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Rehabilitation of a tailing dam at Shimen County, Hunan Province: Effectiveness assessment

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ABSTRACT

This study was conducted to assess the effectiveness of phytoremediation on a tailing dam located in Shimen County, Hunan Province. Quadrat survey method was employed to investigate and sample the dominant plant species growing on the rehabilitated tailing dam. The fertilities of the soils were assessed, and concentrations of arsenic and other heavy metals in the plant and soil samples were measured. The results showed that no difference was found on the effect of soil capping with top and non-topsoils for rehabilitation of plants on the tailing dam. After rehabilitation, stable vegetation coverage types were established, 39 plant species were found to grow on the tailing dam, and the minimal area for plant communities was 30 m^2. The dominant plant species were planted *Pteris vittata* and natural colonizing *Miscanthus sinensis*. The contents of organic matter, nitrogen and phosphorus in the soils were low, while the potassium content was at a middle level; however, plots where *Legumina* plants grew were found to have higher level of nitrogen and phosphorus in the growing soils. Arsenic (As) and Cadmium (Cd) concentrations in the soils were 8 and 7 times of the grade III value of the National Standard for Soil Quality (GB15618-1995), respectively; while in tailings these were 81 and 68 times. The available As concentration in the soils ranged as 3.7–29.5 mg kg^{-1}, whereas the available As concentration in tailings was as high as 61.1 mg kg^{-1}. Concentrations for most of the heavy metals were in the normal range of terrestrial higher plants, except As and Cd in *P. vittata* and *M. sinensis*, and As in the roots of *M. sinensis*. It is concluded that phytoremediation project has reduced the ecological and health risks caused by the tailing dam to the ambient environment. However, the plants growing on the tailing dam which contained high As and Cd should be kept from entering into food chain in order to protect the health of local residents.

1. Introduction

Arsenic (As) is a toxic and carcinogenic element [1,2], it is usually present in coals or the ores with various sulfur-containing minerals. Anthropogenic activities such as mining, smelting and coal combustion have resulted in the release of As into land surface environment, causing serious As-contamination [3]. Approximate 70% of total As deposits are distributed in China, however, an average of 70% of the exploited As remain in tailings during the mineral processes under current technique level in China [4]. The open pit dumping of As-containing tailings has released large amounts of hazardous matters into soils and surface waters through wind and hydraulic erosion. Several As poisoning incidents that causing many people sick have been reported in Yunnan, Guangxi and Hunan Provinces, these were usually related with the leaching of heavy metals in tailings that had entered into the surface water and groundwater systems [3]. Arsenic can enter livestock and human bodies via food chain, rendering detrimental effects to human health. Endemic epidemics of arsenicosis have occurred in 37 counties and eight provinces in China [5,6].

Currently, several technologies are available for remediation of arsenic contamination in tailings, including physical–chemical remediation and bioremediaiton (employing microorganisms or plants) approaches. Phytoremediation has the advantages in cost-effectiveness, effect-efficiency and no further contamination, it is also easy to be implemented [7,8]. Pilot experiments and surveys on the remediation of tailing dams have been conducted in Dexing copper mines in Jiangxi, Tongling copper mines in Anhui and Shaoguan lead–zinc mines in Guangdong [9–11]. These studies assessed the remediation effects only through the comparison of the values between detected target pollutants and those of the national soil environmental quality standards [12]. However, no information is available relating the rehabilitation processes with plant colonization and soil fertility improvement; in addition, the potential ecological and health risks due to the uptake and accumulation of various heavy metals by the plants are also left to be resolved. Therefore, the objectives of this study were: (1) to characterize

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the ecological and chemical processes of phytoremediation in tailing dam, by analysis the community structure of plants habitated in Shimen tailing dam, the changes of soil fertilities, and the concentrations and fractionations of As and other hazardous heavy metals in soils; (2) to estimate the effects of phytoremediation as well as the ecological and health risks associated with phytoremediation. It is expected to provide references for the choice of candidate plants and post-management in future practice of phytoremediation.

2. Materials and methods

2.1. Site descriptions

The tailing dam is located at Shimen Realgar Mine, Baiyun village, Shimen County, Hunan Province, with east longitude of 110°29′–110°33′ and north latitude of 29°16′–30°08′. The site has a monsoon climate condition as changing from mid-subtropical to subtropical zone. Annual precipitation and average temperature is 1560 mm and 16.7 °C, respectively.

The mine has the biggest reserves of realgar in Asia, and has been exploited for more than 1500 years. The discharge of waste gases and solid wastes has led to heavy contamination since 1958 [13]. Arsenic concentrations in three villages in the vicinity of mining area were previously recorded as 84.17–296.19 mg kg^{-1} and 0.5–14.5 mg L^{-1}, in the soils and river waters, respectively, far exceeding the values of the corresponding soil and water environmental quality standards [14]. During 1992–1994, tailings were open pit dumped, forming a dam with 3.5 m in height and 6200 m^2 in area. Arsenic concentration was as high as 5.24% in the tailings. The intensive wind and hydraulic erosion led to vegetation-less landscape on the tailing dam. One monitored arsenic level in the runoff waters of the tailing dam during a rainstorm was recorded as high as 5 mg L^{-1}, the tailing dam thus had produced serious contamination to ambient farmland and water system.

