Indian Journal of Advances in Chemical Science

Review Article

Integrated Organic Amendment and Phytoremediation Strategies for the Remediation of Iron Ore Mine Tailings

S. Srinivasa Gowd[1]*, T. Chandrasekhar[2], G. Nagalakshmi[1], C. Krupavathi[1]

[1]Department of Geology, Yogi Vemana University, Kadapa, Andhra Pradesh, India, [2]Department of Environmental Sciences, Yogi Vemana University, Kadapa, Andhra Pradesh, India

ABSTRACT

Natural ecosystems are harmed by mining operations because they generate many tailings from mines. Mine tailings are left untreated in open ponds or dams in search of valuable metals such as iron ore are extracted. In order to lessen the detrimental effects on the ecosystem, tailings must be rehabilitated. This review compares the cost, reliability, and durability of current physical, chemical, and phytoremediation techniques for the rehabilitation of mine tailings. The discussion led to the conclusion that while amendment-assisted phytoremediation has received a lot of attention, selecting the appropriate phytoremediators is the most crucial step in the process. Further research is required to determine whether this strategy is suitable for the precise situation.

Key words: Biochar, Meadows, Phytoremediation, Tailings, Topsoil

1. INTRODUCTION

Despite producing massive amounts of tailings, important sectors for the production of metals include mining, mineral processing, and extractive metallurgy [1]. Mine tailings are the byproducts of the extraction of valuable minerals from unprofitable materials [2,3]. They are typically left untreated in uncovered tailings impoundments for an elongated period of time [4,5], with an estimated 14 billion tonnes generated in 2010; the annual volume of mineral production is comparable to the billions of tonnes of tailings produced by the global mining sector. Because iron ores are complex, tailings generation varies by location; in Western Australia, tailings generation is estimated to be two tonnes per tonne of iron ore [6].

It is unknown how much tailings waste is generated throughout the process of extracting iron, but reports from India indicate that the waste may contain 10 million tonnes of fines each year [7]. Large, barren landscapes are created as a result of the massive amounts of tailings that are created during the extraction of iron from the ore and dumped into the surrounding environment [8]. According to Adiansyah *et al*. [2], tailings must be handled and restored over extended periods of time, both temporally and spatially in relation to the storage area. These tailings ponds lose nearby land resources and seriously contaminate the environment [4]. Nonetheless, managing mine tailings is a vital concern in mining activities due to the permanent impacts of the tailings. According to reports, mine tailings pose serious risks to both the environment and human health [9,10]. Metals have been shown to negatively affect a variety of plant processes, as well as oxidative stress, fluorescence, stomatal resistance, photosynthesis and chlorophyll, reproductive activities, seed germination, morphology, and physiology [11].

Human health may also be at risk from ingestion of tailings dust, inadvertent inhalation, and skin contact with mine tailings. Since several heavy metals (loid) (As, Ni, Cd, Cr, and Pb) are oncogenic and can cause problems with the skin, kidneys, lungs, skeleton, and digestive system, food crops grown on mine tailings should not be consumed. (W/w) SiO_2 57%, AlO_3 10%, TiO_2 1%, and Fe_2O_3 25% are commonly found in Australia's iron ore tailings.

The physicochemical belongings of tailings make it challenging to create physically as well as chemically stable landscapes. This review attempts to offer a general idea of the knowledge regarding iron ore mine tailings, as well as to highlight the significance of green solutions in relation to rehabilitation and potential future applications of cutting-edge technology. Over a 10-year period, an open-access literature search was carried out using Google Scholar through the terms "iron ore," "mine tailings," "phytoremediation," "fertilizer," "topsoil," "biochar," as well as "straw."

2. PHYSICOCHEMICAL AND CHARACTERIZATION AND STRATAGEMS TO DEVELOP IRON ORE MINE TAILINGS

2.1. Physicochemical Characterization of Iron Ore Mine Tailings

Low tailings often have unfavorable physicochemical characteristics [Figure 1], for instance, low water-holding capacity [12,13], excessive pH [14], high salinity [15], high metal concentrations, residuals of processing chemicals, poor structure [16], and a fine-grained mixture of ground-up stone particles [17]. Iron ore tailings have small particle sizes [18], and the quantity of heavy metals in tailings is influenced by

