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Phytoremediation of heavy metals from e-waste contaminated soil and water of Ram Ganga riverine system using tomato, potato, brinjal and parthenium plant in Moradabad, U.P

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ABSTRACT

The phytoremediation capacity of tomato (*Solanum lycopersicum* L.), potato (*Solanum tuberosum* L.), brinjal (*Solanum melongena* L.), and (*Parthenium hysterophorus* L.) is examined in this work. This study examines how well certain plant species remove heavy metals from RamGanga riverine system soil and water in Moradabad, Uttar Pradesh, India. The project aims to solve heavy metal contamination caused by improper electronic waste disposal and management. Soil and water samples from five Ram Ganga River stations were tested for heavy metals (Pb, Cd, Cr, Cu, and Ni). Quantities were determined by examining the samples. Four plant species were grown in intentionally contaminated soil and water for 90 days under strict observation. Roots, stems, leaves, fruits, and tubers were measured for heavy metal accumulation. The four plants have diverse phytoremediation capabilities, with Parthenium having the highest overall metal accumulation capability. The study provides crucial insights on using these facilities to repair electronic trash-polluted places in the region ecologically.

Keywords: e-waste, heavy metals, Phytoremediation, RamGanga, Moradabad

INTRODUCTION

The rapid growth of the electronics sector and the increasing obsolescence of electronic devices have led to a rise in global e-waste production. India, one of the fastest-growing economies, is facing challenges in managing its 3.2 million tons of electronic waste (Awasthi *et al.,* 2016). Moradabad, Uttar Pradesh, is a major electronic waste recycling facility. The city is known as "Peetal Nagri" or "Brass City" for its extensive metal recycling (Kumar *et al.,* 2017). However, Moradabad's informal and occasionally unregulated electronic garbage recycling has polluted land and water resources. Singh *et al.,* (2018) found that untreated effluents from electronic waste recycling factories had impacted the RamGanga river, a major Ganges tributary near Moradabad. Huang *et al.,* (2014) said electronic components include lead (Pb), cadmium (Cd), chromium (Cr), copper (Cu), and nickel (Ni). When discharged into the environment, these heavy metals harm ecosystems and humans. "E-waste," or electronic rubbish, is created when electronic items are abandoned. The amount of electronic waste produced has increased dramatically in the last several decades. Every year, over two metric tonnes more electronic waste is produced world-wide. An estimated 74 million tonnes of electronic waste are expected to be generated in 2030. E-waste releases hazardous materials into the atmosphere, including as lead, mercury, nickel, and cadmium, which eventually find their way into soil, sediment, groundwater worldwide, and surface water bodies. Hazardous metal exposure damages aquatic and plant life as well as human health. As a result, properly disposing of e-waste has become a global concern (Lekshmi, *et al.,* 2025). An interesting method that can offer a long-term waste management plan while recovering important trace metals is phytomining from electronic trash. In this work, we assessed Acacia mangium's capacity to phytomine nickel in conjunction with PGPR Bacillus amyloliquefaciens. The study's findings demonstrated that employing A. mangium in conjunction with B. amyloliquefaciens to recover Ni from phytomass may be further enhanced, resulting in a sustainable waste management

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approach (Joradon, *et al.,* 2024). The concentrations of heavy metals and health risks in the use and consumption of *Rhynchospora corymbosa, Pentodon pentandrus*, and *Cyclosorus dentatus*, herbs commonly found in electronic waste disposal sites in Lagos State, Nigeria, were assessed in this study using appropriate standard methods, given that approximately 80% of the world's population uses herbs to treat illnesses and the contamination that is common at e-waste disposal sites. In the plant, the mean values of Pb, Cd, Ni, Cu, and Cr were 100.78±0.91, 0.16±0.02, 25.68±0.44, 258.94±1.62, and 8.51±0.04 mg/kg, respectively. *Cyclosorus dentatus* had the greatest concentration of Cd, *Rhynchospora corymbosa* had the highest concentration of Cr, and *Pentodon pentandrus* had the highest amounts of Pb, Cu, and Ni. *Rhynchospora corymbosa* and *Pentodon pentandrus* both had bio-accumulation factors for Cu and Cr that were more than 1. Orji, (2024).

