

Retraction

Retracted: Numerical Simulation Method for Microbial Remediation Effect of Nano Heavy Metal Contaminated Soil

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This article has been retracted by Hindawi following an investigation undertaken by the publisher [1]. This investigation has uncovered evidence of one or more of the following indicators of systematic manipulation of the publication process:

- (1) Discrepancies in scope
- (2) Discrepancies in the description of the research reported
- (3) Discrepancies between the availability of data and the research described
- (4) Inappropriate citations
- (5) Incoherent, meaningless and/or irrelevant content included in the article
- (6) Peer-review manipulation

The presence of these indicators undermines our confidence in the integrity of the article's content and we cannot, therefore, vouch for its reliability. Please note that this notice is intended solely to alert readers that the content of this article is unreliable. We have not investigated whether authors were aware of or involved in the systematic manipulation of the publication process.

Wiley and Hindawi regrets that the usual quality checks did not identify these issues before publication and have since put additional measures in place to safeguard research integrity.

We wish to credit our own Research Integrity and Research Publishing teams and anonymous and named external researchers and research integrity experts for contributing to this investigation.

The corresponding author, as the representative of all authors, has been given the opportunity to register their agreement or disagreement to this retraction. We have kept a record of any response received.

References

- [1] L. Liang, "Numerical Simulation Method for Microbial Remediation Effect of Nano Heavy Metal Contaminated Soil," *Journal of Nanomaterials*, vol. 2022, Article ID 3318917, 9 pages, 2022.

Research Article

Numerical Simulation Method for Microbial Remediation Effect of Nano Heavy Metal Contaminated Soil

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Heavy metal soil remediation is an important component in mitigating environmental problems, and microbial remediation has good treatment effect, good environmental affinity, and high treatment cost treatment efficiency. Numerical simulations of soil remediation effects enable the selection of suitable remediation methods and the determination of the optimal remediation input ratio. However, the current numerical simulation mainly relies on a single mathematical model, and the simulation error is large when applied to the microbial remediation with large variability. Numerical simulation methods of microbial remediation impacts of heavy metal contaminated soils will be investigated to overcome the foregoing problems. By researching the migratory law of heavy metal contaminated soil components, the process of microbial remediation of heavy metal contaminated soil will be examined, and a microbial proliferation model will be constructed. The numerical simulation of microbial remediation effect is realized by using HYDRUS to inverse solve the data of small laboratory tests and obtain the relevant parameters for numerical simulation. The maximum simulation error of the method studied at the time of testing was 2.1%, the simulation trend was consistent with the real remediation effect, and the simulation results were reliable. Although the simulation results of the numerical simulation method of the microbial remediation effect of heavy metal polluted soil proposed in this paper differ from actual values of the microbial remediation of heavy metals in soil, the overall trend of changes in soil heavy metal content is similar. It reveals that the outcomes of the approach investigated in this work are somewhat trustworthy when numerically modeling the effect of microbial remediation of heavy metals in soils. In other words, the numerical modeling approach utilized in this work to examine the impact of microbial remediation of heavy metal-contaminated soil is highly precise and effective.

1. Introduction

Heavy metal pollution of soils is a phenomenon that originates from the deterioration of environmental conditions or the destruction of ecosystems by human activities that cause heavy metal levels to exceed natural background values. With the rapid increase in population in society, the continuous expansion of industrial production, the accelerated pace of urbanization, the use of large quantities of chemical fertilizers and pesticides in agricultural production, and the use of sewage for irrigation, substances containing large amounts of heavy metals reach the soil through different pathways, thus changing the original. Heavy metal pollution of the soil is caused by the physical and chemical structure of the soil [1, 2]. Heavy metals, on the other hand, are difficult to transfer and cannot

be destroyed by microbes, so they will remain in the soil for a long time, making it extremely difficult to clean polluted soil. At present, soil remediation techniques at home and abroad mainly include (i) physical methods, including guest soil/soil exchange, electric remediation, thermal treatment, and mulching [3]; (ii) biological methods, including phytoremediation, bioremediation, and microbial remediation [4, 5]. Third, chemical methods include acid/base conditioning, curing/stabilization, and chemical drenching [6]. Among them, physical remediation requires special equipment, which is relatively costly and prone to secondary pollution; biological remediation has a long cycle time; chemical remediation has the characteristics of short cycle time, wide applicability, and diversification of treatment methods, but chemical remediation requires a large amount of chemical reagents to be

invested; the heavy metal content of the soil needs to be constantly and repeatedly tested during the remediation process; and the production of chemical reagents cannot achieve low-carbon environmental protection. Microorganisms are components of nature itself, and the use of microorganisms' own metabolic products to react with heavy metals in the soil can minimize the impact of the soil remediation process on the local ecological environment. With the development of biotechnology, the application of microbial remediation in the process of soil pollution treatment is becoming more and more widespread. However, the conditions of laboratory small tests are still far from the actual site conditions, and the actual site conditions are so varied that numerical simulations are needed to obtain values as close as possible to the actual ones in order to improve the effectiveness of remediation. Compared with traditional physical and chemical remediation methods, bioremediation has the characteristics of good treatment effect, good environmental affinity, and high treatment cost and treatment efficiency. When using microbial methods for remediation of heavy metal contaminated soil, small laboratory experiments are usually used to obtain the remediation effect of microorganisms as well as the mechanism [7–9].

