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Microbial Ecological Effects and Remediation of Heavy Metal-contaminated Soil Estimated by Simultaneous Equations Based on Panel Data

Saravan Sridevi*

Jimma Institute of Technology, Ethiopia

**corresponding author*

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Abstract: Microorganisms also play an important role in soil ecosystems. Microorganisms can adsorb heavy metals in soil. Therefore, microbial remediation technology is widely used in the remediation of heavy metal-contaminated soils. It is of great significance to carry out research on soil microbial ecological effects in polluted areas to solve the problem of remediation and improvement of contaminated soil. This paper collects soil samples contaminated by heavy metals in a certain area, and measures the panel data such as pH value, electrical conductivity, and heavy metal content of the soil samples, and then uses microbial remediation technology to remediate the contaminated soil, and estimates the analysis results through the combined removal of heavy metals and soil remediation. It was found that the organophosphate-solubilizing bacteria OPW2-6 could increase the soil pH, thus improving the soil properties and achieving a good remediation effect.

1. Introduction

Soil is the foundation of people's survival. Without land, there is no place to live. However, due to human production activities, many soils and soils have been seriously polluted by heavy metals. Heavy metal pollution in soil will lead to excessive heavy metals in food, which is related to people's livelihood and the health of the whole country. Therefore, both the country and the people are eager to improve soil heavy metal pollution [1].

So far, many scholars have conducted in-depth research and exploration on the microbial ecological effects and remediation of heavy metal-contaminated soils. For example, a certain scholar has fully proved through the dissolution experiments of fungi on soil heavy metal Pb that phosphochlorenite exists stably in lead ore and Pb-contaminated soil, which brings difficulties to phytoremediation [2]. However, recent studies have shown that fungi are able to dissolve lead in picofenite and detect lead oxalate formation, which suggests that microorganisms can play an important role in phytoremediation [3]. Some scholars have proved that adding the microbial culture solution and weakly acidic water containing ammonium and phosphate ions to the plowed soil, irrigating the soil with this solution, and adjusting the initial soil humidity to about 45%-50%, can To ensure the most basic nutrients for microorganisms in the soil [4]. Some studies have shown that for areas with high concentrations of heavy metal polluted soil, only through the action of microbial adsorption can not achieve a good removal effect of heavy metals. This method only converts the available state of heavy metals into potentially available It still exists in the soil all the time. Once affected by external environmental conditions, it may cause the reactivation of the passivated heavy metals, resulting in secondary pollution [5-6]. Although good research results have been achieved on the restoration of heavy metal-contaminated soil areas, the restoration process is difficult due to the heavy metal damage to the contaminated land. More effective restoration techniques need to be developed to remove large-scale soil heavy metals.

This paper first analyzes the microbial ecological effects of heavy metal contaminated soil, and then proposes a geological accumulation index method for analyzing heavy metal pollution in soil. Then, the experimental content of this paper is introduced. The remediation effects of different microbial reagents on contaminated soil were analyzed by comparative methods.

2. Related Research and Methods

2.1. Study on the Microbial Ecological Effects of Heavy Metal Contaminated Soil

At present, most researches focus on the use of PCR-DGGE, fluorescence quantitative PCR and other biotechnologies combined with traditional microbiological methods to study the microbial and molecular ecological changes in heavy metal-contaminated soils under field experimental conditions, and to obtain soil microbial structure and functional composition under heavy metal pollution, providing a strong experimental basis for the restoration of heavy metal soil ecosystems [7-8]. Soil organic matter can control soil water content and water availability, and soil organic matter, as a routine measurement index, can be used to measure soil water retention and its availability [9]. Heavy metal elements enter the soil environment as a pollutant, and its effectiveness is not only related to the total amount of heavy metals, but also must be affected by the basic properties of the soil in the soil environment [10]. For example, the form of sulfur in soil has a great influence on the bioavailability of heavy metals. The form of soil sulfur is closely related to the activity of microorganisms (sulfur redox bacteria). It is of great significance for the control of soil heavy metal pollution [11].