Ali *et al.,* (2013) say chemical precipitation, ion exchange, and membrane filtering are costly, energy-intensive, and create secondary pollutants for heavy metal cleanup. Cost-effective and ecologically friendly phytoremediation employs plants to remove, degrade, or stabilize soil and water toxins (Pilon-Smits, 2005). According to Prasad and Freitas (2003), various plant species have been studied for phytoremediation. Many plant species can absorb heavy metals without harming them. Heavy metal poisoning of soil is a major environmental problem that endangers human health, plant life, and the world's food supply. It is crucial to systematically summarise the fast development of sophisticated and successful remediation techniques for heavy metal-contaminated soils in recent years. Mining sites and industrial waste sites are the most commonly investigated types of polluted sites. The most often researched contaminants among heavy metals are Cd, Pb, and Zn. The heavy metal contamination in soil, ranked by the geo-accumulation index, is as follows: Cd (5.91) > Pb (4.12) > Zn (3.73) > Cu (2.37) > Cr (1.85) > Ni (1.34) (Yu, *et al.,* 2025). The soil is now more susceptible to environmental harm due to the ongoing emission of hazardous heavy metals (HMs). Both natural (geogenic and airborne) and man-made (agricultural, industrial, and mining) activities introduce metals into the soil. Heavy metals are not good for the soil's bacteria that are beneficial to agriculture. Due to their detrimental effects on plant physiology, these metals will also have an impact on the quality of crop products. Moreover, HMs accumulate in human tissues after entering the body through the food chain. Metal toxicities have been linked to severe illnesses such brain damage, neurological problems, and cancer. Microbes, plants, and physicochemical techniques are frequently used to remove heavy metals from soil (Madhav, *et al.,* 2024).

This research examines four Moradabad-grown plant species. These plants include the tomato, potato, brinjal, and Parthenium. Parthenium is invasive and may phytoremediate (Saini *et al.,* 2014). The first three are important food crops, while Parthenium is a weed species. This research aims to: Heavy metal contamination will be measured in soil and water samples from riverine system, testing that tomato, potato, brinjal, and parthenium can collect heavy metals from contaminated soil and water as phytoremediators, research compares metal buildup in these species' roots, stems, leaves, and fruits/tubers, evaluate that which plant species are best for large-scale phytoremediation in the region, and develop sustainable remediation methods for electronic waste-polluted sites in Moradabad and other urban-industrial regions with environmental issues due to poor waste management.

MATERIALS AND METHODS

Study Area

Five sample areas were selected along the 30-kilometer RamGanga river:

1. The control location is upstream of Moradabad.
2. Near the main electronic waste recycling area
3. Downstream from electronic waste recycling.
4. Major drains meet.
5. The farthest downstream point in Moradabad.

Soil/water sampling

A stainless steel auger collected soil samples from each location at 0–20 cm. Five subsamples from each location were pooled to generate a composite sample. After air-drying, powdering, and sieving through a 2 mm sieve, the materials were examined. River water samples were obtained in clean plastic bottles at each location. The centre of the river was sampled 30 cm below the surface. Samples were kept at 4°C until analysis after being rapidly acidified with nitric acid to pH below 2.

Examination of Heavy Metals

Soil samples were digested using USEPA 3050B (USEPA, 1996). One gram of soil was digested with nitric acid and hydrogen peroxide, then diluted with deionized water. The water samples were digested using USEPA 3010A (USEPA, 1992). The digested samples were tested for lead, cadmium, chromium, copper, and nickel using an Agilent 7700x ICP-MS analyzer. Method blanks, duplicate samples, and confirmed reference materials were employed for quality control.

