Heavy Metal Contamination in Farmland Soil and Bioremediation Measures: A Case Study of the Mining Area in Shaoguan

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Abstract With the rapid development of mining, the soil heavy metal contamination is increasingly serious in Shaoguan, directly affecting the production of crops. This paper analyzes the farmland soil heavy metal contamination in the mining area of Shaoguan and the causes of heavy metal contamination in recent years, brings forward the bioremediation measures to control soil heavy metal contamination, and points out the development direction of bioremediation in farmland soil heavy metal contamination in the mining area.

Key words Farmland soil, Heavy metal contamination, Bioremediation

1 Introduction

The soil heavy metal contaminants typically include biologically toxic Pb, Cr, Cd, Hg, As, Cu and Zn, which can not only damage crops, reduce crop production and lower crop quality[1], but also endanger human health through food chain enrichment. At present, about 16.1% of China's arable land is polluted, and the heavy metal contaminants mainly based on Pb, Cd, Hg and As exceed the standard about 82.8%[2]. In the northern areas of Guangdong, 10% of arable land is contaminated by heavy metals to different degrees due to local mining activities[3]. On the one hand, the heavy metals in the wastes of the mining area, infiltrate into the base soil through the pores of waste rock and tailing heap or enter into the surrounding farmland soil through the surface runoff. On the other hand, it enters into the downstream hydrological system or infiltrates into the groundwater by surface runoff, and the runoff carries heavy metals into the farmland soil, causing the water and soil contamination in the mining area and even the surrounding areas, and affecting the entire ecosystem.

2 Current situation of heavy metal contamination

Shaoguan is in northern Guangdong, and rich in mineral resources, with a long history of mining. Nowadays the mines exploited include Dabaoshan mining area, Shaoguan metallurgical plant, Fankou lead zinc mine and Lechang lead zinc mine. A lot of acidic mine waste water generated during the exploitation of metal mine, the toxic heavy metals generated during the weathering and leaching of tailings heap, and the waste gas and water discharged from the metal production plant, are the main heavy metal contamination problems for the surrounding ecological environment in the mining area[4]. In recent years, the issues concerning heavy metal contamination of farmland soil and vegetables around the mining area in Shaoguan have been getting worse, becoming a hot topic of scholars. Zhou Jianming *et al.* monitor the farmland soil and vegetables around the mining area in Shaoguan, and find that Pb and Cd are seriously over the standard in various kinds of vegetables and rice[5]. Through survey and research, Xu Chao *et al.*[6] conclude that the paddy soil pollution around Dabaoshan mine is Cd and Cu-based multi-metal composite pollution, the average concentration of Cd, Zn, Pb and Cu in paddy soil is 2.19 $mg \cdot kg^{-1}$, 244.94 $mg \cdot kg^{-1}$, 179.93 $mg \cdot kg^{-1}$ and 287.91 $mg \cdot kg^{-1}$, respectively, and the composite pollution index of Cd, Zn, Pb and Cu is 15.07, 2.03, 2.07 and 8.98, respectively. The correlation analysis results show that Cd, Zn, Ph and Cu are mainly from acidic waste water for irrigation. The findings of Fu Shanming *et al.*[7] show that the Cd pollution is most serious, and Pb, Zn are also at the level of moderate to severe pollution; in low-lying Shangba Village with serious pollution, the total concentration of Pb, Zn, Cd and Cu in farmland topsoil reaches 257.762 $mg \cdot kg^{-1}$, 350.235 $mg \cdot kg^{-1}$, 5.08 $mg \cdot kg^{-1}$ and 186.901 $mg \cdot kg^{-1}$, respectively, exceeding the national standard by 1.03, 1.75, 16.9 and 3.7 times, respectively. Vegetable and Fruit Quality Supervision and Testing Center of the Ministry of Agriculture (Guangzhou) investigated the soil heavy metal content in four villages of two districts in Shaoguan City in May 2009. Survey results show that the soil heavy metal content is seriously over the standard, and the highest value of Cd, Pb, Hg, As is 30, 2.6, 2.8 and 1.1 times of soil environmental quality standards, respectively. The pH of farmland soil in the mining area is 4.58-7.41, with an average of 6.07, and the soil is mainly acidic soil (Table 1). Soil organic matter content is 0.62 %-5.32%. The average content of Pb, Cd in soil is 120.43 and 3.21 $mg \cdot kg^{-1}$, respectively, much higher than the background value of Guangdong Province[8]. Based on the above analysis, it is found that the farmland soil around the mining area in Shaoguan shows the high concentration complex heavy metal pollution. According to the