Methods for simulating bioremediation of petroleum-contaminated soils mainly include analytical and numerical modeling methods. Compared with the analytical modeling method, the numerical modeling method is relatively flexible and can simulate more complex problems. The objectives of simulating the microbial degradation remediation process with the numerical modeling method include clarifying the spatial and temporal distribution characteristics of the remediated contaminants, quantitatively revealing the amount of contaminant concentration reduction and remediation time by microbial remediation techniques. The problem with the model in the reference [10–13] is that it cannot consider the selective or competitive degradation of individual pollutants and can only simulate pollutants as a whole, which tends to ignore the influence of some factors on the remediation effect in the remediation process and increases the error of the numerical simulation results. The numerical simulation method in the reference [14–16] simplified the redox reactions involving microorganisms, which may lead to some deviations between the simulation results and the reality. The reference [17] uses two-dimensional numerical simulations that are only applicable to two-dimensional properties and have limitations. In order to target the use of microorganisms to treat soil contaminants and achieve better microbial remediation of heavy metal soils, this paper will investigate the numerical simulation method of microbial remediation effects of heavy metal contaminated soils and conduct an experimental study on the actual simulation performance of the method.

2. Study on Numerical Simulation Methods for Microbial Remediation Effects of Heavy Metal Contaminated Soil

2.1. Study on the Migration Pattern of Heavy Metal Contaminated Soil Components. Heavy metals in polluted

soil are mostly transported and disseminated throughout the soil by rainwater flushing and groundwater carryover. We shall primarily investigate the movement pattern of heavy metals in polluted soil under the conditions of poor irrigation in this work. Indoor soil column leaching experiments are used to investigate the migration and transformation processes of heavy metals after they enter the soil through sewage, as well as the migration and accumulation of total and effective state heavy metal contents in the vertical direction of soil under the compound leaching mode, in order to determine the heavy metal migration pattern in soil under foul irrigation conditions.

The column is made of PVC and consists of a 10.2 cm inner diameter, 100 cm high column, and a 5.1 cm radius hemispherical funnel connected to it by a flange. The columns were filled according to the total soil mass required, based on the field soil capacity and initial moisture content. The columns are filled from bottom to top with porous glass plates, 100 mesh filter, 5 cm of quartz sand (soaked in acid and dried after washing with deionized water as a backfilter to prevent soil loss), 100 mesh filter (to separate the soil from the quartz sand), and 90 cm of soil (filled in the order of natural soil layers, 0–20 cm, 20–40 cm, and 40–90 cm, taking care to compact the considering that the soil may sink during the experiment, the filling height is slightly higher than the setting height by 3–5 cm), and 100 mesh nylon mesh is placed at the top of the soil layer (to evenly distribute water). The filled soil columns were first wetted with deionized water to reach the field water holding capacity, and to obtain the transport parameters of heavy metals in different soils, easy mixing experiments with conservative solutes were required for tracing, and usually conservative, nonreactive solutes were selected as tracers [18]. In this paper, 0.05 mol/L CaCl_2 solution was chosen as the tracer, the pump speed was adjusted, the solution was added from the top of the soil column, and the filtrate was collected regularly until the Cl^- concentration in the effluent was close to 0.1 mol/L. The tracer experiment was stopped, and the Cl^- ion content was determined by AgNO_3 titration. Then, the experiment was continued with a solution of water and heavy metal ions, and the effluent was collected at the lower end to determine the concentration of heavy metals (Figure 1).

At the end of the experiment, the soil column was left for a period of time to allow the internal soil moisture to approach its natural state, and the column was dissected and sampled at high density, one sample every 2 cm from 0 to 20 cm and one sample every 5 cm from 20 to 90 cm, dried and ground through a sieve, and then the heavy metal content and effective state content of the soil samples were determined. Soil samples were digested in the sT-60₄ automatic graphite digester. 0.1000 g of soil samples sieved through 100 mesh was weighed into the digestion tube, placed on the graphite furnace digester, and the drugs used in the digestion process were prepared in advance. After 30 min, 1 ml of 1:1 nitric acid solution was added, and the liquid in the digestion tube was rinsed into a volumetric flask with deionized water and filtered with a fixed volume. The content of heavy metals in the solution was determined

