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Evaluation and analysis of soil migration and distribution characteristics of heavy metals in iron tailings

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ABSTRACT

Migration and transformation trend of heavy metals have close relationship with soil safety. In this research, we aim to provide reliable basis for prevention and management of local soil contaminants. We choose Anshan tailings for field investigations and laboratory research, analyze vertical and horizontal migration characteristics of five heavy metals (Cu, Zn, Pb, Cd, and Cr) and the role of *Amaranthus blitoides* in tailings. According to Single factor contaminant index and Nemerow composite index, the five heavy metals condition different migration trend in the vertical direction (Cd > Zn > Cr > Pb > Cu) in the soil properties and threaten the groundwater of Anshan tailings. They had strong migration capability in horizontal direction resulting in surrounding pollution. The highest migration capability was found in Cr followed by Pb > Zn > Cd > Cu under specific climatic condition. *Amaranthus blitoides* as dominant species can grow well in harsh environment and can effectively remove heavy metals in mine tailings.

1. Introduction

As an important subsystem, soil is usually considered as main stack area of various pollutants (Chibuike and Obiora, 2014). Polluted soil by heavy metals not only impairs physical and chemical properties, but also affects the soil organisms. Organisms have the ability to accumulate heavy metals through air, food, or water resources, finally to pose a threat to human health including hypophosphatemia, heart disease, liver damage, and neurotoxicity (Zoeteman et al., 1981). Heavy metals show great ecological significance because of high toxicity, persistence and bioaccumulation capacity. Although heavy metals contamination from an aquatic source shows negatively affect on organisms at all trophic level along the food chain (Tao et al., 2012), terrestrial organism reproductive success is reduced in the soil environment contaminated by heavy metals because chronic exposure can cause physiological abnormalities (Zhang et al., 2016). Therefore the pollution of heavy metal in soil greatly influences the health of ecosystem, and the study on heavy metals distribution mechanism has great significance (Oti et al., 2012).

The content of heavy metals in tailings is influenced by many factors, including anthropogenic and lithogenic sources, the textual characteristic, organic matter content, mineralogical composition and depositional environment. Grain size is one of the essential factors influencing heavy metal contents in soil (Jung, 2008). Fine-grained sediments often show high concentrations of heavy metals due to their greater surface to volume ratio and enrichment of organic matter and Fe–Mn oxides. The behavior of heavy metals in sediments is strongly dependent on redox gradients. The metal profiles are affected by sedimentary redox processes, which can be monitored by means of Mn and Fe concentrations (Vink, 2002). Iron is an important electron acceptor during early diagenesis and the reduction of iron plays a significant role in the cycling of heavy metals. Heavy metals show strong affinity with iron oxides in the environment, and the reduction of iron oxides has a direct influence on the cycling of heavy metals. The complexation of heavy metals with organic matter is important in the understanding of metal bioavailability and mobility in natural aquatic systems. Recent studies show phytoremediation is a safe and efficient way to handle heavy metal in soil (Kotrba et al., 2009).

Phytoremediation inhabiting potentially polluted areas yields an assessment and protection of overall ecosystem health. Many of the current phytoremediation efforts rely on special hyper-accumulator, showing higher demand on soil quality. Local plants can withstand harsh environment and have the capability to accumulate heavy metal. Local wild-type is the best choice for in -

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situ ecological restoration. *Amaranthus blitoides* (*Caryophyllales, Amaranthaceae, Amaranthus*) is widely distributed in North America and Liaoning China. *Amaranthus blitoides can tolerate harsh environment and effectively accumulate the heavy metal, showing great application prospects* in - situ remediation (Río et al., 2002).

Anshan city located in northeast of China engaged in development of mineral resources. Mining tailings and other wastes occupied a large area of the site, finally resulted in destruction of ecosystems in stacked field (Andrade et al., 2006). There was much heavy metal in tailings shown in Fig. 1. Large amount of toxic heavy metals released and migrated through surface runoff, airborne particulates. That had serious impact on the surroundings (Wang et al., 2007). In this study, we chose Anshan as sample area and employed phytoremediation to assay the migration of heavy metals in the vertical and horizontal direction to assess the environment pollution and discovery potential threat (Serrano et al., 2016). The main pollutants of heavy metal are Cu, Zn, Pb, Cd, and Cr and showing certain migration capability. Transportation area was prone to be secondary source of pollution. Monitoring and remediation are necessary for mine tailings.

