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Heavy metal contents and enrichment characteristics of dominant plants in wasteland of the downstream of a lead-zinc mining area in Guangxi, Southwest China

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A R T I C L E I N F O

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A B S T R A C T

A field investigation on the content of heavy metals in soils and 17 kinds of dominant plants from wasteland of the downstream of a Pb-Zn mine in Northwest Guangxi Zhuang Autonomous Region was carried out. The absorption and accumulation characteristics of heavy metals between plants and soil were compared, and the candidate species for ecosystem restoration of the area were selected. The results indicated that the soils had been subjected to pollution of heavy metals in varying degrees. The concentrations of Cd, Pb, Zn were 46.5, 57.3 and 23.7 times higher than their corresponding background values, respectively. The contents of Cd, Pb and Zn in the most analyzed plants exceed the normal ranges and the phytotoxic level. *C. crepidioides*, *S. nigrum*, *B. pilosa*, *C. Canadensis*, *A. conyzoides*, *I. denticulata* and *E. crusgali* showed strong capability in accumulation and transport of Cd, and they could be used as good candidates for Cd- phytoextraction. Among which, Cd concentration in the aerial part of *C. crepidioides* exceeded the threshold of Cd-hyperaccumulator. Thus, *C. crepidioides* demonstrated the basic characteristics of a Cd-hyperaccumulator. The lower translocation ratios for Cd, Cu, Zn and Pb in *P. vittata* and *C. chinensis* make them suitable for phytostabilization in the study area.

1. Introduction

Mineral resources represent the key material foundation for socio-economic development, e.g. the utilization of mineral resources has been making a great contribution for economic development in China (Li et al., 2014). However, due to long-term improper mineral utilization, a large amount of mining wastes was generated without proper management. These wastes are usually deposited on the ground as tailings which occupy a huge area of land surface. In many cases, the mine tailings are characterized by high metal and metalloid concentrations (Conesa et al., 2007). Heavy metals from tailing would be leaded into soils and groundwater via rainfall, runoff and wind blowing, resulting in environmental contamination of the surrounding terrestrial and aquatic ecosystems, followed by the decline in crop quality and agricultural production. Even worse, heavy metals can also be accumulated in the human body through the food chain, breathing and skin adsorption, which represents a serious threat to human health (Banza et al., 2009; Lei et al., 2016). It is estimated that 1.5 million ha of wasteland have been generated by mining in China, and the annual increase of mining wasteland of 46,700 ha serves as a growing and persistent source of pollutants (Zhuang et al., 2009b). There are increasing evidences that heavy metal pollution of mined areas in China cause health damage to the local inhabitants (Lei et al., 2015; Shen et al., 2017; Xiao et al., 2017; Zhang et al., 2012; Zhuang et al., 2009a).

Rehabilitation of mine wastelands was a priority issue to be addressed for many provincial governments in China because the shortage of cultivated land was increasingly outstanding, especially for the karst regions in the southwest part like Guangxi Zhuang Autonomous Region, which are rich in the metallic ore resources (Li and Yang, 2008). Phytoremediation technology is regarded as one of the promising methods for reclaiming soils contaminated with toxic metals (Lasat, 2002; Marrugo-Negrete et al., 2016; Mulligan et al., 2001). Phytoremediation is defined as the use of plants to remove pollutants from soils or to render them harmless (Ali et al., 2013). Since it is performed in-situ and solar driven (LeDuc and Terry, 2005), phytoremediation is a sustainable approach which is economically viable and environmentally safe

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(Mahar et al., 2016). It is important to use native plants for phytoremediation because these plants are often better in terms of survival, growth, and reproduction under environmental stress than plants introduced from other environments (Yoon et al., 2006). However, minesoil is characterized by elevated heavy metal concentrations, poor physical structure, deficiency of available nutrients, extreme acidity and/or salinity, drought, and other stressful factors (Nirola et al., 2016; Shu et al., 2002). Nevertheless, there were still some plants that are adaptable to contaminated soil with high concentrations of heavy metals. This indicates that the plant itself has generated a series of physiological and biochemical reactions in the long-tern natural evolution for absorption and accumulation of heavy metals to form a series of mechanisms for suitable growth, resistance, tolerance and detoxification, which adapted to the specific environmental conditions (Dazy et al., 2009; Malik et al., 2010). These plants play a decisive role in the restoration and phytoremediation of heavy metal contaminated soil.

Guangxi Zhuang Autonomous Region, one of the most well developed karst areas, ranks the fourth of China in terms of Pb/Zn mining (Wang et al., 2012). The study area was located in a wasteland of the downstream of a Pb-Zn mine in Northeast Guangxi, which was one of the relatively large mine in Guangxi. The mine tailings were disposed by damming at the valley, which are unstable and prone to erosion. In 1970s, the collapse of the Pb-Zn mine tailing dam led to the spread of mining waste spills on the farmland along the river due to a catastrophic flood. Some former farmlands were abandoned due to serious pollution. Therefore, by sampling soil and dominant plants from wasteland of the downstream of the Pb-Zn mine, and by analyzing the concentrations of heavy metal in soil and dominant plants, the main objectives of this study were to evaluate metal accumulation and migration potentials in dominant plants and to screen out candidate species for application in rehabilitation of mining wasteland. This research will provide information for recovering areas affected by mining wastes and polluted soils in the study sites and in other similar areas affected by the same problems in southern China.