2.2. Analysis Method of Soil Heavy Metal Pollution

The geological accumulation index method is an analytical method to quantify heavy metal pollution [12]. This method is one of the most commonly used evaluation methods for land disaster detection in the study area. It not only considers the pollution impact caused by natural geology, but also attaches great importance to the impact of human factors on soil pollution [13]. The calculation formula of the geological accumulation index method I is:

$$I = \log_2 (P_i (1.5 k_i) \tag{1}$$

Among them, Pi is the measured value of heavy metal elements, ki is the soil pollution level caused by various comprehensive factors, and 1.5 is the correction index.

3. Research Experiments

3.1. Collection of Soil Samples

Sampling the soil of an area contaminated by heavy metals. In addition to industrial plants, the area also has living areas around it, such as planting areas and grazing areas for residents. The farthest collection area in this area is near the river basin, surrounded by a shipyard. The soil samples were distributed by grid method, and the distance between each sample collection point was 20 m. The sampling depth is about 15cm, and about 1kg of soil layer samples are collected from each sampling point, stored in bags, and recorded at the same time. The collected soil samples were naturally air-dried, sieved separately, and ground for analysis and testing [14-15]. The test content is as follows: using different concentrations of EDTA-Na2 and FeCl3 to analyze the removal efficiency of these two reagents on soil heavy metals, select the reagent with better effect, and then mix it with distilled water, biochar, slaked lime, and organophosphate solubilizing bacteria OPW2-6 Comparison of other remediation techniques, test soil pH value to compare the remediation effect [16-17].

3.2. Soil Heavy Metal Content Test

When soil pollution is detected, soil sampling is required. After sampling, microorganisms are used to remove heavy metals in the samples. This requires the preparation of a certain concentration of microorganism solution, and then the solution is extracted into soil samples, and then the soil heavy metal content is tested [18-19]. The calculation formula is:

$$X = \frac{c_2(V_1+V_2)-c_1V_1}{W} \tag{2}$$

Among them, W is the weight of the soil after air-drying, c1 and c2 are the concentrations of the microbial solution before and after dropping the soil sample, and V1 and V2 are the volumes of the microbial solution before and after dropping the sample.

4. Experimental Results

4.1. Panel Data Analysis of Soil Heavy Metal Elements

Table 1. Soil chemical properties

	Average value	Maximum value	Minimum	Standard deviation	Coefficient of variation
pH	7.26	8.71	4.63	1.47	0.15
Organic matter (%)	2.23	5.27	1.48	0.97	1.64
Conductivity (ms/cm)	3.53	11.88	0.76	2.39	2.72
Salt content (g/L)	1.94	4.78	0.35	2.41	1.86

As shown in Table 1, the soil pH value in this area is between 4.63-7.26, and the coefficient of variation is small, indicating that basically the soil pH value in this area does not change too much, and there may be some changes in the pH value of individual sampling points. Most of the other sampling points are in neutral distribution and the soil condition is good. In addition, the organic matter in this area ranges from 1.48% to 5.27%, the electrical conductivity ranges from 0.76% to 11.88%, and the salt content ranges from 0.35 to 4.78.

Table 2. Content of heavy metal elements in soil

	Average value	Maximum value	Minimum	Standard deviation	Coefficient of variation
Zn	34.54	41.21	10.39	3.57	0.28
Cu	11.25	23.07	8.62	4.16	0.75
Ni	48.63	70.42	21.76	8.64	0.86
As	4.17	9.84	0.00	2.81	0.13
Cr	29.78	36.53	5.36	12.44	0.94
Pb	3.32	15.68	0.00	5.26	0.83
Cd	15.05	17.82	13.43	1.73	0.65

