Visakhapatnam Chapter

Proceedings of Indian Geotechnical Conference 2020
December 17-19, 2020, Andhra University, Visakhapatnam

Decontamination of Heavy Metal Contaminated Soils by Phytoremediation: Pot Experimentation

Puram Rajasekhar[1] and Somenath Mondal[2]

[1] *M*.Tech scholar, Department of Civil Engineering, National Institute of Technology Jamshedpur, Jamshedpur-831014, Jharkhand. Email: sekharr766@gmail.com
[2] Assistant professor, Department of Civil Engineering, National Institute of Technology Jamshedpur, Jamshedpur-831014, Jharkhand. Email: smondal.ce@nitjsr.ac.in

Abstract: Environment is experiencing severe depletion due to several anthropogenic activities and careless attitude of human beings. In this context, one of the significant issues is soil contamination because of unplanned dumping of hazardous waste from the industries. It should be noted that there are various types of decontamination methods for hazardous chemically contaminated soils however those methods are high energy-intensive, expensive and they further may disturb the natural ecosystem and biodiversity. Therefore, Phytoremediation, a sustainable eco-friendly decontamination treatment, is gaining popularity in the arena of contemporary soil remediation practices. On this note, the aim of this present study is to finding out a single plant species and planting density that can decontaminate the high concentration of different heavy metals in contaminated soils. The soil sample has been collected in pots of capacity 3 kg in each from the farming land and spiked with cadmium (150 mg/kg of soil), copper (800 mg/kg of soil) and zinc (1000 mg/kg of soil). Plant species which have been selected for this research are Setaria Italica, Sesamum Indicum and Vigna Radiata. Chemical analysis has been carried out on soil sample at an interval of 1 week up to 28 days of duration. Subsequently, the experimental observations reveals that the germination, growth rate, biomass production and contaminant removal of Setaria Italica is better in a very low water content compared to all other plant species.

Keywords: Setaria Italica; Heavy metal; Phytoremediation; Decontamination; Vigna Radiata.

1 Introduction

Due to the rapid growth of population and industrialization, waste has been generated in huge scale. According to food and agriculture organization of the United Nations approximately 110 million mines, industrialization and other unexploded pieces of ordnance are scattered across 64 countries on all continents, remnants of war that can have deadly consequences for farmers and heavy metals and organic contaminants released by weathering. 1.3 billion tons of municipal solid waste was generated all around the world per year up to 2012, it is expected to rise to 2.2 billion tonnes annually by 2025. In the recent years, geotechnical engineers and researchers were concentrating on phytoremediation to clean up the contaminated lands.