2. Materials and methods

2.1. Study site description

This study was carried out in the wasteland produced by upstream tailing dam collapse in a village, located 7 km southwest of the Pb-Zn mine. The area is characterized by a typical subtropical monsoon climate with a mean annual temperature of 19.5 °C and a mean annual precipitation of approximately 1700 mm. The soil types in this area are mainly limestone soil and siliceous soil with separate distribution.

2.2. Sample collection

Field surveys of the dominant plants and soils in the wasteland were carried out in May 2016. Natural settled dominant plant species which are vigorous, representative and great coverage were selected. There were three replicates of each species. For each replicate, five or more individual plants were randomly gathered within the sampling area and mixed to give a composite whole plant sample. Simultaneously, the associated soils (0–15 cm) of the sampled plants were also collected and homogenized for total metal analysis. Different parts of the plant, such as root, stem and leaf, were separated. All soil and plant samples were sealed in polythene bags for transport to the laboratory.

2.3. Analytical methods

Soil samples were air-dried, ground and passed through a 100 mesh plastic sieve. After being carefully and repeatedly washed with tap water and rinsed with deionized water, the plant samples were treated by high temperature desiccation under 105 °C for 30 min, then oven dried at 65 °C to constant weight. The dried plant tissues were milled to a fine powder. All procedures of handling were carried out without contacting any metals to avoid potential cross-contamination of the samples.

Soil pH (1:5 soil to water, w/w) was measured with conventional pH meter. For the analysis of heavy metals, the soil samples were digested using concentrated HNO_3-$HClO_4$-HF with a ratio of 6:2:2, and the plant samples were digested with a 4:1 ratio of concentrated HNO_3-$HClO_4$. The residuals were re-dissolved by HNO_3 (2%) and diluted with distilled water. The solutions from the digested samples were stored at 4 °C until analysis. Water used for dilution and dissolution was purified using a Millipore deionizing system at 18.2 MΩ. The utilized HF, HNO_3, and $HClO_4$ were suprapur reagents. The total metal concentrations in digestate solutions were determined by inductively coupled plasma optical emission spectrometry (ICP-OES, Optima 5300DV, PerkinElmer, US). Standard reference materials (GSS- and GSV-) obtained from the Center of National Standard Reference Materials of China, as well as blank samples, were included in each batch of analyses for quality assurance and quality control (QA/QC) procedures. All samples were analyzed in duplicate and the analytical precision was accepted when the relative standard deviation was within 5%.

2.4. Statistical analysis

The experimental data is processed by adopting Microsoft Excel (Ver. 2010) for analysis of the means, standard deviation and coefficient of variation, as well as for drawing analysis.

3. Results

3.1. Composition and characteristics of dominant plants

After a long period of natural succession, the vegetation of the wasteland had formed a natural community (Table 1). There were 17 dominant plant species in this survey belonging to 8 families (Compositae, Pteridaceae, Gramineae, Umbelliferae, Buddlejaceae, Solanaceae, Cyperaceae, Chenopodiaceae). Of these species, *A. conyzoides*, *C. crepidioides*, *B. davidii*, *P. vittata*, *I. cylindrical* and *P. revolutum* were most frequently encountered. Regarding the life form of plants, the wasteland vegetation was dominated by herbaceous plants, which accounted for 94.1%. This observation may be related to the survival potential and characteristics of herbs, like their ability to grow quickly, survive in barren sites, and drought resistance (Yang et al., 2014). In addition, herb plants with fine or light seeds can be easily distributed by wind (Li et al., 2007; Mikołajczak et al., 2017). Therefore, herbs were more likely to form heavy metal tolerance.

Table 1
List of dominant plant species growing on the study area.

Family	Species	Life Form
Compositae	*Conyza canadensis* (Linn.) Cronq.	Annual Herb
Compositae	*Ageratum conyzoides* Linn.	Annual Herb
Compositae	*Taraxacum mongolicum* Hand.-Mazz.	Herbs Perennial
Compositae	*Bidens pilosa* Linn.	Annual Herb
Compositae	*Artemisia iavandulaefolia* DC.	Herbs Perennial
Compositae	*Crassocephalum crepidioides* (Benth.) S. Moore	Annual Herb
Compositae	*Ixeris denticulata*	Annual Herb
Compositae	*Senecio scandens* Buch.-Ham. ex D. Don	Herbs Perennial
Pteridaceae	*Pteris vittata*	Herbs Perennial
Pteridaceae	*Pteridium revolutum*	Herbs Perennial
Gramineae	*Echinochloa crusgali* (Linn.) Beauv.	Annual Herb
Gramineae	*Imperata cylindrica*	Herbs Perennial
Umbelliferae	*Centella asiatica* (Linn.) Urban	Herbs Perennial
Buddlejaceae	*Buddleja davidii* Fr.	Deciduous Shrub
Solanaceae	*Solanum nigrum* Linn.	Annual Herb
Cyperaceae	*Carex chinensis* Retz.	Herbs Perennial
Chenopodiaceae	*Chenopodium ambrosioides Linn.*	Annual Herb