Environmental Pollution 210 (2016) 174–181

Contents lists available at ScienceDirect

Environmental Pollution

journal homepage: www.elsevier.com/locate/envpol

Spatial pattern of heavy metals accumulation risk in urban soils of Beijing and its influencing factors

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ARTICLE INFO

Article history:
Received 17 June 2015
Received in revised form
23 November 2015
Accepted 24 November 2015
Available online

Keywords:
Beijing
Urbanization
Soil pollution
Regression tree
Heterogeneity

ABSTRACT

Accumulations of heavy metals in urban soils are highly spatial heterogeneity and affected by multiple factors including soil properties, land use and pattern, population and climatic conditions. We studied accumulation risks of Cd, Cu, Pb and Zn in unban soils of Beijing and their influencing based on the regression tree analysis and a GIS-based overlay model. Result shows that Zinc causes the most extensive soil pollution and Cu result in the most acute soil pollution. The soil's organic carbon content and CEC and population growth are the most significant factors affecting heavy metal accumulation. Other influence factors in land use pattern, urban landscape, and wind speed also contributed, but less pronounced. The soils in areas with higher degree of urbanization and surrounded by intense vehicular traffics have higher accumulation risk of Cd, Cu, Pb, and Zn.

1. Introduction

Urbanization processes not only changed inherent properties of the affected soils, such as their pH, texture, cation exchange capacity, and bulk density but also inadvertently caused harmful substances such as heavy metals to deposit in the soils (Vega et al., 2004; WRB, 2006; Obrador et al., 2007). The pollutant accumulations often led to environmental ills (Pouyat and McDonnell, 1991; Bermea et al., 2009; Chabukdhara and Nema, 2013). In China, the Cd, Cu, Pb and Zn concentrations of urban soils were frequently found to exceed the baseline and the levels were rising (Wei and Yang, 2010; Wang et al., 2012a,b).

Besides, urban development altered the natural landscapes and microclimatic features, created man-made topographies, and concentrated the human populations and activities that in turn would influence the pollutant deposition processes (Lin et al., 2002; Xia et al., 2011). Industrial establishments, transportation networks, residential communities, and other support systems were integrated across the urban horizons to make depositions of heavy metal in urban soils a complicated undertaking (Legret and Pagotto, 2006; Han et al., 2006; Mmolowa et al., 2011). Statistical methods, such as the correlation and regression analyses, were utilized to empirically link heavy metals deposited in the urban soils to potential causative urban factors (Zeng et al., 2011; Palumbo et al., 2000). The methods had not been entirely successful as the outcomes were simplistic and failed to consider the complex spatial and interactive nature of the causative factors. For a complicated system such as the urban metropolises, the classification and regression tree (CART) analysis would be an efficient approach to deduce relationships between heavy metal depositions and causative factors and to distinguish influences of the factors (Kheir et al., 2014; Greve et al., 2012). The CART was capable to search for the non-additive and non-linear relationships, and to uncover the hidden structures in complex data matrices (Breiman, 2001; Henderson et al., 2005; Razi and Athappilly, 2005).

The geo-statistical tool Kriging would convert the soil pollutant levels measured at point locations into spatial distribution of pollution across the urban landscape. The outcomes, however, tended to gloss over the distinctive local highs and lows because of the smoothed extrapolation technique (Journel et al., 2000) thus failed to preserve the highly variable nature and skewed pollutant distributions of the actual urban environment and reduced the accuracy of assessments (Goovaerts, 2000), especially for the highly heterogeneous urban environment. A more robust approach to evaluate the spatial variation of heavy metal contaminations in urban area would be the GIS-based model that linked and integrated the spatial distribution of heavy metals with the spatially referenced data of causative factors (Desmet and Govers, 1996).

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http://dx.doi.org/10.1016/j.envpol.2015.11.044
0269-7491/

We hypothesized that the soil, land use, demographic, and climatic factors influenced the spatial distribution of heavy metals in urban soils. Used the CART analysis and a GIS-based model to illustrate how causative factors including soil properties, urban land use, demographics, and microclimatic conditions would affect the distribution of Cd, Cu Pb and Zn in the urban soils throughout Beijing.

2. Materials and methods

2.1. Study area

The urban built-up areas of Beijing (Fig. 1), which encompassed areas inside of the 5th ring road of Beijing and included the Dongcheng and Xicheng Districts and parts of the Haidian, Chaoyang, Fengtai, and Shijingshan Districts were the study template. The area belonged to warm temperate semi-humid continental monsoon climate and the prevalent winds were northwest and south in directions. The cinnamon and fluvo-aquic were the dominant soils with parent materials consisted of weathering rocks and loose quaternary sediment. The city in recent decades experienced drastic and rapid urban renewal and developments. From 1949 to 2012, the population increased from 1.8 to 20.7 million, while the built-up areas increased from 109 to 670 km^2.