***Corresponding Author**
S. Srinivasa Gowd,
ssgowd@gmail.com

ISSN NO: 2320-0898 (p); 2320-0928 (e)
DOI: 10.22607/IJACS.2026.1403007

Received: 11th May 2026;
Revised: 30th July 2026;
Accepted: 11th August 2026
Published: 1st September 2026

a variety of factors, such as textural characteristics [19], mineralogical composition, and depositional environment [20]. The importance of soil characteristics like clay content and particle size distribution on the behaviour of heavy metals in tailings has been shown in numerous studies [21,22]. The situation is critical due to permeability [23] and high bulk density. High tailings bulk density raises mechanical resistance, which restricts aeration and lowers water and nutrient infiltration to the roots [24]. High solute concentrations lead to low nutrient levels and possible ionic stress [25]. Such as Si, Al, Ca, and Mg [26], iron ore tailings consist of iron-bearing silicates, characterized by silica skeletons formed by (SiO_4) tetrahedra that form an intricate composition and stable construction by Fe3+, Ca2+, and Mg2+. This suggests that iron ore tailings may be used as an environmentally friendly substance by controlling the framework construction, but not for plant development [26]. Furthermore, the high organic matter content can improve elevated salinity (~60 dS/m), minimal organic matter (1.5 g cm^{-3}), and low microbial content and diversity (360 mg/g). The physical, chemical, and biological properties of iron ore mine tailings are shown schematically in Figure 1.

Iron ore tailings can occasionally exhibit great alkalinity, which lowers other nutrients. N, P, Ca, and Mg availability, for example [27]. Iron-bearing iron ore tailings have low water-holding capacity, low permeability, and a high bulk density that limits aeration and reduces nutrient and water infiltration to the roots. Low nutrient levels and possible ionic stress are also caused by high concentrations of solutes such as Si, Al, Ca, and Mg. In addition, the large amount of organic matter may enhance metal adsorption and reduce kinesis in the environment; however, mine tailings absence nutrients and organic matter [28], making them an unsuitable substrate for plant development [29]. On the other hand, acidic mine tailings increase metal solubility in the soil environment and lower the soil exchange capabilities of metal cations, increasing the mobility of heavy metals.

2.2. Methods to Enhance Iron Ore Tailings' Physicochemical Characteristics

Reducing detrimental effects on the surrounding ecosystem and human health in abandoned mines requires the development of a sustainable pollution control strategy [30]. Physical and chemical methods, which require less time, are the most frequently used techniques for mine tailings remediation. However, it has been noted that these processes are expensive, harmful to soil structure and biodiversity, and disruptive to the environment [31-33]. Physical remediation uses techniques such as heat treatment, electro-remediation technology, and covering the tailings with new or semi-new soil for melioration to restore their fertility and make them suitable for the growth of vegetation [34].

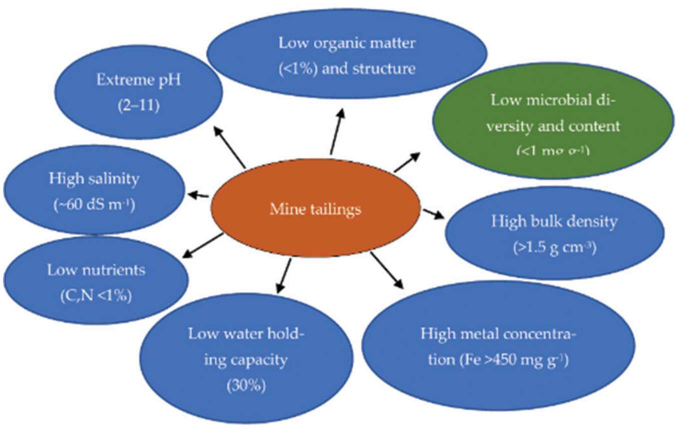

Figure 1: The physicochemical and biological properties of iron ore mine tailings.

Nonetheless, one of the most popular methods, covering the ground with fresh soil, has yielded positive outcomes and satisfied Chinese agricultural soil quality standards [35]. This physical approach is very costly and labor-intensive, despite some success in tailings restoration.

In addition, because of ecological destruction and disturbance, precipitation, slope gradient, slope features, and thickness of the cover in the new soil gathering area and the tailings region put the system at high risk of collapse [36]. Chemical remediation uses techniques like ooze, organic fertiliser, chelating, and fixing agents to enhance pollution control and tailings [37]. According to some research [38], adding alkaline minerals ($CaCO_3$) to tailings may improve metal sorption by the soil by raising the pH of the tailings and lowering the concentration of phytoavailable heavy metals [39]. It has been shown that adding phosphate-based substances, like highly soluble diammonium phosphate, is incredibly effective at immobilizing Cd, Pb, and Zn in soil [40]. However, chemical processes such as soil washing and leaching/acid extraction are more effective and successful than physical treatments, and for small tailings facilities with a high pollutant load, they can be utilized as an intensive treatment [41]. Nevertheless, this method significantly limits chemical remediation and deteriorates the soil's physical characteristics [35]. As of July 2022, Table 1 contrasts the costs of chemical, biological, and physical remediation techniques [42]. Table 1 compares the costs of various mine tailings remediation techniques, expressed in Australian dollars, based on research published by [42].

