



ROLE OF ORGANIC AMENDMENTS IN BIO MANAGEMENT AND ENVIRONMENTAL RISK ASSESSMENT OF TRACE ELEMENTS IN MINING SOIL: A LABORATORY SCALE STUDY

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ABSTRACT:

A laboratory-scale experiment was conducted to evaluate the bioremediation of trace element-contaminated mining industrial soil using 5 L glass pot bioreactors. Mixed organic amendments including sheep manure, pig manure, vegetable waste, dry leaves waste, and stone slurry were applied. After treatment, soil pH increased from 5.30 to 7.54 and electrical conductivity decreased from 4510 to 3220 $\mu\text{S}/\text{cm}$. Significant removal efficiencies were observed for copper (85–88%), manganese (91–93%), lead (75–80%), zinc (55–62%), and iron (89–92%). The results demonstrate that microorganisms combined with organic amendments effectively improve soil properties and reduce toxic trace metals, indicating that this method is a feasible and sustainable approach for the treatment of contaminated mining soil.

KEYWORDS:

MINING INDUSTRIAL SOIL, CONTAMINATED, AMENDMENTS, BIOREACTOR, MANURE.

PAPER ACCEPTED DATE:

5th April 2026

PAPER PUBLISHED DATE:

7th April 2026

1. INTRODUCTION

Trace elements are naturally present in soil in small amounts, but their concentration increases significantly due to mining, industrial activities, and disposal of metal-rich wastes. Mining operations disturb the soil structure and release toxic trace metals such as copper (Cu), lead (Pb), zinc (Zn), manganese (Mn), iron (Fe), cadmium (Cd), and nickel (Ni) into the environment. High concentrations of these elements can reduce soil fertility, affect microbial activity, inhibit plant growth, and pose risks to human health through the food chain.

Trace metals are persistent and non-biodegradable, making their removal difficult using conventional physicochemical methods, which are often expensive and may produce harmful by-products.

Bioremediation using microorganisms and organic amendments such as animal manure, compost, vegetable waste, and plant residues is considered an eco-friendly, economical, and sustainable approach for reducing trace metal toxicity. These organic materials improve soil physicochemical properties, increase pH, enhance microbial activity, and reduce the mobility and bioavailability of toxic metals (Sheoran et al.,2012 and Manzoor et al.,2024). This study aims to develop a sustainable and scalable treatment system that can be applied at different mining and industrial sites for effective restoration and management of contaminated soil.

2. MATERIALS AND METHODS

Five organic amendments were used in this study, including sheep manure, pig manure, vegetable waste, dry leaves waste collected from the local market area, and stone slurry obtained from a nearby marble factory. All materials were collected, air-dried, and manually ground into a fine powder before use. Based on comparative evaluation with commercially available chemical treatments, these organic amendments were found to be economically viable and suitable for soil remediation (Sheoran et al.,2010).

2.1 CONTAMINATED MINING SOIL:

The landscape surrounding the lignite mining area was selected for field investigation. The Matasukh Lignite Mining Area located in Nagaur district of Rajasthan, lies approximately 195–200 km east of Jodhpur by road distance. Soil samples were collected from three depth intervals: 0–15 cm, 15–30 cm, and 30–60 cm. At each depth, three sub-samples (a, b, and c) were collected to ensure representative sampling of the study area. The sub-samples obtained from each depth were thoroughly mixed to form composite samples, resulting in three main samples designated as Sample A, Sample B, and Sample C. These composite samples represent the soil profile at different depths and were used for the determination of trace element concentrations and other physicochemical characteristics.

2.2 EXPERIMENTAL DESIGN

A laboratory-scale study was conducted to evaluate the effectiveness of bioremediation for the treatment of mining soil contaminated with trace elements. The experimental system was designed to be simple, cost-effective, and environmentally sustainable by utilizing waste-derived and readily available organic amendments.