The phytoremediation project was put in practice in July 2003. Surface of the tailing dam was evened, followed with construction of drainage ditches and cement barriers across the dam. The tailing dam was then capped with a cover of 35 cm soils dug from the nearby hillsides. The dam was divided into three separated plots, including plots I, II and III; among which, plots I and II were capped with non-topsoils whiles plot III was capped with topsoils (Fig. 1). *Pteris vittata* were planted with a spacing of 80 × 80 cm.

2.2. Plot survey and sampling

The survey and sampling were carried out in April 2008. Plot surveys were conducted in three different plots separated by different types of capping soils as non-topsoils and topsoils with different dominant plant communities. *P. vittata* and *Miscanthus sinensis* were the dominant plant species in plots I and II capped with non-topsoils, respectively; while *P. vittata* dominated in plot III capped with topsoils (Fig. 1). A total of 21 quadrats (10 × 10 m area) were applied in the tailing dam. The numbers and names of plants species colonizing in every quadrat were recorded, simultaneously the associated soil samples were collected.

Three to four dominant plant samples in each quadrat (perennial *P. vittata* or *M. sinensis*) were collected and mixed as one composite sample. Soils about 1 cm thick adhered to the roots of collected plants were sampled as the rhizosphere soils. In each quadrat, about 20 cm soils in depth where no plants colonized were sampled as non-rhizosphere soils. The height of each plant was recorded, and the vegetation coverage was estimated via eye-measurement.

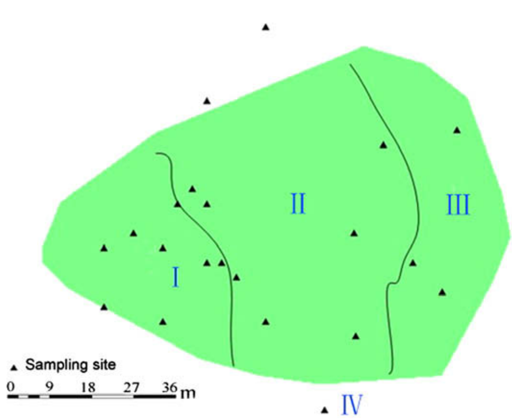

Fig. 1. The sketch map of the sampling sites on the tailing dams.

2.3. Treatment and analysis of samples

Soil samples were air-dried and ground to pass through a 2 mm mesh sieve, then homogenized for measurement of pH (1:5 ratio of soil to water), texture and other physical–chemical properties. The content of organic matter was analyzed using the Walkleye–Black method. The cation exchange capacity (CEC) assay was performed in accordance with barium chloride–magnesium sulfate method. Active iron (Fe) and aluminum (Al) were assessed by a buffer solution of oxalic acid–ammonium oxalate (pH 3.0), while available potassium (K) and phosphorus (P) by 1 mol L^{-1} (pH 7.0) and 1 mol L^{-1} (pH 4.8) ammonium acetate, respectively. Total nitrogen was assayed following the method of Kjeldahl Distillation [12]. The sequential extraction of various As forms in soils was performed according to the method of Wenzel et al. [15]. A portion of 10 g of each soil sample was ground to be less than 150 μm in particle size, and digested using mixture of HNO_3 and H_2O_2 following the method of USEPA-3050B. Concentrations of P and heavy metals in soils were determined using ICP-OES (inductively coupled plasma atomic emission spectroscopy), arsenic in the digest was determined using a hydride generation atomic fluorescence spectrometer (HG-AFS) (AFS820, Beijing Titan Instruments Co., China). Standard reference material (GBW07401) was used to check the accuracy of the analysis.

Plant samples were rinsed thoroughly with tap water, followed with deionized water 2–3 times. After air-dried, the plant samples were oven dried at 55 °C, then separated into aboveground and roots portions, and pulverized using a high-speed electric miller. The plant tissues were digested using concentrated composite solution of HNO_3–$HClO_4$, As concentrations were determined using HG-AFS. The concentrations of phosphorus and other heavy metals were assayed using ICP-OES. The certified plant standards (poplar leaf, GBW07604) were also analyzed as a quality control procedure.

2.4. Data analysis

Data were analyzed and tested using SPSS and Origin8 software, with one-way ANOVA and multiple comparisons by Duncan's test at $P < 0.05$.

3. Results

3.1. Rehabilitation of plants in tailing dam and accumulation of elements

3.1.1. Rehabilitation of plants in tailing dam

According to the species-area curve, the minimal area of plants in the tailing dam was determined as 30 m^2 based on relevé