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Analysis of the spatial relationship between heavy metals in soil and human activities based on landscape geochemical interpretation

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ABSTRACT

The development and formation of chemical elements in soil are affected not only by parent material, climate, biology and topology factors, but also by human activities. The pollution sources of heavy metals in the environment are mainly derived from anthropogenic sources, and heavy metal elements in soil have been considered to be powerful tracers for monitoring the impacts of human activities. The present study attempts to analyze whether and how a connection can be made between macroscopical control and microcosmic analysis, to estimate the impacts of human activities on heavy metals in soil, and to determine a way to describe the spatial relationship between heavy metals in soil and human activities, by means of landscape geochemical theories and methods. In addition, the disturbances of human activities on Zn, Cr, Cu, Pb, Hg, Cd, Ni and Ag are explored through the analysis of the spatial relationship between human disturbed landscapes and element anomalies, thereby determining the diversified rules of the effects. The study results show that the rules of different landscapes influencing heavy metal elements are diversified, and that the Zn, Ni, Pb, Hg and Ag elements are closely related with city landscapes, but Cu and Cd are not significantly affected by city landscapes; furthermore, the elements Ni, Pb, Hg, Ag and Cd are shown to be closely related with river landscapes, while evidently Zn is not affected by river landscapes; the relationships between mine landscapes and the elements Cr, Cu, Pb, Ni and Hg are apparent, among which Zn is not included; the relationships between the elements Zn, Cr, Cu, Pb, Hg, Cd, Ni and Ag and road landscapes are quite close, which shows that road landscapes have significant effects on these elements. Therefore, the conclusion is drawn that the response mechanism analysis of human disturbance and soil chemical element aggregation is feasible, based on the landscape geochemical theories and methods. The results of the study provide the possibility for applying spatial information techniques, such as remote sensing and geographic information systems, to study chemical elements in soil, thereby realizing the effective combination of macroscopic spatial information and microscopic mechanism of soil element migration research.

1. Introduction

With the rapid development of the modern economy, environmental pollution and ecological damage are becoming more and more serious, thereby threatening the quality of air, water and soil, which are crucial for human health (Cisneros et al., 2010; Dankoub et al., 2012; Lescot et al., 2013; Li, 2010). Soil is a key natural resource for human survival, because more than 80% of the heat, 75% of the protein and the vast majority of the fiber consumed by humans are derived from soils (Wang, 2009), thus soil environmental quality will directly affect the daily lives of human beings. Therefore, the exploration of spatial distribution characteristics of chemical elements in soil is meaningful for further understanding the surface of environmental pollution and degradation, monitoring of climate and environmental change, and ensuring the safety of the human environment (Plant et al., 2001).

Development and formation of chemical elements in soil are affected not only by parent material, climate, biology and topology factors, but also by human activities. Many practices, such as mining, industry, agriculture, waste treatment and transportation, have a detrimental effect on the quantity and quality of soil organic matter, which in turn affects soil physical, chemical and biochemical properties, especially the soil elements (Caravaca et al., 2002; Takamatsu et al., 2010). Heavy metals are mainly distinguished by their high toxicity, wide range of sources, non-degradable pollutions by biological processes, and bioaccumulative behavior. They pose a serious threat to human health, other living organisms, and natural ecosystems (DeForest et al., 2007; Diagomanolin et al., 2004). According to numerous studies, the pollution sources of heavy metals in the environment are mainly derived from anthropogenic sources, and heavy metal elements in soil have been considered

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to be powerful tracers for monitoring the impact of human activities (Guo et al., 2012; Kelly et al., 1996; Manta et al., 2002; Wei and Yang, 2010).

In the past several decades, considerable attention has been paid to the issue of soil contamination from heavy metals, to prevent further environmental deterioration and examine applicable methods of pollution source analysis. Fraser et al. (2011) established a baseline of the spatio-temporal distribution of heavy metals in mussels from the Baie des Chaleurs, based on the ecosystem approach. Bastami et al. (2012) investigated heavy metal (Zn, Cu, Cr and Pb) concentration spatial distribution and enrichment factor index in surface sediments of the Gorgan Bay. Eze et al. (2010) evaluated the distribution, controlling variables and potential sources of heavy metals in the soils of the Legon Hill catena, and prominent soils of Accra Plains, Ghana, West Africa. Lin et al. (2011) estimated not only the spatial patterns of hazardous probability based on only the observed heavy metal data using indicator kriging (IK), but also those which considered auxiliary variables by logistic regression (LR) and regression kriging (RK), by defining the hazard zone as the heavy metal contents which exceed the corresponding control standard. Nanos and Martín (2012) explored the spatial variation and covariation of seven heavy metals (Cd, Cr, Ni, Pb, Zn, Cu and Hg) in the agricultural soils of the Duero River basin (one of the largest in Spain), where both anthropogenic activities (mainly agriculture and industry) and natural factors may be responsible for their total concentration. Bai et al. (2011) collected surface sediment (0–15 cm) samples from 31 different grid points throughout Yilong Lake in April 2004. The samples were subjected to a total digestion technique and analyzed for As, Cd, Cr, Pb, Ni, Cu and Zn, in order to study the spatial distribution characteristics based on the Kriging method, and assess the ecological risks posed by these heavy metals.

