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Study on Heavy Metal Content and Microbial Ecology of Soil in Coal Mining Area and Application Prospect of UWB Radar

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Abstract

In order to solve the problem of regional economic sustainable development caused by the ecology and environment in the coal mining area, the coal mining subsidence area is taken as the research object, and the total amount of heavy metals in the soil and various chemical combination states are determined. The characteristics of heavy metal pollution in the subsidence area were evaluated. The law of morphological transformation and migration of heavy metals in the subsidence area was clarified. The effects of soil heavy metal pollution on soil enzyme activity and soil microbial properties in subsidence area and surrounding farmland were analyzed. The interactions and mechanisms of microorganisms with heavy metals were studied. The results show that the research provides a basic understanding framework for the geochemical evolution of heavy metals in coal mining subsidence area, and provides scientific decision theory basis for the development and utilization of mineral resources and the evaluation and prediction of ecological environment impact. Therefore, the study of soil heavy metal content and microbes in contaminated soil can improve the environmental quality of coal mining areas and optimize regional industrial layout and industrial configuration. This has promoted the sustained and rapid development of the entire regional economy. In addition, it provides theoretical guidance and technical support for soil pollution control and treatment in other similar mining areas. This method has important social benefits. UWB radar based on pulse system has superior performance in geological research and mining exploration.

Keywords: coal mining, metal content, microbial ecology, UWB radar

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INTRODUCTION

As the most important disposable energy in China, coal accounts for about 70% of the primary energy production and consumption. Coal provides an important energy guarantee for China's economic and social development. However, its large-scale exploitation and utilization will inevitably have a huge impact on the ecological environment, and bring a series of ecological and environmental problems (Yuksel 2015). With the large-scale exploitation of coal resources, especially the irrational development and utilization, if the waste is not properly treated, it will cause serious pollution to the soil environment around the coal mine. The ecological environment has been destroyed and people's health and safety have been affected. The sustainable development of the national economy is constrained (Adamczyk-Szabela et al. 2015). In the process of mining, washing and utilizing coal resources, a large amount of mining solid waste is generated. Coal gangue and coal-fired products of power plants have always been the largest industrial wastes with the largest cumulative storage and the largest area in China. These heavy metal-rich solid wastes are exposed to the ground and accumulate over time. Under a series of physical and chemical effects, the biotoxic heavy metal elements are released and transferred to the surface environment medium, which seriously affects the supergene environment. Among them, heavy metal pollution in soil has aroused widespread concern.

Due to long-term large-scale coal resource exploitation, large area of ground subsidence, soil

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degradation and ecological environment deterioration are caused in coal mining subsidence area. At the same time, there are a lot of coal aragonite and coal products from power plants stored in the mine area. Therefore, the pollution status and accumulation characteristics of heavy metals in the mining area are accurately understood, and the ecological and environmental problems of the mining area are analyzed. The vegetation in the dump was restored. This is the basis for preventing and controlling the heavy metal pollution in the mining area and the key to alleviating the ecological pressure of the mining area and solving environmental problems.

The major advantages of UWB radar include: (1) strong penetrating ability, long transmission distance; (2) high resolution; (3) low average power, simple structure, low costs. The UWB radar can obtain more abundant information of deep geological mining resource, so it is the most effective means to obtain and detect complex geological mining structures.