3. PHYTOREMEDIATION

Phytoremediation is a harmless and capable method to control heavy metals in soil, according to recent studies [43]. This method is economical [44], and the outstanding capacity of plants to concentrate elements as well as chemicals from their surroundings and change a variety of molecules in their tissues is exploited in plant-based remediation strategies [45]. Studies show that phytoremediation of one square meter of Pb-polluted soil (AUD 0.1) is 50–65% less expensive than conservative renovation techniques such as quarrying and landfilling (AUD 0.2). Bringing plants into a damaged environment can help restore soil fertility and lessen metal (loid) migration throughout the ecosystem.

Numerous factors, including metal focuses in tailings, the movement of heavy metals, the ultimate focuses of goal metals, plant biomass and plant growth charges, influence how long it takes to restore mining tailings sites [46]. However, traditional phytoremediation techniques are not appropriate for large-scale applications due to a number of drawbacks. According to Robinson *et al*. [47], the conventional methods of phytoremediation, phytoextraction, phytostabilization, phytovolatilization, and phytomining, have changed, and a new idea has surfaced that combines conventional and contemporary methods, including phytoremediation aided by organic additions. The ecological

Table 1: Comparison costs of various mine tailings remediation techniques

Method	Cost (AUD$/ton)		Features to be careful
	[4]	[42]	
Physical remediation	140–720	-	Movement, excavation, and observation
Chemical remediation	140–720	90–420	Recycling contaminants through phytoremediation
Chemical remediation	7–60	-	Long-term monitoring

environment of the damaged soil can be improved by plants and their associated microbiome absorption, breaking down, or immobilising contaminants from contaminated soil and water [48], but not metals. Poisonous dense metals and organic impurities are the main goals of phytoremediation [49,50]. Phytoremediation was first proposed by Chaney [51], later, phytoextraction, phytofiltration, phytostabilization, phytovolatilization, and phytodegradation are methods of phytoremediation. However, either organic amendment amelioration or microorganism inoculation should be used in conjunction with a phytoremediator when phytoremediating mine tailings [Figure 2].

3.1. Phytoextraction

The most crucial phytoremediation method for eliminating metalloids from contaminated soils, water, biosolids, and sediments is phytoextraction [52]. This approach seems to be a simple and economical way to clean up metal-polluted soils because it uses plant absorption to extract metals and other pollutants from soils, sediments, or water [53]. For phytoextraction to be successful, pollutant concentrations must be reduced to satisfy environmental requirements. From an economic standpoint, this ought to be less expensive than other technologies or doing nothing [54]. Nonetheless, it is proposed that eliminating the time constraint on the process will ensure successful phytoextraction and that any costs incurred will be commensurate with the duration of the process [55]. The efficiency of phytoextraction is influenced by a number of variables, such as soil characteristics, metal speciation, phytoremediator properties, and metal availability to plants [56]. As a result, the plant types or genotype chosen for phytoextraction should have the following traits: (i) a fast growth rate that produces a lot of biomass; (ii) a heavy metal hyperaccumulator that moves metal from the root to the shoot; and (iii) forbearance to the harmful effects of heavy metals, (iv) resistance to pests and diseases, (v) easy growing and harvesting, good climatic adaption, and (vi) lack of herbivore appeal to prevent the metal entry into the food chain [57]. The main determinants of which plant species are best suited for metal phytoextraction are shoot metal concentration and biomass. Two different phytoextraction methods have been applied based on these criteria: (i) hyperaccumulators with low shoot biomass and (ii) plants with greater shoot biomass but less heavy metal accumulation [58]. Since it is usually impractical to harvest root biomass, metal translocation to shoots is a desirable biochemical and physiological process in successful phytoextraction [59].

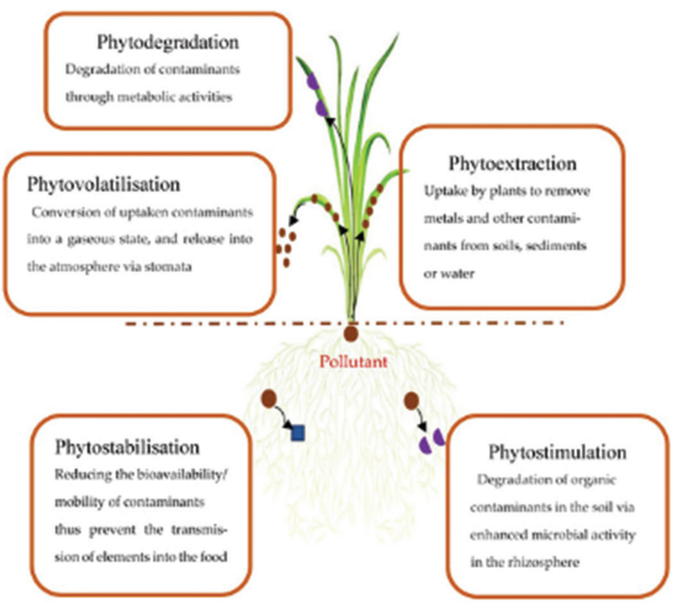

Figure 2: Diagrammatic illustration of various phytoremediation processes.