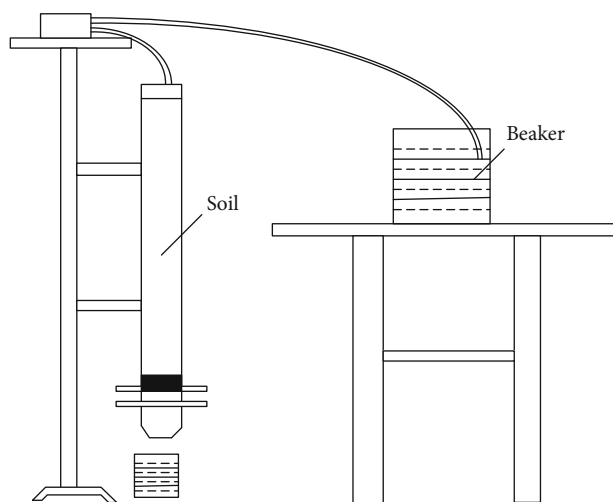


FIGURE 1: Schematic diagram of drenching.

using XSeries-2 inductive scour plasma emission mass spectrometer and 6000 Series inductive scour plasma emission spectrometer [19, 20]. DTPA was used as the extractant for the extraction of the effective state of heavy metals. 5 g of the soil sample was weighed through 10 mesh sieve in a triangular flask, 25 ml DTPA extractant was added, the sample was extracted at 180 r/min for 2 h at room temperature in an oscillator and then filtered, and the effective state of heavy metals was determined using an XSeries-2 inductive scour plasma emission mass spectrometer and 6000 Series inductive scour plasma emission spectrometer. The effective state of heavy metals was determined using XSeries-2 inductive scour plasma emission mass spectrometer and 6000 Series inductive scour plasma emission spectrometer.

Before fitting the penetration curve of heavy metal ions, it is necessary to estimate the average pore velocity and hydrodynamic dispersion coefficient D of each soil column. D is a parameter related to soil characteristics. In this paper, the hydrodynamic dispersion coefficient is estimated based on the approximate solution of vertical dispersion coefficient of saturated soil, and the calculation formula is as follows [21].

$$D = \frac{v^2}{8t_1} (t_2 - t_3)^2, \quad (1)$$

where t_1 , t_2 , and t_3 are, respectively, the time when the relative concentration of heavy metal ions in the outflow liquid reaches different values; v is the average pore velocity of liquid in soil during leaching, which can be approximated by L/t_1 . L is the distance from the bottom of the soil column to the beginning of the soil column. The values of t_1 , t_2 , and t_3 are calculated by interpolation method and solved according to the time when the heavy metals at the adjacent upper and lower points reach the corresponding relative concentration, as shown in formula.

$$t_{\text{mid}} = t_h + \frac{c_{\text{mid}} - c_h}{c_l - c_h} (t_l - t_h), \quad (2)$$

where c_{mid} is the relative concentration value to be obtained; t_{mid} is the time to obtain the relative concentration value; c_h and c_l are the relative concentration values of the upper and lower adjacent of the penetration curve of heavy metals in soil, respectively. t_h and t_l are the time to reach the upper and lower adjacent concentration values. The concentrations of heavy metals at different times, at different depths, and at different pollution levels were calculated by the above formula, and the migration rules of heavy metals in contaminated soil were summarized.

2.2. Analysis of Microbial Remediation of Heavy Metal Contaminated Soils

2.2.1. Analysis of Factors Affecting the Effectiveness of Microbial Soil Remediation.

Under practical conditions, the native microorganisms in the soil of heavy metal contaminated areas do not efficiently and rapidly degrade the heavy metal pollutants in the soil because of the limitations of environmental factors. However, it was found that the proliferation of microorganisms and the rate of degradation of heavy metal pollutants could be effectively promoted in the soil environment of the contaminated area, i.e., the growth environment of microorganisms, was appropriately changed. The main environmental factors affecting the remediation effectiveness of microorganisms in heavy metal contaminated soils are as follows [22–24].

(1) *Supply of Nutrients.* The growth and reproduction of microorganisms are inseparable from the supply of nutrients, and with a suitable nutrient supply, microorganisms can effectively use nutrients for various physiological activities, so it is said that the supply of nutrients determines whether native microorganisms can efficiently degrade heavy metal pollutants, and the demand for nutrients is also the basic guarantee for the life activities of microorganisms.

It has been shown that the nitrogen to phosphorus ratio in the soil has an important influence on the growth of microorganisms, and only at the right ratio can microorganisms proliferate and grow quickly and efficiently. It is generally believed that when the ratio of nitrogen to phosphorus in the soil is closer to the internal nitrogen to phosphorus ratio of microorganisms, the more favorable the growth and proliferation of microorganisms.

