The Bioscan AN INTERNATIONAL QUARTERLY JOURNAL OF LIFE SCIENCES 21(1) S (1) 529-534, 2026 www.thebioscan.com

Comparative heavy metal composition of coal mine soils in microphytoremediation and reclamation

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DOI: https://doi.org/10.63001/tbs.2026.v21.i01.S.I(1).pp529-534

KEYWORDS
Reclamation, heavy metals, remediation, coal mine soils.

Received on:

01-01-2026

Accepted on:

16-02-2026

Published on:

28-02-2026

Abstract

Reclamation of polluted soils in proper way actually adds economy because they can be reused with minimal treatment. The understanding of microbial remediation combined with phytoremediation plays a vital role in such restoration mechanisms. Coal mine soils are the most neglected soils because of their high heavy metal content. The biotic and abiotic factors always thrive to balance the ecological niche of microbes and there by promoting vegetation. This natural process if explored with proper ways can be helpful for reclamation of even coal mine soils. Such attempt have been made in the present study where, in coal mine rhizosphere and non-rhizosphere soils of Telangana region the supportive heavy metal degrading bacterial community using abiotic factors have successfully reclaimed the coal mine soils which was evident by the vegetation growth in the study areas. Not only vegetation growth, it was also notable that the dominant vegetation was *Abutilon indicium, Bergera koenigii* and *Bambus vulgaris* with dominant microbial remediators as *Bacillus* and *Pseudomonas species*.

1.INTRODUCTION

Ecological degradation has been a serious problem for coal mine soils because of heavy metal contamination which have been a part of bioaccumulation due to industrial revolution (Xiong et al.2025 and Gopinathan et al.2023). The degradation of rhizosphere soils due to anthropogenic activities in which coal mining is also a part has tremendously increased the heavy metal content making it a polluted area (Bastabak et al.2021;Chen et al.2018;Finchtner et al.2014;Homburg and Sandor,2011;Pundyte et al.2011; Wall et al.2015; Wang et al.2017; Ye et al.2019).Replacement of ions with heavy metals in living systems causes severe metabolic damage in humans and excess accumulation of heavy metals breaks proteins including peptide bonds so that free radical formation is accelerated causing failure of vital organs in humans (Morcillo et al.2016;Wijayawardena et al.2016). Trees, herbs and shurbs are considered excellent remediators of heavy metals by accumulating and modifying them into useful minerals and release them back into environment (Gomes et al.2012; Shah and Daverey, 2020). In this process the role of microbes enhance the phytoremediation for better reclamation (Pundyte et al.2011; Wall et al.2015; Ye et al.2019). The microbial community work depending upon the availability of minerals, pH, and thus the heavy metals are remediated and released into the nature in less toxic forms (Guo et al.2020; Zhalnina et al.2015).The microbial diversity found in the remediation process of coal mine soils also depends upon the heavy metal content. The mineral, metal content profiling of soils can reveal the relationship of the potent microbial remediators (Krauet-Cohen et al.2023). In the present study the mineral, metal and pH of coal mine soils were determined which helped to understand the microbial diversity for further microbial remediation as well as phytoremediation.Ecological degradation has been a serious problem for coal mine soils because of heavy metal contamination which have been a part of bioaccumulation due to industrial revolution (Xiong et al.2025 and Gopinathan et al.2023). The degradation of rhizosphere soils due to anthropogenic activities in which coal mining is also a part has tremendously increased the heavy metal content making it a polluted area (Bastabak et al.2021;Chen et al.2018;Finchtner et al.2014;Homburg and Sandor,2011;Pundyte et al.2011; Wall et al.2015; Wang et al.2017; Ye et al.2019).Replacement of ions with heavy metals in living systems causes severe metabolic damage in humans and excess accumulation of heavy metals breaks proteins including peptide bonds so that free radical formation is accelerated causing failure of vital organs in humans (Morcillo et al.2016;Wijayawardena et al.2016). Trees, herbs and shurbs are considered excellent remediators of heavy metals by accumulating and modifying them into useful minerals and release them back into environment (Gomes et al.2012; Shah and Daverey, 2020). In this process the role of microbes enhance the phytoremediation for better reclamation (Pundyte et al.2011; Wall et al.2015; Ye et al.2019). The microbial community work depending upon the availability of minerals, pH, and thus the heavy metals are remediated and released into the nature in less toxic forms (Guo et al.2020; Zhalnina et al.2015).The microbial diversity found in the remediation process of coal mine soils also depends upon the heavy metal content. The mineral, metal content profiling of soils can reveal the relationship of the potent microbial remediators (Krauet-Cohen et al.2023). In the present study the mineral, metal and pH of coal mine soils were determined which helped to understand the microbial diversity for further microbial remediation as well as phytoremediation.