4. PHYTOREMEDIATION OF HEAVY-METAL-POLLUTED MINE TAILINGS WITH PLANTS IN THE POACEAE FAMILY

Fast-growing, deeply rooted, easily reproducing plants with a high biomass output and the capacity to tolerate and accumulate the target metal are ideal for effective phytoremediation. To ensure self-sustaining vegetative cover, choosing the right plant species is essential. According to Shabani and Sayadi [48], a plant is considered a hyperaccumulator if it accumulates more than 1000 mg/kg of Cu, Co, Cr, Ni, and Pb or more than 10 mg/kg of Mn and Zn. In general, species that can accumulate large amounts of heavy metal in aerial portions are considered superior. The physiological features of the plants utilized and the benevolent of contaminants have a significant impact on the efficacy and efficiency of phytoremediation technologies. However, due to their small biomass [50], the majority of hyperaccumulators are useless because, when burned or transformed into bioenergy, they rapidly release a large number of heavy metals back into the environment. However, since they frequently have outsized biomasses and high-pressure resistance [51], they might be appealing candidates for hyperaccumulators; only a few of these are displayed in Table 2. *Vetiveria zizanioides*, Smilo grass (*Piptatherum miliaceum*), Italian ryegrass (*Lolium multiflorium*), tropical grass (*Brachiaria brizantha*), and perennial ryegrass (*Lolium perenne*) are a few examples of grasses with large, deep root systems that can grow in a range of challenging climates. In semiarid Western Australia, a triplex sp. is regarded as a pioneer plant that acts as a phytostabilizer on mine tailings. The ability of vetiver grass (*V. zizanioides* (L.) Nash) to withstand high levels of heavy metals, clean up oil shale disposal heaps, and have strong resistance to unfavorable environments [52]. Plants gathered in the field and in greenhouse research, metal buildup in Esparto grass (*Lygeum spartum* (L.), which is known to colonize acidic mine tailings sites in Mediterranean areas) was investigated, according to Sarathchandra *et al*. [53].

According to a study [57], Rhodes grass (*Chloris gayana* Kunth cv. "Pioneer") would be highly successful in Australia's tropical and subtropical areas and is well adapted to metalliferous mined land revegetation. *Arundo donax* and *Miscanthus sacchariflorus* are two potential perennial energy grasses because of their quick growth rate and very high biomass (30–40 t/ha) [55]. According to Kirk *et al*. [58], *Perennial ryegrass* (*L. perenne*) drastically altered the rhizosphere bacterial population in petroleum-polluted soil, which helped break down the petroleum hydrocarbons in the polluted soil. Because it grows widely, is manageable, produces a lot of biomass, has a high tolerance for heavy metals, and is more inexpensive than

Table 2: Grass species used to clean up metal-polluted areas

Meadow	Metal Remediation	Build-Up in Shoots (mg/kg)	References
Vetiver grass (*Vetiveria zizanioides*)	Pb2+	300	[52]
Perennial ryegrass (*Lolium perenne*)	Cu2+, Zn2+	15, 180	[53]
Esparto grass (*Lygeum spartum*)	Zn2+	>4100	[54]
Rhodes grass (*Chloris gayana*)	Mn2+, Fe2+	164, 830	[15]

other species, ryegrass is favoured for phytoremediation over the majority of hyperaccumulators [59,60]. However, grasses' use in phytoremediation is still relatively new due to a lack of research on their ability to accumulate metals in field settings [61].

5. CONCLUSIONS AND FUTURE PERSPECTIVES

Mine tailings rehabilitation is a crucial ecological management strategy because it protects the neighboring atmosphere, which includes the air, soil, and water. Traditional phytoremediation methods have certain disadvantages when compared to physical and chemical rehabilitation methods. These include: (i) cleaning up contaminated soil takes a long time, and low above ground biomass production limits the phytoextraction capacity of hyperaccumulator plants; (ii) only a small percentage of metals are bioavailable, and this bioavailable concentration is applicable to sites with low or moderate contamination and varies with soil pH, organic matter, competitive cations, calcareousness, etc.; (iii) ignorance of agronomy, breeding potential, insect pests, and the range of diseases; and (vi) any negligence or poor management could contaminate the food chain. Conventional ideas were altered to guarantee the extensive use of phytoremediation and prevent these situations. To maintain a sustainable plant cover, it is important to begin biological restoration in addition to applying organic amendments.