Most of these researches proved that the geospatial method was an effective approach in comprehending the polluted sites, as well as recording images of these points within a vast area. In addition, quantitative geochemical methods, such as the enrichment factor (EF) and geo-accumulation index (I_{geo}) based on the principle of mathematical statistics, were successfully used to estimate the impact of human activities on soil quality (Cevik et al., 2009; Cuadrado and Perillo, 1997; Villaescusa Celaya et al., 2000). In the future, the issue of whether or not the geospatial method can be used to estimate the impacts of human activities on heavy metals in soil will be put forward, because the geospatial method has the advantages of good immediacy, readability, generality and comprehensibility.

Landscape geochemistry is a combination of geochemistry and geography. It is also an application of geochemical theory in a geographical environment. The main research content of landscape geochemistry is the interaction rules among chemical elements and geology, landform, climate, hydrology, soil, plants and animals. In essence, the main task of landscape geochemistry is to explore the characteristics and causes of chemical element migration, and combination or distribution influenced by geographical landscape factors (Bilieerman, 1958). Early studies of landscape geochemistry mainly focused on natural landscapes of Earth. Beginning in the 1960s, the interferences of human activities on the original natural landscapes have become more and more prominent. Exploring the rules of chemical element migration and distribution in soil under high strength human disturbance is becoming an important research field in landscape geochemistry (Yin, 1992).

A combination of geographical landscape description and geochemical analysis is the main research method of landscape geochemistry. It is a technical route integrating macroscopical control and microcosmic analysis, which provides the probability that we may apply new techniques of landscape information extraction and analysis, such as geographic information system (GIS) and remote sensing (RS), in the landscape geochemistry field. Many researches have proven the feasibility and validity of these new techniques in geochemical applications (Comero et al., 2012; Li and Cheng, 2006; Liu, 2007; Mashyanov and Reshetovb, 1995; Neto and Silva, 2004; Zhang et al., 2007).

The objectives of this paper are to analyze whether and how a connection can be made between macroscopical control and microcosmic analysis, to estimate the impacts of human activities on heavy metals in soil, and to determine a way to analyze the spatial relationships between heavy metals in soil and human activities, using landscape geochemical theories and methods.

2. Materials and methods

2.1. Study area

The study area is located within 28°55′–30°27′ north altitude and 105°20′–106°22′ east longitude, in the west of Chongqing Municipality (Fig. 1), which includes the seven counties of Tongnan, Shuangqiao, Yongchuan, Changrong, Dazu, Bishan and Hechuan. The regional climate is sub-tropical humid monsoon with an annual precipitation of approximately 1000 mm. The average temperature ranges from 5–7.9 °C in January to 28.6–34.4 °C in July, with a long frost-free period.

Several factors had been taken into consideration when this region was chosen as the study area: First, this region plays a very important role in the economic development of Chongqing, and is also an indispensable component of the Chengyu National Economic Development Zone; second, the region has a typical landscape and ecosystem of southwestern China; third, sampling work may be easily performed here due to the convenience of transportation. In addition, during the process of development and utilization in the past several decades, the conflict between people and land is representative, which makes it suitable for carrying out analysis of spatial relationships between heavy metals in soil and human activities.

2.2. Data

Data pertaining to elevation, slope, landform distribution, soil type distribution, stratigraphic distribution, river networks, road networks, mines and building land spatial distribution were produced using the GIS and RS methods, to explore the spatial relationships between chemical elements in soil and landform, soil, geology and human disturbance (Figs. 2, 3, 4, 5, 6, 7 and 8). Landform, soil and geology data are used to explore whether or not the geochemical anomaly is mainly affected by geographical background, and river, road, mine and building land data are used to explore whether or not the geochemical anomaly is mainly affected by human disturbance. This type of comprehensive data analysis will ensure that the analysis results are objective and scientific.

A total of 2314 soil samples were collected in the year 2010. The sampling points were regularly distributed in the study area based on a regular grid of 2×2 km^2, and each grid had one sampling point (Fig. 7). The exact locations (longitudes and latitudes) of each sample point were recorded using a hand-held global positioning system (GPS), and environmental observations were described during the fieldwork. Eight heavy metals (Cr, Cu, Zn, Pb, Ni, Hg, Ag and Cd) were chosen for use in the analysis. The chemical parameters were measured according to the Specifications of the Multi-purpose Regional Geochemical Survey, carried out by the Chinese Geological Survey (CGS).

2.3. Methods

Spatially continuous data of soil variables without any gaps are critical for studies which require construction of soil element spatial distribution. In the present study, the spatial distribution data of eight heavy metals without any gaps were accomplished by interpolating soil point samples based on distance-based weighting spatial interpolation methods (Simanton and Osborn, 1980) with ArcGIS.

Separation of anomaly from background is a crucial and challenging issue in geochemical exploration. Through the comprehensive analysis of heavy metal spatial distribution and regional geochemical background and baseline values, the geochemical anomalies were gained