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Effect of phytoremediation on the geotechnical properties of heavy metal contaminated soil

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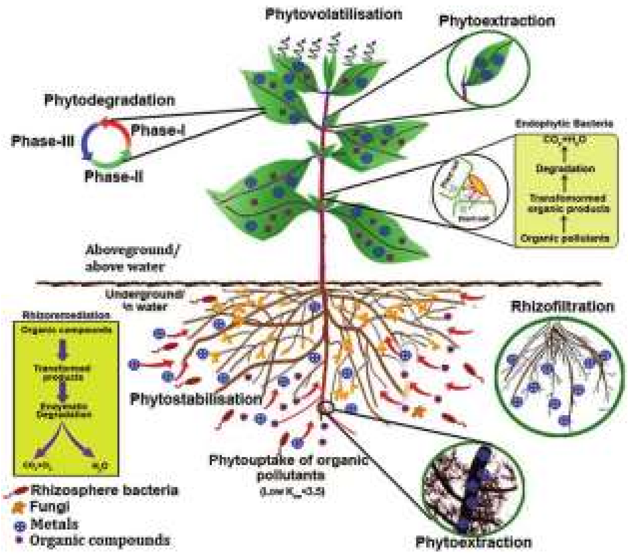
Graphical abstract



Abstract

The accumulation of heavy metals in soils increases rapidly due to various natural processes. Heavy metal pollution changes the geotechnical properties of soil and poses a serious threat to human health and ecosystems, so soil pollution remediation is particularly important. Phytoremediation is an environmentally friendly approach that can be used as a successful mitigation measure to restore heavy metal-contaminated soils cost-effectively. The plants extract and remove elemental contaminants or reduce their bioavailability in soil and improve the geotechnical properties. In this study, we are conducting a pot experiment with Amaranthus by adding Zn salt as a contaminant and determining the rate of removal of metal.

Keywords: Amaranthus, bioavailability, geotechnical properties, heavy metals, phytoremediation

1. Introduction

Heavy metal poisoning of soil is a global concern that threatens both the production of safe food and human health. Apart from exceptional geogenic causes, anthropogenic activities such as mining, smelting, combat and military training, e-waste, burning fossil fuels, improper waste disposal, unauthorized use of agrochemicals, and irrigation unintentionally release heavy metal pollutants into the soil (Vinicius, n.d.; Yan and Yang, n.d.; Nazir, n.d.). Heavy metal contamination is commonly caused by improperly disposing of mine waste, industrial waste, and building trash in the soil. Heavy metals enter the lithosphere primarily through the use of phosphorus (P) fertilizers, copper-based insecticides, biosolids, animal manure, crop irrigation with sewage water, and improperly treated industrial effluent.

The heavy metals lead (Pb), chromium (Cr), arsenic (As), zinc (Zn), cadmium (Cd), and copper are the ones that are most frequently found at affected locations. On this have a look at we have taken lead, zinc, cadmium, and copper. Land infection is not only dangerous for the subsurface water aquifers but it additionally poses grave damage to the systems present in it (Yah, n.d.; Zi, n.d.; Yan, n.d.; Loader, n.d.). Any fluctuations in engineering properties and composition of soil strata can also cause loss of bearing ability, a boom in the total or differential agreement of the inspiration device of structures consequently leading to failure of systems inflicting potential lack of property and existence (Reddy, n.d.; Orekanti *et al*., n.d.; Yang, n.d.).

In-situ remediation does not require excavation and transportation of the tainted soil to off-web page treatment centers and consequently, disruption of soil balance is minimized, vulnerabilities of exposure in workers and the encompassing public to the contaminants is reduced, and the remedy cost was affordable. But, precise field elements have to be taken into consideration, including climate, soil permeability, contamination depth, and ability deep leaching of chemical compounds (Nan, n.d.; Sumiahadhi, n.d.; Yang, n.d.; Oh and Cao, n.d.).

More recently, scientists have started employing plants to clean up toxic soils. This method is now becoming a viable, economical, and environmentally benign way to address heavy metal contamination. Many plant species have been diagnosed that use heavy metals for their metabolism (Oh *et al*., n.d.; Cang *et al*., n.d.). Those florae acquire the heavy metals from the soil with specificity both for unmarried or a couple of heavy steel. According to estimates, these hyperaccumulator plants can store heavy materials 100 times more efficiently than nonaccumulator plant life. Because of their accelerated need for heavy metals, these plants use a unique mechanism to remove heavy metals from soil (Ruby and Appleton, n.d.; Poniedzialek *et al*., n.d; Zadeh and Savaghebi, 2008; Fellet and Marchiol, n.d.). A few hyperaccumulator plant life secrete chelating dealers that help them extract the heavy metallic contaminants from less insoluble soil fractions. Owing to their risky effect on existing forms, heavy metal contamination is categorized as a critical risk to the atmosphere. Therefore, remediation of land contamination is very critical (Azhar *et al*., 2006; Blaylock *et al*., 1997).

