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Spatial analysis, source identification and risk assessment of heavy metals in a coal mining area in Henan, Central China

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A B S T R A C T

The purpose of this study is to investigate the heavy metal (HM) concentration of the gangue and HM pollution of the soil in a coal mining area. On the basis of determination of the concentrations of cadmium (Cd), lead (Pb), copper (Cu), zinc (Zn) and chromium (Cr) in the samples from the gangue and surface soils, the spatial distribution of toxic metals, contamination sources, potential ecological risks, potential health risks were studied. The content of Cd, Pb, Cu and Zn in the surface soils exceeded China National Standard (CNS, GB15618-1995). The spatial distributions of Cd, Pb, Cu and Zn are similar, exhibiting a declining trend from the gangue dump to the surrounding farmland. Results of Pearson correlation matrix and principal component analysis indicate that the origin of Cd, Pb, Cu and Zn elements is the gangue dump. The potential ecological risk index ranges from 97.2 to 619.5, and its spatial distribution is similar to those of Cd, Pb, Cu and Zn. Our results indicate that the HMs exceeded the corresponding CNS and posed noticeable ecological risks, which suggest that monitor and remediation measures should be taken in order to protect the health of the residents and the safety of the crops.

1. Introduction

Coal mining industry generates a large volume of gangue wastes, from which a considerable amount of toxic HMs could be released during weathering of the waste under the joint effects of water, microorganisms, vegetation, sunlight radiation and heat (Larocque and Rasmussen, 2011). These hazardous substances enter the ecosystem by a variety of pathways where they could be detrimental to crops and animals, and might be taken up by human through direct contact (ingestion, dermal absorption and inhalation) or food chains (Sun et al., 2013). Even at low concentrations, these contaminations are toxic to human health (Arora et al., 2008; Memon and Schröder, 2009), especially to children's health (Ljung et al., 2006; Poggio et al., 2009; Chabukdhara and Nema, 2013), by causing gastrointestinal disorders, diarrhea, stomatitis, and neurological system malfunctions like tremor and ataxia (USEPA, 1986; Singh et al., 2010).

Environmental studies of coal mining areas were conducted by many researchers from USA (Finkelman, 1999; Finkelman and Gross, 1999), Europe (Szczepanska and Twardowska, 1987; Panov et al., 1999) and China (Ding et al., 2001). However, HM contamination in the soil around coal gangue dumps has not drawn enough attention than it deserves. The HM pollution has multiple sources, such as parent material, industrial emission, application of fertilization and pesticides (Fulekar et al., 2009; Wuana and Okieimen, 2011; Nanos and Martín, 2012). Natural and anthropogenic sources of soil HMs could be identified by employing multivariate analysis, including correlation analysis and principal component analysis (PCA) (Lu et al., 2012; Fu and Wei, 2012; Shan et al., 2013). In addition, some spatial analysis techniques could map distributions of HM and identify the possible hotspots in soils. Therefore, the combination of the above methods could be more reliable to differentiate the sources in soil environment (Lv et al., 2014).

Yanma coal mine is a large state-owned mine in Henan and has more than 50 years of mining history. The gangue dump with a weight of 3×10^5 t might be a great threat to at least 3000

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residents, 2 km^2 farmland and 6 farms by releasing toxic metals. However, few investigations have been performed about the impacts of HMs on the local environment in this particular area. Therefore, it is essential to investigate the source and distribution of the contaminants. Moreover, analysis of different HM contents in contaminated soils could evaluate their potential ecological and health risks. The scientific basis of targeted contamination management, residents' health protection, crop production safety and environmental remediation in this area remains unclear until the problems mentioned above are solved.

2. Materials and methods

2.1. Sampling and analysis

The study area (N35°16′2.1″,E113°21′8.2″) is located at Yanmazhuang, Jiaozuo coal mining area, Henan (Fig. 1). The terrain gradually declines from northwest to southeast; groundwater flow direction is SE/130°. The area belongs to the front Taihang piedmont alluvial-pluvial fan, which is under control of a temperate continental monsoon climate. The groundwater depth is between 1 m and 3 m. Prevailing wind directions are northeastward and southwestward. Annual average temperature, precipitation and average evaporation are 14 °C, 610 mm and 2039 mm, respectively.