Shorter range and longer range of spatial continuity of degradation of total petroleum hydrocarbons showed by the St. Augustin grass and Sorghum. Rye grass and St. Augustin grass decontaminated the total petroleum hydrocarbons contaminated soil 25% more than the Sorghum (Nedunuri et al. 2000). Methyl tertiary butyl ether (MTBE) was taken up by hybrid poplar saplings through water, half of the MTBE mass reduced through volatilization yielding 25% reduction in aqueous MTBE concentration and 30% reduction in MTBE mass over a 1-week period significantly greater than the controls (Anu Ramaswamy and Ellen Rubin (2001). Hybrid poplar trees can grow significantly in Pb-Zn contaminated soils by using cattle manure as soil amendment at a pH of 6 to 6.3 (Pierzynski et al. 2002). The removal of heavy metals (Cd, Cr and Ni) from heavy metal contaminated aqueous solution with Rhizosphere consortium bacteria as amendment was 32.9%, 42.5% and 16.5% at a span of 12days by changing the pH from 4.5 to neutral (Hong Chen et al. 2003). Pteris Vittata plants have an excellent removal (68% of 220ppb) of arsenic from arsenic contaminated water (Matthew Denafo 2007). The accumulation of heavy metals (Zn and Cd) was more in the shoot portion of Transgenic Arabidopsis plants compared to wild type Arabidopsis plants (Weifeng Xu et al. 2008). The growth of wheat plant and removal of phenanthrene and pyrene was significant in both planted and unplanted contaminated soil with live micro bacterium sp. F10a inoculated pot planted contaminated soil (Sheng et al. 2009). Aspalathus linearis exudate the aluminium chelating organic acids ligands such as citric, malic, malonic acids. Brachiaria Decumbens plant extracted the copper from the copper contaminated soil; the highest copper content was in the roots of the plant and prevents the ground water pollution by reducing the copper leachate and this plant used as bio energy plant after harvesting (Robson Andreazza et al. 2013). The germination, survival and biomass production of sunflower plant was good in both heavy metal (lead, cadmium and chromium) and organic (Phenanthrene and naphthalene) contaminated soils (Reshma et al. 2014). Sunflower plant had better contaminant removal from the both contaminated (phenanthrene, naphthalene, chromium cadmium and lead) soil (Reshma and Krishna Reddy 2015). The reduction of cadmium and lead with sunflower plant by soil amended with Biochar and compost was good compared to unamended plant (Reshma and Krishna Reddy 2015). The accumulation of zinc and copper by alfalfa plant inoculated with Pantoea Sp. Strain Y4-4 as plant growth promoting bacteria was 30.3% and 15% more compared to non-inoculated plant (Shuhuan li et al. 2016). The cadmium content decreased in root, stem, leaf of lavender plant by 17.5%, 43.8% and 27% respectively by Biochar addition to the soil contaminated with cadmium, compared to no-Biochar amended plant-soil system (Seyyed Behrad Hashemi et al.

2017). The toxicity zones were created in the soil by using electro phytoremediation with barley as plant species (Claudio Cameselle and Susana Gouveia 2019). Helianthus annus plant has better heavy metal (Cd, Cr and Pb) removal from the contaminated soil (Eswara Reddy Orekanti et al. 2019).

From the background of the study, it can be observed that there is a depth of investigations where local plants have been employed to decontaminate heavy metal contaminated soil. Hence, in the present study an attempt has been made to utilize the local plants and study its performance in decontaminating heavy metals from the soil. Before starting the phytoremediation we have done research on low compressible clay contaminated with heavy metals without plant species. And it has been observed that no reduction of heavy metal concentration.

2 Experimental Methodology

2.1 Soil Properties

The soil sample collected from the farm land is red soil which is nearer to the Galiveedu (M), Kadapa (dist.) Andhra Pradesh. The geotechnical properties of soil was done as per Indian standard code of practice and mentioned in the table.1. The grain size distribution curve of collected soil was shown in the figure.1