The word "phytoremediation" comes from the Greek prefix "Phyto" which means "plant" and the Latin suffix "remedium" which means, "to remedy”. Phyto technology uses plants to remediate various strata of the biosphere impacted via unique kinds of contaminants. Hydroponics (Kochian, n.d.). Phytotechnologies can be used to remediate common organic contaminants such as petroleum hydrocarbons, fuel condensates, crude oil, chlorinated chemicals, insecticides, and explosive substances. The inertized inorganic pollutants include salts, heavy metals, metalloids, and radioactive substances. Groundwater, surface water, wastewater, stormwater, sludge, sediments, and soils may all be treated with phytotechnology (Krishnamurti *et al*., 1997).

The plant used in the study was Amaranthus, which was chosen because it is a fast-growing plant that can tolerate high levels of heavy metal contamination. It has a deep root system that can penetrate the soil and extract contaminants effectively.

1.1. Characteristics of amaranthus

Amaranthus is an annual plant that can grow up to 1.5 meters tall. It has a deep taproot system that can reach depths of up to 2 meters. It is a fast-growing plant that can germinate in a wide range of soil conditions. It has a high biomass production, which makes it suitable for phytoremediation.

The purpose of the study was to investigate the effectiveness of phytoremediation in reducing heavy metal pollution in contaminated soil and to evaluate the changes in the geotechnical properties of the soil after phytoremediation. The significance of the research is to provide an environmentally friendly and cost-effective method for the remediation of heavy metal-contaminated soils, which can have significant economic, ecological, and health benefits.

The geotechnical properties measured before and after phytoremediation included specific gravity, particle size distribution, Atterberg limits, compaction characteristics, and unconfined compressive strengthSpecific gravity is a measure of the density of a material relative to the density of water. It was measured before and after phytoremediation to determine if the plant roots had any impact on the density of the soil. Particle size distribution was also measured to determine the proportion of different-sized particles in the soil, which can affect its porosity and permeability.

Atterberg limits were measured to determine the soil's behavior with changes in moisture content. The Atterberg limits include the liquid limit, plastic limit, and shrinkage limit. The liquid limit is the moisture content at which the soil transitions from a plastic to a liquid state, while the plastic limit is the moisture content at which the soil transitions from a solid to a plastic state. The shrinkage limit is the moisture content at which the soil volume does not decrease any further with a decrease in moisture content.

Compaction characteristics were also measured before and after phytoremediation. This includes the maximum dry density, optimum moisture content, and compaction curve. These measurements determine how well the soil can be compacted for use in construction or other purposes.

Finally, unconfined compressive strength was measured to determine the soil's ability to resist deformation under compression. This measurement was taken before and after phytoremediation to determine if the roots of the plants had any impact on the soil's strength.

Phytoremediation is the process of using plants to remove, detoxify, or stabilize pollutants from contaminated soil, water, or air. It involves the use of plants that can accumulate, translocate, and detoxify pollutants from the environment. In the process of phytoremediation, the plants uptake the pollutants from the soil through their roots, transport them to their aerial parts, and transform them into less toxic or inert compounds.

2. Phyto technology

There are six predominant mechanisms associated with Phyto technology Figure 1.

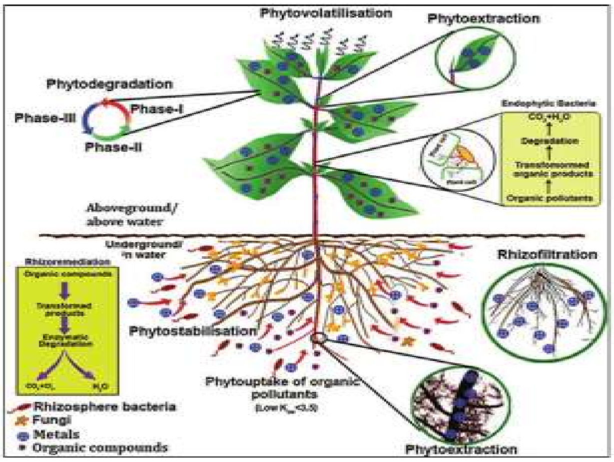


Figure 1. Phyto technology

3. Objectives

- To determine the appropriate plant this is suitable to develop in our soil circumstance for the software of phyto remediation.
- To take a look at the reaction of every plant closer to extraordinary styles of heavy metals.
- The contrast of geotechnical residences of the soil before and after phytoremediation.

4. Experimental program

4.1. Materials

4.1.1. Soil

A locally available soil is used to prepare the test bed. The soil was collected from Nedumbal, Thrissur district Figure 2.

Figure 2. Soil

4.1.2. Heavy metals

Water-soluble salts of heavy metals which include lead acetate, zinc nitrate, copper nitrate, and cadmium chloride are used to artificially contaminate the soil Figure 3. Here zinc salts are taken thinking about the burden of soil this is 50 mg weight of salt is taken for 1 Kg weight of soil and dissolved in water and implemented in soil incrementally. All of the chemical substances taken in this look are analytical reagent grade.