LITERATURE REVIEW

Mining activities are one of the important sources of heavy metal pollutants in soil. Mining activities are one of the important sources of heavy metal pollutants in soil (Shi et al. 2015). Deng et al. found that coal gangue stacking in mining area would cause heavy metal pollution to surrounding soil (Deng et al. 2015). In 2015, Halim et al. surveyed the soil environment in the copper mines in New South Wales, Australia, and found that the soil heavy metals (Pb, Cu, As, and Zn) in the mining area were significantly higher than the local soil background values (Halim et al. 2015). In 2015, Guo et al. studied the heavy metals in the soil around the Russian coal field and found that the contents of Hg, As, Pb, Zn and Cd in the soil exceeded the standard (Guo et al. 2015). In 2015, Ociepakubicka et al. found that Cd, Cu and Zn have higher accumulation characteristics in surface waters in the Drake mine area of Australia (Ociepakubicka et al. 2015). In 2016, Shen et al. investigated the pollution of heavy metals in the Au-Ag mining area in South Korea, and combined the comprehensive pollution index (Pi) to evaluate the status of heavy metal pollution in soil. The results show that the soil pollution index near the mining area is greater than 1.0. Mineral mining has caused some pollution to the soil in the area (Shen et al. 2016). In 2016, Hietala et al. studied heavy metals in sediments at the bottom of rivers in the mining area. The mining area is contaminated by heavy metals such as Pb, Cu, Ni, Fe and Zn (Hietala et al. 2016).

Soil microbial activity refers to the overall metabolic activity of microorganisms in soil, which can sensitively reflect the health status of soil ecosystems (Zhang et al. 2016). In 2016, Liu et al. found that the number of soil microorganisms in the mining area was significantly inhibited (Liu et al. 2016). In 2017, Tunc and Sahin studied the soil of copper mine wasteland. The results show that the soil biochemical intensity and soil microbial activity in the mining area are significantly reduced (Tunc and Sahin 2017). In 2017, Ray et al. studied the microbial activity of eroded soil in lead-zinc-silver mining areas. The amount of microbial biomass and culturable bacteria in the eroded soil of the mining area was significantly reduced, and the soil microbial metabolism was significantly increased (Ray et al. 2017). In 2017 Shi Wei group study on soil microflora after coal mine pollution. They isolated some bacteria that are highly effective in decontaminating sudden contamination (Wei et al. 2017). Soil respiration is the sum of all metabolic relationships in the soil. Studies have shown that under normal circumstances, soil contaminated with low concentrations of heavy metals is conducive to the release of CO_2. However, high concentration of heavy metal pollution can significantly inhibit soil respiration. In 2018, Liu et al. found that basal respiration in soils with heavy metal pollution was much higher than that in slightly polluted soils (Liu et al. 2018). In 2018, Lima et al. found that the addition of low concentrations of Cd and Zn promoted soil respiration. Soil respiration is enhanced by the stimulation of heavy metals (Lima et al. 2018).

METHODOLOGY

When changes in natural environment or changes in ecosystem composition and structure caused by human activities lead to changes in ecosystem functions and losses, it is necessary to quantitatively predict the risks of various risk sources on the ecosystem and evaluate the acceptability of the risks. This is called the ecobgical risk assessment (ERA). Therefore, ecological risk assessment is the quantitative and basis for ecological environmental risk management and decision-making. At the same time, it is also a new research field that has gradually emerged and developed along with the changes in environmental management objectives and environmental concepts. The ecological risk assessment of heavy metals in soil is widely applied by the ground accumulation index method, the potential ecological risk index method and the risk assessment code.

Table 1. Earth accumulation index classification and pollution level

Indicator classification	Index range	Level of pollution
0	Igeo≤0	clean
1	0< Igeo≤1	Light pollution
2	1< Igeo≤2	Moderate smudges
3	2< Igeo≤3	Medium pollution
4	3< Igeo≤4	Emphasis on pollution
5	4< Igeo≤5	Heavy pollution
6	Igeo>5	Serious pollution

Table 2. Risk assessment code classification standard

Risk Assessment Coding (RAC) Index Classification	
RAC< 1	No risk
1%<RAC<10%	Low risk
10%<RAC<30%	Medium risk
30%<RAC<50%	High risk
50%<RAC	Very high risk

The Geoaccumulation Index was proposed by Professor Mullers of the Institute of Sediment Research at the University of Heidelberg, Germany. This method is a quantitative indicator widely developed in Europe in the late 1960s to study the degree of heavy metal pollution in rivers and lake sediments. It is now widely used for the evaluation of heavy metal pollution in soils and sediments. The formula for calculating the cumulative index is:

$$I_{geo} = I_{og2}[C_n/(K \bullet B_n)] \quad (1)$$

In the formula, C_n is the concentration of heavy metals ($mg \cdot kg^{-1}$). B_n is the background value of the local soil environment. K is the variation conversion factor, which is usually 1.50.

