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Assessment of trace metal contamination and ecological risk in the forest ecosystem of dexing mining area in northeast Jiangxi Province, China

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ABSTRACT

Samples of soil, earthworms, and tree roots from the forest ecosystem in the Dexing Pb/Zn mining area of Jiangxi Province were collected and the status of trace metal pollution analyzed to assess potential ecological risks. Chemometric and geographic information system methods were used to identify and describe the spatial distributions and the main contamination sources of trace metals. The order of potential ecological risks of trace metals in this area are as follows: cadmium (Cd) > arsenic (As) > copper (Cu) > nickel (Ni) > lead (Pb) > chromium (Cr) > zinc (Zn). Elemental spatial distribution maps showed the existence of zones heavily polluted by trace metals around the mining area. Earthworms and roots of three tree species were also heavily contaminated, with concentrations of trace metals in earthworms much higher than in previous studies. The potential ecological risk index and other soil quality indices indicated that soil had moderate to severe contamination and there were high ecological risks, with Cd making the greatest contribution. Multivariate statistical analyses showed that Cd, As, Cu, Pb, and Zn in soil came from a mining activity source, whereas Ni and Cr primarily originated from a natural source.

1. Introduction

Forest ecosystems are regarded as the most diverse terrestrial ecosystems because they contain most of the world's terrestrial species, such as trees, insects, and animals. They also play an important role in maintaining the global ecosystem and include 75% of the gross primary productivity and 80% of the plant biomass on earth. Forest ecosystems are also considered effective sinks of resource consumption and chemical emission, and trace metals and organic pollutants are frequently found in their soil, plants, and animals (Schaubroeck et al., 2012). Due to rapid industrial and economic development, contamination of forest ecosystems has become a common and increasingly serious environmental problem.

The mining and smelting of ore deposits exposes underground minerals to the surface environment, resulting in changes in chemical composition and physical state of minerals, and increasing the release of trace metals into the environment. At the same time, due to oxidation of sulfide minerals to produce acid, they can acidify water and increase inorganic salt composition and water hardness. The harm to people, animals and plants can be marked, and mine development can often effect and pollute the surrounding ecological environment (Moon et al., 2011; Ahmad et al., 2012). In the mining production process, mining and selecting ore are the most important ways by which trace metal pollutants are released into the soil and water environments. Due to the cumulative effect of trace metals in living organisms, organisms absorb trace metals from the environment through a progressive amplification of the food chain, thereby being enriched by thousands of times in higher organisms and causing their acute or chronic poisoning (Ma et al., 2015).

Trace metals are ubiquitous environmental pollutants, which have attracted increasing attention in recent decades due to being persistent, non-biodegradable, toxic, and bioaccumulative in water, soil, and humans. High concentrations of trace metal contaminants is one possible factor in the deterioration of forest ecosystems and the entire habitat. Their sedimentation may cause long-term damage and complete irreversible degradation of soil of forest ecosystems. Therefore, evaluation of trace metal pollution in soil, animals, and plants in mining areas has become an important part of their pollution control. Many pollution indices have been used to estimate soil conditions, including geo-accumulation index (I_{geo}), contamination factor (Cf), enrichment factor

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(Ef), Nemerow's pollution index (PI), and potential ecological risk (RI) (Gä Siorek et al., 2017). Indices of pollution can provide a complex evaluation of contamination of soil environments with dissimilar geochemical backgrounds. Furthermore, the indices allow determining the origin of trace metals accumulated in soils, determining ecological risk and helping protect forest ecosystems (Table S1).

The Dexing area in the southeast of China has abundant mineral resources. The lead (Pb) and zinc (Zn) mining area is one of the largest opencast mines rich in non-ferrous ore deposits in the area, and has been exploited for more than 50 years (Zhou, 2011). The mines have produced ores containing copper (Cu), silver, Zn, and Pb, with common minerals including sulfide pyrite (FeS_2), chalcopyrite ($FeCuS_2$), galena (PbS), and sphalerite (ZnS) (Yang et al., 2011). The vegetation of the forest ecosystem around the Dexing mining area consists mainly of East China yellow pine (*Pinus ponderosa*), yellow mountain pine (*Pinus taiwanensis Hayata*), south hemlock (*Tsuga chinensis (Franch.) Pritz*), cypress (*Glyptostrobus pensilis (Staunt.) Koch*), red flower tea (*Camellia chekiangoleosa* Hu), camphor tree (*Cinnamomum bodinieri Levl.*), and ferns (*Pteridophyta*). Plants take up trace metals via roots and passively via leaves. Earthworms are commonly used in soil ecological studies because they play significant functional roles in soil containing excess trace metals. They can accumulate high levels of trace metals in their body through ingurgitation or surface absorption (Richardson et al., 2015; Wang et al., 2018).