Heavy metal pollution is the contamination of soil and water with toxic metals such as lead, cadmium, mercury, and arsenic. These metals can have harmful effects on human health, such as neurological damage, cancer, and birth defects. They can also harm ecosystems by killing wildlife, reducing biodiversity, and contaminating food chains.

Figure 3. Salt of Zinc

4.1.3. Seeds

Numerous seeds needed for developing flowers in pot tests is Amaranthus which is collected from Kanjikuzhy, Alappuzha district Figure 4.

Figure 4. Amaranthus Seed

4.1.4. Planting pots

Plastic bags were used for planting seeds. The dimensions of the pots are 20 cm in diameter and 30 cm in height Salt of Lead Figure 5.

Figure 5. Planting Pot

4.2. Experimental setup

The take a look at installation consists of pot experiments. 4 pots of length 20 cm diameter and 30cm peak is selected for each plant take a look at. In the beginning, heavy metal-infected soil turned into artificially prepared. For this, each heavy metallic salt turned into dissolved in water at optimal moisture content material and carefully mixed until it fully dissolved in water. This answer is poured into the soil and blended properly. This soil changed into filled within the pots and seeds are planted in each pot. One pot is packed with local soil and saved as a manipulation point for comparison. Three pots are filled with soil at 50mg, 100mg, and 200 mg concentrations of heavy steel.

Numerous experiments conducted earlier than and after phytoremediation have been defined. The numerous experiments performed on the sample are subsequent:

- Specific gravity determination
- Sieve analysis
- Atterberg limits (Liquid limit, Plastic limit, shrinkage limit)
- Light compaction test
- Unconfined compressive strength test
- Atomic absorption spectroscopy

First of all, the above assessments had been performed on an aircraft soil sample to decide its simple houses. Thereafter, 50 mg, 100 mg, and 200 mg concentrations of heavy metals are delivered to the pattern to contaminate it, and the corresponding residences of contaminated soil are determined. The properties after phytoremediation are carried out.

4.3. Pot experiments

These are the details of model testing conducted in this study.

Large-scale pot experiments are conducted to represent the 3-dimensional field condition. The model tests are conducted under local environmental conditions at the site.

(i) Filling of pots: A predetermined quantity of soil (three fourth height of the pot) is filled in the test pots which contain 50mg, 100mg, and 200mg of heavy metal salts for 1 Kg. After filling the pots are allowed to rest for 24 hrs to achieve a uniform character Figure 6.

Figure 6. Pot filled with soil

(ii) Sowing of seeds: For each plant, three pots are filled with contaminated soil, and one pot is filled with virgin soil. The virgin soil volume makes up about two kilograms of each pot. Around 2 inches of the earth was buried behind the seeds. After sprouting, roughly one seed is sown in each container.

(iii) After planting, pots were placed in an area with all-day sunlight and watered every day as part of the experiment. During 60 days, the plants were allowed to grow, and their development was observed. The soil was removed at the end of the 30th, 45th, and 60th day to be tested for the presence of heavy metals and other geotechnical factors.

Phytoremediation can improve the soil's physical, chemical, and biological properties, including its nutrient content, microbial activity, and water-holding capacity.

5. Result and discussion

5.1. Effect of phytoremediation on contaminated soil properties after 30th day of remediation

5.1.1. Effect of amaranthus on zinc contaminated soil

Zinc contamination is removed from the soil using Amaranthus plants. The effect of phytoremediation on the properties of contaminated soil is listed in detail Figures 7–11.

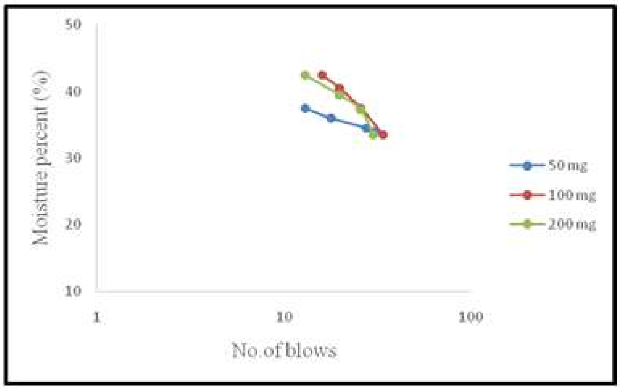


Figure 7. Flow curve of zinc-contaminated soil

The liquid limit is a property that determines the moisture content at which soil changes from a plastic to a liquid state.

The flow curve has no. of blows on the abscissa and moisture percent on the ordinate. The liquid limit changes from 39 to 35%, 40% to 38%, and 45% to 38% for 50mg, 100mg, and 200mg concentrations of zinc. The result shows that the liquid limit value decreases which indicates a reduction in compressibility and swelling characteristics which indicates an increase in the strength of the soil.