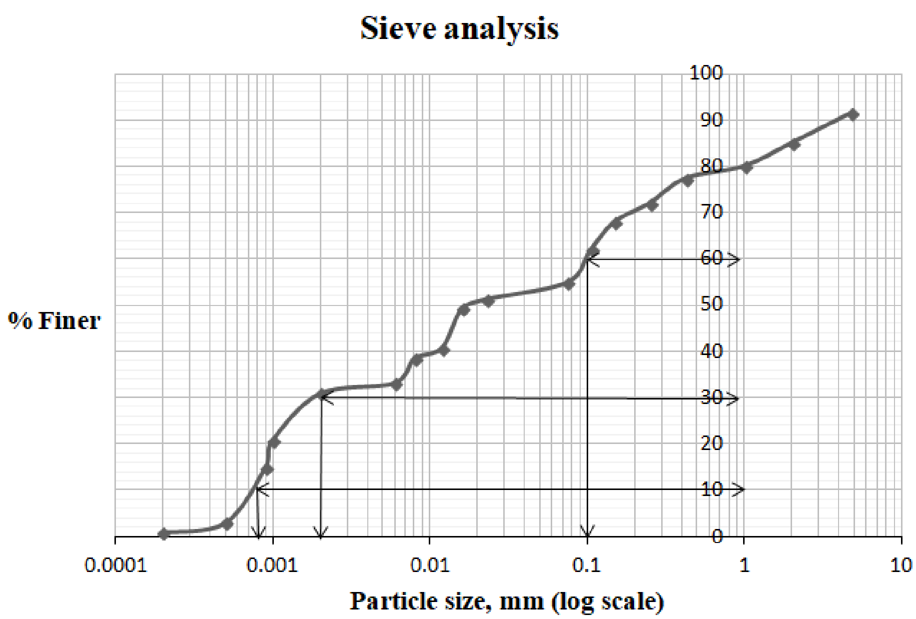

Fig.1. Grain size distribution curve

Table.1 Properties of soil

S. No.	Property of soil	Value
1	Clay (< 0.002 mm)	30 %
2	Silt (0.002 – 0.075 mm)	28 %
3	Sand (0.075 – 4.75 mm)	33.4 %
4	Fine gravel (> 4.75 mm)	8.6 %
5	Organic content (%)	3.2 %
6	Specific gravity	2.71
7	Liquid limit (%)	33.7
8	Plastic limit (%)	22
9	Plasticity index (%)	11.7
10	pH of soil	7.8
11	soil classification	low compressible clay

2.2 Selected Plant Species

So many researchers have been conducted research on different plant species in different contaminated soils. But still so many regional plant species which can grow in critical environmental conditions which have been not conducted research in the field of phytoremediation. Plant species which have been selected for this research are Setaria Italica, Sesamum Indicum, and Vigna Radiate.

2.3 Soil Spiking Procedure

Heavy metal contaminated soil was prepared by adding the 0.613 g of $CdCl_2$, 2.009 g of $CuSO_4$ and 2.46 g of $ZnSO_4$ for each kg of soil in separate pots to get concentration of Cd (150 mg/kg of soil), Cu (800 mg/kg of soil), and Zn (1000 mg/kg of soil). The heavy metals mixed with deionized water (15 % water content by soil) and stirred for one hour using glass stirrer separately in a 100 ml beaker and this solution was mixed in the clean air dried soil. The concentration of chemical contaminants in selected plant species pots were mentioned in the table 2.

The artificial heavy metal (Cd, Cu and Zn) contaminated soil was filled exactly 3 kilograms in each pot and one set of control pots were prepared for each plant species.

The seeds selected for the research were seeded at a depth of ½ inch from soil surface in the pot.

Table 2. Plant species with heavy metal contaminated soil

S. No.	Name of the plant	Heavy metal concentration in soil (mg/ kg)			
		Control	Cadmium	Copper	Zinc
1.	Sesamum Indicum	0	150	800	1000
2.	Setaria Italica	0	150	800	1000
3.	Vigna Radiata	0	150	800	1000

2.4 Pot Setup and Monitoring

Each pot was kept on separate trays to ensure that the leachate does not get mixed up. The pots were placed under sunlight to obtain the desired light intensity. The plants were grown for 28 days and the growth was monitored. Watering was carried out every day in each pot. The locations of the pots were rotated periodically to ensure uniform light intensity to all the pots. Weekly monitoring was done to record the germination, number of plants, plant height, and contaminant removal from the contaminated soil. At the end of the period, harvested plant species were composted or incinerated.

3 Results and Discussions

3.1 Germination

The germination of different plant species can be varied based on chemical behaviour of soils. The following figure.2 represents the germination percentage of three plant species in heavy metal contaminated soils and control soils. Among all three plant species Setaria Italica plant had better germination. In cadmium contaminated soil Setaria Italica plant had 72% germination. In copper contaminated soil Setaria Italica, Sesamum Indicum and Vigna Radiata plants have germination percentages 78%, 64% and 66.66% respectively. In zinc contaminated soil Setaria Italica plant was top 92% germination, Sesamum Indicum and Vigna Radiata plants have 84% and 73.33% respectively.

