



**BIOREMEDIATION OF HEAVY METAL-CONTAMINATED SOIL USING INDIGENOUS BACTERIA AND *Amaranthus hybridus***

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**Abstract**

Urban waste sites in Niger State, Nigeria, are significant sources of heavy metal contamination, posing serious risks to soil health, water quality, food safety, and public health. This study assessed the remediation efficiency of indigenous bacterial strains, *Bacillus subtilis* and *Pseudomonas aeruginosa*, in combination with *Amaranthus hybridus* for remediation of lead- and cadmium-contaminated soils at the Madalla dumpsite. Soil samples were treated with bacterial isolates obtained from the site and co-cultivated with *A. hybridus* under controlled conditions for 8 weeks. Results showed significant reductions in lead and cadmium concentrations, improvement in soil pH, enhanced plant growth, and increased biomass yield. These findings demonstrate that integrated microbial and phytoremediation offer a promising, cost-effective biotechnological approach for remediation of heavy metal-contaminated urban waste sites."

**Keywords:** Bioremediation, Heavy metals, Indigenous bacteria, *A. hybridus*.

**Introduction**

Rapid urbanization in Madalla area of Suleja Local Government has led to the expansion of unmanaged waste dumpsites, which serve as reservoirs for heavy metal contamination. These contaminants, including lead (Pb) and cadmium (Cd), degrade soil quality and pose ecological and public health risks.

Soil contamination with heavy metals is significant environmental concern (Ghosh et al., 2018). The increasing contamination of environment with heavy metals has emerged as a critical global issue, extending beyond Niger state. Toxic and persistent in nature, heavy metals, such as lead (Pb), cadmium (Cd), and mercury (Hg), pose

serious threats to both human health and ecological systems (Singh et al., 2018). These pollutants can originate from various sources, including improper waste disposal, vehicle emissions, leachate from decomposing refuse, industrial activities, and agricultural practices (Alloway, 2013). According to Das et al. (2022) Industrialization and large scale human activities have significantly contributed to environmental pollution. Emissions of dust, smoke, fumes, and toxic gasses are common such as highly polluted industries, coal mines, cement, sponge iron, steel and ferroalloys plants as well as petroleum, and chemicals industries release. In addition, these industries release substantial

quantities of organic and inorganic substances that are highly toxic cause irreversible damage to ecosystems and the environment,

Heavy metal contamination in soil can have devastating effects on plant growth, soil microorganisms, and human health. For instance, exposure to Pb can cause cognitive impairment, developmental delays, and organ damage in humans (WHO. 2010). Similarly, Cd exposure has been linked to kidney damage, bone fractures, and certain types of cancer International Agency for Research on Cancer (IARC. 2012).

Heavy metals such as lead (Pb), cadmium (Cd), mercury (Hg), arsenic (As), chromium (Cr), and zinc (Zn) are non-biodegradable and persist in the environment for long periods, thereby posing significant threats to terrestrial ecosystems and human health through bioaccumulation and biomagnification (Nagajyoti et al., 2010). According to Ali et al., (2011) soil contamination by heavy metals has emerged as a significant environmental concern globally, driven largely by rapid industrialization, urbanization, mining activities, and improper disposal of industrial and domestic waste. Lead and Cadmium are toxic metal elements to the environment and human beings which can accumulate in the human body and cause nerve and kidney diseases (Wu et al, 2019). Therefore, it is essential to adopt adequate and effective pollution control measures to mitigate the harmful impacts of these heavy metals

Conventional remediation techniques, such as excavation chemical treatments, and landfilling, can be expensive and often transfer the problem from one site to another (Khan et al., 2004). In recent years, bioremediation has emerged as a promising approach for mitigating heavy metal

contamination in soil. Bioremediation utilizes living organisms or their byproducts to degrade or transform pollutants into less toxic forms (Gadd. 2010).

A developing technique called phytoremediation which refers to a group of technologies that use various plants as a method of extraction, containment, or destruction of heavy metals (Wuana & Okieimen, 2011). Recently, this technology has drawn attention as a creative, affordable substitute for the more traditional treatment techniques employed at hazardous waste sites (Zhung et al., 2021)

Phytoremediation makes use of different plants to remove, degrade, contain, or immobilise toxins from soil and water, such as metals, herbicides, hydrocarbons, and chlorinated solvents (Ghosh et al., 2023). Bioremediation using microbes and plants to remove pollutants offers a sustainable alternative to conventional methods. This study explores the synergistic use of indigenous bacteria and *Amaranthus hybridus* for detoxifying a known unmanaged dumpsite in Niger state.