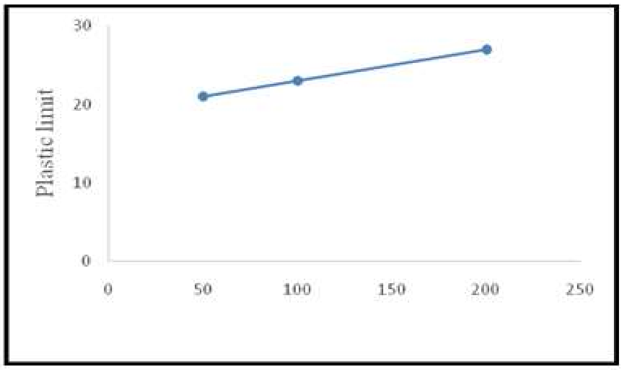


Figure 8. Plastic limit of zinc-contaminated soil

The plastic limit graph has the concentration of contaminants on the abscissa and the plastic limit value on the ordinate. The graph contains plastic limit values of zinc. The plastic limit values have changed from 24 % to 18%, 25% to 20%, and 27% to 19% for 50mg, 100mg, and 200mg concentrations of zinc. The results show a decrease in the plastic limit that shows a decrease in compressibility which indicates an increase in strength.

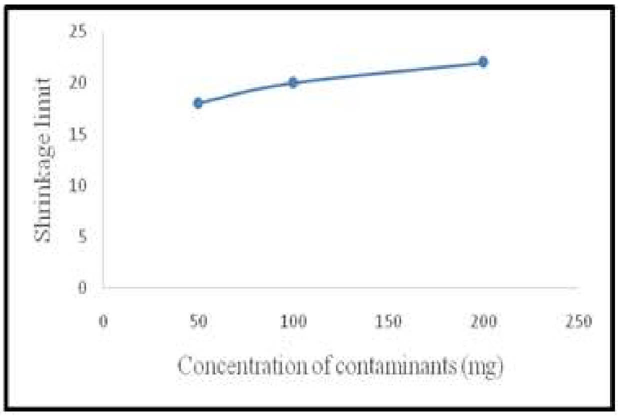


Figure 9. Shrinkage limit of zinc-contaminated soil

The shrinkage limit graph consists of the concentration of contaminants on the abscissa and the shrinkage limit value on the ordinate. The shrinkage limit value changes from 21% to 18%, 22% to 20%, and 24% to 22% for 50mg, 100mg, and 200mg concentrations of zinc. The values from the graph show a decrease in shrinkage limit which indicates a decrease in shrink and swell of the soil that increases the strength of the soil.

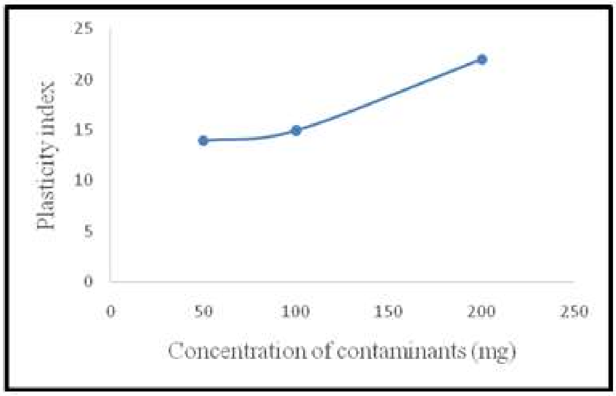


Figure 10. Plasticity index of zinc-contaminated soil

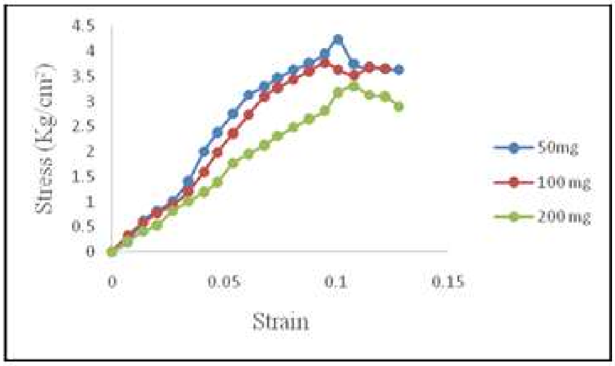


Figure 11. Stress-strain curve of zinc-contaminated soil

The plasticity index graph has a concentration of contaminants on the abscissa and a plasticity index value on the ordinate. The result from the graph shows that the plasticity index value changes from 15% to 14%, 16% to 15%, and 18% to 15% for 50 mg, 100 mg, and 200 mg concentrations of zinc. The results from the graph show that there is a decrease in the plasticity index which changes the compressibility and also increase the strength of the soil.