Since naturally existing hyper accumulators often develop fast and generate relatively more harvestable ground biomass when supported by organic additions like biochar, straw, compost, and topsoil, the improved conventional idea and methods are more cheaply deployed on large quantities. Many countries' economies are dominated and controlled by the profitable mining industry. They would prefer to fund rehabilitation programs to generate revenue. In these circumstances, because it combines lucrative and sustainable land use, phytoremediation is the ideal strategy or situation for repairing mining land. Long-term benefits would also result from co-cropping the tailings-deposited facilities with both native and endemic plants, since the non-native plants enhance the native plants' development by eliminating heavy metals and promoting soil formation. In contrast, non-native plants are invasive in tropical regions, endangering the native ecosystem's establishment and biodiversity. It is crucial to remember that non-native invasive species are powerful phytoremediators because of their ability to tolerate and absorb heavy metals because of their quick growth in unfavorable climates. Hence, the choice of plants for the rehabilitation of mine tailings should be the main factor taken into account. Since an only strategy is neither practical nor feasible for the tactical rehabilitation of mine tailings, coming study should effort on combining dissimilar techniques, such as genetically modified plants and bioremediation combined with organic modifications in maintainable renovation. Future research should close the knowledge gap regarding the biochemical pathways and processes underlying the organic amendments and phytoremediators used in mine tailings.

6. ACKNOWLEDGMENTS

The first author, S. Srinivasa Gowd, is greatly thankful to the Rashtriya Uchchatar Shiksha Abhiyan (RUSA 2.0), Government of India, for financial support through RUSA support for Research Project (No. RUSA-ANU/YVU/Research Project-22/Sanction Order/2024) and also thankful to the Department of Geology, Yogi Vemana University, Kadapa, for the necessary facilities to carry out the research work.

7. REFERENCES

1. I. Park, C. B. Tabelin, S. Jeon, X. Li, K. Seno, M. Ito, N. Hiroyoshi, (2019) A review of recent strategies for acid mine drainage prevention and mine tailings recycling, ***Chemosphere***, **219:** 588-606.
2. J. S. Adiansyah, M. Rosano, S. Vink, G. Keir, (2015) A framework for a sustainable approach to mine tailings management: Disposal strategies, ***Journal of Cleaner Production***, **108:** 1050-1062.
3. J. R. Owen, D. Kemp, E. Lèbre, K. Svobodova, G. Pérez Murillo, (2020) Catastrophic tailings dam failures and disaster risk disclosure, ***International Journal of Disaster Risk Reduction***, **33:** 101361.
4. L. Wang, B. Ji, Y. Hu, R. Liu, W. Sun, (2017) A review on *in situ* phytoremediation of mine tailings, ***Chemosphere***, **184:** 594-600.
5. S. Babel, R. S. Chauhan, N. Ali, V. Yadav, (2016) Preparation of phosphate mine tailings and low-grade rock phosphate enriched bio-fertilizer, ***Journal of Scientific and Industrial Research (JSIR)***, **75:** 120-123.
6. H. K. Thejas, N. Hossiney, (2022) Alkali-activated bricks made with mining waste iron ore tailings, ***Case Studies in Construction Materials***, **16:** e00973.
7. K. A. Ghazaryan, H. S. Movsesyan, T. M. Minkina, S. N. Sushkova, V. D. Rajput, (2021) The identification of phytoextraction potential of *Melilotus officinalis* and *Amaranthus retroflexus* growing on copper- and molybdenum-polluted soils, ***Environmental Geochemistry and Health***, **34:** 1327-1305.
8. N. Chaturvedi, M. J. Ahmed, N. K. Dhal, (2013) Effects of iron ore tailings on growth and physiological activities of *Tagetes patula* L, ***Journal of Soils and Sediments***, **14:** 721-730.
9. D. Yang, D. H. Zeng, J. Zhang, L. J. Li, R. Mao, (2012) Chemical and microbial properties in contaminated soils around a magnesite mine in northeast China, ***Land Degradation and Development***, **23:** 256-262.
10. A. S. Sanchez-Lopez, R. Carrillo-Gonzalez, C. Gonzalez-Chavez Mdel, G. H. Rosas-Saito, J. Vangronsveld, (2015) Phytobarriers: Plants capture particles containing potentially toxic elements originating from mine tailings in semiarid regions, ***Environmental Pollution***, **205:** 30-42.
11. V. M. Ngole-Jeme, P. Fantke, (2017) Ecological and human health risks associated with abandoned gold mine tailings contaminated soil, ***PLoS One***, **12:** e0172517.
12. E. N. Cele, M. Maboeta, (2016) A greenhouse trial to investigate the ameliorative properties of biosolids and plants on physicochemical conditions of iron ore tailings: Implications for an iron ore mine site remediation, ***Journal of Environmental Management***, **165:** 167-174.
13. A. M. Mouazen, S. A. Alhwaimel, B. Kuang, T. Waine, (2014) Multiple on-line soil sensors and data fusion approach for delineation of water holding capacity zones for site specific irrigation, ***Soil and Tillage Research***, **134:** 95-105.
14. T. Nyenda, W. Gwenzi, S. M. Jacobs, (2021) Changes in physicochemical properties on a chronosequence of gold mine tailings, ***Geoderma***, **325:** 115037.
15. X. Li, J. H. Park, M. Edraki, T. Baumgartl, (2014) Understanding the salinity issue of coal mine spoils in the context of salt cycle, ***Environmental Geochemistry and Health***, **36:** 453-465.
16. W. Sun, B. Ji, S. A. Khoso, H. Tang, R. Liu, L. Wang, Y. Hu, (2018) An extensive review on restoration technologies for mining tailings, ***Environmental Science and Pollution Research***, **25:** 30911-30925.
17. S. M. A. Qaidi, B. A. Tayeh, A. M. Zeyad, A. R. G. De Azevedo, H. U. Ahmed, W. Emad, (2022) Recycling of mine tailings for the geopolymers production: A systematic review, ***Case Studies in***