(2) *Temperature.* Microbial degradation reactions and some life activities are a series of enzymatic reactions. These reactions are carried out in the action of various enzymes in microorganisms, and temperature has an important influence on the activity of enzymes in microorganisms. Too low a temperature will reduce the activity of enzymes in microorganisms, while too high a temperature will also reduce their activity or even kill these important active enzymes. In general, the appropriate temperature range for most enzymatic reactions is 20–40 degrees Celsius, and the appropriate temperature can also increase the activity of the substrate for rapid remediation.

(3) *Moisture*. Water is an essential participant in biological reactions, and the water content of the soil and the form in which it is present have a significant impact on the efficiency of microbial remediation. When the moisture content is appropriate, the various reactions that occur in microorganisms can proceed in an efficient and orderly manner. Studies have shown that soil moisture is most suitable for microbial remediation of heavy metal contaminated soils when it is at 30-80% of the maximum water holding capacity.

(4) *pH*. Heavy metal contaminated soil will inevitably change the original environmental pH of the soil, and the pH of the soil plays an important role in the conduct of enzymatic reactions. Therefore, the effect of pH needs to be considered when studying the remediation effect of microorganisms on heavy metal contaminated soils.

(5) *Soil Oxygen Content*. Soil contaminated with heavy metals undergoes changes in soil structure over time, resulting in a decrease in the oxygen content of the soil. The microorganisms used to remediate the soil require varying amounts of oxygen for survival and remediation. Although the moisture in the soil dissolves some of the oxygen in the air, it still affects the effectiveness of microbial remediation of heavy metal contaminated soils.

2.2.2. Modeling Microbial Proliferation. The Monod microbial proliferation model was used in this study to calculate the changes in microbial population for remediation of heavy metal contaminated soil. The Monod equation is a model that describes the specific growth rate of cells in relation to the concentration of the limiting substrate and has a form similar to that of an enzymatic reaction. The basic form of the Monod equation is [25].

$$\mu = \frac{\mu_{\max} s}{K_s + s}, \quad (3)$$

where μ is the growth rate of unit microbial population, that is, the ratio of microbial growth rate to microbial population; μ_{\max} is the maximum growth rate of microorganisms; s is the matrix concentration; K_s is the saturation constant, that is, the matrix concentration at $\mu = \mu_{\max}/2$.

Biological addition is one of the most important microbiological technologies, and simulations of the biological addition process should focus on three processes: nitrifying bacteria enrichment and cultivation, main reactor nitrification, and denitrification. The relevant phosphorus removal mechanism is added to the EASMI model on the basis of ASM1, which can simulate phosphate and phosphorus-accumulating bacteria changes in the repaired soil. The model is simplified by omitting the fermentation, chemical precipitation, and denitrifying phosphorus removal processes.

Microorganisms' growth is influenced not only by growth substrates but also by hydrologic variables in the soil, such as dissolved oxygen change and groundwater movement. As a result, the revised Streeter-Phelps model was used to characterise heavy metal movement in one-dimensional steady-state soil hydrology, as follows:

$$u \frac{\partial C}{\partial x} = \gamma \frac{\partial^2 C}{\partial x^2} + S, \quad (4)$$

where u is the average velocity of groundwater doped with heavy metals in heavy metal contaminated soil, m/s; C is the mass concentration of pollutants flowing through x distance, mg/m³; x is the longitudinal distance of pollutant migration, m; γ is the longitudinal dispersion coefficient, m²/s; S is the source or sink of pollutants, mg/(m³•s).

Based on the methods and theories of Monod model, Streeter-Phelps model, and ASM1 model, combined with the controlled parameters of easily biodegradable COD, dissolved oxygen, and ammonia nitrogen, the related kinetic equation of biological treatment process can be expressed as follows [18].

Easy to biodegrade COD (S_s)

$$\frac{dS_s}{dt} = -u_x \frac{dS_s}{dx} + E_x \frac{d^2 S_s}{dx^2} - \frac{\lambda_{\max H}}{Y_{XH/SS}} \frac{S_s}{K_s + S_s} \left[\eta_i \frac{K_i}{K_i + S_i} \right]. \quad (5)$$

In the above formula, $Y_{XH/SS}$ is the biomass COD formed by removing unit mg COD; $\lambda_{\max H}$ is the maximum specific growth rate of heterotrophic microorganisms; η_i is the correction factor for hypoxic growth of heterotrophic bacteria; K_i is the saturation and coefficient of oxygen during the growth of heterotrophic microorganisms; K_s is the half-full and coefficient of biodegradable substances during the growth of heterotrophic microorganisms; E_x is the longitudinal dispersion coefficient.