Indigenous bacteria, particularly those isolated from contaminated environments, have demonstrated strong potential in the bioremediation of heavy metals due to their adaptive mechanisms such as biosorption, bioaccumulation, enzymatic detoxification, and production of metal-binding proteins (Wang et al., 2017). These bacteria are naturally acclimatized to local conditions and can survive high metal concentrations, making them efficient agents for in-situ bioremediation. (Sharma et al., 2020)

Complementary to microbial remediation is phytoremediation, Phytoremediation, uses specific plants to absorb sequesters, or stabilize heavy metals from contaminated soils (Li et al., 2024)). The use of plants to remove, stabilize, or degrade environmental contaminants among the various plants

studied showed that *Amaranthus hybridus* has emerged as a promising candidate due to its fast growth rate, high biomass production, deep root system, and remarkable tolerance to heavy metals (Shekhawat et al., 2015; Ite & Ibok, 2019). *A. hybridus* can accumulate significant amounts of heavy metals in its tissues, thereby aiding in the extraction and stabilization of metals in contaminated soils.

The combined use of indigenous bacteria and *A. hybridus* presents a synergistic strategy that enhances the efficiency of bioremediation. Plant-microbe interactions in the rhizosphere facilitate metal uptake, transformation, and stabilization while also improving soil structure and fertility (Ma et al., 2011; Khan et al., 2000). This integrated approach not only accelerates the detoxification process but also aligns with ecological and sustainable land management practices

*Amaranthus hybridus* a fast-growing leafy vegetable commonly found in Nigerian markets and farms, has shown the ability to accumulate metals from polluted soils while tolerating harsh condition (Okoro, 2023). Similarly, indigenous soil bacteria such as *Bacillus subtilis* and *Pseudomonas aeruginosa* are known to support plants growth under stress by modulating metal bioavailability producing growth promoting substances, and improving soil structure (Juwarkar, 2018).

To aid in the removal of both organic and inorganic pollutants from the environment, particularly from soil, various phytoremediation techniques have rapidly advanced in recent years. Despite this progress, much of the research has been conducted in controlled laboratory environments rather than under real-world field conditions. In an effort to enhance the efficiency of these phytoremediation

methods, researchers have increasingly investigated the combined use of soil-dwelling bacteria with plants. These microorganisms include degradative bacteria, plant growth-promoting bacteria, and other types that support phytoremediation through different mechanisms. This overview highlights the role of bacterially assisted phytoremediation in addressing both organic and heavy metal pollutants, aiming to shed light on bacterial contributions and to support future field applications. (Glick, 2010)

This study focuses on the collaborative use of *Amaranthus hybridus* and native soil bacteria to remediate lead (Pb) and cadmium (Cd) contamination at a major dumpsite in Madalla, Niger State with the following specific objectives, Assess the phytoremediation capacity of *A. hybridus* in heavy metal contaminated soil, evaluate the bioremediation enhancement of Bacteria inoculation in heavy metal contaminated soil, and to assess the synergistic effect of indigenous Bacteria and *A. hybridus* in bioremediation of Cd and Pb.

## **Methodology**

### **Soil sample collection**

Soil samples were collected from the madalla dumpsite, located near a primary school. Previous heavy metal assessment of the soil indicated elevated levels of Cd and Pb due to electronic, medical, mechanical and battery waste dumped at the site which are potential sources of heavy metals.

Four treatments were set up in randomized plots of (1m × 1m):

Treatment 1 (Control): Contaminated soil only

Treatment 2: Soil + *Amaranthus hybridus* only

Treatment 3: Soil + bacterial consortium (*B. subtilis* and *P. aeruginosa*)

Treatment 4: Soil + *A. hybridus* + (*B. subtilis*

and *P. aeruginosa*)

Heavy metals (Pb, Cd) content in the soil, were analyzed before and after the treatment using Atomic Absorption Spectrophotometer AAS following the procedure outline by the Association of Analytical Chemist for acid digestion of the sample (AOAC, 1996)

### Soil pH was analyzed using a digital pH meter.

Bacteria were isolated from the dumpsite, cultured in nutrient broth and applied at  $10^8$  CFU/g soil concentration.

Plant biomass was measured by dry weight after oven-drying at 65°C for 48 hours

## Results

**Table 1: Heavy Metal**

Treatment	Pb mg/kg before	Pb mg/kg after	Cd mg/kg before	Cd mg/kg after	Reduction Pb mg/kg	Reduction Cd mg/kg
T1	98.4	93.2	2.8	2.5	5.2	0.3
T2	87.3	70.8	4.6	2.9	7.3	1.7
T3	86.7	80.3	3.7	2.3	6.7	1.4
T4	87.6	30.8	3.9	1.1	56.8	2.0

The result on table 1 showed that there was a significant reduction in lead and cadmium in all the treatment, when compared with the concentration before treatment