The stress-strain curve has a strain value on the abscissa and a stress value on the ordinate axis. The result from the graph shows that the value of stress changes from 395 kN/m² to 422.6kN/m², 343.9 kN/m² to 376.3 kN/m², 282.2kN/m² to 330.2 kN/m² for 50 mg, 100mg, 200mg concentrations of zinc. The undrained shear strength value changes from 197.5 kN/m² to 211.3kN/m², 171.95 kN/m² to 188.15kN/m², 141.1 kN/m² to 165.1 kN/m² for 50 mg, 100mg, 200mg concentrations of zinc. The results from the graph show an increase in strength value.

5.1.2. Effect of phytoremediation on contaminated soil properties after 45th day of remediation

5.1.2.1 Effect of amaranthus on zinc contaminated soil

The effect of Amaranthus on zinc-contaminated soil is studied at different concentrations. The change in properties of contaminated soil is listed in detail.

The flow curve has no. of blows on the abscissa and moisture percent on the ordinate. The liquid limit changes from 39% to 32%, 40% to 34%, and 45% to 35% for 50mg, 100mg, and 200mg concentrations of zinc. The decrease in liquid limit indicates a decrease in compressibility and swelling characteristics, which indicates an increase in the strength of the soil Figures 12–16.

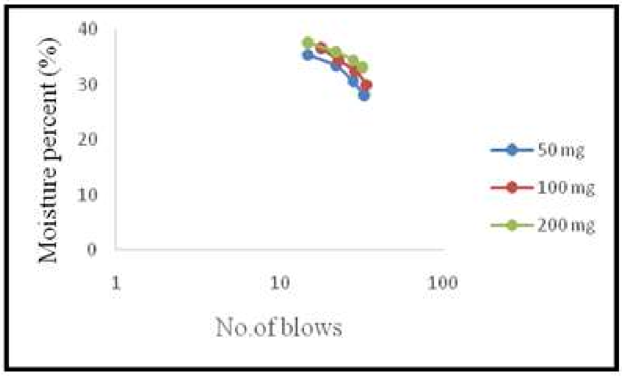


Figure 12. Flow curve of zinc-contaminated soil

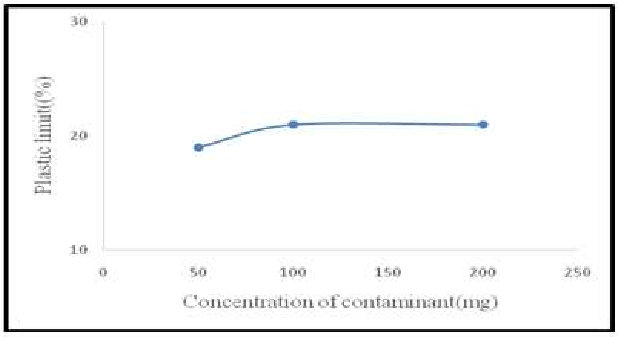


Figure 13. Plastic limit of zinc-contaminated soil

The plastic limit graph has the concentration of contaminants on the abscissa and the plastic limit value on the ordinate. The graph contains plastic limit values of zinc. The plastic limit values have changed from 24 % to 19%, 25% to 21%, and 27% to 21% for 50mg, 100mg, and 200mg concentrations of zinc. The results show a decrease in the plastic limit that shows a decrease in compressibility, which indicates an increase in strength.

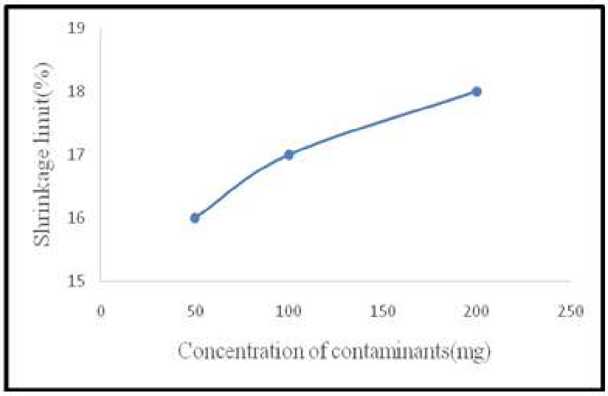


Figure 14. Shrinkage limit of zinc-contaminated soil

The shrinkage limit graph consists of the concentration of contaminants on the abscissa and the shrinkage limit value on the ordinate. The shrinkage limit value changes from 21% to 16%, 22% to 17%, and 24% to 18% for 50mg, 100mg, and 200mg concentrations of zinc. The values from the graph show a decrease in shrinkage limit which indicates a decrease in shrink and swell of the soil that affects the strength of the soil.

The plasticity index graph has a concentration of contaminants on the abscissa and a plasticity index value on the ordinate. The result from the graph shows that the plasticity index value changes from 15% to 13%, 16% to 13%, and 18% to 14% for 50 mg, 100 mg, and 200 mg concentrations of zinc.

The results from the graph show that there is a decrease in the plasticity index, which changes the compressibility, and also increases the strength of the soil.