COD degradation produces particulate concentrations

$$\frac{dX_{ND}}{dt} = -u_x \frac{dX_{ND}}{dx} + E_x \frac{d^2 X_{ND}}{dx^2} (i_{XB} - f_b i_{XP}) (k_{dH} X_H + k_{dA} X_A), \quad (6)$$

where X_{ND} is the concentration of particulate matter generated by COD degradation; i_{XB} is the proportion of component B in biomass COD; i_{XP} is the proportion of component B in the biomass product COD; f_b is the proportion of granular attenuation products; k_{dH} is the attenuation coefficient of heterotrophic bacteria; k_{dA} is attenuation coefficient of autotrophic bacteria; X_H is the number of active heterotrophic bacteria; X_A is the number of active autotrophic bacteria. Based on the aforementioned study, the role of microbial proliferation in heavy metal contaminated soil remediation was investigated, the effect data of microbial remediation of heavy metal contaminated soil were assessed, and HYDRUS was used to do a numerical simulation of the remediation effect.

2.3. Implementing Numerical Simulations of Microbial Remediation Effects. Before using HYDRUS to simulate the remediation effects of microbial remediation under relevant site conditions, it was necessary to first use the inverse solution function of HYDRUS to inverse solve for other transport parameters of each heavy metal in the soil using experimental penetration curves and sorption isotherm parameters. The HYDRUS inverse solution function is used

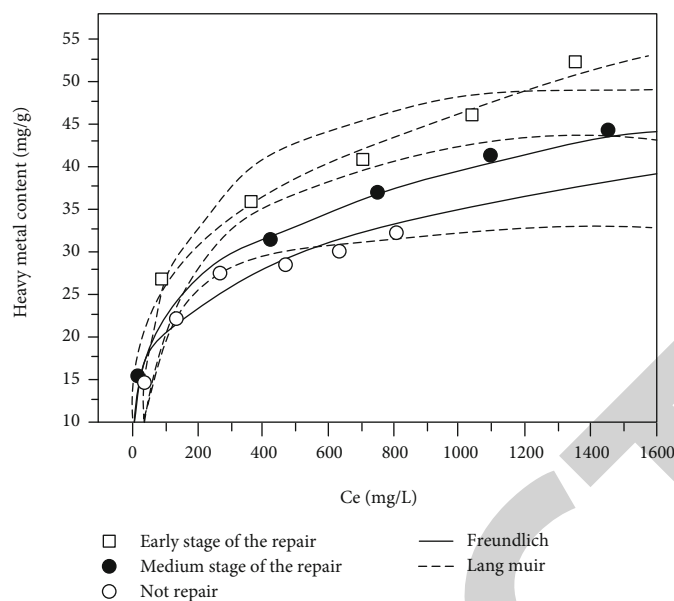


FIGURE 2: Isotherms of Pb sorption by microbially treated and microtreated soils.

TABLE 1: Simulated fitting of Pb sorption parameters for different microbial remediation soils.

	b (Lmg^{-1})	Langmuir model		K_f ($\text{mg}\cdot\text{g}^{-1}$)	French model	
		Q_0 ($\text{mg}\cdot\text{g}^{-1}$)	Correlation coefficient		$1/n$	Correlation coefficient
Microorganism 1	0.01669	33.33	0.996	6.734	0.236	0.979
Microorganism 2	0.008475	52.73	0.977	7.595	0.262	0.989
Microorganism 3	0.007481	46.51	0.985	7.231	0.245	0.988

to simulate the penetration curves of heavy metals and to obtain the following parameters and the following parameters were obtained: dimensionless sorption point assignment parameters as well as first-order rate constants. Since the soil particles in the profile are assumed to be of the same size and material, the van Genuchten-Mualem approach was used for the water transport model assuming no hysteresis in the transport process. The solute transport model uses a chemically nonequilibrium bright spot sorption model under a Crank-Nicolson time weighting scheme. Water flow parameters were predicted by HYDRUS's own neural network prediction model from soil capacitance and sand, powder, and clay percentages. Remediation microorganisms were added at a depth 10 cm more than the soil contamination depth, the amount of remediation microorganisms added was the same as in the small trial in 1.1, the groundwater contamination concentration was set at 5.0 mg/L^{-1} , and the infiltration rate of contaminated groundwater was set at 39 cm/d^{-1} . The parameters were set according to the microbial proliferation rate calculated from the above elements. The sorption isotherm constants were taken from the Langmuir fit of the batch sorption experiment. The dimensionless adsorption point assignment parameters as well as the first-order rate constants were taken from the values obtained from the HYDRUS inverse solution. Finally, the integrated remediation was simulated with the HYDRUS orthoretic solution, and the changes in the concentration of each heavy metal in the 50 cm shallow groundwater and the concentration dis-

TABLE 2: HYDRUS inverse solution fitting of other transport parameters of Pb in soil.

	Pretreatment soils	Midtreatment soil	Untreated soil
Frac.	0.079593	0.081542	0.15234
Alpha	0.006	0.002	0.002

tribution of each heavy metal in the soil profile during the remediation process were recorded after the simulation was completed [26].