Three sampling profiles (L1-L3) were conducted based on the prevailing wind direction, non-prevailing wind direction and groundwater flow direction:

L1 was to the southeast (groundwater flow direction and non-prevailing wind direction, SE/130°) of the gangue dump, the distance between the gangue dump and the south easternmost sampling site was approximately 2000 m;

L2 was to the northeast (the prevailing wind direction, NE/35°) of the gangue dump, the north easternmost sampling site is about 2500 m from the dump;

L3 was located within a distance of 300 m from the southwest of the gangue dump, including the top, hillside, foot.

All sampling sites were chosen cautiously to avoid main roads, railways and other major human activities. Twenty-five surface soil/gangue and three groundwater samples were collected along three sampling profiles. The closer to the gangue dump, the more sampling sites were selected. Each sample contained four subsamples randomly collected in order to form a representative sample (Li et al., 2008b). Three water samples were collected from wells that recharged by shallow groundwater at L1 profile. GPS coordinates of all sampling sites were documented. Soil pH was measured by IQ150 portable pH-conductivity meter.

All the samples were ground, dried and sieved through 100 mesh sieve. An H_2O_2-$HClO_4$-HF-HNO_3 digestion method was employed. A Chinese national standard sample (GBW07427), as well as a blank sample was used as references to control the quality of the entire determination. The total concentrations of cadmium (Cd), lead (Pb), copper (Cu), chromium (Cr), and zinc (Zn) in soil and gangue were measured by inductively coupled plasma-atomic emission spectroscopy (ICP-AES, IRIS Intrepid II XSP). The total concentrations of Cd, Pb, Cu, and Zn in groundwater were measured by ICP-AES (PE Optima 2100DV). The total concentration of Cr in groundwater was determined by ultraviolet visible spectrophotometer (UV, Hitachi U-2900).

2.2. Spatial analysis

The inverse distance weighted method of Geostatistic module in ArcGIS was employed to interpolate the surface of each HM element and to calculate the potential ecological risk index. The values of the surface were estimated by weighting sampling points in accordance with their vicinity in the whole sampling area.

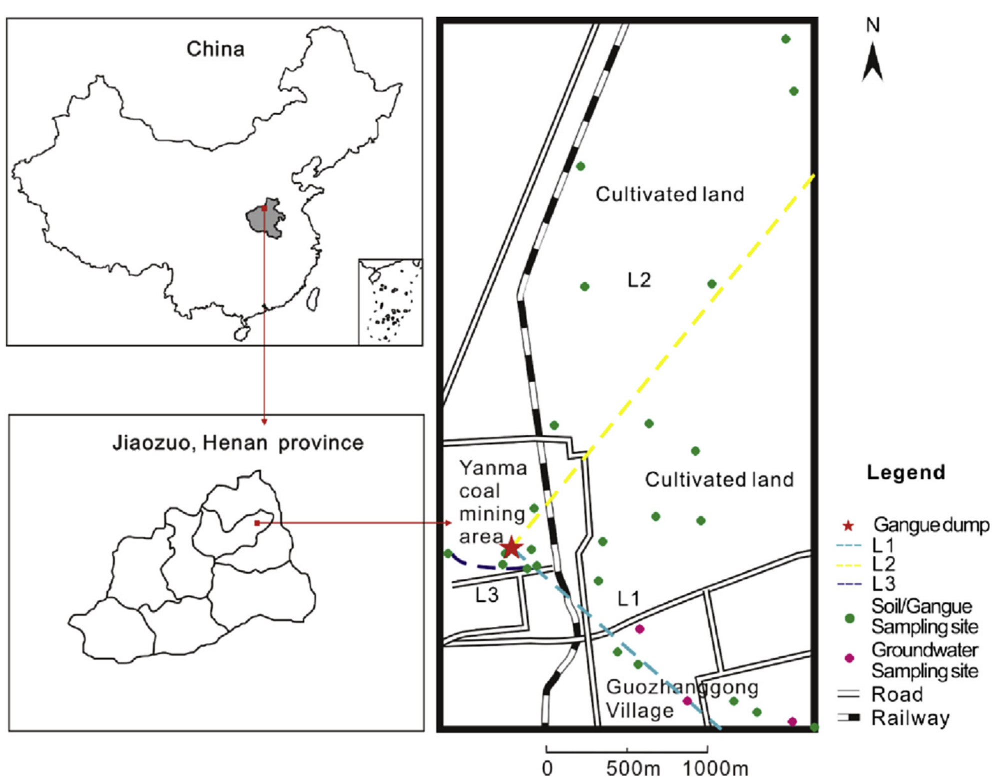

Fig. 1. Map showing the field routes and sampling sites.

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