It can be seen from Table 2 that the soil in this area contains a variety of heavy metal elements, and the content of Zn, Ni and Cr in the soil is relatively high, at 10.39-41.21mg/kg, 21.76-70.42mg/kg and 5.36-36.53mg, respectively. /kg, the average content was 34.54mg/kg, 48.63mg/kg and 29.78mg/kg, respectively. Followed by the higher content of Cu and Cd, the average content was 11.25mg/kg and 15.05mg/kg, respectively. From the analysis of each sampling point, the content of Zn element in sampling point 7 is the highest, and the surrounding area is the grazing area of local residents. The content of Zn element in sampling point 5 is the lowest, and the surrounding area is the rice planting area. Sampling point 8 has the highest Ni content, which is located at the port of the estuary. The surrounding industrial production is dominated by shipyards and jellyfish processing plants. The abnormal Ni content in the surface soil of this area is inseparable from the shipyard. The content of Ni element in sampling point 4 is the lowest, and the surrounding area is the dumping area of local residents' domestic waste. Secondly, the content of Cu and As in the soil is relatively normal, ranging from 9.64-17.33mg/kg and 0-6.81mg/kg respectively, the average The content was 14.25mg/kg and 3.62mg/kg, respectively. The content of Cu element in sampling point 3 is the highest, and the surrounding area is corn planting area, and the content of Cu element in sampling point 2 is the lowest, and the surrounding area is the grazing area of local residents. Sampling point 8 has the highest content of As, which is surrounded by shipyards and jellyfish skin processing plants. There is a certain correlation between the increase of As content in the surface soil of this area and the shipyard. The content of As in sampling point 3 is the lowest, and the surrounding areas are mainly corn planting areas. The content of Pb element in sampling point 1 is the highest, and the surrounding area is mainly sweet potato planting area. The content of Pb element in sampling point 5 is the lowest, and the surrounding area is the rice planting area.

Finally, the contents of Pb and As elements in the soil were low, ranging from 0-15.68mg/kg and 0-9.84mg/kg, respectively, with an average content of 3.32mg/kg and 4.17mg/kg, respectively. The accumulation of Ni element is remarkable and should be paid attention to.