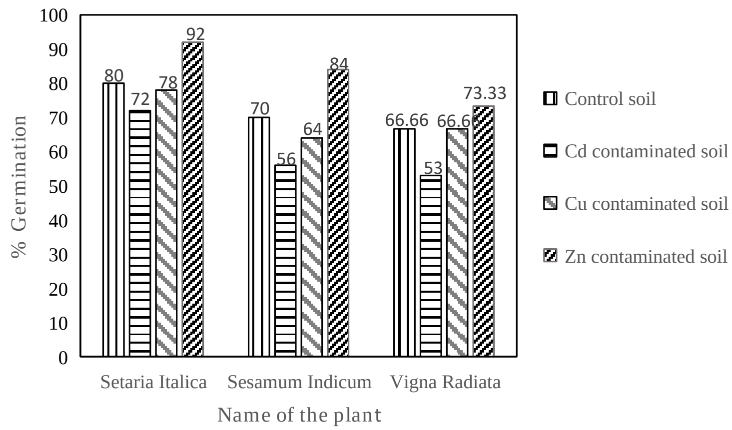

Fig.2 Germination percentages of plant species in different soil conditions

3.2 Percentage Survival of Plant Species

The percentage survival of plant species is defined as the number of plants alive to total number seeds germinated. The percentage survival of plant species depends on toxicity of soil and it has been observed by health of leaves and stem portion of the plants. The percentage survival of plant species after 28 days of duration is represented in the fig.3. The survival of Setaria Italica and Vigna Radiata plant was good in heavy metal contaminated soil.

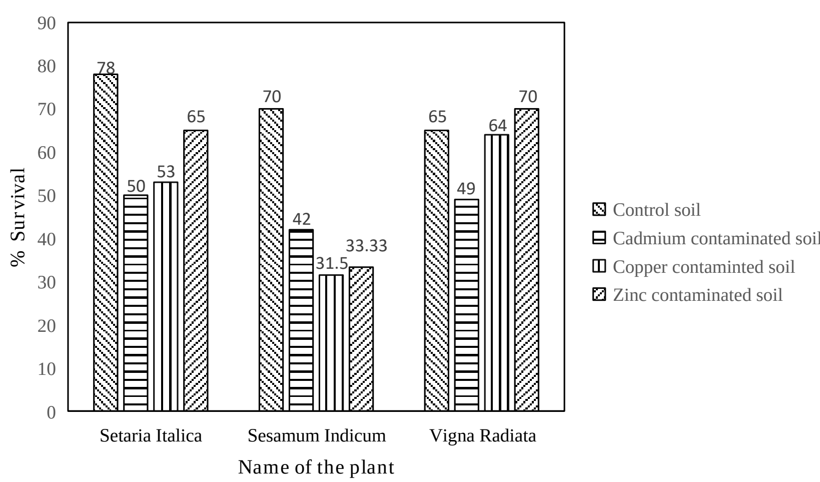

Fig.3. Percentage survival of plant species in different heavy metal contaminated soil

3.3 Mean Heights of the Plant Species

The height of plant species at 28 days of duration can be significantly varied and it depends on chemical behaviour of soil surrounding the rhizosphere. The mean heights of Setaria Italica, Sesamum Indicum and Vigna Radiata plant species were represented in the fig.4. The plant species which are in control soil is having highest growth rate but Vigna Radiata plant had excellent growth in copper and zinc contaminated soils compared to cadmium contaminated soil. Setaria Italica plant is having good growth in cadmium contaminated soil and significant growth in both copper and zinc contaminated soils. Sesamum Indicum plant also having better growth rate in cadmium contaminated soil and half of the growth rate observed in remaining two heavy metal contaminated soils.