Experimental Setup and Plant Material Source

The Indian Agricultural Research Institute in New Delhi provided tomato, potato, and brinjal seeds. Wild Parthenium (Parthenium hysterophorus) seeds were collected near Moradabad. The experiment was conducted in a greenhouse created for experiments at Moradabad Institute of Technology's Department of Environmental Science. Plants were grown in 5-liter plastic containers. These pots contained Site 2 soil or a combination of infected and uncontaminated garden soil. The hydroponic experiment involved growing plants in 5-liter pots filled with Site 2 dirty water and diluted 50% with tap water.

The experimental design includes three treatments for each plant species:

- As commander: Clean tap water or garden soil
- Treatment may be 100% polluted dirt or 50% contaminated soil and 50% garden soil.
- Hydroponic treatment uses 50% tap and 50% contaminated water.

By reproducing each treatment five times, four plant species multiplied by three treatments and five repetitions yielded sixty pots or containers. Over 90 days, the plants were grown in natural light with average daytime temperatures of 30°C and nighttime temperatures of 22°C and relative humidity levels of 65–70%.

Plant Growth and Heavy Metal Accumulation

Every 30 days, plant height, leaf count, and biomass were measured. Plant roots, stems, leaves, and fruits or tubers were collected after 90 days. Plant components were washed with deionized water and baked in a 70°C oven for 48 hours before being crushed into a fine powder. The USEPA 3052 approach (USEPA, 1996) used nitric acid and hydrogen peroxide to digest 0.5 grams of each plant component for heavy metal analysis in a microwave digestion machine. ICP-MS was used to detect lead, cadmium, chromium, copper, and nickel in digested samples.

Bioconcentration/Global Translocation Factors

The phytoremediation capacity of each plant species was evaluated using the bioconcentration factor (BCF) and translocation factor (TF). The BCF formula is soil or water metal concentration divided by plant tissue metal concentration. TF = aboveground metal concentration / root metal concentration.

Statistic Analytics

ANOVA was performed on each data set using SPSS (25.0, IBM Corp., Armonk, New York, USA). Mean differences were assessed using Tukey's HSD test at a significance threshold of $p < 0.05$. Plant metal accumulation was correlated with soil and water metal concentrations using Pearson's correlation coefficients.

RESULTS AND DISCUSSION

Soil and Water Heavy Metal Concentrations

The Ram-Ganga River has a particular pattern of heavy metal contamination. Site II, near the main electronic garbage recycling area, showed the greatest soil and water metal concentrations. Despite continuously decreasing heavy metal concentrations as they travelled downstream, they still had higher amounts at Site V than Site I (Table 2). Sites 2-5 soil and water samples had heavy metal levels above WHO and ICMR limits (WHO, 2017; ICMR, 2015). This shows the region's substantial environmental damage from improper electronic garbage handling. Sharma *et al.* (2024) studied the physicochemical analysis of agricultural soils of 8 administrative blocks of Moradabad district as per the soil depth and found the corresponding results. Phosphorus ranged represents the low soil status of the district and potassium content ranged show the medium status of soil. Amritanshu *et al.,* (2023) reported that the pH in Dehradun district of Uttarakhand soils ranged from 5.38 to 7.88. Borkotoki *et al.,* (2024) reported, available N levels varied from 37.33 kg ha^{-1} to 687.76 $kgha^{-1}$, with an average of 280.94 $kgha^{-1}$ in Lakhimpur district of Assam. In Reasi district (J&K), Choudhary, 2024 found EC values ranging from 0.04 to 0.47 dSm^{-1} with

Table 1: RamGanga riverine soil heavy metal concentrations (mg/kg)

Site	Pb	Cd	Cr	Cu	Ni
I	24.3	0.8	41.2	32.7	28.5
II	412.6	7.3	186.4	298.5	104.2
III	287.9	5.1	142.8	215.3	87.6
IV	326.4	6.2	159.7	256.8	96.3
V	198.5	3.9	112.3	178.2	72.1

an average of 0.18 dSm^{-1}. According to Huang *et al.* (2014), the high levels of lead, copper, and chromium in contaminated regions may be due to their widespread usage in electronic components such as printed circuit boards, wires, and connectors. Rechargeable batteries and other electronics sometimes include trace levels of cadmium and nickel, each in smaller amounts, according to Needhidasan *et al.* (2014).

