heavy metal contamination were specified as 25.04%, 24.71%, 24.99%, and 25.26%, respectively. Considering the above, any attempt to reduce the soil environmental cost of urban development, has to take into account the heavy metal contamination of the topsoil from industries, traffic, and other activities.

1. Introduction

Urban soil has become the focus of environmental science research in view of its characteristics, such as high concentrations of heavy metals and organic compounds, unpredictable layering, less moisture and nutrients, and poor structure (Kabata-Pendias et al., 1992; Tiller et al., 1992). In many parts of the world, the rapid development of industries, agriculture, and urbanization has given rise to ever increasing environmental costs by accelerating the inputs of heavy metals into the environment. In particular, the soils in many cities have been contaminated by various pollutants (Yang et al., 2011; Karima et al., 2014; Li et al., 2014; Mihailovića et al., 2015; Gąsiorek et al., 2017; Peng et al., 2017). Soil trace-element contamination is characterized by complex confidentiality and hysteresis, as well as cumulative, irreversible, and durable harm. Such contamination poses a significant threat to human health through the food chain (Alloway et al., 2013; Burges et al., 2015). The United States Environmental Protection Agency (USEPA) regards As, Cu, Pb, Zn, Ni as the priority pollutants (USEPA, 2014).

Various aspects of the characteristics of urban soil elements have been studied, including pollution assessment, health risks, and spatial distribution (Maas et al., 2010; Iqbal et al., 2011; Mohamed et al., 2014; Liu et al., 2015; Yuswir et al., 2015; Xiao et al., 2015; Chen et al., 2015; Liu et al., 2016a, 2016b). Methods to determine the sources of soil pollutants include source identification based on qualitative analysis, and source apportionment based on quantitative analysis. Compared with the source apportionment method, more results have been obtained by correlation analysis, cluster analysis, factor analysis, and geostatistical analysis using GIS (Facchinelli et al., 2001; Sun et al., 2010; Yuan et al., 2014; Luo et al., 2015). The source apportionment method includes the source known method, such as the chemical mass balance method (CMB), and the source unknown method, such as positive definite matrix factorization analysis (PMF), the UNMIX routine, absolute principal component scores-multivariate linear regression (APCS-MLR), and maximum likelihood principal component analysis (MCR-ALS/MLPCA) (Lee et al., 2008; Mijić et al., 2010; Luo et al., 2014; Chen et al., 2016). The PMF method is recommended by USEPA as a universal tool for source apportionment, and the PMF model has been applied widely for source apportionment of atmospheric pollutants (Kim et al., 2007; Amil et al., 2016; Hsu et al., 2016). In addition, some researchers have succeeded in using PMF for the source analysis of heavy metals in soil (Parra et al., 2014; Xue et al., 2014; Schaefer et al.,

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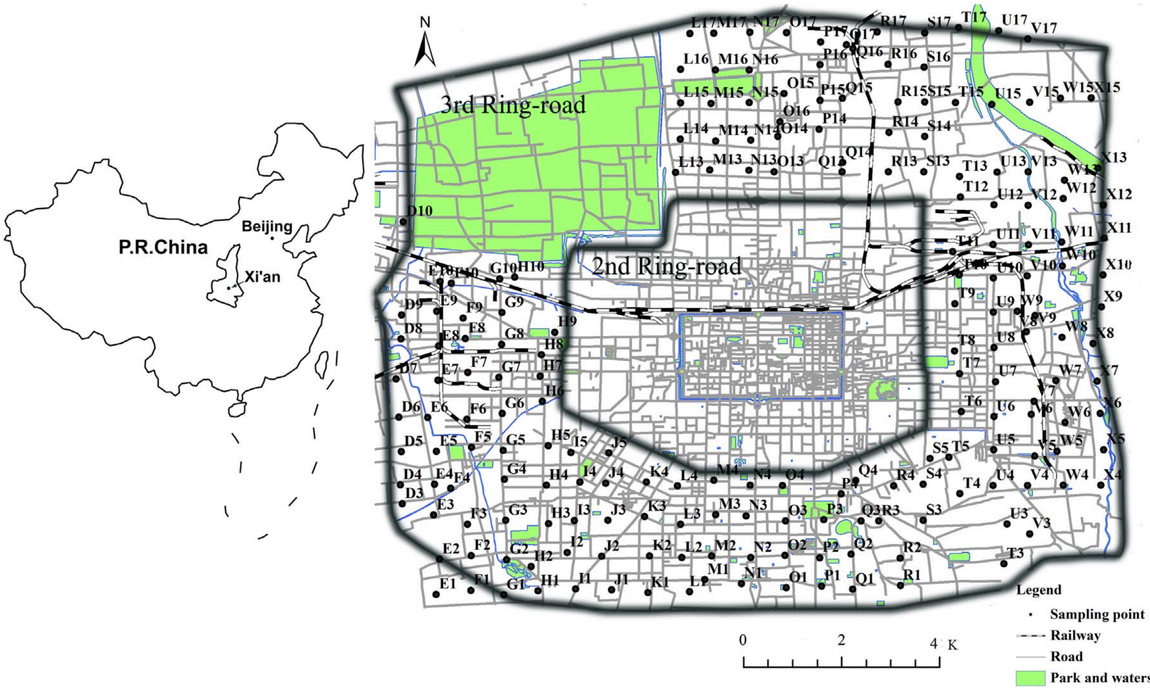