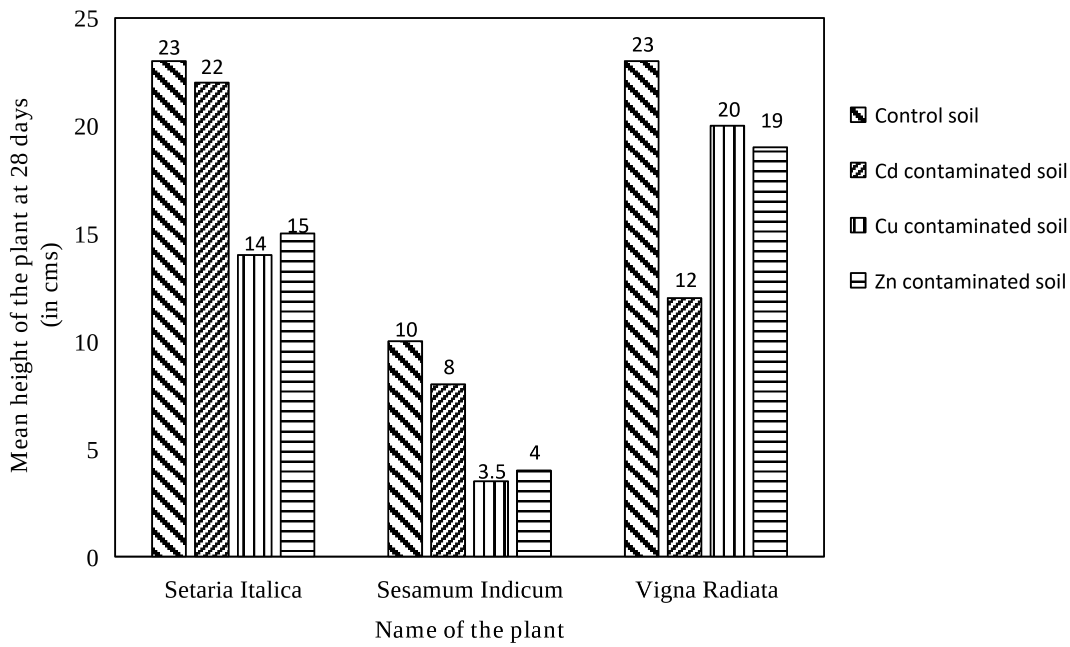

Fig.4. Mean height of plant species at 28 days of duration

The variation of height of Setaria Italica plant at every one week of time interval at different heavy metal
Contaminated soil is shown in the table 3. It has been observed that the Setaria Italica plant is showing phytotoxicity effect in copper contaminated soil.

Table 3 .Mean height of Setaria Italica plant in different heavy metal contaminated soil

S. No.	Time (days)	Mean height of the Setaria Italica plant (Cms)			
		Control soil	Cadmium contaminated soil	Copper contaminated soil	Zinc contaminated soil
1.	0	0	0	0	0
2.	7	0	1	0	0
3.	14	6	4	2	4.5
4.	21	15	9	4	10.5
5.	28	23	22	4	15

The growth rate of Setaria Italica plant at every week of time interval in different heavy metal contaminated soils are graphically shown in the fig. 5. Setaria Italica plant is showing linear variation in control soil, cadmium and zinc contaminated soil, but in copper contaminated soil it is showing constant growth rate up to 28 days of time.

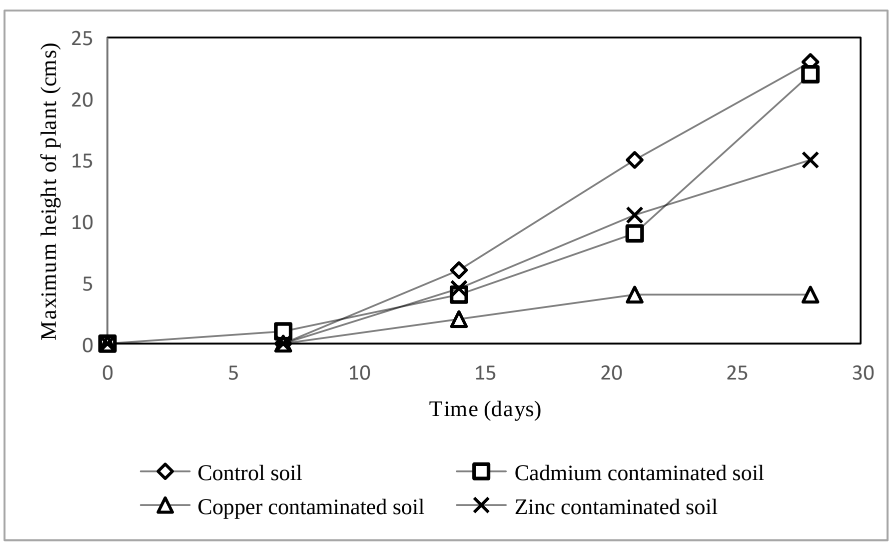

Fig.5. Variation of maximum height of the Setaria Italica plant at different days