Five glass pots (bioreactors), each with a capacity of 5 kg soil, were used in this experiment. The experimental treatments were arranged as follows:

Treatment	Description
Control (T ₁)	Contaminated soil only (without any amendment)
Treatment 1 (T ₂)	Contaminated soil amended with organic manure
Treatment 2 (T ₃)	Contaminated soil amended with organic manure and urea.
Treatment 3 (T ₄)	Contaminated soil amended with organic manure, urea, and EDTA
Treatment 4 (T ₅)	Contaminated soil amended with organic manure, urea, and EDTA (replicate / variation in concentration)

TABLE 1: EXPERIMENTAL TREATMENTS USED IN THE BIOREACTOR STUDY



FIGURE 1: EXPERIMENTAL SETUP FOR SOIL SAMPLES



FIGURE 2: EXPERIMENTAL SETUP FOR SOIL SAMPLES ALIQUOTS A, B AND C

Each pot contained 1 kg of contaminated soil collected from the lignite mining area. The amendments were thoroughly mixed with the soil to ensure uniform distribution. The experiment was conducted under controlled laboratory conditions, and soil samples were

collected at different time intervals (e.g., 1, 7, 15, 30, 60, and 90 days) to evaluate changes in physicochemical properties and trace element concentrations.

Five aliquots of each soil sample were prepared for analysis to ensure accuracy and reproducibility of the results. The analytical data were critically evaluated, and the results were considered acceptable when the standard deviation was less than 10% of the mean value. All organic amendments were thoroughly mixed with the soil and incubated for a few weeks at ambient temperature to enhance microbial growth and activity (Christensen et al., 1996). Microbial activity was confirmed by the formation of a thin black film on the soil surface, indicating active decomposition processes.

After the incubation period, 1 kg of mining-contaminated soil was placed into each reactor (glass pot), and the amended samples were further monitored and analyzed at regular intervals to assess the effectiveness of the bioremediation treatment in reducing trace element concentrations and improving soil physicochemical properties.

Three chemical parameters—pH, electrical conductivity (EC), and trace metal concentrations—were analyzed in the laboratory. Soil samples were collected from each container at predetermined time intervals of 1, 7, 15, 30, 45, 60, and 90 days after incubation. The pH of contaminated soil samples was measured immediately after collection using a digital pH meter (Make: RI, Model: 151R). Electrical conductivity (EC) was determined using a conductivity meter (MS Electronics India Pvt. Ltd., Model 601E) following Method 2510 B described in Standard Methods for the Examination of Water and Wastewater (APHA, 1992). Trace metal concentrations were analyzed using an Atomic Absorption Spectrophotometer (AAS) (Make: GBC, Australia; Model: AVANTA). The determination of trace elements was carried out according to standard procedures described in Carter (1993) in the book Soil Sampling and Methods of Analysis.

3. RESULTS AND DISCUSSION

A laboratory-scale bioreactor study was conducted for approximately three months to evaluate the effectiveness of organic amendments in the bioremediation of mining-contaminated soil. The performance of the developed system was found to be promising, simple, and manageable under controlled laboratory conditions.

3.1 EFFECT ON PH

The initial pH of the mining-contaminated soil used as input in the unamended bioreactor was 5.30, and 5.54, 5.53, 5.59 and 5.56 across the treated bioreactors respectively, indicating acidic conditions commonly observed in mining areas. After treatment, a significant improvement in pH was observed in the amended bioreactors. The pH values of treated soil increased to 7.39, 7.40, 7.47 and 7.31 in bioreactors I, II, III, and IV, respectively, indicating a shift towards neutral conditions. This increase corresponds to an approximate 33.39%,

33.82%, 33.63%, and 31.47% rise in pH in bioreactors I, II, III, and IV, respectively, compared to the initial value.

Organic amendments used in the bioreactors played an important role in increasing soil pH. These amendments act as a carbon source for microbial growth, which enhances microbial activity and contributes to the neutralization of acidity in mining-contaminated soil and water (Tsukamoto et al., 2004). Animal manures, such as pig manure and sheep manure, are known to improve soil properties and assist in the immobilization or removal of trace metals.

In addition, stone slurry acts as an extra electron donor, which stimulates microbial metabolic processes in contaminated soil. The addition of stone slurry also contributes to pH neutralization, creating favorable conditions for microbial growth. Neutral pH enhances microbial activity and promotes the removal of trace elements through precipitation and immobilization mechanisms. The results obtained in this study are consistent with previous findings, which demonstrated that organic amendments and microbial processes significantly improve pH and enhance metal removal efficiency in contaminated soils (Christensen 1996 and Nie et al., 2024).

