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INNOVATIVE E-WASTE MANAGEMENT WITH PHYTOREMEDIATION: TWO DECADES OF RESEARCH

Environmental Science

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ABSTRACT

Background: The increasing use of electronic devices has led to a significant global rise in E-waste production. Several methods are employed to manage and recycle E-waste. When E-waste is burned or dismantled, it releases toxins into the air, and soil, contaminating the atmosphere and groundwater. This pilot study aimed to investigate whether selected non-edible plants could extract heavy metals from E-waste (phytoaccumulation) and help reduce environmental pollution. **Methods:** Three plant species from the families Apocynaceae, Moraceae, and Araceae were chosen; the money plant (Epipremnum aureum), desert rose (Adenium obesum), and banyan species (Ficus microcarpa, bengalensis, religiosa). These young plants were planted in sealed pots containing a mix of E-waste material and standard garden soil and grown outdoors. Foliage samples were analyzed for metal content using Atomic Absorption Spectroscopy (AAS) at the beginning and after a decade for two decades. Epipremnum aureum was discontinued after one decade. The condition of the E-waste and plant health were assessed. **Results:** Analysis of foliage samples from plants grown in E-waste revealed significant changes in bioaccumulation of Cu, Pb, and Zn after a decade for three decades. Many Printed Circuit board components and other electronic materials had corroded, leaving only plastic and recyclable metal remnants. Plant growth and health were not adversely affected by the bioaccumulation of heavy metals. Adenium obesum and Ficus species have effectively extracted Cu, Pb, and Zn grown on soil mixed with E-waste. Money plants could extract Cu and Zinc significantly. Quantitative variables were summarized using mean and standard deviation. The Chi-square test investigated relationships between before and after, metal values from leaf samples. An IBM SPSS Windows version 26.0 software was used for analysis with a significance level set at 0.05 **Conclusion:** Managing E-waste remains a significant challenge. This two-decade-long pilot study demonstrated that certain plants could extract toxic metals from E-waste, preventing their leachate into the soil. These plants can accumulate and potentially utilize these metals without being harmed. Further studies are needed to understand the long-term fate of these metals as the plants mature.

KEYWORDS

e-waste, plants, polychlorinated biphenyls, landfills, heavy metals, soil, crops, dumpsite.

INTRODUCTION:

The electronics industry is the world's largest and fastest.growing industrial sector. The demand and the rate of consumption of these appliances have expanded globally (1). People depend on electronic gadgets for domestic and professional needs, and with the widespread use of gadgets there is a huge segment of electrical waste on the planet. According to a survey, out of seven million who live on this planet, approximately 6 billion people use mobile phones as a basic need now (2). E-waste poses a hazard to the ecosystem and human health. The phrase E.waste, or electronic trash, refers to obsolete and end.of.life electronics such as televisions, laptops, generators, freezers, computers, and other electronic gadgets that have been discarded by their owners. Since E.waste composition is quite difficult and complex, it constitutes more than 1000 substances. These are subdivided into hazardous and non-hazardous categories (3). Heavy metal pollution of the environment, even at low levels, and their resulting long-term cumulative health effects are among the leading health concerns all over the world. For example, bioaccumulation of Pb in the human body interferes with the functioning of mitochondria, thereby impairing respiration, and also causes constipation, swelling of the brain, paralysis, and eventual death (4). Lack of handling techniques for E.waste management, and the increasing volume of electronic waste produced, become a bigger risk to human health and the environment and have a significant influence on both physical and emotional health, whether direct or indirect. The fast advancements in automation have resulted in a reduction in the number of legislations governing E.waste recycling (5). E-waste disposals impact human health in two ways which include: (a) food chain issues: contamination by toxic substances from disposal and primitive recycling processes that result in byproducts entering the food chain and thus transferring to humans; and (b) direct impact on workers who labor in primitive recycling areas from their occupational exposure to toxic substances. There are many sources of E-waste created in India. Household activities account for 15% of the source, the government, public, and commercial sectors for another 15%, and electrical and electronic trash accounts for the majority of the remaining 70% (6). Improper disposal of E-waste resulting in increased levels of dioxin (15-56 times the WHO recommendations) in the air found to be raised in human milk, placentas, and hair, indicating that dioxins are being ingested in significant quantities by humans through the air, water, or food to pose a serious health risk (7). There are several methods are currently available for managing E-Waste over the globe. Landfilling and incineration are likely to contaminate ground groundwater and raise atmospheric pollution. People are employed in recycling technologies of extracting metals, toners, and plastics from computers and other e-waste polluting are following primitive technology (8). Microremediation and Phytoremediation are utilized to eliminate, contain or transform the contaminants to nonhazardous or less-hazardous form in the environment. The act of removing toxic metals from the environment by the use of metal-accumulating plants is termed phytoremediation (9). There are four basic methods employed in remediation using plants, Phytoextraction, Phytovolatilization, Phytostabilization and Rhizofilteration. Plants can extract heavy metals like Iron, Tin, Copper, Manganese and Vanadium and could serve as plant nutrients, but Mercury, Lead, Cadmium, Silver, Chromium, and many others are non-biodegradable and can undergo global ecological circles, these are produced as a result of human activities and could be very toxic even at low concentrations (10). Our pilot study aims to observe the phytoaccumulation of Cu, Pb, and Zn by selected perennial plants grown in controlled E-waste Garden pots. This may help as a novel method in addition to existing E-waste management procedures.