Risk assessment coding (RAC) method takes into account the bioavailability of heavy metals to evaluate the degree of contamination. At present, the use of morphological analysis tools to assess ecological risks at home and abroad is usually to analyze the proportion of the bioavailability of heavy metal elements, and to evaluate the ecological risks and pollution degree of heavy metal.

RESULTS AND DISCUSSION

Content and Distribution of Heavy Metals in Soils in Subsidence Area of Coal Mining

Heavy metals Cd, Cr, CU, Zn, Pb, Ni and Hg are ideal indicators to reflect the degree of soil pollution. The test results of heavy metals in the surface soil of the mining area indicate that the average values of the six heavy metals, Cd, Cr, CU, Ni, Zn and Hg, exceed the background value of the Huaibei soil, except for the Pb element. Among them, Cd and Hg are 3.15 and 2.86 times of the local environmental background value,

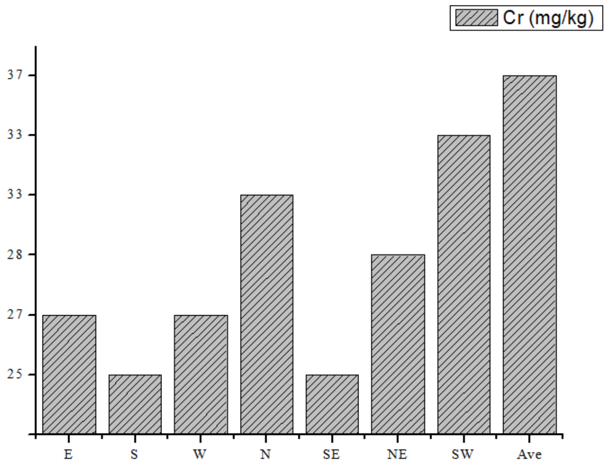

Fig. 1. Soil Cr content in different directions of mining area

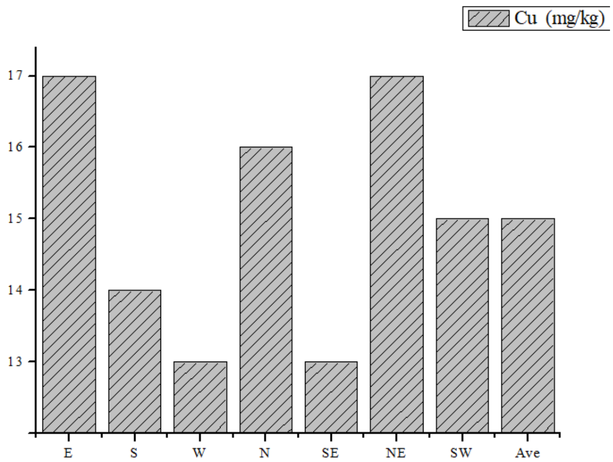

Fig. 2. Soil Cu content in different directions of mining area

respectively. Except for Hg, the average content of other heavy metals exceeds the background value of the soil environment. The enrichment of Zn and Cd is the most serious. The average value of Zn is 1.39021/ $mg \cdot kg^{-1}$, and the variation range is 69.21-266.8/ $mg \cdot kg^{-1}$. The average value of Cd was 0.254/ $mg \cdot kg^{-1}$, and the range of variation was 0.15-0.51/ $mg \cdot kg^{-1}$. The average content of Cd and Zn exceeds the first-class standard of soil environment in China, which indicates that the mining of coal mine will lead to a certain degree of enrichment of heavy metals in the soil and show a certain pollution trend.