2. MATERAIL AND METHOD

2.1: Coal mine soil samples collection:

From two study sites, Ramagundam and Satthupally of Telangana region, coal mine soils were collected in pre irradiated polythene bags and were sent to chemical analysis for various parameters using standard protocols.

2.2: Estimation of pH in soil samples:

By following IS 2720-26(1987) procedure, the rhizosphere soil and non-rhizosphere soil pH was estimated.

2.3: Estimation of minerals and metal content of soil samples:

By following Symbol, (2007) procedures, the minerals and metal content in the soil samples were estimated.

2.4: Isolation of heavy metal degrading bacteria from soil samples:

After serial dilution the 10^{-6} concentration was spread onto nutrient agar plates and were incubated for 24 to 48 hours at 37^0C. The isolated colonies were enumerated into nutrient broth which were supplemented with heavy metals iron, cadmium and chromium and were incubated for 24 to 48 hours at 37^0C at 150 rpm in a shaker incubator. The metal tolerant isolates were then streaked onto fresh nutrient agar plates and growth was observed after incubating at 37^0C for 24 to 48 hours.

2.5: Determination of morphological characters:

The metal tolerant isolates were observed for shape, size, colony formation, spore formation, texture and motility under microscope.

2.6: Determination of biochemical characterisation:

The microbial isolate's genus can be understood by testing for their biochemical characteristics for catalase test, oxidase test, nitrate reductase test, lactose fermentation test and IMViC tests.

2.7: Rainfall supporting the reclamation of coal mine soils:

From Indian Meteorological Department, the rainfall data of the study sites in Telangana region were retrieved to understand the reclamation factors.

3. RESULTS AND ANALYSIS

3.1: Soil sample collection and pH, minerals and metals determination:

From Coal mines of Ramagundam and Satthupally areas of Telangana region, the coal mine rhizosphere soil Ramagundam (CMRSRGM), coal mine rhizosphere soil Satthupally (CMRSSPL) and coal mine non-rhizosphere soil Ramagundam (CMNRSRGM), coal mine non-rhizosphere soil Satthupally (CMNRSSPL) samples collected were determined for pH, minerals and metal content and the reports were shown in the table 1.

Table1: Coal mine soils pH, minerals and metal content from non-rhizosphere and rhizosphere soils of Ramagundam and Satthupally regions

S.No	Parameter	Units	CMNRSRGM	CMNRSSPL	CMRSRGM	CMRSSPL
1.	pH	---	6.0	8.4	6.3	8.4
2.	Total Potassium	mg/Kg	581.5	444.2	865.6	707.6
3.	Total Phosphorous	mg/Kg	143	86	369.9	132.3
4.	Total Nitrogen	mg/Kg	540	700	440	680
5.	Total Iron	% by mass	1.7	2.1	1.4	3.8
6.	Total Manganese	mg/Kg	87.4	125.4	126.7	237.7
7.	Total Copper	mg/Kg	9.0	9.7	8.0	23.3
8.	Total Zinc	mg/Kg	32.7	55.1	58.9	101.8
9.	Total Lead	mg/Kg	9.6	17.9	10.1	28.8
10.	Total Nickel	mg/Kg	17.4	23.3	31.2	44.7