2.2. Soil sampling

To ensure a uniform distribution of sampling sites, the study area was divided by 1 km × 1 km sized grids on Google Earth, and then sample site was selected from each grid based on the land use and topographic conditions (some grids were unavailable for sampling). Finally, 232 sample sites were selected (Fig. 1). Surface soil (0–20 cm depth) samples were collected. Crumbled and free of roots and other organic debris, the specimens were then air-dried and crushed passed through a sieve of 2 mm × 2 mm openings. Each specimen was then subdivided with three quarter of the material preserved for analyzing pH and soil particle size, and the remaining one quarter of the material further ground to pass a sieve of 0.15 mm × 0.15 mm openings to be used in analysis of soil organic carbon and cation exchange capacity. In addition, 100 cm^3 intact soil cores were obtained in metal cylinders made from 5 cm ID straight brass tubing and were kept at the field moisture content in cold storage. Later, they were used to determine the field capacity and bulk density of the soils.

2.3. Chemical analysis

The soil pH was determined in 1:2.5 weigh vs. volume aqueous soil suspension via glass electrodes potentiometry. The soil particle size distribution was determined by a laser particle size analyzer and the outcomes reported according to the United States Department of Agriculture (USDA) soil classification scheme in which the clay content (CLAY) denoted the percentage of particles with sizes less than 0.002 mm. The soil organic carbon content was measured using a C–N–S elemental analyzer, provided the soil aliquot was pretreated with 1 mol/L HCL to remove the inorganic

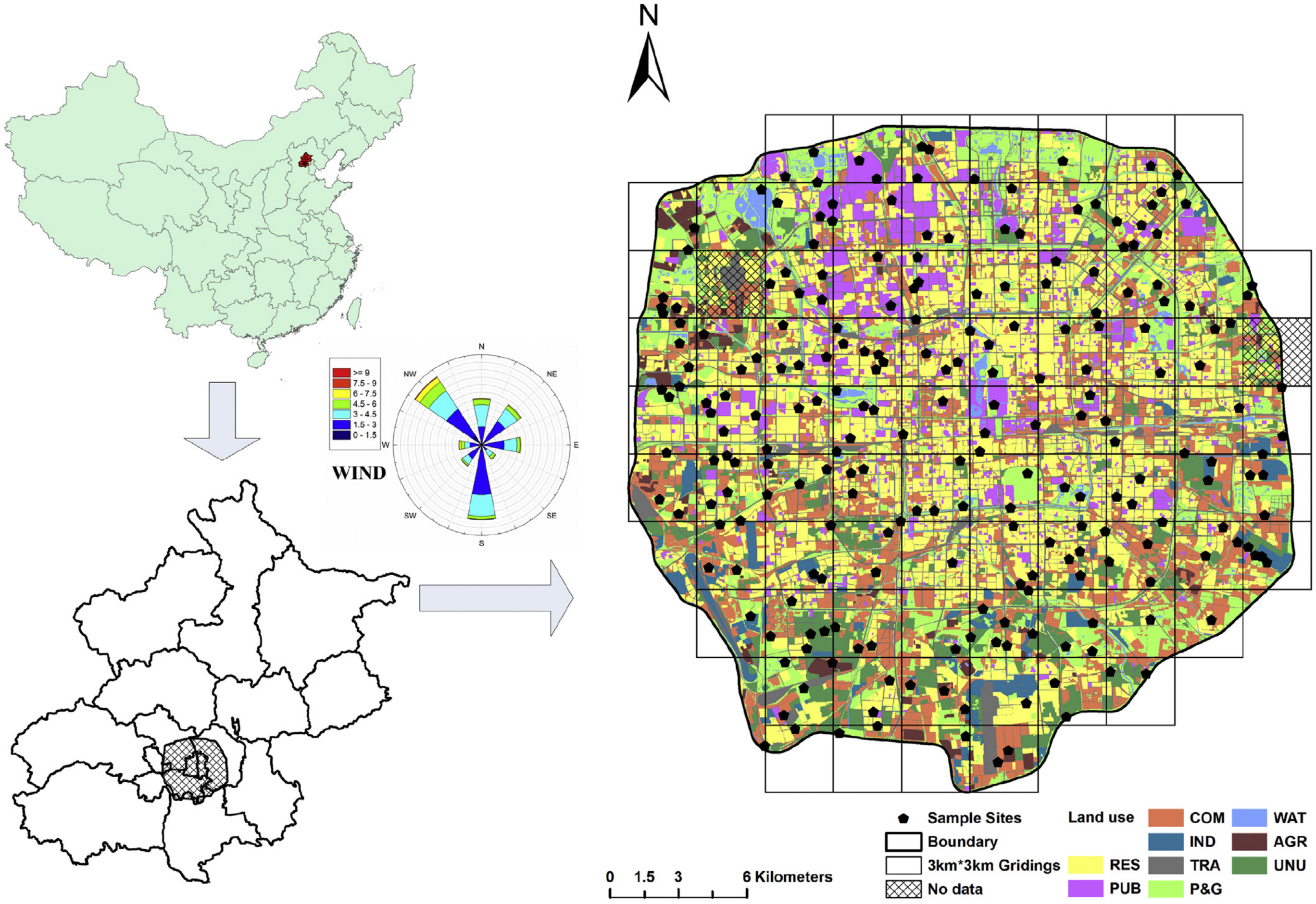

Fig. 1. Study area and soil sampling sites.