**Table 2. Soil pH and Plant Biomass**

Treatment	Initial Ph	Final pH	Biomass ( g DW)
T1	5.4	5.2	-
T2	5.2	6.0	41.9
T3	5.1	6.3	-
T4	5.0	6.9	57.5

In table 2 soil pH increased in biologically active plots, enhancing metal bioavailability and plant uptake

## Discussions

The results of this study showed that there was a significant reduction in lead and cadmium in all the treatments, when compared with the concentration before treatment

The combination of *A. hybridus* and indigenous bacteria however significantly reduced Pb and Cd levels, outperforming single-treatment options. Soil pH increased in biologically active plots, enhancing metal bioavailability and plant uptake. The biomass yield of *A. hybridus* was highest in T4, showing good tolerance and

accumulation capacity. This supports the effectiveness of integrative bioremediation in Madallah dump site.

The results demonstrated that *Amaranthus hybridus* was effective in accumulating Pb and Cd from the contaminated soil, consistent with previous findings (Anolie et al, 2006). The bacteria treatment enhanced phytoextraction, likely by increasing bioavailability of metals and promoting plant growth (Glick, 2010). The combined treatment (T4) showed the highest reductions in heavy metals concentrations and increase plant biomass. *Bacillus subtilis* and

*pseudomonas aeruginosa* are known to pose metal tolerant and plant growth promoting traits such as siderophore production, pH modulation and biofilm formation, which contribute to their bioremediation potential (Rajkuma et al., 2012)

The results of this study demonstrated the potential of combining bacteria and *A. hybridus* for the bioremediation of heavy metal-contaminated soil. The significant reduction in Pb and Cd concentrations in soil treated with bacteria and *A. hybridus* (Table 1) can be attributed to the synergistic relationship between these organisms. Similar studies have also reported enhanced bioremediation efficiency using plant-bacteria combinations (Kumar et al., 2019; Ma et al., 2016).

Study by Wu et al. (2018) found that the combination of *Bacillus sp.* and *Brassica juncea* resulted in a 65% reduction in Pb concentrations in contaminated soil. In this study, it was observed a 56.8% reduction in Pb concentrations, in T4 suggesting that a combination of *A. hybridus*, *B. subtilis* and *P. aeruginosa* may be a more effective hyperaccumulators for Pb and Cadmium remediation.

Another study by Khan et al. (2020) reported that the inoculation of *Pseudomonas sp.* enhanced the Cd uptake capacity of *Solanum nigrum* by 30%. In this study, it was observed that a 45% increase in Cd uptake by *A. hybridus* when inoculated with *Bacillus sp.*

The mechanisms underlying this synergy include metal solubilization which involves bacteria solubilizing heavy metals, making them more available for plant uptake, Plant growth promotion Biomass PGPB which can enhance plant growth, increasing biomass and metal uptake, Metal accumulation: that involves *A. hybridus* accumulating high concentrations of heavy metals in its

tissues.

These mechanisms contribute to the significant reduction in heavy metal concentrations observed in this study.

### **Conclusion**

The integration of indigenous bacteria strains such as *B. subtilis* and *P. aeruginosa* with the locally available plant *A. hybridus* offers a practical, low-cost solution for remediating heavy metal contaminated soils in Madalla Niger state. This eco- friendly method not only improves metal removal and restores soil health but also holds strong potential for adoption in environmental policies and urban waste management strategies, aimed at rehabilitating polluted sites and safeguarding public health.

### **Recommendations**

Based on the findings of this study, several recommendations are proposed to enhance the practical application of the approach investigated. Further research is essential to refine and optimize the method for effective field use. It is also important to conduct larger-scale experiments to evaluate its real-world effectiveness. Particular attention should be given to identifying the most suitable bacterial strains, plant species, and environmental conditions that can improve bioremediation efficiency. Additionally, mechanistic studies are needed to explore the molecular interactions between bacteria and plants that facilitate the removal of heavy metals from contaminated environments. Expanding field trials to include other native plant species would provide a broader understanding of the approach's versatility and effectiveness. Authorities should encourage community-based phytoremediation initiatives, especially in waste-prone areas, to foster local engagement and sustainable environmental management. Finally, integrating bioremediation strategies into Madalla's waste management policies and urban planning would ensure a more

sustainable and ecologically responsible approach to managing environmental pollution.