Figure 2 below shows the isotherms of Pb sorption by microbially treated and microtreated soils, and Table 1 shows the simulated fitted parameters of Pb sorption by different microbially remediated soils.

Figure 2 shows that the Langmuir model fits the sorption isotherm of untreated soil Pb better than the French model, with correlation coefficients of 0.996 and 0.979, respectively, indicating that untreated soil Pb sorption prefers a monolayer and homogeneous sorption, i.e., sorption occurs only at a limited number of defined sorption sites, and each site has the same adsorption [27–29].

The transport parameters of Pb in each treated soil obtained from HYDRUS inverse solution, such as the dimensionless sorption point assignment parameter (Frac.) and the first-order rate constant (Alpha), are given in Table 2 for subsequent HYDRUS simulations of integrated remediation.

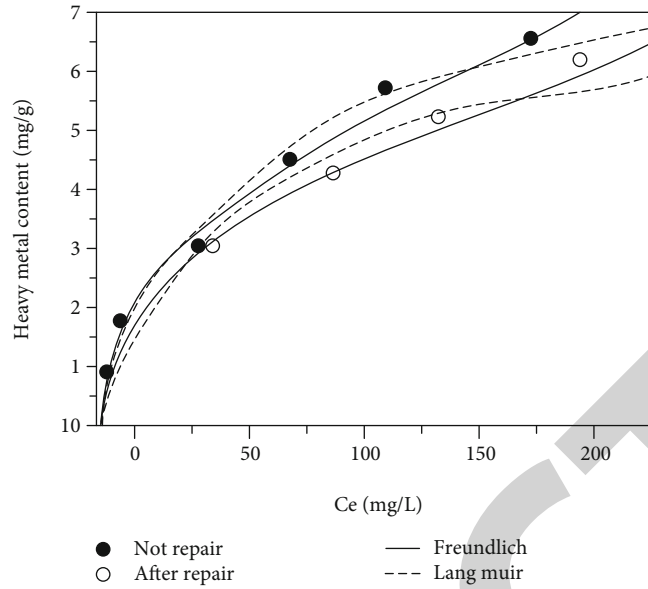


FIGURE 3: Cd sorption isotherms for treated and untreated soils.

TABLE 3: Other transport parameters of Cd in soil by HYDRUS inverse solution fitting.

	Posttreatment soil	Untreated soil
Frac.	0.024986	0.013665
Alpha	0.0024	0.0006

TABLE 4: Basic data of soil samples.

	Sample 1	Sample 2	Sample 3
PH	7.3	7.02	6.31
Sand/%	69.9	80.3	77.9
Silt/%	18.9	15.4	15.9
Slay/%	11.2	4.3	6.2
Pb (mg/kg)	873	12.5	35.5
Cd (mg/kg)	6.5	4.1	0.45
Zn (mg/kg)	286.5	105.2	120.5
Cu (mg/kg)	75.3	21.3	—
Fe (mg/kg)	1.2	2.7	—
Mn (mg/kg)	0.14	—	—

Following the above process, the same isotherms for Cd sorption by treated and untreated soils were obtained as shown in Figure 3.

As can be seen from Figure 3 above, the mechanism of Cd sorption by soil is mainly chemisorption processes, such as precipitation and complexation, and microbial remediation of particles that can provide stronger sorption sites is relatively more effective.

Table 3 below shows the other transport parameters of HYDRUS inverse solution fitting Cd in soil.

After fitting the parameters of microbial remediation of heavy metals in soil by the HYDRUS inverse solution, the

following mathematical model was developed based on the Eulerian multiphase flow mass conservation equation.

$$\frac{\partial}{\partial t} (\alpha_q \rho_q) + \nabla \cdot (\alpha_q \rho_q \vec{v}_q) = HY \sum_{p=1}^n (m_{pq} - m_{qp}). \quad (7)$$

In the above equation, the right-hand side of the equation is the source term; ρ is the density of corresponding phase; \vec{v} is the corresponding velocity; α is the volume fraction of corresponding phase; m_{pq} is the heavy metal mass transfer from p phase (other phases) to q phase; m_{qp} is the heavy metal mass transfer from q phase (other phases) to p phase; HY is the migration parameter matrix fitted by HYDRUS inverse solution. Due to the degradation of degrading microorganisms, the heavy metal complex, which was originally insoluble in water, becomes soluble in water (main phase) and is taken away by water (main phase). This process is reflected in the equation as the mass transfer process between phases. The degradation response rate determines the mass transfer from the secondary phase to the main phase. The main phase to secondary phase mass transfer is 0 and can be ignored. The microbial degradation reaction rate equation is

$$\frac{-dC'}{dt} = K_c, \quad (8)$$

where C' is the mass concentration of a heavy metal pollutant in the soil at any time, mg/L; K_c is the velocity constant (matrix removal constant); t is the microbial repair time. The migration parameters fitted by HYDRUS inverse solution were substituted into the above formula to obtain the remediation effect of microorganisms on a heavy metal in soil. The numerical simulation results of remediation effects