3.2 SOIL ELECTRICAL CONDUCTIVITY (EC)

Electrical conductivity (EC) is a measure of the ability of an aqueous solution to conduct electrical current. This property depends on the presence, total concentration, mobility, and valency of dissolved ions, as well as the temperature at which the measurement is taken. Higher EC values generally indicate a greater concentration of soluble salts in the soil. The electrical conductivity of the input mining-contaminated unamended soil was recorded as 4510 $\mu\text{S/cm}$ and 4261, 4274.5, 4267.5 and 4294 $\mu\text{S/cm}$ across the treated bioreactors respectively. After treatment in different bioreactors amended with organic materials, the EC values of the treated soil decreased to 4053, 4121, 4090 and 4001 $\mu\text{S/cm}$ in bioreactors I, II, III, and IV, respectively. This corresponds to an approximate 4.88%, 3.59%, 4.16%, and 6.82% reduction in EC in bioreactors I, II, III, and IV, respectively, compared to the initial Day 1 values.

The observed reduction in EC indicates a decrease in soluble salt concentration, suggesting improvement in soil quality due to the application of organic amendments and bioremediation processes.

3.3 METALS REMOVAL:

The mining-contaminated soils used in the study initially exhibited low pH values, which increased the solubility and mobility of trace metals, resulting in higher concentrations of dissolved metals in the soil solution. Elevated levels of dissolved metals can

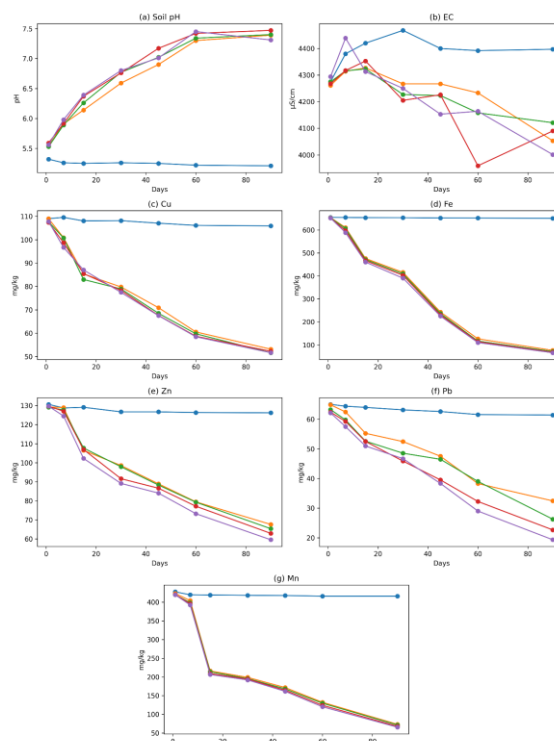


FIG.2: TEMPORAL VARIATION OF PHYSICOCHEMICAL PROPERTIES AND TRACE METAL CONCENTRATIONS IN MINING SOIL UNDER DIFFERENT TREATMENTS.

increase soil toxicity and may negatively affect soil health and biological activity. Changes in electrical conductivity ($\mu\text{S/cm}$) of the industrially contaminated soil in different bioreactors were observed over time, indicating variations in ionic concentration during the treatment process.

Significant reductions in trace metal concentrations were observed after bioremediation treatment. The copper (Cu) concentration in the contaminated soil decreased by 51.21%, 52.05%, 51.33%, and 52.08% in bioreactors I, II, III, and IV, respectively, indicating better stabilization and immobilization of Cu due to the applied organic amendments. Similarly, positive results were obtained for manganese (Mn) removal. The manganese concentration decreased by 82.67%, 82.95%, 83.82%, and 84.37% in bioreactors I, II, III, and IV, respectively, demonstrating high removal efficiency. The lead (Pb) concentration in the contaminated soil was also significantly reduced, showing removal efficiencies of 50.00%, 58.47%, 63.71%, and 68.89% in bioreactors I, II, III, and IV, respectively. Likewise, iron (Fe) concentrations decreased considerably during the treatment process. Iron removal efficiencies of 88.34%, 89.08%, 89.55%, and 89.91% were observed in bioreactors I, II, III, and IV, respectively. Zinc concentrations in bioreactors I, II, III, and IV decreased significantly during the treatment period. The percentage reduction in zinc concentration was recorded as 47.68%, 49.38%, 51.46%, and 54.06%, respectively. Reactors II and III showed similar removal efficiency, indicating that the applied organic amendments provided comparable

conditions for zinc immobilization.

One of the key mechanisms involved in trace metal removal is the adsorption of dissolved metals onto amendment materials such as manure, organic matter, or other added substrate (Santos et al., 2004). These amendments provide binding sites that reduce metal mobility and bioavailability in contaminated mining soil.