The heavy metal content of the soil in the east, south, west, north, southeast, northeast and southwest of the open pit mine was analyzed. The content of heavy metals in soil varies greatly in different directions. According to the actual situation of the mining area and the difficulty of reaching the sampling point, the number of soil samples taken in different directions is different. For example, in the eastward direction of the mining area, the soil is only collected 4km away from the mining area, and 8km away from the mining area in other directions. The calculated mean value may affect the result analysis. To this end, the average value of heavy metal content in the soil within 4km from the mining area was calculated in different directions. The results also show that there are significant differences in the distribution of heavy metal content in different directions of the mining area.

The Cr content in the north and southwest direction of the mining area was 33.44 mg/kg and 33.69 mg/kg, respectively, which was higher than the average of 29.07 mg/kg in the seven directions. In other directions, the Cr content in the soil is lower than 29.07 mg/kg. Cu is higher in the east and northeast directions, 18.52 mg/kg and 18.20 mg/kg, respectively. Cu is 17.59 mg/kg in the north of the mining area, which is higher than the average of 17.01 mg/kg in seven directions.

It is well known that the bioavailability concentration of heavy metals is a very important indicator for assessing environmental risks. The risk assessment coding (RAC) considers the most bioavailable form of heavy metals. Therefore, this can well reveal the environmental risks of heavy metals. The results showed that Cr had no ecological risk in the soil of the study area, while Cu, Ni and Pb had low ecological risk. Zn has no ecological risk at some sampling points, and it has low ecological risk at some sampling points. Cd has produced high ecological risks to extremely high ecological risks, and similar findings have also been reported. Coal mining has been going on for decades in this study area. During the mining, washing and utilization of coal resources, a large amount of coal gangue and fly ash are deposited on the surface. These coal gangue and fly ash may release a large amount of heavy metal ions into the surrounding surface environment under weathering and leaching. Among them, Cd^{2+} can stay in the surface soil for a long time and maintain high bioavailability. Therefore, it brings significant ecological risks to the surrounding surface environment. The results of both the risk assessment code and the potential ecological risk are consistent. Cd in the soil will bring high ecological risks and should be paid attention to by relevant departments.

Effects of Heavy Metal Pollution on Soil Microbial Ecological Characteristics in Subsidence Area

Soil enzymes are mainly synthesized and secreted by soil microorganisms. As a catalyst of soil biochemical reaction, it can promote a series of physiological and biochemical processes such as substance metabolism and energy transfer in soil, maintenance of soil structure, degradation of pollutants and synthesis of compounds necessary for the growth and reproduction of soil microorganisms and plants. Common soil enzymes include hydrolases, oxidoreductases, transferases, and lyases. Some studies have shown that there is a negative correlation between soil enzyme activity and heavy metal pollution. Many researchers believe that soil enzyme activity is very sensitive to heavy metal pollution. Therefore, it is considered as the most sensitive biological index to reflect the change of soil quality. Among the different kinds of soil enzymes, urease, acid phosphatase, dehydrogenase and catalase are especially sensitive to soil heavy metal pollution. The inhibition of urease and acid phosphatase activity by heavy metal contamination has been reported many times in previous studies. The increase in soil enzyme activity is conducive to the conversion of soil nutrients. Appropriate soil bulk density, water content, and pH can promote the increase and function of soil enzyme activity.

Soil microbial biomass can reflect the regulation of nutrient conversion in soil. Like soil enzymes, soil microbial biomass is one of the most promising indicators of soil quality assessment. Microbial biomass carbon and microbial biomass were closely related to soil organic matter content and positively correlated with soil total phosphorus, organic phosphorus and available phosphorus. Soil microbial metabolism reflects the efficiency of soil microbial use of the substrate. It is often used to study the effects of environmental changes on microbial communities. The metabolic function of soil microorganism relates the quantity of soil microorganism with the activity and function of soil microorganism. It is an effective coordination of soil microbial biomass and soil basic respiration. Soil basic respiration reflects the overall activity of soil microorganisms, which can represent the ability of microorganisms to degrade fixed carbon of plants and the ability of soil carbon conversion.