Construction Materials, **16:** e00930.
18. Y. D. Choi, M. K. Wali, (1995) The role of *Panicum virgatum* (switch grass) in the revegetation of iron-mine tailings in northern New York, ***Restoration Ecology***, **3:** 123-132.
19. A. A. Juwarkar, H. P. Jambhulkar, (2008) Phytoremediation of coal mine spoil dump through integrated biotechnological approach, ***Bioresource Technology***, **99:** 4732-4741.
20. X. Zhang, H. Yang, Z. Cui, (2018) Evaluation and analysis of soil migration and distribution characteristics of heavy metals in iron tailings, ***Journal of Cleaner Production***, **172:** 475-390.
21. M. C. Jung, (2008) Heavy metal concentrations in soils and factors affecting metal uptake by plants in the vicinity of a Korean Cu-W mine, ***Sensors***, **8:** 2413-2333.
22. M. O. Fashola, V. M. Ngole-Jeme, O. O. Babalola, M. A. Naeth, (2020) Physicochemical properties, heavy metals, and metal-tolerant bacteria profiles of abandoned gold mine tailings in Krugersdorp, South Africa, ***Canadian Journal of Soil Science***, **100:** 217-230.
23. X. Cui, Y. Geng, T. Li, R. Zhao, X. Li, Z. Cui, (2021) Field application and effect evaluation of different iron tailings soil utilization technologies, ***Resources, Conservation and Recycling***, **173:** 105746.
24. G. F. Esteves, K. R. D. De Souza, L. A. Bressanin, P. C. C. Andrade, V. Veroneze Junior, P. E. Dos Reis, A. B. Da Silva, J. R. Mantovani, P. C. Magalhaes, M. Pasqual, T. C. De Souza, (2020) Vermicompost improves maize, millet and sorghum growth in iron mine tailings, ***Journal of Environmental Management***, **264:** 110468.
25. S. Renault, E. Sailerova, M. A. F. Fedikow, (2002) Phytoremediation of mine tailings and bio-ore production: Progress report on seed germination, survival and metal uptake of seedlings planted at central manitoba (AU) minesite, In: ***Manitoba Industry, Trade and Mines; Manitoba Geological Survey,*** Winnipeg, MB, Canada, Manitoba Industry, p255-265.
26. X. Han, Y. Wang, N. Zhang, J. Meng, Y. Li, J. Liang, (2021) Facile synthesis of mesoporous silica derived from iron ore tailings for efficient adsorption of methylene blue, ***Colloids and Surfaces A: Physicochemical and Engineering Aspects***, **617:** 126321.
27. J. J. James, R. L. Tiller, J. H. Richards, (2005) Multiple resources limit plant growth and function in a saline-alkaline desert community, ***Journal of Ecology***, **93:** 113-126.
28. V. Gagnon, M. Rodrigue-Morin, A. Tardif, J. Beaudin, C. W. Greer, B. Shipley, J. P. Bellenger, S. Roy, (2020) Differences in elemental composition of tailings, soils, and plant tissues following five decades of native plant colonization on a gold mine site in Northwestern Quebec, ***Chemosphere*, 250:** 126234.
29. C. A. Lange, K. Kotte, M. Smit, P. W. Van Deventer, L. Van Rensburg, (2012) Effects of different soil ameliorants on karee trees (*Searsia lancea*) growing on mine tailings dump soil-part I: Pot trials, ***International Journal of Phytoremediation***, **14:** 908-924.
30. G. M. Tordoff, A. J. M. Baker, A. J. Willis, (2000) Current approaches to the revegetation and reclamation of metalliferous mine wastes, ***Chemosphere***, **41:** 219-228.
31. L. Benidire, S. Pereira, W. Aboudrar, M. Hafidi, P. Castro, A. Boularbah, (2021) Remediation of metal-contaminated mine tailings by the application of organic and mineral amendments, ***Journal of Soils and Sediments***, **22:** 392-495.