Microorganisms grow actively in the nutrient-rich medium of the bioreactors, contributing to the reduction of metal toxicity. Microbial processes such as biosorption, bioaccumulation, and bioprecipitation play an important role in decreasing the concentration of dissolved metals. The mining effluent contains dissolved metal ions that contribute to soil acidity. As treatment progresses, microbial activity and organic amendments help neutralize soil pH, creating favourable conditions for metal precipitation.

Copper was removed first among the trace metals, followed by zinc. Divalent metal ions precipitate in alkaline conditions; for example, Zn^{2+} precipitates at pH values above 9 (Kalin et al., 2006). Manure is considered an effective source of organic carbon that supports microbial growth and enhances metal removal efficiency (Reynolds et al., 1991). The formation of black precipitates at the soil interface indicates favorable anaerobic conditions for microbial activity and metal sulfide formation. Organic amendments added to the bioreactors provided suitable conditions for microbial growth and improved metal removal. Similar observations were reported by Tsukamoto (2004). Microorganisms involved in metal reduction require anaerobic conditions with a pH range of 5–8 for effective metal removal (Willow and Cohen, 2003).

4. CONCLUSIONS

The study demonstrates that organic amendments are highly effective for the bioremediation of mining-contaminated soil. Sheep and pig manure showed the best initial performance, while stone slurry, vegetable waste, and dry leaves also enhanced remediation efficiency over time by promoting microbial activity. The bioreactor system proved to be a sustainable and chemical-free technology for reducing trace metal contamination and improving soil quality.

The results indicate that amendment-based bioremediation has strong potential for treating contaminated soils and effluents from small-scale metal industries. Further research through pilot-scale studies and continuous-feed systems is recommended to evaluate long-term performance and cost effectiveness. Overall, the study highlights an environmentally friendly and efficient approach for trace element stabilization in mining-affected soils.

5. ACKNOWLEDGEMENT

The authors express all their gratitude to Dr. Vimla Sheoran for helping in editing the manuscript.

REFERENCES

- Christensen B, Laake M and Lien T (1996) Treatment of acid mine water by sulfate-reducing bacteria; results from a bench scale experiment. *Water Research* 30(7), 1617-1624.
- Kalin M, Fyson A and Wheeler W N (2006) The chemistry of conventional and alternative treatment systems for the neutralization of acid mine drainage. *Sci. Total Environ.* 366(2-3), 395-408.
- Manzoor, M.Z., Sarwar, G., Alamery, S., Ibrahim, M., Sami, A., Ahmed, B., Ahsan, F., Gul, S., Attia, K.A., Fiaz, S., & Ullah, I., 2024 -Efficacy of various amendments for immobilization of potentially toxic elements in waste water contaminated soils. *Scientific Reports*, 14, Article 17350, Nature.
- Nie, Baisheng, et al. "Experimental Study on the Mechanical Stability and Mesoscopic Damage Characteristics of Coal Under Different Mining Disturbance Rates: Nie et al." *Rock Mechanics and Rock Engineering* 57.5 (2024): 3841-3861.
- Reynolds J S, Machermer S D, Wildeman T R, Updegraff D M and Cohen R R (1991) Debrmination of the ra1e of sulfide production in a construc1ed wetland receiving acid mine drainage'. *Proc. Amer. Soc. Mining and Reclamation* 175-182.
- Santos S, Machado R, Correia M J N and Carvalho N J R (2004) Treatment of acid mining waters. *Minerals Engineering* 17(2), 225-232.
- Sheoran V, Chaudhary R and Tholia N (2012) Bioremediation of Acidic Industrial Wastewater by Sulphate Reducing Bacteria. *Biological Sciences and Engineering* 3, 184-189.
- Sheoran A.S., Sheoran V. and Choudhary R.P., 2010 - Bioremediation of acid-rock drainage by sulphate-reducing prokaryotes: A review. *Minerals Engineering* 23(14):1073-1100
- Tsukamoto T K, Killion H A and Miller G C (2004) Column experiments for microbiological treatment of acid mine drainage: low- temperature, low-pH and matrix investigations. *Water Research* 38(6), 1405- 1418.
- Waybrant K R, Blowes D W and Ptacek C J (1998) Selection of reactive mixtures for use in permeable reactive walls for treatment of mine drainage. *Environ. Sci. Technol.* 32(13), 1972-1979.
- Willow M A and Cohen R R (2003) pH, dissolved oxygen and adsorption effects on metal removal in anaerobic bioreactors. *J. Environ. Quality* 32(4), 1212-1221.