4.2. Analysis of Joint Estimation Results of Heavy Metal Removal and Soil Remediation

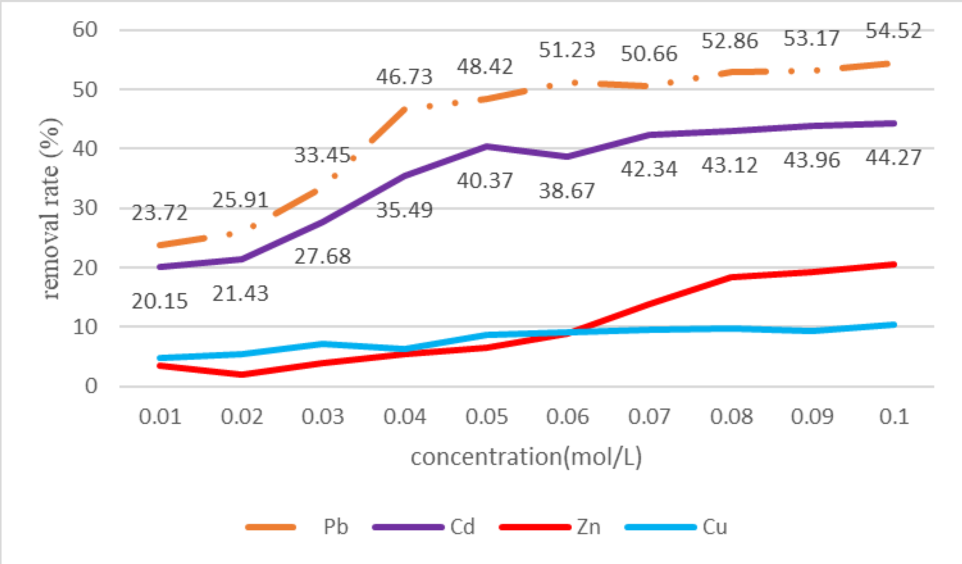

Figure 1. Removal rate of heavy metals by different concentrations of EDTA-Na2

Figure 1 reflects the removal rates of heavy metals in polluted soil by EDTA-Na_2 with different concentrations. It can be seen that the removal rates of Pb, Cd, Cu, and Zn by EDTA-Na_2 have similar trends, and they all increase with the increase of EDTA-Na_2 concentration. However, the removal effects of the four heavy metals were different. EDTA-Na_2 has the best removal effect on Pb, and the removal rate ranges from 23.72% to 54.52%. When the concentration of EDTA-Na_2 is less than 0.05mol/L, the increase of the removal rate of Pb is larger, but the increase of the removal rate of Pb decreases when the concentration of EDTA-Na_2 is greater than 0.05mol/L. The growth trend of Cd removal rate by EDTA-Na_2 was similar to that of Pb, and the removal rate ranged from 20.15% to 44.27%. The removal rate of EDTA-Na_2 to Zn is low, and the removal rate ranges from 3.56% to 20.63%. When the concentration is less than 0.06mol/L, the removal rate of Zn increases slowly, and when the concentration is greater than 0.06mol/L, the increase rate becomes larger. EDTA-Na_2 had the worst removal effect on Cu, the removal rate ranged from 4.68% to 10.42%, and the growth trend was gentle, which may be due to the weak chelation ability of EDTA-Na_2 and Cu^{2+}, and less stable compounds were formed.

Table 3. Removal rates of heavy metals with different concentrations of FeCl3

	0.05	0.1	0.15	0.2	0.25	0.3	0.35	0.4	0.45	0.5
Pb	18.57	19.62	22.75	27.54	29.36	31.25	28.67	26.45	25.87	24.21
Cd	25.64	28.96	31.27	33.58	36.41	37.45	39.60	41.52	43.78	45.19
Cu	6.38	14.72	17.64	21.33	41.75	56.47	62.85	64.12	65.37	67.98
Zn	4.26	6.42	7.91	9.76	12.35	13.64	14.84	16.74	17.55	18.63

Table 3 shows the removal rates of heavy metals in the polluted soil in the study area with different concentrations of $FeCl_3$. Because $FeCl_3$ can dissolve to form hydroxide, thereby releasing H^+, and the complexation of each metal ion with Cl helps to remove heavy metals in soil, so the removal effect is good. It can be seen from Table 2 that with the increase of $FeCl_3$ concentration from 0.05 mol/L to 0.5 mol/L, the removal efficiency of Pb, Cd, Cu, Zn has been increasing, but the increase range is with the increase of $FeCl_3$ concentration. significantly decreased. When the concentration of $FeCl_3$ was 0.5mol/L, the removal rate of $FeCl_3$ to heavy metals was: Cu>Cd>Pb>Zn, which were 67.98%, 45.19%, 24.21%, and 18.63%, respectively. $FeCl_3$ has the best removal effect on Cu, and the removal rate ranges from 6.38% to 67.95%, and the removal rate increases greatly from 21.33% to 56.47% when the concentration increases from 0.2mol/L to 0.3mol/L. When the concentration is higher than 0.3 mol/L, the upward trend tends to be flat. The removal rate of $FeCl_3$ to Cd ranges from 25.64% to 45.19%, and the increasing trend tends to be linear and stable. The higher the $FeCl_3$ concentration, the higher the removal rate. The removal efficiency of $FeCl_3$ for Pb increased first and then decreased. The removal rate ranged from 18.57% to 31.25%, and reached the highest when the concentration was 0.3mol/L, with a removal rate of 31.25%, and then showed a downward trend. $FeCl_3$ has the worst removal effect on Zn, and the removal rate is less than 20%. But compared with the removal efficiency of EDTA-Na_2, the removal effect of $FeCl_3$ is better.