As can be seen from **Table 3**, the mining of coal mines and the use of coal resources lead to the soil pollution of mining areas by heavy metals to varying degrees. The soil microbial properties have undergone major changes. Part of the soil respiration increased, and the microbial biomass carbon and nitrogen decreased. There were significant differences in respiration and microbial biomass of soil samples. Metabolic, microbial, and microbial biomass carbon-nitrogen ratios have the

Table 3. Description of soil microbiological properties

Variable	Unit	Min	Max	Mean	SD	CV
Basic Breathing	CO_2-Cmgkg^{-1}d^{-1}	7.92	106.68	40.63	25.02	61.57
Microbiological mass C	Cmgkg^{-1}	16.24	467.04	187.03	752.60	81.59
Metabolic entropy qCO_2		0.03	2.59	0.50	0.61	121.58
Microbiological mass N	Cmgkg^{-1}	2.02	184.86	24	42.17	110.28
Microbial carbon to nitrogen ratio		0.23	67.42	13.12	17.46	133.09

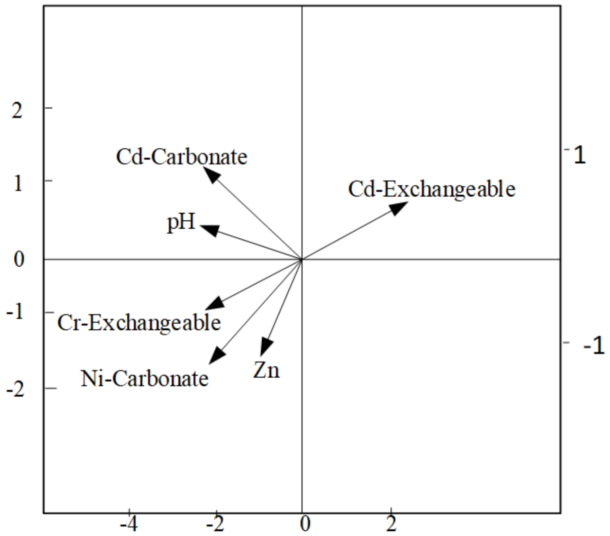

Fig. 3. Effect of factors on ecological characteristics of microorganism

largest coefficient of variation, exceeding 100%, which were 121.58%, 110.28% and 133.09% respectively. It shows that the microbial properties of the soil environment in the coal mine area and surrounding areas have been damaged to varying degrees with the increase of heavy metal content.

The environmental factors affecting the ecological characteristics of microorganisms were analyzed by CCA (Canonical correspondence analysis). The test results show that the soil microbial ecological characteristics of the mining area are significantly affected by the exchangeable state of the heavy metal Cd, the carbonate binding state, the exchangeable state of Cr, the carbonate binding state of Ni, Zn and pH ($o<0.05$). Based on the CCA analysis results of soil microbial ecological characteristics and soil-related environmental variables and soil samples, in the first two axes of CCA, the contribution rate of axis 1 and axis 2 was 39.47% and 24.19% respectively. Therefore, for the mining soil in this study, the exchangeable state of heavy metal Cd, the exchangeable state of carbonate binding state, the exchangeable state of Cr, the carbonate binding state of Ni, Zn and pH have extremely important influence on the ecological characteristics of soil microorganisms.

Effects of Heavy Metals Cd, Hg and their Combined Pollution on Soil

Soil microbes are one of the sensitive indicators for characterizing soil quality. Soil microbial activity is the main source of soil-based respiration. Soil basic respiration represents the turnover rate of soil carbon and the overall activity of microorganisms. This can reveal environmental stress to a certain extent and is closely related to soil environmental quality. Under the single and combined pollution of Cd and Hg, the soil-based respiration was higher than that of the control without adding heavy metals Cd and Hg. With the increase of heavy metal concentration, soil basic respiration is obviously strengthened, which indicates that soil microbes are enhanced by heavy metal inhibition. At the same treatment concentration, the degree of inhibition of soil basal respiration by Cd and Hg was different. The combined pollution of Cd and Hg had the strongest inhibitory effect on soil basal respiration. In a single heavy metal contamination, the inhibition of Hg is greater than Cd. In the culture time, the soil basic respiration gradually became stronger with the prolongation of the cultivation time, and reached the highest on the 14th day of cultivation. Two weeks after the culture, the soil basal respiration decreased sharply. Soil basal respiration is considered to be an important basis for soil microbial activity. In this study, a sharp rise in basal breathing during the first two weeks may be due to exposure of microbial soils to heavy metal environments. Over time, microorganisms in the soil adapt to the polluted environment.

