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The distribution characteristics of halogen elements in soil under the impacts of geographical backgrounds and human disturbances

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ABSTRACT

Soil chemical elements are important parameters for soil origin diagnosis, and are sensitive indicators of human disturbance process. The present study attempts to evaluate the influence from human activities on halogen elements (fluoride and iodine). This study also attempts to seek a route to explore the spatial relationships between human disturbances and halogen elements according to geospatial theories and methods. Moreover, the spatial correlations between element anomalies and human disturbed landscapes are calculated to explore the influence from human activities on halogen elements, thereby determining the specific response mechanism. The study results indicate that landscapes influence halogen elements in diverse ways and that element iodine is closely related with road and mine landscapes. Furthermore, strong relationships exist between fluoride and road landscapes, which suggest that this element is affected by road landscapes significantly. Fluoride and iodine are unrelated with city landscapes, and fluoride is unrelated with mine landscapes. These provide a reference for the research on the interaction mechanism between halogen and environment. Therefore, it can be concluded that a response mechanism exploration of soil element aggregation and human disturbance is practicable according to geospatial theories and methods, which provides a new idea for studying the soil element migration.

1. Introduction

Soil is a unique and valuable natural resource for supporting the life on earth. It is essential to human survival because almost 96% of human food is obtained from the soil (Pimental and Hall, 1989). As an essential substance for plant growth, soils play a key role in the biogeochemical cycling of heavy metal, halogen and other elements, affecting the chemical composition and substance circulation in the atmospheric and hydrologic environment (Van Breemen and Buurman, 2003).

Soil formations are slow natural processes which take place as a result of biological, physical and chemical procedures (Hakeem et al., 2016). However, soil development is also influenced by a range of environmental conditions, and human interventions accelerate and change these processes dramatically. Soil chemical elements not only are important parameters for soil origin diagnosis, but also are sensitive indicators of human disturbance process, because human activities have a detrimental effect on the chemical elements in soil (Mirsal, 2008; Hettiarachchi and Ardakanian, 2016; Scheffer et al., 2001; Foley et al., 2005). Therefore, analyzing the spatial distributions of soil elements can provide important information on the environmental pollution and degradation, which is significant for the environmental protection work (Yu et al., 2014, 2016).

Halogens are very important constituents of humans, but excessive intake can cause poisoning, so they have a very close relationship with human health (Zeng and Zeng, 2002). Because these elements are common in the soil and plant system and influence ecological balance and human life, they have been received increasing attention (Zou, 1984). Among halogens, fluoride (F) is one of the most influenced by humans, and it is mainly derived from the earth's lithosphere. However, human activities, especially the aluminum and phosphate fertilizer industry, as well as the production of organic fluoride, directly or indirectly emit great amounts of fluoride to the soil environment. Ceramic and cement industries may also release some fluoride into the soil environment in the use processes of clay and coal (Zou, 1984; Omueti and Jone, 1980). Iodine (I) is a necessary nutrient for animals and humans. Its content in soil depends on the rocks, atmospheric deposition and biological cycle between plants and soil. Iron, aluminum oxide and organic matter in soil have an important influence on the fixation and release of iodine. Therefore, the concentration and distribution of iodine in soil are closely related with these components, which provide a

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possible way for human activities to influence the distribution characteristics of iodine (Whitehead, 1973, 1978; Zou, 1985). However, other halogens: chlorine and bromine are prevailingly distributed in the oceans, apart from where they are only found in evaporites that are formed from the evapotranspiration of lake or ocean water (Eggenkamp, 2014). In addition, the halogens show trends in many characteristics moving from top to bottom of the periodic table, so F and I were considered as the typical elements in this analysis.

Over the past several decades, halogen distribution characteristics in soil have been given considerable attention. Vinogradov (1959) illustrated the role of the ocean for the accumulation of iodine in his monograph, in which a large number of samples and quite extensive territories were used. Lag and Steinnes (1976) studied the iodine, bromine, and chlorine distribution in the soils of Norwegian forest through analysis of neutron activation. The halogen concentrations present a sharply decrease with increasing distance from the ocean, revealing that precipitation may be one of the main supplier for these elements in soil. Orberger et al. (1990) studied the halogen distribution in the Acoje ophiolite block, to investigate the role of F, Cl, Br and I transport in hydrothermal solution. Olof et al. (1995) analyzed the organohalogen (organic chlorine) distribution patterns in a coniferous soil profile and in spruce litter resolved in field, to analyze if situ production was a major source of the organohalogens found in soil. The results strongly indicated that during decomposition of organic matter, organically bound halogens are subjected to both production and mineralisation. Kimmo et al. (2001) studied the organic halogen origin in Boreal Lakes through an analysis of elements in the water and sediments of two lakes, to explore the factors that affect the organohalogen inputs in natural ecosystem. This study strengthens the conclusions of numerous authors that bleaching pulp mills is one of the main sources for organohalogen accumulation.