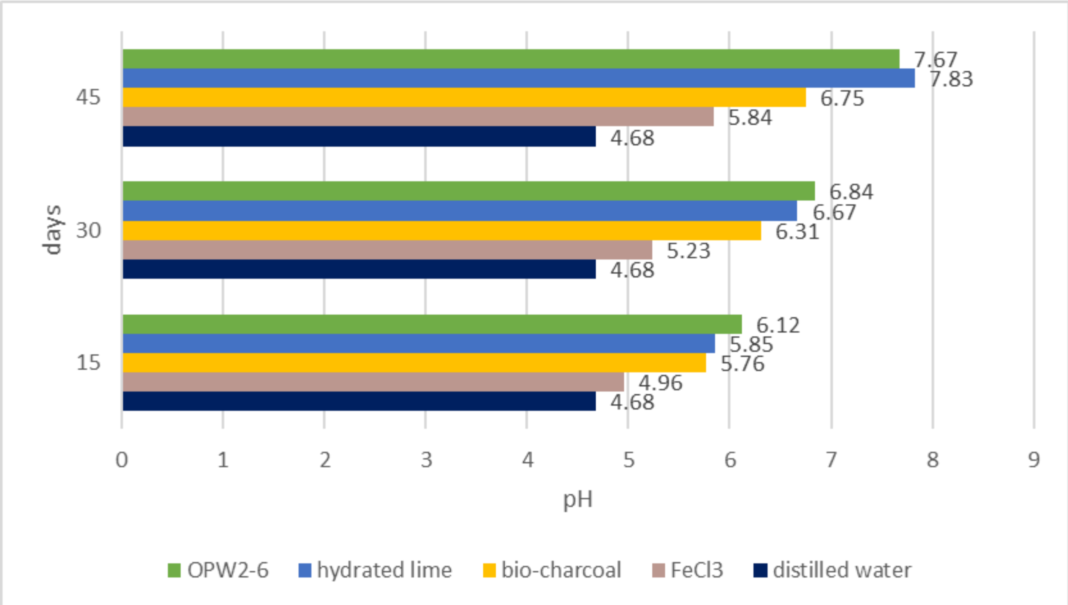

Figure 2. Soil pH changes

Soil pH mainly affects soil quality by changing soil pH. From Figure 2, the soil pH value after $FeCl_3$ leaching was 5.84, and the soil pH after adding distilled water did not change significantly at 15d, 30d and 45d, indicating that the effect of distilled water on soil pH was not obvious. The soil pH after adding biochar continued to slowly rise, reaching 6.75 at 45d; the soil pH after adding slaked lime increased significantly, reaching 7.83 at 45d, which may be due to the fact that slaked lime itself is an alkaline improver; adding organophosphate solubilizing bacteria OPW2 The pH value also showed an upward trend after -6, and rose to 6.12 after 15 days, 6.84 after 30 days, and 7.67 after 45 days. Compared with the addition of $FeCl_3$, the pH value after adding OPW2-6 has a larger increase, which shows that organophosphate-solubilizing bacteria OPW2-6 played a significant role in increasing soil pH, and soil properties could be improved by adjusting soil pH.

5. Conclusion

As one of the main technical means of soil remediation, microbial remediation technology is favored by the majority of researchers. This paper also studies the use of microbial remediation technology to remove heavy metals in soil. In this regard, a simulation experiment was carried out in this paper to collect soil samples from a certain metal-contaminated soil area, analyze the heavy metal content in the soil, and use organophosphate solubilizing bacteria OPW2-6 and other reagents to improve soil pH. The results show that, compared with adding $FeCl_3$ reagent, OPW2-6 has better removal effect of heavy metals.

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Data Availability

Data sharing is not applicable to this article as no new data were created or analysed in this study.

Conflict of Interest

The author states that this article has no conflict of interest.

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