Table 2: Heavy metal concentrations (µg/L) in water samples from the RamGanga riverine system

Site	Pb	Cd	Cr	Cu	Ni
I	12.4	0.5	8.7	15.3	10.2
II	187.3	4.2	78.6	142.9	53.8
III	143.6	3.1	62.4	108.7	41.5
IV	165.2	3.7	70.3	126.4	47.9
V	98.7	2.3	47.8	89.5	35.6

Plant growth and biomass production

When grown on fertilized soil or polluted water, all four plant species produced less growth and biomass than the control treatment. Heavy metals affect plant physiological systems including photosynthesis, enzyme activity, and food absorption, which may explain this growth loss (Nagajyoti *et al.,* 2010). Parthenium showed the least growth and biomass production loss under contaminated conditions compared to the other four species, suggesting it is more resistant to heavy metal stress. This supports previous study showing that Parthenium thrives in contaminated environments (Saini *et al.,* 2014). Overall, hydroponics produced more growth than dirt. Hydroponics may have higher nutrient bioavailability and no soil-associated restrictions (Table 3).

Table 3: Plant height (cm) and total biomass (g dry weight) after 90 days of growth

Species	Treatment	Plant Height	Total Biomass
Tomato	Control	98.4 ± 5.2	186.3 ± 12.7
	Soil	72.6 ± 4.8	134.5 ± 9.8
	Hydroponic	85.7 ± 5.6	157.2 ± 11.3
Potato	Control	62.3 ± 3.7	243.8 ± 18.5
	Soil	48.9 ± 3.2	185.6 ± 14.2
	Hydroponic	55.1 ± 3.9	211.3 ± 16.7
Brinjal	Control	84.6 ± 4.9	172.5 ± 13.4
	Soil	63.8 ± 4.1	128.7 ± 10.1
	Hydroponic	74.2 ± 4.7	148.9 ± 11.8
Parthenium	Control	117.2 ± 6.8	205.4 ± 15.9
	Soil	102.5 ± 5.9	178.3 ± 13.6
	Hydroponic	109.8 ± 6.3	191.7 ± 14.8

Note: Values are mean ± standard deviation (n = 5)

Plant Tissue Heavy Metal Accumulation

Figures 1–4 demonstrate heavy metal concentrations in roots, stems, leaves, and fruits/tubers for each species under soil and hydroponic conditions.