11.	Total Cadmium	mg/Kg	0.3	0.3	0.3	0.5
12.	Total Chromium	mg/Kg	33.6	8.8	42.3	19.6

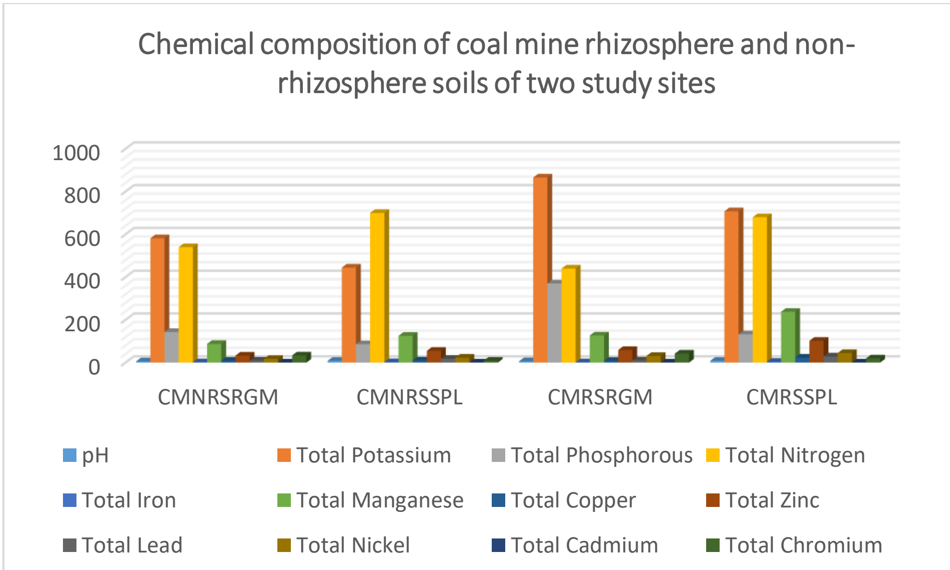


Figure 1: Comparative chemical composition of coal mine rhizosphere and no-rhizosphere soils data from Ramagundam and Satthupally

3.2: Morphobiochemical characteristics of isolated microbes:

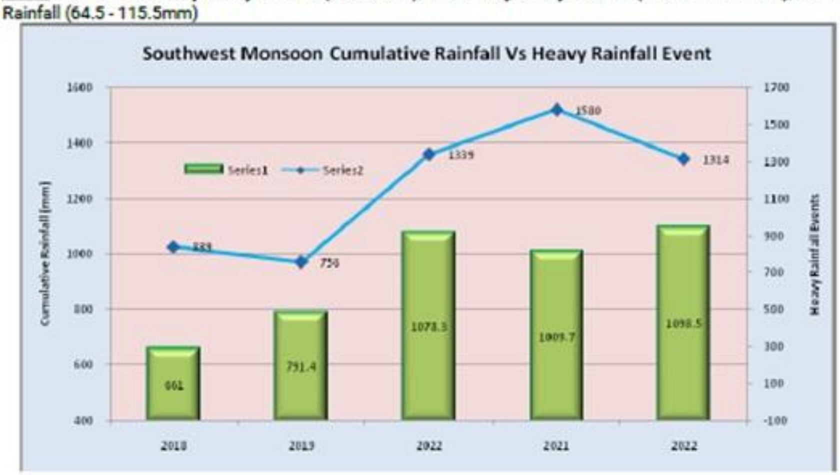
From the isolated microbes, it was observed that bacteria were dominant as per the morphological features. The biochemical characterization helped in identifying the bacteria in the soil samples. The data for the rhizosphere soil isolates was shown in (Kondapally Rajani and Sreelatha, 2026). It was observed that the non-rhizosphere soil also showed dominantly *Bacillus* and *Pseudomonas* species as shown in table 2.