3.4 Heavy Metal Concentration after 28 Days of Duration

After 28 days of duration, the heavy metal concentration in the pots which contains the Setaria Italica plant
was represented in the fig.6. The reduction of cadmium, copper and zinc concentrations were 20mg/ kg, 40 mg/kg and 190mg/kg of soil respectively.

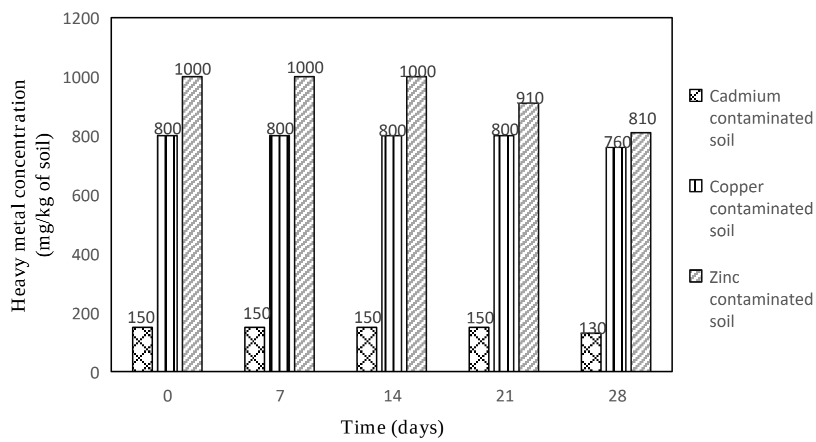

Fig.6. Heavy metal concentration present in soil contains the Setaria Italica plant

The soil sample collected at every one week of interval from the pot which contains the Sesamum Indicum Plant and chemical analysis of soil sample carried out and it has been observed that after 28 days of duration the removal of cadmium, copper and zinc concentrations are 11.5 mg/kg, 0 mg/kg and 135 mg/kg of soil respectively. The heavy metal concentration in the pots contains the Sesamum Indicum plant at every week was mentioned in the fig.7. Sesamum Indicum plant starts the removal of cadmium and zinc after 14 days.

The soil sample collected at every one week of interval from the pot which contains the Sesamum Indicum plant and chemical analysis of soil sample carried out and it has been observed that after 28 days of duration the removal of cadmium, copper and zinc concentrations are 11.5 mg/kg, 0 mg/kg and 135 mg/kg of soil respectively. The heavy metal concentration in the pots contains the Sesamum Indicum plant at every week was mentioned in the fig.7. Sesamum Indicum plant starts the removal of cadmium and zinc after 14 days.