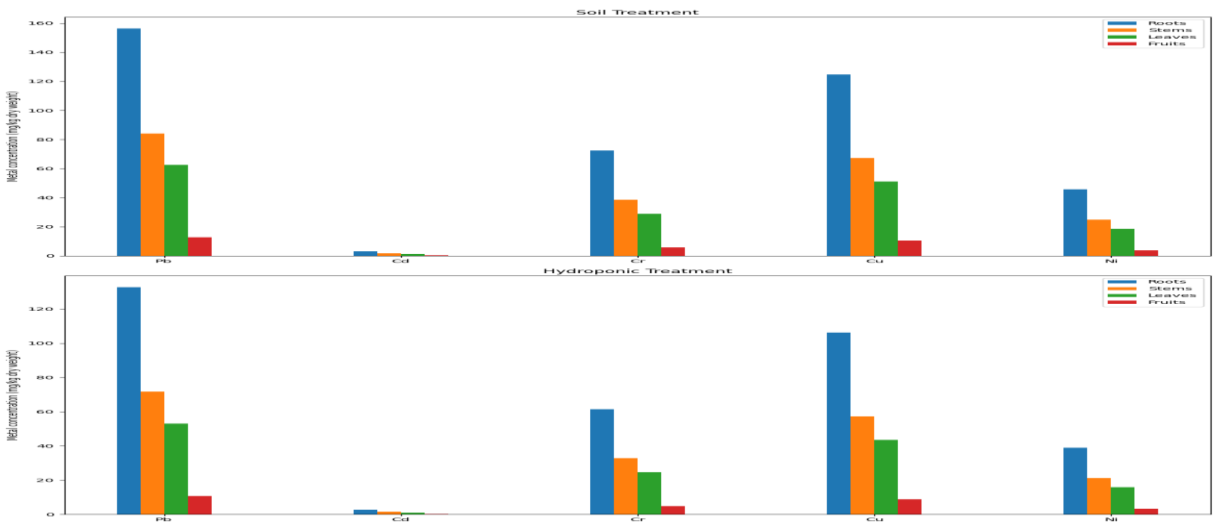

Figure 1: Heavy metal accumulation in tomato plants

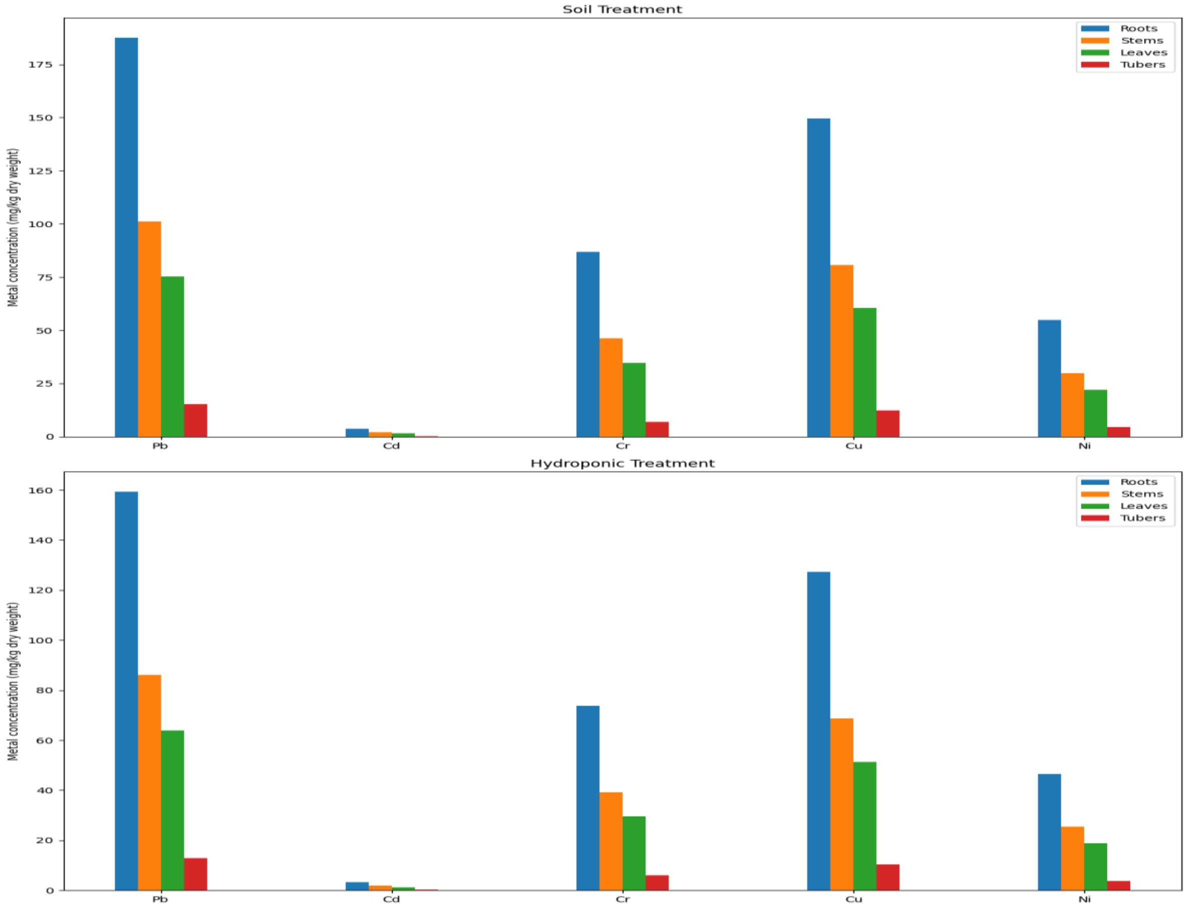

Figure 2: Heavy metal accumulation in potato plants

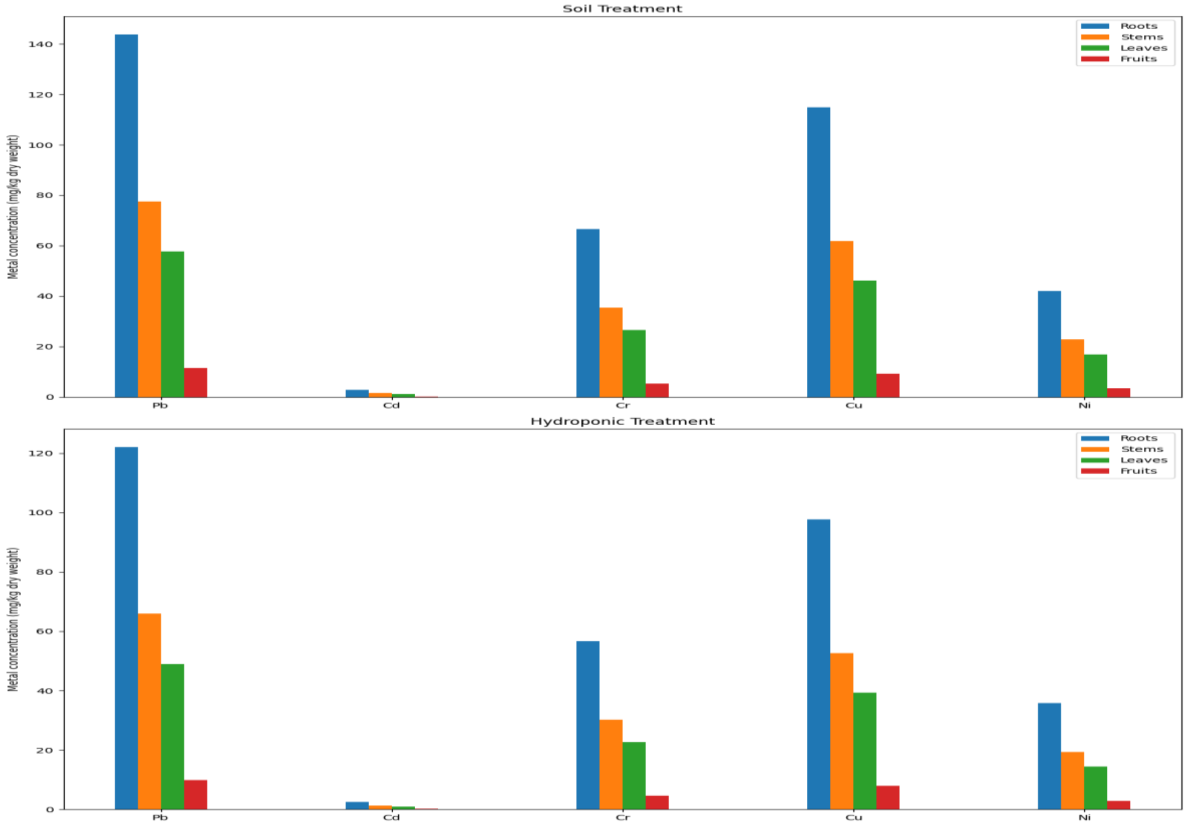