Fig. 1. Sketch map of soil sampling sites in study area.

2016; Jiang et al., 2017).

The urban space of Xi'an city has expanded rapidly since the start of the 21st century. The urban built-up area has increased from 197.28 km^2 in 2000–531.31 km^2 in 2016. To the north, northeast, and southwest, the spread of the city has been more rapid. The implementation of various national policies, such as the western development strategy, the construction of an international metropolis, and the belt and road policy has prompted the expansion of the focus of development from the inner to the outer of the Second Ring Road, and this region has since expanded to the Third Ring Road. Many cultivated lands and garden plots have been converted into construction land in the area between the two ring roads and the utilization efficiency of the original construction land has been improved significantly. As industrial and commercial activities are more concentrated in this region, the effects of such human activities on the accumulation of soil inorganic pollutants, for example heavy metals, have intensified. Various studies have been conducted to evaluate the contamination of soil heavy metals in the urban parks, urban industrial areas, and sewage irrigation districts in Xi'an city. In previous work (Chen et al., 2012, 2013), we presented a systematic discussion of the pollution characteristics, spatial distribution, health risks, and source identification of various common soil trace elements in the Second Ring Road in Xi'an city. However, few studies have been conducted on soil pollution in the ring zone from the Second to the Third Ring Road of the city, particularly by using the receptor model to analyze the sources of these elements. Therefore, more research is needed on the level of heavy metal pollution in this ring zone to contain the accumulation of heavy metals; as such accumulation could pose serious health risks. With this objective, we concentrated mainly on (1) measuring the concentrations of heavy metals in topsoil in this ring zone, (2) assessing the heavy metals contamination, (3) apportioning the probable sources of the studied elements, and (4) establishing individual contribution rates for every source.

The results of our study indicated the source contributions of soil heavy metals clearly. Such information facilitates the adoption of management and restoration measures by the city environmental management department and the planning department to avoid the health risks associated with soil heavy metal contamination.

2. Materials and methods

2.1. Background of study area

Xi'an city (33°39′–34°45′N and 107°40′–109°49′E), the capital of Shaanxi province in the northwest of China, is located in the Wei River plain. The Qinling Mountain is regarded as the boundary in the south and east, and the Loess Plateau as the boundary in the north. The city covers an area of 10,096.81 km^2, and the urban population numbers approximately 8.8 million. The average annual temperature is 13.0–15.0 °C and the annual mean precipitation is 500–700 mm, with the climate classified as continental monsoon (Song, 1988; Lu et al., 2011). With the completion and opening to traffic of the Third Ring Road, the urban spatial structure of Xi'an city was changed into three spheres, with the region from the Second to the Third Ring being the outermost sphere. With such rapid expansion development, this area has become the main space for urban industrial activities, commercial activities, and residential activities. The east of the city is the national defense industry district, the south is the education research area, the west is a comprehensive residential and non-polluting industries area, the north is the equipment-manufacturing industry region, the southeast is the ecological tourism resort area, the northeast is a residential ecological tourism area, and the southwest is a high-tech industrial zone.

2.2. Soil collection and experimental determination

A total of 193 surface soil samples (from approximately the top 20 cm of the soil) were collected from the area between the two ring roads of Xi'an city (Fig. 1). Each sample was composited with five subsamples from nearby sites, located within approximately 5 m from the main sample sites. At each sampling site, we collected samples of 1.5 kg, mixed by the quartile method, with a stainless-steel shovel and placed them in polyethylene plastic bags for transporting and storing. After air-drying at room temperature, the samples were kept in plastic bag for subsequent analysis.

The samples were sieved through a 0.9 mm nylon mesh to remove the impurities, such as stones, coarse material, and tree leaves. By using