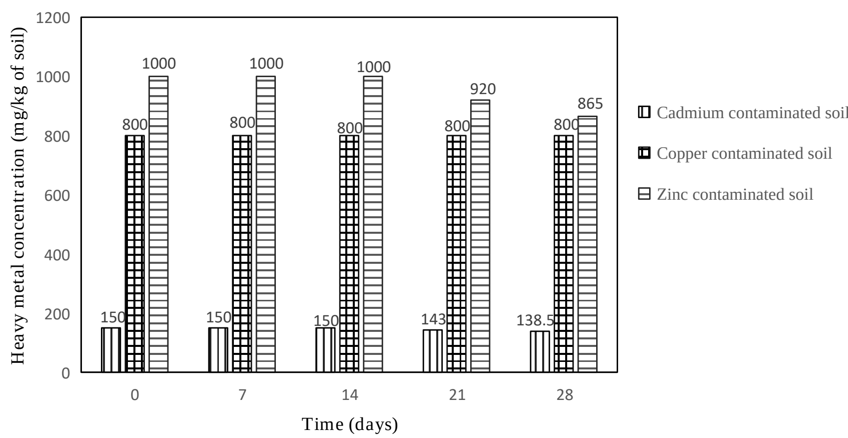

Fig.7. Heavy metal concentration present in soil contains Sesamum Indicum plant

The chemical analysis were conducted at every week of duration on soil sample collected from the pot contains Vigna Radiata as phytoremediation plant. The results of chemical analysis were demonstrated in the fig.8. The removal of cadmium, copper and zinc after 28 days of duration is 21.31 mg/kg, 18 mg/kg and 174.22 mg/kg of soil. It has been observed that the removal of cadmium by using Vigna Radiata plant is better than the other two plant species.

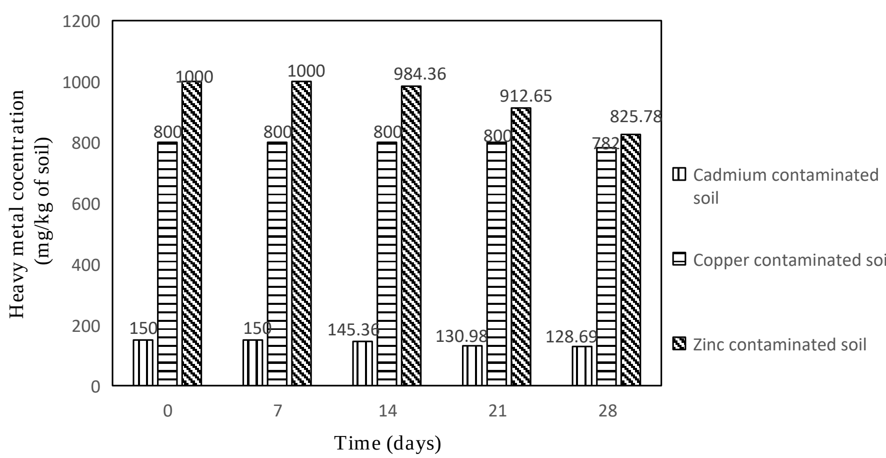

Fig.8 Heavy metal concentration present in soil contains Vigna Radiata plant.

4 Conclusions

From the present study the following conclusions can be drawn.

1. The percentage germination, Survival of three selected plant species had significant negative effect in Cadmium contaminated soil.
2. After 28 days duration the degradation of Cadmium, Copper and Zinc with the Setaria Italica plant was 20mg/kg, 40mg/kg and 190 mg/kg of soil.
3. Sesamum Indicum plant removes the Cadmium, Copper and Zinc from the heavy metal (Cadmium, Copper and Zinc) contaminated soils are 11.5 mg/kg, 0 mg/kg and 135 mg/kg of soil.
4. The reduction of Cadmium, Copper and Zinc by using Vigna Radiata as phytoremediation plant is 21.31 mg/kg, 18 mg/kg and 174.22 mg/kg of soil. From this study it has been concluded that the removal Cadmium with Vigna Radiata was significantly better. Overall, the degradation of heavy metals with Setaria Italica plant is an excellent and the removal of Zinc from the Sesamum Indicum plant species is good.

