



Research on Heavy Metal Pollution and Comprehensive Prevention and Control of Soil Around Coal Mining Area

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Abstract

A large amount of wastes such as fly ash or gangue will be generated during the production and mining of coal resources, coal washing and coal preparation. The accumulation of these wastes will cause serious heavy metal pollution to the surrounding surface. After the soil is polluted by heavy metals, it will inevitably affect the growth quality of crops, and even pose a threat to people's life and health. Therefore, it is of great practical significance to discuss the problem of heavy metal pollution and pollution sources around the coal mining area, and to take targeted countermeasures.

Keywords

Coal Mine; Soil; Heavy Metal Pollution; Prevention and Control Measures

Introduction

As the world's primary energy source, coal provides approximately 27% of the world's energy annually, and its global consumption continues to grow. The processes of coal mining and washing generate large amounts of waste such as gangue and fly ash, which severely pollute surface soils when accumulated. Coal mine waste contains significant amounts of minerals like iron sulfide, which are easily weathered or oxidized in the natural environment, releasing heavy metals such as nitrogen (Ni), zinc (Zn), and phosphorus (Pb). Therefore, heavy metal pollution in coal mining areas is a critical pollution problem that urgently needs to be addressed. Heavy metals entering the soil not only drastically alter its properties and affect its productivity but also pollute water sources and crops, damaging the living environment and posing a serious threat to human health. Thus, heavy metal pollution in coal mining areas has become a key focus of current environmental governance.

1. Analysis of the Hazards of Heavy Metal Pollution

The large amount of heavy metal elements in the soil will gradually accumulate with the growth of plants and animals, and will gradually accumulate in the human body under the action of the food chain. When the heavy metals in the human body accumulate to a certain level, they will cause irreversible harm to the human body (Ou et al., 2022). For example, when a person ingests a large amount of lead through the food chain, most of the lead will be absorbed by the intestines and gradually diffuse into human organs and blood tissues, and will also enter human bones. However, the lead compounds stored in the human body are excreted very slowly, which will lead to chronic poisoning. When the human body ingests excessive cadmium, it will cause the human body to be unable to fully absorb calcium, which will cause symptoms such as osteoporosis. In this case, the human bones will become soft. Excessive intake of

cadmium will cause edema or bone pain disease. In addition, arsenic compounds will accumulate in different tissues through the flow of human blood, which will cause poisoning. This heavy metal element is also considered to be one of the most toxic substances. Excessive intake of mercury will cause central nervous system disorders, and will even cause serious harm to the human digestive system and kidneys. The human respiratory system, blood, eyes, skin and other tissues will be affected. Although cadmium is an essential trace element for the human body, excessive intake can lead to symptoms such as arteriosclerosis, serious damage to the liver and kidneys, and even cancer.

2. Sources of heavy metal pollution in coal mining soil

2.1 Heavy metal pollution caused by wastewater discharge from coal mining areas

Currently, most coal mining in my country is underground. To ensure the safety of underground mining, a large amount of mine water will inevitably be discharged during the coal mining process. Moreover, different coal mining areas have significant differences in geographical location, climate, geological structure, mining depth, etc., which leads to great differences in the quality of mine water in different mining areas. Under such circumstances, a large amount of mine water will be discharged into the soil, and the large amount of heavy metal elements contained in the mine water will cause heavy metal pollution in the soil, which shows uncertainty and complexity.

The content of heavy metals in the soil may increase due to the water quality of mine water. For example, if the mine water is acidic, the amount of heavy metal elements that can be dissolved will be greater, thus making them more toxic. In some cases, the heavy metal elements will even have a synergistic effect, which will not only increase the amount of heavy metal elements absorbed by crops, but also increase the harm of heavy metals to the soil. In this case, the production quality of crops will be greatly affected. For most mine water, even after purification treatment, there will still be many pollutants. Long-term use of these mine waters for agricultural irrigation will inevitably pose a serious threat to the soil environment (Li & Zhu, 2021). Moreover, the actual discharge of mine water during the coal production and mining process is very large, and the range of impact is also very wide. Due to people's understanding of mine water and the influence of coal mining technology, the heavy metal pollution of the soil will become more and more serious. Therefore, it is of great practical significance to study the mechanism and law of soil heavy metal pollution caused by mine water in various parts of China.

2.2 Air pollution in coal mining areas leads to

The production and mining processes in coal mines cause severe air pollution in the mining areas. These pollutants gradually settle on the ground with dust, thus becoming a significant source of soil pollution. A study on the cold mining area of Pingdingshan, Henan Province, found that coal dust and soot deposition were the main pollutants in the soil of the entire Shilong District.