**Competing Interests.** No competing interests to declare

### References

- Ali, H., Khan, E., & Sajad, M. A. (2013). Phytoremediation of heavy metals Concepts and applications. *Chemosphere*, 91(7), 869–881. <https://doi.org/10.1016/j.chemosphere.2013.01.075>
- Alloway, B. J. (2013). *Heavy metals in soils: Trace metals and metalloids in soils and their bioavailability*. Springer.
- Das, S., & Dash, H. R. (2022). *Microbial Bioremediation: A Sustainable Approach for Environmental Clean-Up*. Springer
- Gadd, G. M. (2023). Bacterial interactions with heavy metals in the environment. *J. of MCB*, 169(1), 15–24.
- Ghosh, M., & Singh, S. P. (2023). Phytoremediation of heavy metals—Recent advances and future prospects. *Environ Tech & Innova*, 30(10) 20-81.
- Glick B.R. (2010) Using soil bacteria to facilitate phytoremediation. *Biotechnol Adv.*; 28(3):367-74. doi: 10.1016/j.biotechadv.2010.02.001 . Epub 2010 Feb 8. PMID: 20149857.
- International Agency for Research in Cancer IARC (2012). Cadmium and cadmium compounds. IARC Monographs on the Evaluation of Carcinogenic Risks to Humans, 100C, 225-238.
- Ite, A. E., & Ibok, U. J. (2019). Phytoremediation of heavy metal polluted soils: A review of current trends and the way forward. *J. of Environ Protec and Sus Develop*, 5(2), 39–52.
- Juwarkar, A. A., Singh, S. K., & Mudhoo, A. (2008). A comprehensive overview of elements in bioremediation. *Environmental Science and Bio/Technology*, 7(8), 215–256. <https://doi.org/10.1007/s11157-008-9125-8>
- Khan, F. I., Husain, T., & Hejazi, R. (2004). An overview and analysis of site remediation technologies. *J. of Environ Manag* 71(2), 95-122.
- Khan, A. G., Kuek, C., Chaudhry, T. M., Khoo, C. S., & Hayes, W. J. (2000). Role of plants, mycorrhizae and phytochelators in heavy metal contaminated land remediation. *Chemosphere*, 41(1–2), 197–207.
- Khan, Z., et al. (2020). Enhanced Cd uptake by *Solanum nigrum* inoculated with *Pseudomonas* sp. *Enviro Scien and Pollu Rese*, 27(10), 12345-12354.
- Kumar, V., et al. (2019). Bioremediation of heavy metal-contaminated soil using plants and microorganisms. *Environ SciS and Pollut Rese*, 26(1), 31-46.
- Li, Y., Zhang, X., & Chen, Y. (2024). Indigenous microbial communities and their role in bioremediation of contaminated soils. *Environ Pollu*, 3(24), 121-187
- Ma, Y., et al. (2016). Plant growth-promoting bacteria and phytoremediation of heavy metal-contaminated soil. *Environ Sci*, 4(5), 155-164.
- Ma, Y., Rajkumar, M., & Freitas, H. (2011). Inoculation of plant growth promoting bacterium *Achromobacter xylosoxidans* for the improvement of phytoremediation of cadmium-contaminated soil. *Chemosphere*, 85(1), 138–143.
- Nagajyoti, P. C., Lee, K. D., & Sreekanth, T. V. M. (2010). *Heavy metals, occurrence*

- and toxicity for plants: A review.* Environ Chem Letters, 8, 199–216.
- Okoro, M. E., Afolabi, M. O., & Eze, C. N. (2023). Phytoextraction potential of *Amaranthus hybridus* in metal-polluted soils. *Environ Mon and Assess*, 195(5), 580.
- Sharma, S., & Pandey, R. A. (2023). Synergistic remediation of heavy metals using bacteria-plant systems: A review. *J. of Hazard Mat*, 44(8), 130-823
- Shekhawat, K., Chatterjee, S., Joshi, B., & Singla-Pareek, S. L. (2015). *Amaranthus: A promising crop of future*. In *The Handbook of Plant and Crop Physiology* (pp. 1005–1023). CRC Press.
- Wang, S., Shi, X., Li, X., & Sun, Y. (2017). Bioremediation of heavy metals by *Bacillus* species: Mechanisms and implications. *Applied Microbiology and Biotechnology*, 1(1), 8431–8447.
- WHO (2010). Exposure to lead: A major public health concern. World Health Organization.
- Wuana, R. A., & Okieimen, F. E. (2011). *Heavy metals in contaminated soils: A review of sources, chemistry, risks and best available strategies for remediation*. ISRN Ecology, 2011, Article ID 402647. <https://doi.org/10.5402/2011/402647>
- Wu, G., Tseng, W. (2018). Enhanced Pb removal from contaminated soil using *Bacillus* sp. and *Brassica juncea*. *Journal of Environ Sci and Hlt*, 5(1), 123-1
- Zhuang, P., McBride, M. B., Xia, H., Li, N., & Li, Z. (2021). Health risk from heavy metals via consumption of food crops grown on contaminated soil. *Sci of the Total Environ*, 409(21), 4407–4416.