References

1. IS 2720-part 2: Methods of test for soils -Determination of water content (second revision), Bureau of Indian standards, New Delhi (1973).
2. IS 2720 (Part 3/Sec 2): Methods of test for soils - Determination of specific gravity (Section 2) Fine, medium and coarse grained soils (first revision), Bureau of Indian standards, New Delhi (1980).
3. IS 2720 - Part 4: Methods of test for soils- Grain size analysis (second revision), Bureau of Indian standards, New Delhi (1985).
4. IS: 2720 - Part 5: Method of test for soils - Determination of liquid and plastic limit (second revision), Bureau of Indian standards, New Delhi (1985).
5. Nedunuri, K, V., et al.: "Evaluation of Phytoremediation for Field Scale Degradation of Total Petroleum Hydrocarbons." Journal of environmental engineering,.126:483-490. ASCE. (2000).
6. Melwanki, M, B., et al.:"Spectrophotometric Determination of Chromium In Soil And Steel Samples Using Methdilazine Hydrochloride." (2001).
7. Anu Ramaswamy et al.: "Measuring phytoremediation parameters for volatile organic compounds: Focus on MTBE." ASCE. (2001).
8. G. M. Pierzynski et al.: "Phytostabilization of Metal Mine Tailings Using Tall Fescue." Practice periodical of hazardous, toxic and radioactive waste management, Vol.6, No.4. ASCE. (October 1, 2002).
9. Hong Chen et al.: "Preliminary Evaluation of Microbially Mediated Precipitation of Cadmium, Chromium and Nickel by Rhizosphere Consortium." Journal of Environmental Engineering. Vol. 129, No.1. ASCE. (January 1, 2003).
10. Matthew Denafo et al.: "Removal of arsenic with the process of phytoremediation using Pteris Vittata ferns." ASCE. (2007).

11. Weifeng Xu et al.: “Enhanced zinc and cadmium tolerance and accumulation in transgenic Arabidopsis plants constitutively over expressing a barley gene (HvAPX1) that encodes a peroxisomal ascorbate peroxidise.” NRC Canada. (2008).
12. X.F. Sheng et al.: “Characterization of micro bacterium sp. F10a and its role in polycyclic aromatic hydrocarbon removal in low-temperature soil.” Vol. 55. Can. J. Microbiol. (2009).
13. Robson Andreazza et al.: “Copper Phytoextraction and Phytostabilization by Brachiaria decumbens Staff. In Vineyard Soils and a Copper Mining Waste.” Journal of soil science. Vol. 3. 273-282. (2013).
14. Chirakkara, R. A., and K. R. Reddy.: “Synergistic Effects of Organic and Metal Contaminants on Phytoremediation.” In proc., Geo-congress 2014 Technical Papers, 1703-1712. Reston, VA: ASCE. (2014).
15. Chirakkara, R. A., and K. R. Reddy.: “Phytoremediation Of Mixed Contaminated Soils-Effects Of Initial Concentrations.” Geo-environmental engineering GSP 241, 1-10. ASCE. (2014).
16. Chirakkara, R. A., and K. R. Reddy.: “Plant Species Identification for Phytoremediation Of Mixed Contaminated Soils.” Journal of Hazardous, Toxic, and Radioactive Waste, 04015004, 1-10. ASCE. (2015).
17. Chirakkara, R. A., and K. R. Reddy.: “Phytoremediation of Mixed Contaminated Soils: Enhancement with Biochar and Compost Amendments.” IFCEE, 2687-2696. ASCE. (2015).
18. Adeola Alex Adesuyi et al.: “Assessment of Heavy Metals Pollution in Soils and Vegetation around Selected Industries in Lagos State, Nigeria.” Journal of Geoscience and Environment Protection, 2015, 3, 11-19. (2015).
19. Shuhuan li et al.: “The Effects Of Pantoea Sp. Strain Y4-4 On Alfalfa In The Remediation Of Heavy-Metal-Contaminated Soil, And Auxiliary Impacts Of Plant Residues On The Remediation Of Saline–Alkali Soils.” Can. J. Microbiol. 63: 278–286. (2016).
20. Seyyed Behrad Hashemi et al.: “Biochar Effect on Cadmium Accumulation and Phytoremediation Factors by Lavender (Lavandula stoechas L.).” Open Journal of Ecology, 2017, 7, 447-459. (2017).
21. Claudio Cameselle., and Susana Gouveia.: “Phytoremediation Of Mixed Contaminated Soil Enhanced With Electric Current.” Journal of hazardous materials, 361, 95-102. ELSEVIER. (2019).
22. Eswrara Reddy Orekanti et al.: “Pilot Study on Phytoremediation of Contaminated Soils with Different Plant Species.” Journal of hazardous, toxic, and radioactive waste, ISSN: 2153-5493, 1-7. ASCE. (2019).