32. D. E. Salt, R. D. Smith, I. Raskin, (1998) Phytoremediation, ***Annual Reviews of Plant Physiology and Plant Molecular Biology***, **49:** 634-668.
33. N. Sarwar, M. Imran, M. R. Shaheen, W. Ishaque, M. A. Kamran, A. Matloob, A. Rehim, S. Hussain, (2017) Phytoremediation strategies for soils contaminated with heavy metals: Modifications and future perspectives, ***Chemosphere***, **171:** 710-721.
34. J. Zhan, Q. Sun, (2012) Diversity of free-living nitrogen-fixing microorganisms in the rhizosphere and non-rhizosphere of pioneer plants growing on wastelands of copper mine tailings, ***Microbiological Research***, **167:** 157-165.
35. A. Pérez-de-Mora, P. Burgos, E. Madejón, F. Cabrera, P. Jaeckel, M. Schloter, (2006) Microbial community structure and function in a soil contaminated by heavy metals: Effects of plant growth and different amendments, ***Soil Biology and Biochemistry***, **31:** 327-341.
36. A. Burges, I. Alkorta, L. Epelde, C. Garbisu, (2018) From phytoremediation of soil contaminants to phytomanagement of ecosystem services in metal contaminated sites, ***International Journal of Phytoremediation***, **20:** 314-327.
37. R. G. Lacalle, J. M. Becerril, C. Garbisu, (2020) Biological methods of polluted soil remediation for an effective economically-optimal recovery of soil health and ecosystem services, ***Journal of Environmental Science and Public Health***, **4:** 112-130.
38. J. M. Khan, D. L. Jones, (2008) Chemical and organic immobilization treatments for reducing phytoavailability of heavy metals in copper-mine tailings, ***Journal of Plant Nutrition and Soil Science***, **171:** 908-916.
39. C. N. Mulligan, R. N. Yong, B. F. Gibbs, (2001) Remediation technologies for metal-contaminated soils and groundwater: An evaluation, ***Engineering Geology***, **60:** 193-207.
40. C. Vargas, J. Perez-Esteban, C. Escolastico, A. Masaguer, A. Moliner, (2016) Phytoremediation of Cu and Zn by vetiver grass in mine soils amended with humic acids, ***Environmental Science and Pollution Research***, **23:** 13521-13530.
41. M. L. Guerinot, D. E. Salt, (2001) Fortified foods and phytoremediation. Two sides of the same coin, ***Plant Physiology***, **125:** 164-167.
42. L. Van Nevel, J. Mertens, K. Oorts, K. Verheyen, (2007) Phytoextraction of metals from soils: How far from practice? ***Environmental Pollution***, **150:** 34-40.
43. Z. Wei, Z. Hao, X. Li, Z. Guan, Y. Cai, X. Liao, (2019) The effects of phytoremediation on soil bacterial communities in an abandoned mine site of rare earth elements, ***Science of The Total Environment***, **670:** 950-960.
44. D. Mani, C. Kumar, (2013) Biotechnological advances in bioremediation of heavy metals contaminated ecosystems: An overview with special reference to phytoremediation, ***International Journal of Environmental Science and Technology***, **11:** 834-872.
45. I. Alkorta, J. Hernández-Allica, J. M. Becerril, I. Amezaga, I. Albizu, C. Garbisu, (2004) Recent findings on the phytoremediation of soils contaminated with environmentally toxic heavy metals and metalloids such as zinc, cadmium, lead, and arsenic, ***Reviews in Environmental Science and Biotechnology***, **3:** 71-900.
46. C. S. Seth, (2011) A review on mechanisms of plant tolerance and role of transgenic plants in environmental clean-up, ***The Botanical Review***, **78:** 32-62.
47. B. H. Robinson, C. W. N. Anderson, N. M. Dickinson, (2015) Phytoextraction: Where's the action? ***Journal of Geochemical Exploration***, **151:** 34-40.
48. N. Shabani, M. H. Sayadi, (2012) Evaluation of heavy metals