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evaluation criteria of Guangdong's soil background values and Secondary National Soil Environmental Quality Standard, it indicates that the farmland soil in the mining area of Shaoguan is contaminated by some heavy metals and non-metallic harmful elements in the order of Cd > Cu > Zn > Hg > Pb > As.

Table 1 Evaluation criteria of soil heavy metal (mg/kg)[9-10]

Items	Cu	Pb	Zn	Cd	As	Hg	pH
Guangdong's soil background values (red soil)	14.38	34.38	48.75	0.034	10.50	0.075	–
Secondary National Soil Environmental Quality Standard	50	250	200	0.3	30	0.3	<6.5

3 Causes of farmland soil heavy metal contamination in the mining area

3.1 Contamination of mine waste water and tailings Along with acidic mine waste water and tailings, the harmful heavy metals, generated during the mining and processing of mines, are drained away in the leaching process, leading to excessive farmland soil heavy metals in the mining area.

3.2 Heavy metals in the soil due to atmospheric deposition Via natural sedimentation and precipitation, heavy metals enter into soil. It greatly affects the farmland around the industrial and mining areas, and it is dominated by Pb, Zn, Cd, Cr, As and Cu contamination. The tailing dusts during mining fly into soil, and by rain erosion and leaching, some toxic and harmful gas components can easily infiltrate into the soil, resulting in strong acidic soil pollution, organic toxic pollution and heavy metal pollution.

3.3 Sewage irrigation in the mining area In the mining area, the heavy metals in wastewater are over the standard, and the wastewater with considerable heavy metals flows into rivers and groundwater systems. Farmers use such wastewater as irrigation water for their farmland, and a lot of the heavy metals are brought into agricultural soils, resulting in excessive heavy metals in soil and then food chain.

4 Bioremediation measures for the farmland soil heavy metal contamination in the mining area

Currently, the common remediation technologies for heavy metal contamination include physical remediation, chemical remediation and bioremediation. Physical remediation generally uses the methods of excavation, covering with other soil for melioration, and deep ploughing, and this approach requires a lot of manpower and material resources. This method is just suitable for light pollution. Chemical remediation means applying suitable chemical substances in the soil to stabilize and deactivate heavy metals in soil, and this approach is likely to cause heavy metal reactivation. Compared with the physical remediation, chemical remediation and other remediation technologies, biotechnology is safe and non-destructive[11]. There is high concentration complex heavy metal environmental pollution in the farmland of Shaoguan's mining area, so the choice of bioremediation method can be a successful solution to such pollution. Bioremediation technology can solve the damage of tailings, waste land and waste residue during mining to soil environment, as well as many reclamation problems[12]. The bioremediation technology has advantages of good effect, low investment, low cost, easy management and operation, and non-pollution, so increasing attention has been paid to this technology, and it becomes a hot spot of contaminated soil remediation study. Biotechnology control measures include phytoremediation, microbial remediation and combined plant-microorganism remediation.