2. Materials and methods

2.1. Sampling procedure

In order to know the effects of heavy metals on deep soil and groundwater, we analyzed five typical heavy metal elements (Cu, Zn, Pb, Cd, and Cr) to study the migration of heavy metals in the vertical direction. Three one-meter profile were dug and divided into five 20 cm depth gradient from the surface to different depths (Rosling et al., 2003). Soil columns were collected from the mine tailings. Each column consisted of five distinct soil horizon which could be distinguished by their colour and found at the following depths: P1,0–20 cm; P2,20–40 cm; P3,40–60 cm; P4,60–80 cm; P5,80–100 cm. To ensure pure material of each layer, centered sample were collected. Soil samples were coded according to column and profile. According to the flow direction and the characteristics of the tailings, we set up ten sampling points to study migration rules in the horizontal direction. Also, we collected and identified the dominant species from local and sparse plants that grow in the tailings. The rhizosphere soil was tested to evaluate the role of plants in tailings and sought for plant species with heavy metal accumulation (Zhang et al., 2012). All samples were plugged into an auto-sealed polyethylene plastic bag and sealed with tape immediately at site for lab analysis. In the lab, the sediment cores were divided into sub-samples at 2 cm intervals with knife under room conditions. Each sub-sample was immediately sealed in the plastic bag after squeezing out the air, and stored in the refrigerator at 4 °C. Before analysis, the samples were dried at 25 °C, ground with pestle and mortar until all particles passed through a 200 mesh nylon sieve.

Fig. 1. Study area in this research.

2.2. Soil chemical analysis

pH values were determined at a 1: 5 (soil: water, w/w) ratio using a digital ion meter (PXS-215, RIDAO Instrument Co., Ltd, China) (Qiang et al., 2006). Soil particle size was analyzed by malvern laser particle size analyzer (MS2000MU) (Uner et al., 2005). Soil porosity and water content of soil were referred to Determination of forest soil water – Physical properties (LY/T 1215-1999). Soil organic matter was measured using the Walkley and Black method (Walkley and Black, 1934).

For each sample, approximately 3.00 g soil was digested in a high-pressure microwave system (XT-9900A, Xintuo Analytical Instruments Co., Ltd, China) (Fu et al., 2014). Before the digestion process, 5 mL of HNO_3, 5 mL of HF, and 3 mL of $HClO_4$ were mixed with the soil samples in a polytetrafluoroethylene vessel. After the microwave process, the vessel was taken out, uncovered, and heated to expel the acids until the residue was a viscous colorless or light yellow fluid. After adding 10 mL of deionized water, the crucible was then gently heated to dissolve the residues. 1 mL of HNO_3 was added to the final solution and made up to 50 mL with deionized water. The concentrated solutions of HCl, HNO_3, HF and $HClO_4$ were used in the process. The concentration of heavy metals in the soil samples were determined by inductively coupled plasma - atomic emission spectrometry (ICP-AES) (Cui et al., 2017).

2.3. Data evaluation

The single factor contaminant index and the Nemerow composite index were applied to assess heavy metal pollution (Bin et al., 2012). The formulas are as follows:

$$Pi = Ci/Si;$$

$$P_N = \{[(Ci/Si)_{max} + (Ci/Si)_{ave}]/2\}^{1/2}$$

C_i is the measured concentration of pollutant i; Si is the background value or control land or standard values of pollutant i. Chinese background value (AM) (Li, 2014) is selected as S_i.

Multivariate statistical analysis was used to identify the relationship and the pollutant sources of different heavy metals. In this study, all statistical analysis in this paper was carried out using SPSS 12.0. The statistical differences in heavy metal concentrations among samples were determined using one-way ANOVA.

3. Results and discussion

3.1. Physical and chemical properties

Statistical data of the soil properties are shown in Table 1. Soil particles are mainly consist of sand, 19.2% medium sand, 43.5% fine sand and 3.68% 3.68% clay, with low water holding capacity (Chen et al., 2006). Particle size determines the migration of particles in runoff erosion process, small particle size causes great erosion rate (Zamani and Mahmoodabadi, 2013). The pH values demonstrate that the soil in the study area is saline alkali soil (Richards, 1968). Soil porosity in tailings is much lower than normal range of soil (55%–75%). Low soil permeability seriously affects respiration of