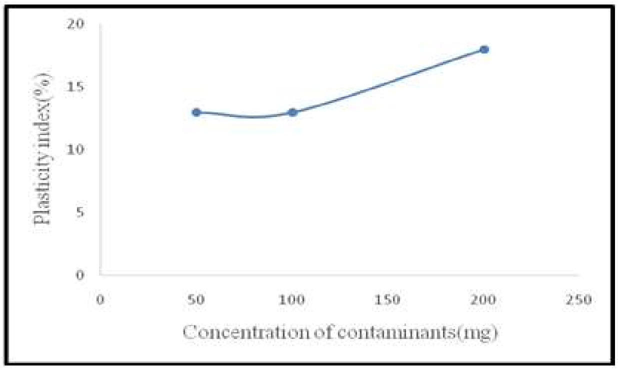


Figure 15. Plasticity index of zinc-contaminated soil

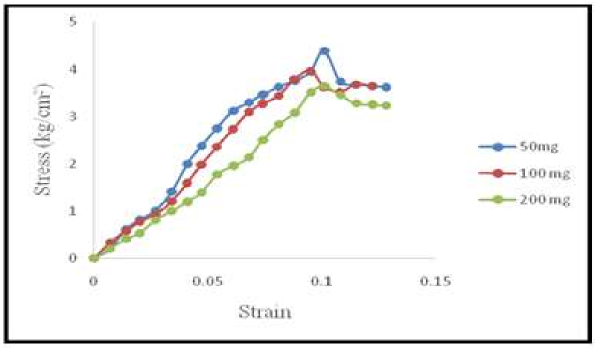


Figure 16. Stress-strain curve of zinc-contaminated soil

The stress-strain curve has a strain value on the abscissa and a stress value on the ordinate axis. The result from the graph shows that the value of stress changes from 395 kN/m² to 439kN/m², 343.9 kN/m² to 396.3 kN/m², 282.2N/m² to 363.7 kN/m² for 50 mg, 100mg, 200mg concentrations of zinc.

The undrained shear strength value changes from 197.5 kN/m² to 219.5kN/m², 171.95 kN/m² to 198.15kN/m², 141.1 kN/m² to 181.5 kN/m² for 50 mg, 100mg, 200mg concentrations of zinc. The results from the graph show an increase in strength value.

5.1.3. Effect of phytoremediation on contaminated soil properties after 60th day of remediation

The flow curve has no. of blows on the abscissa and moisture percent on the ordinate. The liquid limit changes from 39% to 29%, 40% to 31%, and 45% to 32% for 50mg, 100mg, and 200mg concentrations of zinc Figures 17–20.

The decrease in liquid limit indicates a decrease in compressibility and swelling characteristics which indicates an increase in the strength of the soil.

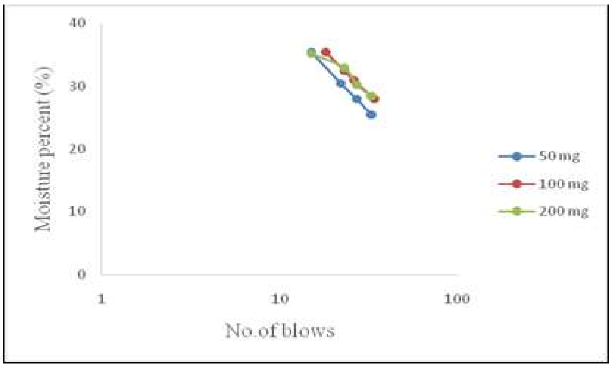


Figure 17. Flow curve of zinc-contaminated soil

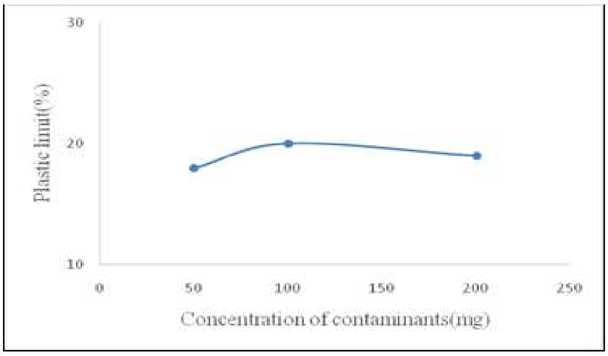


Figure 18. Plastic limit of zinc-contaminated soil

The plastic limit graph has the concentration of contaminants on the abscissa and the plastic limit value on the ordinate. The graph contains plastic limit values of zinc. The plastic limit values have changed from 24 % to 18%, 25% to 20%, and 27% to 19% for 50mg, 100mg, and 200mg concentrations of zinc.

The results show a decrease in the plastic limit that shows a decrease in compressibility, which indicates an increase in strength.