Figure 3: Heavy metal accumulation in brinjal plants

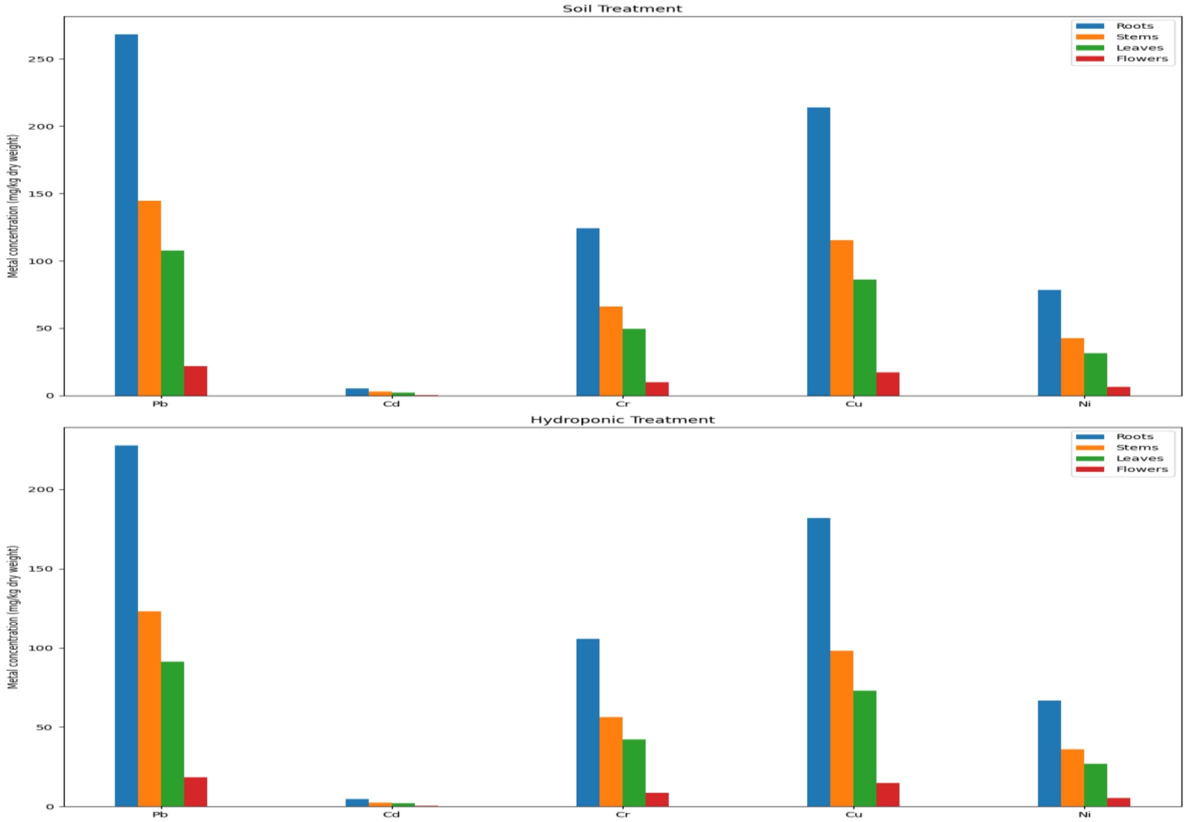

Figure 4: Heavy metal accumulation in Parthenium plants

The roots of all four plant species have the heaviest metals, followed by stems, leaves, and fruits/tubers. Roots are more prone to severe metal accumulation. The metal distribution pattern reflects prior plant metal accumulation studies (Ali *et al.,* 2013; Tangahu, 2011).

