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Effects of natural factors on the spatial distribution of heavy metals in soils surrounding mining regions

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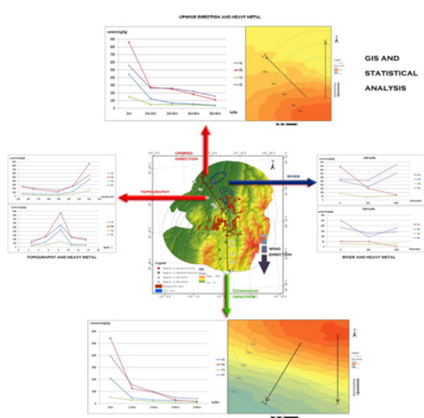
HIGHLIGHTS

- Distributions of As, Pb, Cu, Zn under influences of natural factors are explored.
- Distributions of heavy metals with slopes are different from that of elevations.
- Perennial wind promotes the spread of heavy metal to downwind direction.
- Influence ranges of river on Pb, Zn and Cu in surrounding soil are within 800 m.
- Influence of terrain on distributions of heavy metals is greater than wind.

GRAPHICAL ABSTRACT



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ABSTRACT

Various studies have shown that soils surrounding mining areas are seriously polluted with heavy metals. Determining the effects of natural factors on spatial distribution of heavy metals is important for determining the distribution characteristics of heavy metals in soils. In this study, an 8 km buffer zone surrounding a typical non-ferrous metal mine in Suxian District of Hunan Province, China, was selected as the study area, and statistical, spatial autocorrelation and spatial interpolation analyses were used to obtain descriptive statistics and spatial autocorrelation characteristics of As, Pb, Cu, and Zn in soil. Additionally, the distributions of soil heavy metals under the influences of natural factors, including terrain (elevation and slope), wind direction and distance from a river, were determined. Layout of sampling sites, spatial changes of heavy metal contents at high elevations and concentration differences between upwind and downwind directions were then evaluated. The following results were obtained: (1) At low elevations, heavy metal concentrations decreased slightly, then increased considerably with increasing elevation. At high elevations, heavy metal concentrations first decreased, then increased, then decreased with increasing elevation. As the slope increased, heavy metal contents increased then decreased. (2) Heavy metal contents changed consistently in the upwind and downwind directions. Heavy metal contents were highest in 1 km buffer zone and decreased with increasing distance from the mining area. The largest decrease in heavy metal concentrations was in 2 km buffer zone. Perennial wind promotes the transport of heavy metals in downwind direction. (3) The spatial extent of the influence of the river on Pb, Zn and Cu in

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the soil was 800 m. (4) The influence of the terrain on the heavy metal concentrations was greater than that of the wind. These results provide a scientific basis for preventing and mitigating heavy metal soil pollution in areas surrounding mines.

1. Introduction

In soil, heavy metals are persistent, do not easily decompose, are easily concentrated and are highly toxic (Odukudu et al., 2014). Heavy metals that accumulate in the soil can inhibit soil functions, poison plants and contaminate the food chain (including humans) (Duan et al., 2015; Wu et al., 2016). As natural components of the Earth's crust, heavy metals are generally present at low concentrations in natural soils. However, anthropogenic heavy metal inputs have greatly increased the heavy metal contents in soils (Facchinelli et al., 2001). Due to the impacts of frequent and sustained mining activities, soil heavy metal pollution around mining areas has become a severe problem worldwide (Pan et al., 2016). Consequently, a great deal of research has been conducted on the distribution of heavy metals in soils near mining areas around the world.

Recent studies on the spatial distribution of heavy metals in soils surrounding mining areas have mainly described soil heavy metal concentrations in one of two ways. In some studies, the study area is divided into mining areas, dumps and other regions based on certain principles to compare the heavy metal contents in the soil samples between the different regions (Guo et al., 2011; Loredo et al., 2003). In other studies, spatial interpolation methods, such as inverse distance weighting and ordinary kriging, are used to describe the spatial distribution of soil heavy metals (Ogunkunle and Fatoba, 2014; Yan et al., 2015). Although both methods characterize the distribution of soil heavy metals throughout a study area, they neglect the relationships between the soil heavy metal contents and natural factors such as terrain, wind direction and the distances from rivers.