The shrinkage limit graph consists of the concentration of contaminants on the abscissa and the shrinkage limit value on the ordinate. The shrinkage limit value changes from 21% to 15%, 22% to 15%, and 24% to 17% for 50mg, 100mg, and 200mg concentrations of zinc. The values from the graph show a decrease in shrinkage limit which indicates a decrease in shrink and swell of the soil that affects the strength of the soil.

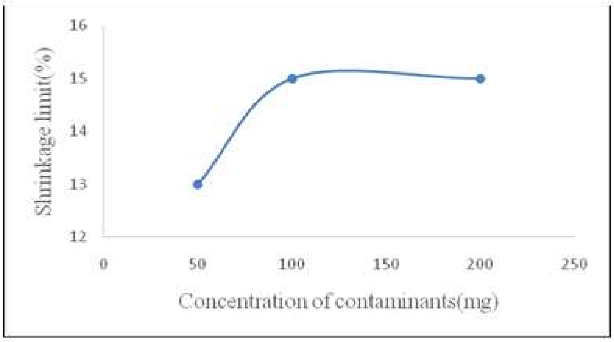


Figure 19. Shrinkage limit of zinc-contaminated soil

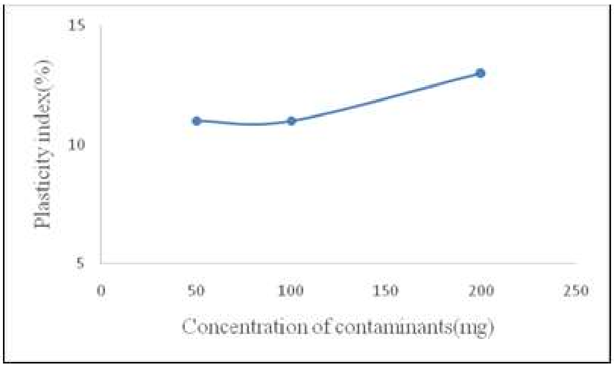


Figure 20. Plasticity Index of zinc-contaminated soil

The plasticity index graph has a concentration of contaminants on the abscissa and a plasticity index value on the ordinate. The result from the graph shows that the plasticity index value changes from 15% to 18%, 16% to 11%, and 18% to 13% for 50 mg, 100 mg, and 200 mg concentrations of zinc. The results from the graph show that there is a decrease in the plasticity index, which changes the compressibility, and also increases the strength of the soil.

The stress-strain curve has a strain value on the abscissa and a stress value on the ordinate axis. The result from the graph shows that the value of stress changes from 395 kN/m² to 484kN/m², 343.9 kN/m² to 426 kN/m², 282.2N/m² to 393 kN/m² for 50 mg, 100mg, 200mg concentrations of zinc. The undrained shear strength value changes from 197.5 kN/m² to 242kN/m², 171.95 kN/m² to 213kN/m², 141.1 kN/m² to 196.5Kn/m² for 50 mg, 100mg, 200mg concentrations of zinc. The results from the graph show an increase in strength value Figure 21.

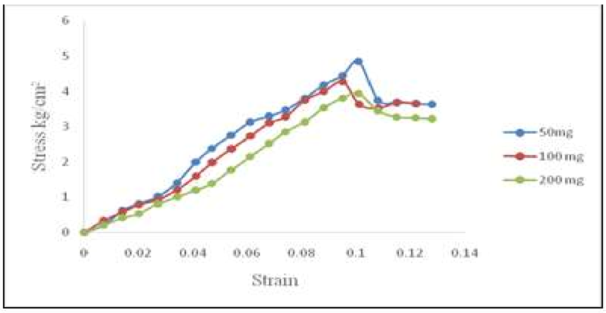


Figure 21. Stress-strain curve of zinc-contaminated soil

5.1.4. Effect of contaminated soil on plant germination and seed growth

Among the four plants, the selected Amaranthus also shows the best result for germination Figures 22–26.

Figure 22. Control soil

Figure 23. 50 mg pot

Figure 24. 100 mg pot

Figure 25. 200 mg pot

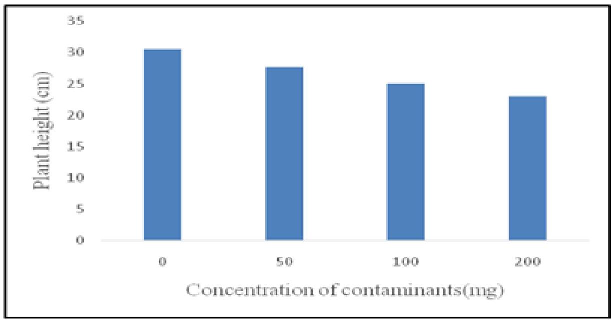


Figure 26. Variation in Plant height of Amaranthus

5.1.4.1 Effect of phytoremediation on plant growth after 45th day of remediation

Helianthus Annuus, one of the four plants chosen, displayed a very strong phytoremediation impact in comparison to the other plants. Amaranthus exhibits strong plant growth, however, it does not absorb much. Although not survive until the end of the testing period, Vigna radiata still demonstrated phytoremediation of Cadmium metals.