Soil basal respiration is the sum of CO_2 produced by all soil metabolic processes. Soil microbial activity is the main source of soil-based respiration. At the same treatment concentration, Cd and Hg combined pollution had the greatest inhibitory effect on soil microbes. Under the action of a single heavy metal, the inhibition of Hg is greater than that of Cd. This may be because the biotoxicity of heavy metals inhibits or even

Table 4. Linear regression equation of Hg, Cd concentration and respiration of heavy metals

Cultivation time	Heavy metal	Linear regression equation	Coefficient of correlation
7d	Hg	y=0.025x+2.558	r=0.392
	Cd	y=0.017x+2.745	r=0.547
14d	Hg	y=0.008x+3.647	r=0.164
	Cd	y=0.023x+2.932	r=0.639
21d	Hg	y=0.012x+2,360	r=0.366
	Cd	y=0.012x+2.223	r=0.641
28d	Hg	y=0.015x+1.822	r=0.467
	Cd	y=0.009x+1.705	r=0.45 7

kills the sensitive flora in soil microorganisms, leading to the decline of soil basic respiration. Bringmark et al. observed a slight increase in the respiration of Hg and Pb contaminated soil bases. After seven days of culture, basic respiration decreased significantly, which was consistent with the results of this study. However, there have been some studies that have shown an increase in soil-base respiration at specific concentrations of heavy metals. In this study, the increase of soil basal respiration in the first two weeks may be due to the biological toxicity of Cd and Hg killing the sensitive flora. These sensitive floras are caused by the breakdown of some of the surviving resistant flora. When the soil environment is stressed by heavy metals, microorganisms need more energy to maintain their life activities, which leads to the decrease of the utilization efficiency of carbon source by soil microorganisms.

Effects of Single Factors of Heavy Metals Cd and Hg and their Combined Pollution on Soil Microbes

The diversity of soil microbial community was characterized by four indices: Shannon-Wiener, Simpson, Chao and ACE. The Shannon-Wiener index is used to assess species diversity. The larger the Shannon index value, the higher the diversity of the flora. The Simpson index is used to assess the dominance of some of the most common species. The larger the Simpson index, the lower the diversity of the flora. The Chao and Ace indices are used to assess species richness. As can be seen from **Fig. 4**, with the increase of concentrations of heavy metal Cd and Hg, the Shannon index of bacteria decreased. In the treatment of single heavy metal Cd and Hg, the increase of heavy metal Hg concentration has a higher effect on the Shannon index than the single Cd. This is because the ecotoxicity of heavy metal Hg is stronger than Cd. In the combined treatment of heavy metals Cd and Hg, when the concentration of Cd and Hg reached 30 mg/kg, the Shannon diversity index of bacteria was minimized. This indicated that heavy metals Cd and Hg had a synergistic effect on soil bacterial diversity. The Simpson index increases as the concentration of heavy