accumulation by two emergent macrophytes from the polluted soil: An experimental study, ***The Environmentalist*, 32:** 91-98.

49. H. Ali, E. Khan, M. A. Sajad, (2013) Phytoremediation of heavy metals--concepts and applications, ***Chemosphere***, **91:** 869-881.
50. M. Zacchini, F. Pietrini, G. Scarascia Mugnozza, V. Iori, L. Pietrosanti, A. Massacci, (2008) Metal tolerance, accumulation and translocation in poplar and willow clones treated with cadmium in hydroponics, ***Water Air and Soil Pollution*, 197:** 23-34.
51. W. W. Wenzel, F. Jockwer, (1999) Accumulation of heavy metals in plants grown on mineralised soils of the Austrian Alps, ***Environmental Pollution***, **104:** 145-155.
52. B. O. Otunola, M. P. Aghoghovwia, M. Thwala, O. O. Ololade, (2022) Heavy metal phytoremediation potential of Vetiver grass and Indian mustard update on enhancements and research opportunities, ***Water Air and Soil Pollution***, **230:** 154.
53. S. S. Sarathchandra, Z. Rengel, Z. M. Solaiman, (2022) Remediation of heavy metal-contaminated iron ore tailings by applying compost and growing perennial ryegrass (*Lolium perenne* L.), ***Chemosphere***, **288:** 132573.
54. H. M. Conesa, B. H. Robinson, R. Schulin, B. Nowack, (2007) Growth of *Lygeum spartum* in acid mine tailings: Response of plants developed from seedlings, rhizomes and at field conditions, ***Environmental Pollution***, **145:** 700-707.
55. M. Mantineo, G. M. D'Agosta, V. Copani, C. Patanè, S. L. Cosentino, (2009) Biomass yield and energy balance of three perennial crops for energy use in the semi-arid Mediterranean environment, ***Field Crops Research***, **114:** 204-213.
56. D. Scordia, S. L. Cosentino, J. Lee, T. W. Jeffries, (2012) Bioconversion of giant reed (*Arundo donax* L.) hemicellulose hydrolysate to ethanol by *Scheffersomyces stipitis*, ***Biomass Bioenergy*, 32:** 296-305.
57. S. M. Keeling, G. Werren, (2005) Phytoremediation: The uptake of metals and metalloids by Rhodes grass grown on metal-contaminated soil, ***Remediation*, 15:** 53-61.
58. J. L. Kirk, J. N. Klironomos, H. Lee, J. T. Trevors, (2005) The effects of perennial ryegrass and alfalfa on microbial abundance and diversity in petroleum contaminated soil, ***Environmental Pollution***, **130:** 455-465.
59. C. Gu, Y. Bai, T. Tao, G. Chen, Y. Shan, (2013) Effect of sewage sludge amendment on heavy metal uptake and yield of ryegrass seedling in a mudflat soil, ***Journal of Environmental Quality*, 33:** 331-338.
60. H. Sarma, (2011) Metal hyperaccumulation in plants: A review focusing on phytoremediation technology, ***Journal of Environmental Science and Technology***, 4: 118-131.
61. S. Sinha, R. K. Mishra, G. Sinam, S. Mallick, A. K. Gupta, (2013) Comparative evaluation of metal phytoremediation potential of trees, grasses, and flowering plants from tannery-wastewater-contaminated soil in relation with physicochemical properties, ***Soil and Sediment Contamination (formerly Journal of Soil Contamination)***, **22:** 958-983.

***Bibliographical Sketch**

Dr. S.Srinivasa Gowd obtained Ph. D. Degree from Sri Venkateswara University, Tirupati. He has many publications in the peer reviewed national and international Journals. He is currently working as Professor in the Department of Geology, Yogi Vemana University, Kadapa. He completed more than 17 years of teaching experience in Geology.He has been awarded with CSIR-Research Associate, CSIR-Sr. Research Associate (Scientists' Pool Scheme), and DST-Young Scientist Post-Doc fellowships and projects worked at National Geophysical Research Institute (NGRI), Hyderabad and Sri Venkateswara University, and Tirupati.His research interests are in the areas of Environmental Geochemistry, Hydrogeochemistry, Remote Sensing & GIS and he has supervised four Ph.D. and 16 M.Sc. students' projects.

Mr. Dhrubajit Brahma is a student of Science College, Kokrajhar, Assam. He has completed his B.Sc. degree having Chemistry as Major Subject. This is his 2^{nd} research publication as an undergraduate Student. He has completed Project works on Air and Water Quality assessments under the supervision of Dr. Mehdi Al Kausor, Associate Prof., Department of Chemistry, Science College, Kokrajhar.

G. Nagalakshmi Devi completed M.Sc., in 2021 from Yogi Vemana University, Kadapa. She is working as Project Fellow in the RUSA 2.0 project. Her research interests are in the areas of Hydrogeochemistry, Heavy metal pollution, and Remediation methods.

Dr. C. Krupavathi completed Ph.D. as DST-Inspire fellow awarded by the Department of science and technology, New Delhi in the year of 2023. She completed M.Sc., from Yogi Vemana University, Kadapa.Her research interests are in the areas of Hydrogeology, Water quality, Contamination of Water, Remediation methods. Her contribution has been recognized in many peer-reviewed journals and book chapters