5.1.4.1.1 Effect of Phytoremediation on plant growth of Amaranthus on zinc contaminated soil

Among the four plants, the selected Amaranthus also shows the best result for germination Figures 27–31.

Figure 27. Control soil

Figure 28. 50 mg pot

Figure 29. 100 mg pot

Figure 30. 200 mg pot

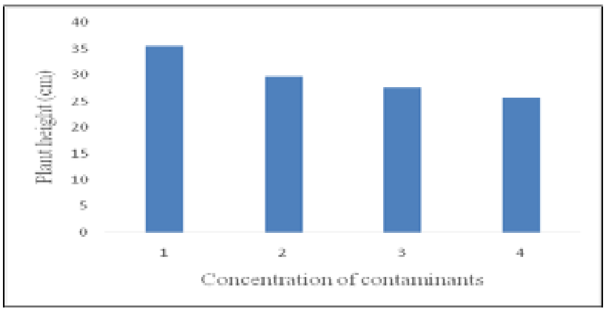


Figure 31. Plant height variation of Amaranthus

5.1.4.2 Effect of Phytoremediation on plant growth after 60th day of remediation

Helianthus annuus, one of the four plants chosen, displayed a very strong phytoremediation impact in comparison to the other plants. Although not survive until the end of the testing period, Vigna radiata still demonstrated phytoremediation of Cadmium metals.

5.1.4.2.1 Effect of Phytoremediation on plant growth of Amaranthus on zinc contaminated soil

Among the four plants, the selected Amaranthus also shows the best result for germination Figures 32–36.

Figure 32. Control soil

Figure 33. 50 mg pot

Figure 34. 100 mg pot

Figure 35. 200 mg pot

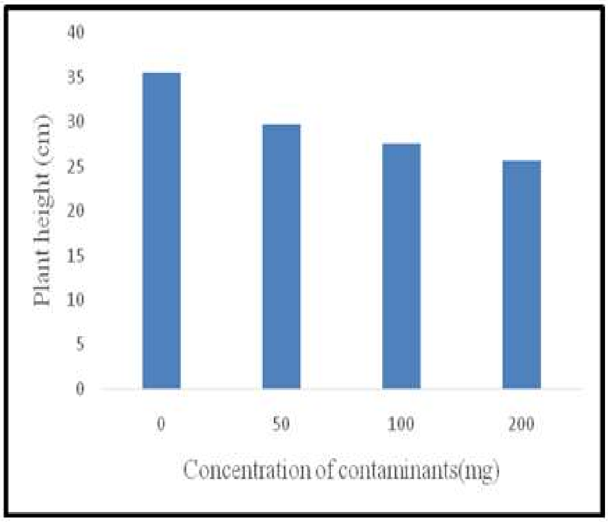


Figure 36. Variation in plant height of Amaranthus

5.1.5. Effect of phytoremediation on the heavy metal content of the lead-contaminated soil using Helianthus Annus

The rate of removal of metal ions using Helianthus Annus shows the best result Table 1.

Table 1. Atomic Absorption spectroscopy result of Helianthus Annus

S. No	Amount of samples tested	Amount of concentration of heavy metal before phytoremediation	Amount of concentration of heavy metal after phytoremediation
1	20 g	50 mg/l	Below 0.5 mg/l
2	20g	100 mg/l	Below 0.5 mg/l
3	20 g	200 mg/l	Below 0.5 mg/l

6. Conclusion

- Amaranthus has shown better results in germination as well as a rate of removal of metal ions.
- After the 60th day of Phytoremediation, the properties of the soil changed to the soil of low compressibility and strength also get improved.
- Amaranthus have attained their maximum growth on control soil and slight difference in contaminated soil.
- The rate of removal of metal ions as per Atomic Absorption Spectroscopy has shown that every plant has absorbed contaminants to a great level.
- In this study, we use one plant in one pot and each sample has shown a result of below 0.5 mg/l.

Further research in the field of phytoremediation and soil remediation can include

a) Investigation of the effectiveness of phytoremediation on different types of contaminated soils with various levels of heavy metal pollution.

b) Identification and selection of plant species that are tolerant to high levels of heavy metals and have a high capacity for metal uptake and accumulation.

c) Exploration of the potential of using a combination of phytoremediation with other remediation techniques, such as bioremediation and electrokinetic remediation, to enhance the efficiency of soil remediation.

d) Study of the long-term effectiveness of phytoremediation in reducing heavy metal pollution in soil.

e) Investigation of the potential risks associated with the accumulation of heavy metals in plants used for phytoremediation, and their impact on the food chain.

Ethics approval and consent to participate

No participation of humans takes place in this implementation process.

Human and Animal Rights

No violation of Human and Animal Rights is involved.

Funding

No funding is involved in this work.

Conflict of Interest

Conflict of Interest is not applicable in this work.

Authorship contributions

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