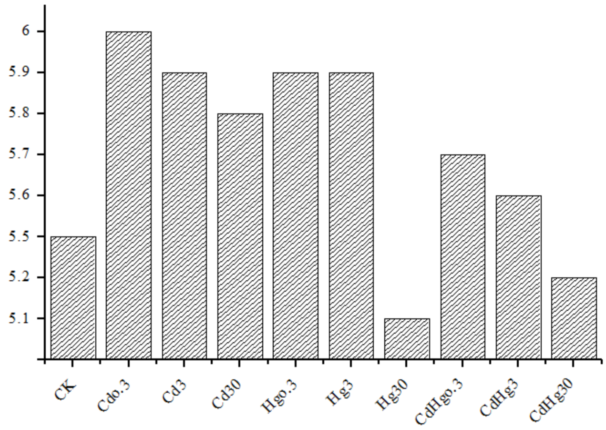

Fig. 4. Effects of heavy metals on soil bacterial diversity

metals Cd and Hg increases. It is indicated that as the concentration of heavy metals increases, the resistant strains appear, the dominance increases, and the diversity decreases. As the concentration of heavy metals increases, the richness index (Chao and Ace index) decreases. Therefore, the increase in the concentration of heavy metals Cd and Hg changes the diversity of soil bacterial communities, which is consistent with previous studies.

The results showed that the high concentration of Hg treatment and the high concentration of Cd and Hg combined treatment have changed the community structure of bacteria in the soil. The low or high concentration of Cd treatment did not change the bacterial community structure. The composite treatment has the highest degree of separation from other treatments on the NMDS map of bacteria, indicating that Cd/Hg complex pollution has a synergistic effect. This synergy is also reflected in the Shannon diversity index and fluorescence quantification of bacteria. However, the NMDS spectrum of the fungi showed that there was no significant separation between the heavy metals treated with different concentrations, indicating that the heavy metals treated with different concentrations did not change the community structure of the fungi. The community structure of bacteria was affected by high concentration Hg treatment and high concentration

Cd/Ha combined treatment, but not by single Cd treatment. The results of this study are inconsistent with those of other studies. Studies have shown that soil mercury pollution initially leads to a decrease in the number of bacterial cells, but this is followed by a large increase in the hg-tolerant flora. Contaminants in the soil can cause DNA damage, such as DNA single-strand or double-strand breaks in organisms, base modifications, and the like, leading to important structural changes. In contrast, in this study, the fungal community structure did not change significantly in both low-concentration heavy metal treatment and high-concentration heavy metal treatment. A large number of studies have also shown that compared to bacteria, fungi often have strong tolerance to long-term heavy metal pollution.

As the concentration of heavy metals Cd and Hg increased, the Shannon index and richness index (Chao and Ace) of soil bacterial diversity decreased. The Simpson dominance index increases with the increase of heavy metal Cd and Hg concentrations. This indicated that with the increase of heavy metal concentration, resistant strains appeared, dominance increased and diversity decreased. The NMDS spectrum of fungi showed that heavy metals Cd and Hg at different concentrations did not change the community structure of fungi. The dominant phyla of fungi in all treated and controlled soils was ascomycota, with a relative abundance of 43.7 - 99.3%. High concentrations of Cd and Hg did not further affect the taxonomic group of soil.

CONCLUSION

Taking the subsidence area of coal mine as the research object, the total amount of heavy metals in the soil and the contents of various chemical combination states were determined. The pollution characteristics of heavy metals in the mining area were evaluated. The law of morphological transformation and migration of heavy metals in the mining area was clarified. The effects of heavy metal pollution on soil enzyme activity and soil microbial properties in the mining area and surrounding farmland were analyzed. The interactions and mechanisms of microorganisms with heavy metals are discussed. Its characteristics and innovations are reflected in the following two aspects: First, the effects of heavy metals on the diversity of microbial community structure were studied by means of molecular biology. Based on the analysis of the relationship between soil microbial characteristics and heavy metal pollution in mining areas and surrounding farmland, the morphological transformation and migration of heavy metals in soil were clarified. These studies can provide new ideas and methods for the discussion of soil heavy metal morphological transformation and microbial ecological characteristics. Second, the relationship between soil heavy metals and various forms on soil enzymes, microbial activity and microbial community structure diversity in the subsidence mining area was analyzed and discussed in the studied samples.

UWB radar based on pulse system has good ability to detect geological conditions around wells, which shows that the pulse system based on UWB radar has superior performance in geological research and mining exploration, and lays a good foundation for the follow-up work.

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