There is great scientific interest in the pollution status of trace metals in the environment adjacent to mining areas and on potential ecological adverse effects (FAO, 1972). Consequently, our research was conducted to (1) determine the contamination of trace metals in soils, roots of three tree species and earthworms in the Dexing forest ecosystem, (2) to assess the ecological risk of forest soil and its pollution status using comprehensive quality indicators, and (3) identify the sources of trace metals and the high environmental-risk zone using multivariate analysis and GIS mapping.

2. Material and methods

2.1. Study area and sampling

Samples of soil, earthworms (*Pheretima tschiliensis*) and tree roots were collected in the forest ecosystem around the mining area in summer 2015. The sampling sites spanned latitude 29°04′90.95″–28°92′57.58″N and longitude 117°52′13.12″–117°69′32.88″E in the Dexing mining area (Fig. 1). A hand-driven stainless steel soil auger was used to gather surface forest soil samples (0–5 cm). To minimize error, five subsamples were mixed to constitute a composite soil sample (about 100 g). The samples collected were transported to the laboratory and stored at −20 °C until further analysis. The soil specimens were air-dried at room temperature and filtered through 63-µm mesh for chemical analysis.

Earthworms (*Pheretima tschiliensis*) of similar size (approximately 10 cm long) were collected to make about 60–100 g of biomass (n = 7). Roots of *Pinaceae*, *Pinus massoniana* and *Cinnamomum camphora Presl.* were collected to obtain about 200–400 g of biomass (n = 6). These species were selected because they represented different families and were characterized by high frequency and/or cover, with a large potential effect on metal fate in the ecosystem. The trees were about 2.5–3.0 m in height, but it was difficult to evaluate their exact age as plant development on polluted soil may be delayed by adverse environmental conditions. Both earthworm and root samples were washed with deionized water and excess moisture removed with filter paper. Moreover, at the same time for collection earthworms (*Pheretima tschiliensis*) and roots of pant (*Pinaceae*, *Pinus massoniana* and *Cinnamomum camphora Presl.*), the soil around the sampling sites were also collected to calculate bioaccumulation factor (BAF).

2.2. Chemical analysis

Aliquots of 0.25 g of ground and dry soils were digested using 10 mL of a mixture of acid solution (HNO_3/HCl/HF, 5:4:1, v/v/v). The digested soil was cooled, filtered; and the digested solution was evaporated to almost dryness and finally diluted to 25 mL (Loring and Rantala, 1992). Each batch of specimens (five specimens per batch) included blanks and certified geo-standard reference materials (GBW07428). Inductively-coupled plasma mass spectrometry (ICP-MS, 7500cs, Agilent, USA) was applied to detect the following trace metals: iron (Fe), cadmium (Cd), chromium (Cr), (Pb), nickel (Ni), arsenic (As), (Cu) and (Zn). Among the elements, Cd, Cr, Pb, Ni, As were toxic elements, while Cu and Zn were essential elements. The accuracy of the analytical methods was evaluated by recovery measurements of the GBW07428 geo-standard material. Repeated analysis of GBW07428 gave a recovery of 92–111% compared with the certified value (Cd 111.0 ± 4.9%, Cr 92.0 ± 5.3%, Pb 95.9 ± 2.7%, Ni 106 ± 4.3%, As 105.3 ± 2.2%, Cu 97 ± 2.5% and Zn 107 ± 4.4%).

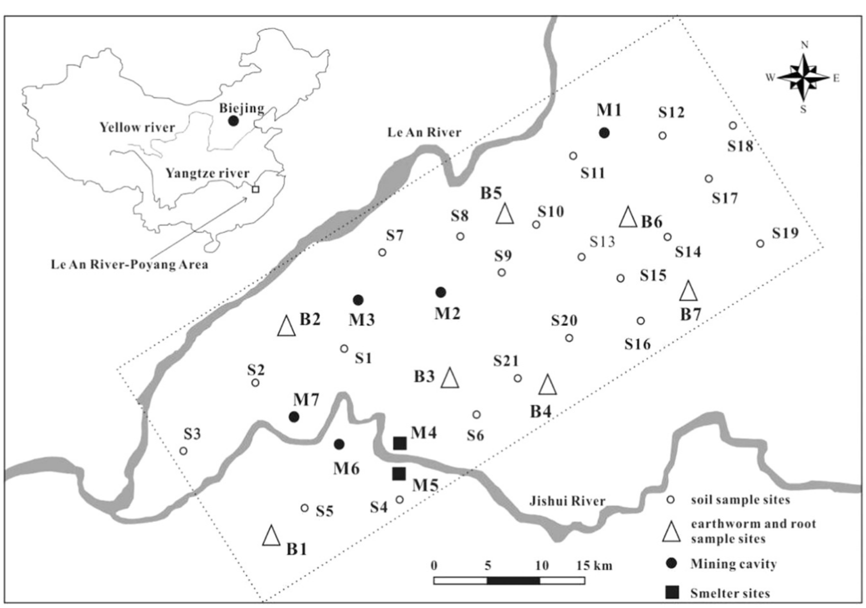

Fig. 1. Map of the study area and locality of sampling sites.