Analysis of the migration pattern of atmospheric dust in coal mining areas shows that the dust settling, rain leaching and other related effects generated during the production, mining, processing and stockpiling of coal mines will have a certain impact on the soil. Areas far from coal mining areas will also be polluted by the settling of a large amount of coal seams and dust particles floating in the air. After pollutants settle to the surface, they eventually enter organisms through the geochemical chain, food chain and other processes, which will seriously threaten the food safety, ecological safety and social harmony of residents around the mining area (Tong et al., 2019).

2.3 Solid waste causes heavy metal pollution in soil

During the production and mining process of coal mines, a large amount of coal gangue is generated. When coal gangue is transported to the surface, it is very easy to weather in the natural environment. Moreover, the large amount of toxic heavy metal elements contained in it will eventually enter the soil environment through the dissolution and separation of rainwater and surface water, which will lead to huge changes in the heavy metal content of the soil in the mining area.

3. Heavy metal pollution in coal mine soil

A certain coal mine, built in the 1970s, has an annual production capacity of approximately 2 million tons. While playing a vital role in local economic development, its years of operation have severely damaged the local ecological environment. Furthermore, the mining process has led to a massive accumulation of coal gangue in the surrounding

area, causing surface subsidence in several locations, and resulting in severe heavy metal pollution in the surrounding soil. To effectively improve the ecological environment of the coal mining area, it is essential to address the surrounding ecological problems through restoration. Before any restoration efforts can begin, a thorough investigation of the heavy metal pollution in the soil is necessary.

Effective remediation of heavy metal pollution in coal mining area soil requires a detailed evaluation of the types, contents, and degree of heavy metal pollution in the soil. The geoaccumulation index (I) method is used in this evaluation. Based on the I value, heavy metal pollution in the soil can be classified into the following levels: I value below zero indicates no pollution; I value between 0 and 1 indicates light to moderate pollution; I value between 1 and 2 indicates moderate pollution; I value between 2 and 3 indicates moderate to severe pollution; I value between 3 and 4 indicates severe pollution; I value between 4 and 5 indicates strong to extremely severe pollution; and I value above 5 indicates extremely severe pollution. After detailed testing of the heavy metal content in the soil of this coal mining area using professional heavy metal element detection technology, the test results were compared with the background values of various heavy metal elements in the region, and the comparison results were evaluated. The specific evaluation results are shown in Table 1 below.

Table 1. Geoaccumulation Index Method and Evaluation Results of Heavy Metal Elements in Soil

	Zinc	lead	copper	cadmium	manganese	arsenic
Earth Accumulation Index	-0.2364	-0.1267	-0.4985	2.4369	-0.6872	-0.1235
pollution level	Pollution-free	Pollution-free	Pollution-free	Moderate to severe pollution	Pollution-free	Pollution-free

Analysis of the table above reveals that the soil in this coal mining area mainly contains several heavy metals, including zinc, lead, copper, cadmium, manganese, and arsenic. Cadmium is the most severely polluted element, reaching a moderate to severe level. The other heavy metals are present in relatively low concentrations, thus their pollution is negligible. Therefore, it is evident that the treatment of heavy metal pollution in this coal mining area should focus on controlling cadmium levels, employing targeted remediation measures to effectively control the content of heavy metals in the soil.

4. Practical Application of Bioremediation Technology in Coal Mine and Soil Heavy Metal Remediation

4.1 Overview of Bioremediation Technology

The so-called bioremediation technology mainly refers to adding corresponding organisms according to the specific heavy metal pollution type and degree of soil, using the metabolism of organisms to effectively reduce the concentration of heavy metal content in the soil, and at the same time effectively inhibiting the activity of heavy metals. In this way, the adverse effects of heavy metals on soil can be effectively controlled. In the practical application of bioremediation technology, there are three main types: ecological restoration, phytoremediation and microbial restoration (Chen et al., 2019).

4.1.1 Phytoremediation

Phytoremediation of soil heavy metal pollution mainly utilizes the ecosystem composed of plants and symbiotic microorganisms to absorb heavy metal elements in the soil. In the current treatment of various heavy metal pollution in coal mining areas, the absorption of heavy metal pollutants in soil mainly utilizes the absorption, volatilization and stabilization characteristics of hyperaccumulating plants. Absorption mainly refers to the absorption of heavy metal elements by plant roots. Volatilization mainly refers to the conversion of heavy metal elements into a volatile state after absorption and accumulation by the soil. Stabilization mainly refers to the effective inhibition of the activity of heavy metals in the soil by plants, so that the concentration and toxicity of heavy metals gradually decrease, thereby achieving the effect of removing heavy metal pollutants. Currently, there are many kinds of wild plants in China. Among them, the heavy metal tolerant and hyperaccumulating plants that grow in nature, such as canna, sunflower and schefflera, can effectively absorb many heavy metal elements such as zinc, lead, copper and cadmium, and have a good effect on soil heavy metal pollution remediation (Xu et al., 2018).