4.1 Phytoremediation By the plant absorption, evaporation, rhizofiltration, degradation and stabilization, this technology can purify the contaminated water or soil, so phytoremediation is a green technology to clear environmental pollution. Phytoremediation plays a long-term sustainable role in restoration of the mining area, and it has low cost and obvious ecological benefits[13]. Compared with the traditional repair methods, this technology has lost and simple process, and it is really an environmentally friendly soil remediation method. Chen Tongbin *et al.* have used the arsenic-accumulating plants such as *Pteris vittata* L. and *Pteris nervosa Thunb. P. cretica auct. Non* L. for the remediation of the mining area polluted by arsenic. The phytoremediation demonstration project is established in the arsenic-contaminated soil of Chenzhou in Hunan and Huanjiang in Guangxi[14-16]. Phytoremediation, based on the theory of plant enduring and excessively accumulating one or several chemical elements, is an environmental control technology, and an emerging environment application technology, which uses plants and the coexisting microbial system to remove contaminants in the environment.

4.2 Microbial remediation Microbial remediation takes advantage of the role of some soil microorganisms in absorbing, precipitating, oxidizing and reducing heavy metals, so as to reduce the toxicity of heavy metals in soil. The microbial adsorption technology uses the role of microorganisms in adsorbing heavy metals to change the form of heavy metals in the soil, thereby affecting the bioavailability, reducing bioavailability and hazards, or combining it with other techniques for remediation. Microbial adsorption of heavy metals can be divided into three categories[17]: extracellular adsorption, cell surface adsorption and intracellular adsorption. Mycorrhizal fungi include endotrophic mycorrhizal fungi, ectotrophic mycorrhizal fungi, and some other types of mycorrhizal fungi. They can infect the roots of most higher plants in the nature to form a symbiotic system of mycorhiza. Many studies show that mycorrhizal fungi often exist in the soil contaminated by heavy metals, and the mycorrhizal fungi can be tolerant of heavy metals and infect the plants growing in the soil contaminated by heavy metals. However, there are few studies on the bioavailability of mycorhiza in remediation of the soil contaminated by heavy metals.

4.3 Plant-microorganism remediation The plant-microorganism remediation for soil contamination consists of two forms. (i) The microorganisms produce the cells containing Fe, and secrete biological surfactants and organic acids, to improve the metal mobility in the soil and promote plant absorption of heavy metals. (ii) The rhizosphere bacteria promoting plant growth is combined with mycorrhizal fungi to improve plant biomass, and increase the accumulation of heavy metals[19]. The combined plant-microorganism remediation, especially the combined effect of plant root and rhizosphere microorganisms, has achieved good results in the laboratory and small-scale remediation. Through the study on combined *Scutellaria sessilifolia Hemsl*-microorganism remediation of the soil contaminated by As, it is found that Comamonas sp. Ts37 and Delftia sp. Ts41 can significantly reduce the mass fraction of occluded arsenic, mycorrhizal fungi can significantly increase the available soil arsenic content[20], Glomus intraradices can increase aboveground biomass and increase the shoot absorption of As[21].

5 Conclusions and recommendations

5.1 Conclusions Bioremediation technology is a promising new technology, which has advantages of simple operation, small investment and little interference with the environment. Therefore, bioremediation technology, as a method with high efficiency, low control cost and strong operability, can be widely used in farmland soil remediation in the mining area, improvement of the soil contaminated by heavy metals, and waste water purification in the mining area. It has great practical value of controlling composite heavy metal pollution.

5.2 Recommendations There are different degrees of heavy metal contamination in farmland soil around the mining area in Shaoguan, and the Cd pollution is particularly serious. Therefore, it is necessary to further search and select hyperaccumulators and tolerant plants, take the existing plant germplasm resources as the study object, strengthen the study on the stable remediation mechanism for multi-metal composite soil contamination, and carry out the study on the microorganism-plant remediation system with plant stability and plant extraction as core technology as well as the remediation mechanism. There is a need to study how to recycle the heavy metals in hyperaccumulators and avoid the recontamination caused by the plants that can not be recycled[22]. In addition, it is necessary to research and develop a reasonable farmer-based ecological compensation mechanism for farmland soil pollution, to protect farmers' basic production and living, enhance the enthusiasm of farmers and effectively promote the smooth implementation of China's farmland soil heavy metal contamination prevention and control work.

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