Studies on the effects of natural factors on the spatial distributions of soil heavy metal concentrations are very important for understanding the distribution characteristics of soil heavy metals with respect to natural factors. However, few relevant studies have been conducted, and in the existing studies, only simple natural factors have been considered. For example, more studies have focused on wind direction than on terrain, and very few studies have considered the influence of the distance between a given location and a river on the soil heavy metal contents in areas surrounding mines. For example, Li et al. (2004) collected soil samples from around a gangue pile using a sector method and statistically analyzed the soil heavy metal contents. These authors concluded that the heavy metal contents were affected by the wind direction and decreased with increasing distance from the coal gangue pile. Li et al. (2015) compared the soil heavy metal contents along a transect parallel to the main wind direction near a lead/zinc smelter in southwestern China and found that the Cd, Pb, and Zn concentrations in the topsoil decreased more rapidly in the upwind direction than in the downwind direction. Chu and Zhou (2014) used a statistical grading method to analyze changes in the heavy metal contents in soil samples with different slopes around the Pingdingshan mining area in China and concluded that the Cu, Cr and Pb contents increased as the slope decreased. As illustrated by these research methods, most researchers have used statistical methods, and very few researchers have used spatial analysis methods.

In this paper, we selected an 8 km buffer zone surrounding a typical non-ferrous metal mining area in the Suxian District of Chenzhou City in Hunan Province, China, as the study area. We obtained descriptive statistics and performed spatial autocorrelation and interpolation analyses of the concentrations of As, Pb, Cu, and Zn in the soil and then studied the distributions of these heavy metals under the influences of several natural factors, including terrain (elevation and slope), wind direction and distance from a river. Then, the layout of the sampling sites, changes in the soil heavy metal contents at high elevations and concentration differences between upwind and downwind directions were evaluated. The results of this study provide a scientific basis for the comprehensive prevention and remediation of heavy metal pollution in the soils of mining regions.

2. Materials and methods

2.1. Study area

Abundant mineral resources exist in the Suxian district of Chenzhou City in Hunan Province, China, such as coal in Xujiadong, Pb and Zn in Qiaokou, Cu and Sn in Yejiwei, Fe and Mn in Manaoshan and several metals in Shizhuyuan. Liao et al. (2005) indicated that the Shizhuyuan mine affected soils as far away as 24 km, and Song et al. (2013) indicated that the mines in the Suxian District increase the risk of disease-related mortality within a distance of approximately 7 km. Due to restrictions resulting from cost, time, and the locations of water bodies, cliffs, valleys and other natural features in the mining area, we selected a buffer zone of 8 km around the central large metal mines in the Suxian District as the study area (Fig. 1) (25°38′14″–25°52′14″ N, 113°0′24″–113°16′15″ E). The study area extends over 467.58 km^2 and includes Bailutang, Aoshang, Bailudong, Dakuishang, Tangxi and many other villages and towns. The study area is mainly dominated by hilly terrain that is higher in the southeast and lower in the northwest and contains the East River, West River and many other smaller rivers. The region has a sub-tropical humid monsoon climate with typical mountain climate characteristics and large differences in temperature between day and night. The dominant wind direction is from the north, with an average wind speed of 1.8 m/s. The soil of the study area is significantly dominated by clay, and the average pH and organic matter contents are approximately 5.6 and 28.7 g/kg, respectively. This region is famous worldwide for its polymetallic deposits, with large reserves of W, Sn, Mo, Bi, Be, Fe, Mn, Cu, Pb, Zn, Au and Ag, among others. Up to 143 types of mineral resources have been identified in the non-ferrous metal deposits in Shizhuyuan, and the region has been called “the world museum of non-ferrous metals” by geological experts. Over 1000 years of mining history have resulted in great economic benefits to the region at the cost of producing serious soil heavy metal pollution in the areas around the mines.

2.2. Data collection and processing

2.2.1. Basic geographic data

The basic geographic data, including the administrative divisions and digital elevation model (DEM) produced with spatial information technology, are from the Chinese Academy of Environmental Science Data Center Resources and have been widely applied in research by experts and scholars (Wang et al., 2012, 2015; Ji et al., 2014).

2.2.2. Soil heavy metal contents

2.2.2.1. Soil sampling. The upwind and downwind sampling lines radiate outward from the mining area in the study area (Fig. 1). The upwind sampling line was located to the north of the mining area. Some small mining and ore dressing plants are present in the north-south direction through the mining center. Because of the relatively flat terrain, these plants have an important influence on the distribution of heavy metals