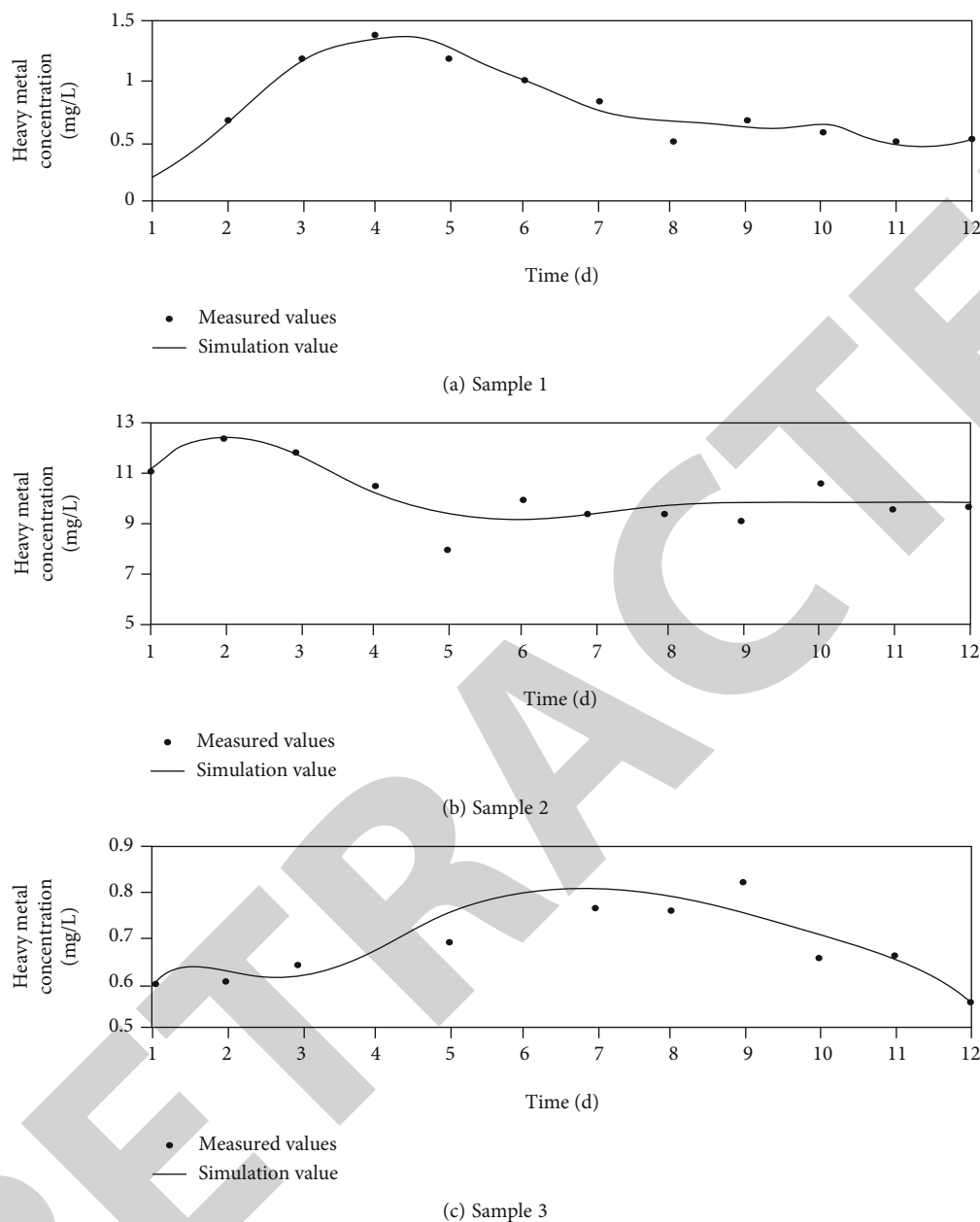


FIGURE 4: Numerical simulation results.

of heavy metal contaminated soil by microorganisms were obtained by integrating the simulation results of all heavy metal pollutants, and the numerical simulation method of remediation effects of heavy metal contaminated soil by microorganisms was completed.

3. Experiments on Numerical Simulation Methods

The numerical simulation method for the effect of microbial remediation of heavy metal contaminated soil was proposed above, and in this paper, the theoretical content of the above study will be experimentally time, and the performance of the method will be experimentally verified.