4.1.2 Microbial remediation

Microbial remediation of heavy metal pollutants in soil primarily utilizes artificially cultured or wild-caught microbial communities exhibiting specific functions. Under specific conditions, these microbial communities can effectively inhibit the activity of heavy metal pollutants in the soil, transforming them into non-toxic substances. Microbial remediation of heavy metal pollutants in soil mainly includes three remediation principles: enrichment, adsorption, and transformation. Enrichment refers to the storage of heavy metal elements in the soil by microorganisms in different parts of the body or on the extracellular matrix. Simultaneously, the microorganisms' own metabolic processes achieve the precipitation of heavy metal ions, or they undergo mild chelation on soluble or insoluble biopolymers, thereby effectively removing heavy metal pollutants or controlling their concentration. Adsorption mainly utilizes the negative charge carried on the surface of microbial cells and the various functional groups such as aldehydes and amino groups within the cells to adsorb and fix heavy metal ions, achieving effective removal or reduction of heavy metal ion toxicity. Microbial transformation mainly includes several types such as demethylation, bio-oxidation-reduction, and heavy metal dissolution. Using microorganisms to remediate heavy metal pollutants in soil has several advantages, such as simple operation and minimal soil disturbance.

4.1.3 Animal restoration

Animal remediation for heavy metal pollution in soil mainly utilizes animal communities to absorb, transform, and decompose the pollutants. Through these processes, the physical and chemical properties of the soil are effectively improved, soil fertility is further enhanced, and the growth of plants and microorganisms is also positively promoted, ultimately achieving effective remediation of heavy metal pollutants in the soil.

4.2 Remediation of Heavy Metal Pollution in Soil of a Coal Mining Area

Based on the above analysis, it can be seen that cadmium is the most serious heavy metal pollutant in the soil of this coal mining area, and its pollution level has reached the level of severe pollution. Therefore, when selecting plants for remediation, it is essential to fully consider the actual characteristics of the heavy metal pollution in the soil. The selected plants must be able to effectively absorb cadmium from the soil and also exhibit strong accumulation capabilities. During the plant's growth, it should effectively absorb cadmium from the soil, and after harvesting and processing, the concentration of cadmium in the soil can be effectively controlled. Existing research shows that black nightshade exhibits good absorption and accumulation capabilities for cadmium; therefore, black nightshade was chosen for phytoremediation of the soil in this mining area. Furthermore, to further enhance the remediation effect of black nightshade on cadmium in the mining area soil, a resistant strain was cultivated in the laboratory using a high-cadmium-concentration culture medium. This strain has a very significant resistance to cadmium and also promotes the absorption of cadmium by the plant.

To conduct a detailed comparison of the application effects of bioremediation technology in the treatment of heavy metal pollution in the coal mining area, three areas of heavy metal pollution were randomly divided in the coal mining area. In the first polluted area, insect-resistant strains were added before planting black nightshade seeds; in the second area, black nightshade was planted directly without any treatment; and the third area served as a control without any treatment.

4.2.1 Evaluation of the application effect of bioremediation technology

(1) The effect of antimicrobial strains on the growth of *Solanum nigrum*. Statistical analysis of the germination rate and average plant height of *Solanum nigrum* plants in regions 1 and 2 revealed that without the addition of antimicrobial strains, the germination rate reached 60%, and as an annual plant, the average plant height was approximately 75 cm. This demonstrates that *Solanum nigrum* plants exhibit relatively high survival rates and good growth in cadmium-contaminated soil. After adding antimicrobial strains to the soil, the germination rate reached 73%, and the average plant height reached 97 cm after one year of growth. This indicates that adding antimicrobial strains to heavy metal-contaminated soil can effectively promote the growth of *Solanum nigrum* plants. This is mainly because microorganisms can better promote biological metabolism, thus actively promoting cyclical growth.

(2) Analysis of Cadmium Pollution Levels in Soils of Different Regions. Samples of black nightshade plants from three plots were taken and analyzed after one year of growth. Based on these samples, the geoaccumulation index and pollution level of cadmium were evaluated (see Table 2 below). Analysis of this table shows that while the geoaccumulation index decreased in the untreated area, the decrease was not significant, and the area remained classified as moderately polluted. Compared to the control plots, the actual reduction rates of the geoaccumulation index

in the areas where black nightshade was planted and in the areas where antibacterial strains were added and black nightshade was planted reached 19.87% and 28.66%, respectively. This indicates that black nightshade can effectively control the concentration of cadmium in the soil.

5. Conclusion

Heavy metal pollution of soil is inevitable during the current coal mining process. Therefore, it is necessary to use advanced technologies to effectively treat heavy metal pollution in soil in order to avoid harm to human health.

Table 2. Comparison of cadmium levels in soils of different regions

	Anti-strain strain + <i>Solanum nigrum</i>	Black nightshade	5
Earth Accumulation Index	1.6832	1.8973	2.3649
pollution level	Moderate pollution	Moderate pollution	Moderate to light pollution

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