Table 2: Bacterial genera presence and absence in isolates

S.No	Bacterial isolates	*Bacillus species*	*Pseudomonas species*	*Enterobacter species*
1.	CMNRSRGM	Present	Present	Absent
2.	CMNRSSPL	Present	Present	Absent
3.	CMRSRGM	Present	Present	Present
4.	CMRSSPL	Present	Present	Present

3.3: Rainfall report of study sites in understanding reclamation:

Note: Ex. H = Extremely Heavy Rainfall (>204.4mm), V H = Very Heavy Rainfall (115.6 – 204.4mm), H = Heavy Rainfall (64.5 - 115.5mm)



Cumulative Rain (y-axis left) and Number of Heavy Rainfall (>64.5 mm) (y-axis right) days during Southwest monsoon season.

The above figure shows an increasing trend in heavy rainfall events during the last five years.

Figure 2: Rainfall report of Telangana region from Indian Meteorological Department Source:https://mausam.imd.gov.in/responsive/rainfallinformation_swd.php

3.4: Reclamation of coal mine rhizosphere and non-rhizosphere soils:

The coal mine rhizosphere and non-rhizosphere soils from the two sampling area's heavy metal content, bacterial genera and rainfall data helped in reclamation of soils which was evident by the vegetation grown in the sampling areas as shown in figure 3 and 4.

Figure 3: Reclamation of rhizosphere and non-rhizosphere soils at Ramagundam study site

Figure 4: Rhizosphere and non-rhizosphere soils reclamation at Satthupally study site

4. DISCUSSION

Soil reclamation needs support from microbial community, the minerals, metals availability and pH of the soil. These factors should coordinate with rainfall to get the maximum restoration in the necessary areas. Plant microbe interaction have been evident for these restoration strategies from many years of research. This very natural phenomenon was understood in the present research where soil reclamation was seen with the growth of vegetation.

Plants are good bioremediators of heavy metals but it depends upon mobility of metal ions which should be supported by pH and the soil nature (Thakur et al.2016). The transporter proteins such as heavy metal ATPases, Zinc regulated transporter and cation diffusion catalysts proteins show alteration in expression when the plants are exposed to heavy metals (Chandra et al.2017; Thakur et al.2016). Plant microbe interaction in particular bacteria association with soil helps plants to survive under stress conditions such as heavy metals (Sharma et al.2020). Heavy metal resistant bacteria isolated from rhizosphere soils of polluted area with lead, cadmium, copper and zinc where plants are grown are *Pseudomonas* and *Bacillus* species (Jiang et al.2017). Our results correlate with this work where the coal mine soils both rhizosphere and non-rhizosphere soils are dominant with *Pseudomonas* and *Bacillus* species as shown in table 2.

The comparative chemical composition of coal mine rhizosphere and non-rhizosphere soils from Ramagundam and Satthupally study sites were shown in table 1 and figure 1, where potassium concentration was high in all samples followed by nitrogen, phosphorous and manganese. This shows the heavy metals have been converted by the microbial action and increase in potassium and nitrogen content actually helped in promoting plant growth and making these bacteria as potent plant growth promoters. *Bacillus* and *Pseudomonas* species also activated phosphate solubilisation and nitrogen fixation properties of the respective microbes as shown in (Pinter et al.2017) and the results were in line with our findings.

The rainfall data shown in figure 2 of Telangana from past five years where it was notable that the rainfall was increasing. Rainfall is one of the abiotic factor for the microbial remediation where continuous increase and then decrease for one year gave enough time and space for the reclamation to happen which was evident by the reclaimed areas of Ramagundam and Satthupally coal mine areas with diverse vegetation as shown in figures 3 and 4. The dominant plants found in the reclamation sites were *Abutilon indicum*, *Bergera koenigii* and *Bambusa vulgaris*. This shows plant microbe joint interaction helped in sustainable reclamation of coal mine soils.

5. CONSLUSION

The joint microbial and phytoremediation mechanisms helped in coal mine soil reclamation. The role of microbes in contributing to phytoremediation was understood. Further investigation of these plants from the reclaimed sites for their phytochemicals may open gates for pharmacognosy studies which may help in treating many ailments after purification.

Acknowledgements:
The authors are thankful to R&D wing of Lalata Technologies (www.lalatatechnologies.com) for continuous support in article processing towards publication. The authors are also thankful to Telangana Tribal Welfare Residential Education Society, Hyderabad for the support.

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