Most of these studies proved that quantitative geochemical methods according to mathematical statistics could be triumphantly applied to evaluate the influence of human disturbances on soil elements (Cuadrado and Perillo, 1997; Villaescusa-Celaya et al., 2000; Cevik et al., 2009). In addition, many studies have demonstrated that the element distribution characteristics in soil could be analyzed by geospatial method effectively (Bastami et al., 2012; Eze et al., 2010; Lin et al., 2011; Nanos and Martín, 2012; Bai et al., 2011). Geospatial analysis is an approach to applying statistical analysis and other analytic techniques to data which has a geographical or spatial aspect (https://en.wikipedia.org). Such analysis provides a special view on the world, through which to inspect events, patterns and processes that take place on the surface of our planet, and makes use of information that links features and phenomena to their locations (De Smith et al., 2015). Such geospatial method offers important implications for spatial problem analysis, including the analysis of element distribution characteristics in soil (Lamsal et al., 2006; Lamsal et al., 2009; Aich et al., 2013; Ki et al., 2015; Wolf et al., 2015; Zewdu et al., 2017; Mikhailova et al., 2016; Thomazini et al., 2016; Kumar et al., 2016).

The objectives of this paper are (a) to evaluate the impacts of geographical backgrounds and human disturbances on halogen element spatial distribution characteristics, and (b) to seek a route for analyzing the spatial relationships between soil halogen elements and influencing factors based on geospatial theories and methods availably.

2. Materials and methods

2.1. Location of the study area

Two study areas are situated within 28°55′–30°27′ N, 105°20′–106°22′ E, and within 29°38′–29°59′ N, 106°30′–106°58′ E, respectively, to the west and north of Chongqing city (Fig. 1). Yongchuan, Tongnan, Changrong, Shuangqiao, Bishan, Dazu, Hechuan and Yubei counties are included in these study areas. These regions were chosen as the study areas, considering the economic status, typical

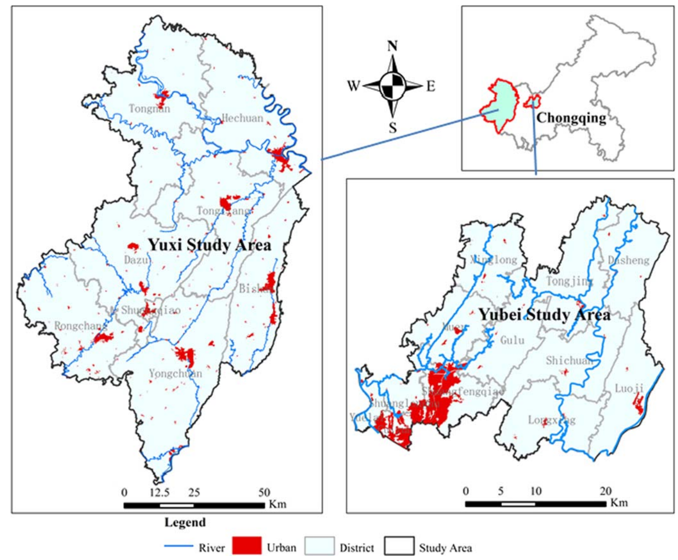

Fig. 1. Location of the study area in Chongqing, China.

landscape and ecosystem, convenience of transportation, the conflict between people and land are representative and typical.

2.2. Data source and preprocessing

RS and GIS techniques were applied to produce spatial distributions of building lands, road networks, mining plots, soil types, landform types and geological times (Figs. 2–9). The spatial distribution characteristics of geochemical anomalies under the geographical backgrounds are explored based on the soil, landform and geology data, to analyze whether the geochemical anomalies are mainly affected by human disturbances under the same natural backgrounds, which is also an effective way to exclude the natural factors' influences on the geochemical anomalies. Whether the geochemical anomalies are influenced by human disturbances will be explored based on the building land, road and mine data. Land cover interpretation using remote sensing images is an important task that allows the extraction of landscape information that is useful for many applications. The visual interpretation is executed based on features such as texture, shape and colour of objects and patterns that can be observed in the images, as well as other discernible attributes of the image such as spatial relationship. People obtain the target object information in the image by means of direct observation or simple technique. The building land, road and mine data were obtained through remote sensing image interpretation, and the buffering regions of them were produced in average 1 km or 2 km with ArcGIS software. The landform, stratigraphic and soil type data were produced through digitizing a thematic map.

In total, 2314 and 3920 soil samples were collected at the Yuxi and Yubei study areas, respectively, in 2010 and 2011. The sampling locations were steadily scattered in the study areas with square grids of $2 \times 2\ km^2$ and $0.5 \times 0.5\ km^2$, and each sampling point situated in one grid (Figs. 5 and 9). The chemical parameters of F and I were tested in terms of the Specifications of Multi-purpose Geochemical Survey, conducted by Chinese Geological Survey. The calibrations of the instruments, detection limit analysis and analytical quality controls had been strictly implemented and the results fully met the relevant standards and requirements.

2.3. Analysis methods

Spatial interpolation creates a continuous surface from a set of points to predict all the value of certain variable within a region. In the