3.1. Experimental Content. Ten groups of $1\text{ m} \times 1\text{ m}$ in size were randomly selected from different locations of a heavy metal contaminated area at a site as the collection area for soil samples. The soil samples were tested for composition and content before the experiment according to the soil sampling and testing procedure described below. Afterward, the soil was remediated by selecting appropriate microorganisms based on the initial soil heavy metal content test results. The soil data from the determination of heavy metal content is used as the raw data for the numerical simulation method, and data such as temperature, humidity, and sunlight hours in the vicinity of the soil area are collected according to the parameters required for the numerical simulation to facilitate the numerical simulation of the remediation effect of the microbial remediation of the heavy metal content of

the soil. The numerical simulation values were compared with the real values to obtain the accuracy of the numerical simulation method in this paper.

3.2. Soil Sampling and Processing and Testing. The soil was separated into three portions by soil depth along the radial direction, 0-4 cm, 4-8 cm, and 8-12 cm, and then removed in layers, placed on kraft paper, and air dried for two weeks in an electric drying oven at 40°C. After air drying, the soil was crushed and broken through a screen (1 mm) before being placed aside.

3.2.1. The Total Amount of Heavy Metal. The total amount of heavy metals in soil was assessed using the HNO₃/H₂O₂ digestion process and then measured using an atomic absorption spectrometer with a continuous light source. 30.5 g of the material was mixed with 10 mL of 1:1 HNO₃ in a graphite furnace for 2 hours at 105°C for digestion. If needed, the amount of acid can be increased, and the digestion time extended. The sample was then cooled, and a certain amount (multiple of 500 μ L) of H₂O was added, making the sample completely digested, continued to heat for 15 min, cooled and passed through a 0.45 μ m filter membrane, and finally diluted to 50 mL with deionized water, covered the digestion tube, mixed completely, and the sample was ready for analysis.

3.2.2. Soil Heavy Metal TCLP Extraction Experiment. After passing through a 1 mm sieve, the soil was accurately weighed at 2.00 g, and 40 mL of TCLP extract (pH 2.880.05, obtained by dissolving 5.7 mL glacial acetic acid in water and fixing the volume to 1000 mL) was added to a solid-liquid ratio of 1:20, with the pH measured by shaking at 30 r/min-1 for 182 hours. After that, the extract was centrifuged for 8 minutes at 4000 r/min-1 and passed through a 0.45 μ m filter membrane. Flame atomic absorption AAS was used to assess the amounts of heavy metals Pb, Cd, and Zn in the extracts. (3) XRD physical phase analysis.

Each upper soil sample was taken, passed through an 80 mesh sieve, ground using a mortar and then passed through a 320 mesh sieve, and subsequently analyzed for its physical composition using an X-ray diffractometer (D/max-2200/PC, Japan Rigaku Corporation). Analytical conditions: Cu K α rays were scanned from $2\theta = 100$ to $2\theta = 500$ at a rate of $1^\circ 2\theta$ min⁻¹ steps of 0.02° . The results were analyzed using JADE (Version 6.5) software.

The heavy metal contaminated soil was treated according to the above method to obtain the most accurate values of heavy metal contamination. Table 4 below shows the basic data of the soil samples used for the experiment.

The pre-experimental soil heavy metal contamination values were used as raw data for the numerical simulation method. The heavy metal content of the treated soil was measured according to the numerically simulated heavy metal contamination treatment time points, and the measured data were used as reference values for the numerical simulation method to evaluate the performance of the numerical simulation method.

3.3. Experimental Results. Figure 4 below shows the simulated versus real values of the effectiveness of the microbial remediation of heavy metals in soil by the method of this paper.

The greatest divergence of the numerical simulation findings from the real values is only 2.1 percent, as shown in Figure 4, which fits the requirements of the actual investigation of microbial remediation effects. Furthermore, while the simulation results of the numerical simulation method of microbial remediation effect of heavy metal polluted soil proposed in this paper differ from real values of microbial remediation of heavy metals in soil, the overall trend of heavy metal content changes in soil is similar. It demonstrates that when numerically modeling the effect of microbial remediation of heavy metals in soils, the results of the method explored in this work are relatively reliable. That is, the numerical simulation method used in this research to study the effect of microbial remediation of heavy metal contaminated soil is very accurate and performs well.

4. Conclusion

Many heavy metal pollutants enter the soil in a variety of ways as the economy develops, resulting in a considerable quantity of heavy metal enrichment in the soil and soil heavy metal pollution. Soil metal pollution is one of the most serious environmental issues confronting the world's agricultural development. Soil heavy metal pollution not only causes changes in soil function and structure, inhibits microbial activities, but also slowly accumulates heavy metals in soil, which are indirectly absorbed by animals and even human beings in different ways, harming human health. The accuracy of the numerical modeling approach for microbial remediation effect of heavy metal contaminated soil was proved by tests in this research.

Data Availability

Data are available on request.

Conflicts of Interest

The authors declare that they have no conflicts of interest regarding the publication of this paper.

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