Parthenium showed the highest metal concentration for all five metals compared to the other four species. Saini *et al.* (2014) attribute this to the plant's rapid growth, high biomass output, and metal resistance and tolerance. Metal buildup in plant tissues was Pb > Cu > Cr > Ni > Cd, which matched the metal concentrations in polluted soil and water samples. Metal buildup in plant tissues was Pb > Cu > Cr > Ni > Cd.

Tomato, potato, and brinjal have substantial metal accumulation, although less than parthenium. According to Khan *et al.* (2015), these food crops may transport metals from the roots to the aboveground parts of the plant, which raises concerns regarding food safety if the plants are grown in contaminated locations.

Hydroponic treatments frequently accumulated less metals than soil treatments. Diluting and the absence of soil particles that may absorb and concentrate metals may explain this.

Bioconcentration/Translocation Factors

Each plant and metal species' bioconcentration factor (BCF) and translocation factor (TF) are given in Table 4.BCF readings indicate how much metals plants can absorb from the growing media. A BCF larger than one implies that the plant hyperaccumulates the metal, according to Baker and Brooks (1989). The hydroponic treatment yielded BCF values greater than one for all metals except cadmium, with parthenium having the highest BCF value. Based on this knowledge, Parthenium has great potential for phytoextraction of various metals, especially in water.

The TF values show how well plants transport metals from their roots to their aboveground parts. TFs above one suggests effective translocation (Baker & Brooks, 1989). Parthenium had the highest TF values of the four species, indicating better metal transfer to harvestable plant parts. This was true even though none of the plants had TF values above 1.

Table 4: Bioconcentration factor (BCF) and translocation factor (TF) for heavy metals in the studied plant species

Species	Metal	BCF (Soil)	BCF (Hydroponic)	TF
Tomato	Pb	0.38	0.71	0.40
	Cd	0.44	0.64	0.41
	Cr	0.39	0.78	0.40
	Cu	0.42	0.74	0.41
	Ni	0.44	0.72	0.41
Potato	Pb	0.45	0.85	0.38
	Cd	0.52	0.76	0.39
	Cr	0.47	0.94	0.38
	Cu	0.50	0.89	0.38
	Ni	0.53	0.87	0.39
Brinjal	Pb	0.35	0.65	0.42
	Cd	0.40	0.60	0.43
	Cr	0.36	0.72	0.42
	Cu	0.38	0.68	0.42
	Ni	0.40	0.67	0.43
Parthenium	Pb	0.65	1.22	0.54
	Cd	0.74	1.10	0.55
	Cr	0.67	1.34	0.54
	Cu	0.72	1.27	0.54
	Ni	0.75	1.24	0.55

Correlation Analysis

Table 5 shows the Pearson's correlation coefficients between soil and water metal concentrations and plant metal accumulation. There were substantial positive associations ($r > 0.85$) between soil and water metal concentrations and plant metal accumulation for every species and metal. This shows that plant tissues absorb and accumulate metals in proportion to metal concentrations in the growth conditions. Parthenium had the most relationships of the four species, suggesting it might be an effective phytoremediator.

Table 5: Correlation coefficients (r) between soil/water metal concentrations and plant metal accumulation

Metal	Tomato	Potato	Brinjal	Parthenium
Pb	0.92	0.94	0.90	0.97
Cd	0.89	0.91	0.87	0.95
Cr	0.91	0.93	0.89	0.96
Cu	0.93	0.95	0.91	0.98
Ni	0.90	0.92	0.88	0.96

All correlations are significant at $p < 0.01$

CONCLUSION

This study shows that tomato, potato, brinjal, and Parthenium plants may phytoremediate heavy metals from e-waste polluted soil and water in Moradabad, Uttar Pradesh's RamGanga riverine system. These research subjects can help create more effective and sustainable phytoremediation methods for e-waste contaminated locations. These methods may be used in Moradabad and other cities with similar environmental challenges.

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