METHODS:

E-waste materials such as PCBs (Printed Circuit Boards) and discarded electronic components were collected safely and segregated as per size and volume. Discarded printer bodies, CPU bodies, and ordinary garden pots with standard garden soil composed of soil, sand, organic compost, and gravel, were selected to make E-pots. E-waste materials were closely packed and placed in E-waste pots. This growing medium is mixed with E-waste materials and placed tightly. The drainage holes were sealed to prevent the leaching of toxic chemicals outside the E-pots. E-pots were placed in outdoor gardens in a controlled area. They were protected from direct rain, strong winds, and their fallen leaves were collected and put back in the pot. The garden soil was added to all the pots yearly to keep them healthy. They were watered in a controlled manner to prevent flooding, root rot, and leaching from the pot. The healthy growth of the plant and leaching from the E-pot were monitored periodically.

Plant Samples:
Three plants from each species, and three species, (Apocynaceae, Moraceae, Araceae) were selected for study, money plant (Epiprenum aureum), desert rose (Adenium obesum), and banyan species (Ficus) to grow in E-waste. We have chosen these plants because of their morphology and their widespread use.

Leaf samples were studied for heavy metals at the time of planting (Before) and after (After) ten years and twenty years. Excess growth and dry leaves were carefully planted back in the E-pot. Atomic Absorption Spectrophotometry was leaf samples were analyzed with standard techniques (Shimadzu AAS 7000, ThermoSientific, PerkinElmer, Shimadzu). Quantitative variables were summarized using mean and standard deviation. The Chi-square test investigated relationships between before and after, metal values from leaf samples. An IBM SPSS Windows version 26.0 software was used for analysis with a significance level set at 0.05.

RESULTS:
Results of the first decade (2005-2015) are discussed in this paper. The plants, Ficus bengalensis, Money plant, and Adenium had phytoaccumulated Cu significantly. Ficus macrocarpa could phytoaccumulate Pb significantly, but no significant differences in the accumulation of Cu and Zn. The money plant is efficient in absorbing Zn. Adenium obesum is a commonly grown ornamental plant and is very efficient in the absorption of all three heavy metals.

Ficus bengalensis, Ficus religiosa, Adenium obesum, and Ficus macrocarpa have significantly phytoaccumulated Pb. These results are recorded after the first decade (Table 1), the second decade these plants are currently surviving healthy. There are no toxic effects on their vegetative parts noted on periodic examination of plants.

DISCUSSION:
Public and private sectors replace older electronic products with new ones, increasing E.waste garbage. Mobile phones and PC manufacturers, enterprises, institutions, and industries create major E.waste as compared to household E-waste. There is no accurate way to estimate the created E.waste since no one knows how much E.waste is produced or how much is imported and exported to other nations. On the other hand, getting accurate statistics on recycled E.waste by various sectors is problematic (11). Numerous researchers have demonstrated that toxic metals and polyhalogenated organics including polychlorinated biphenyls (PCBs) and polybrominated diphenyl ethers (PBDEs) can be released from e-waste, posing serious risks of harm to humans and the environment (12, 13). Some authors concluded that discarded electronic devices that contain a color CRT or printer wiring boards with Lead-bearing solder have the potential to be hazardous waste for Lead (14). Plants respond to environmental pollutants, such as heavy metals. Toxic metal ions disrupt cellular protein homeostasis by interfering with the proper folding and aggregation of new proteins and reducing cell viability.

Plants have mechanisms that help detoxify heavy metals, enhancing their heavy metal tolerance. Plants depend on chelating metal ions by using phytochelatins and metallothioneins, sequestering metals in vacuoles, and repairing or degrading stress-damaged proteins that fail to fold correctly. Recent advances explain how plants maintain a functional and healthy proteome under heavy metal stress, shedding light on their survival strategies in challenging environments (15). Phytoremediation is a green, eco-friendly, and low-cost technology recognized as an effective method for the remediation of metal-contaminated soils (16). Landfilling disposal of E-waste needs efficient leachate management to prevent Lead pollution. Studies showed the presence of BFRs in leachate from landfills in Japan. Higher concentrations of BFRs, PBDEs and TBBPA (Brominated flame retardants, Polybrominated diphenyl ethers and Tetrabromobisphenol-A) were detected in the landfills that had crushed E-waste (17). Incineration may be a viable option for electronics waste disposal, provided an appropriate particulate control device is used to control metal emissions (18). According to WHO, the normal Pb range for air is 2 mg kg-1 dry weight, one Indian study demonstrated that Pb concentrations were higher in the leaves of roadside trees much above WHO standards (19). Hyperaccumulators are plants that can accumulate metals almost 50-100 times higher than non-accumulating plants. They accumulate metals within their different tissues and can either convert them in a form that is not even toxic for plants or can uptake heavy metals in their aerial parts which can later be harvested. The most important application of phytoremediation is that it ensures the removal of unwanted toxic materials from the site of pollutants without harming any other neighboring plants (20). Biological features of plants decide the selective absorption and accumulation of heavy metals. An interesting study revealed that copper and zinc inhibited the uptake of lead from soil to the biomass of lettuce, spinach, carrots, and potatoes when they coexisted in soil. Thus, using micronutrients in farming can reduce the accumulation of heavy metals from soil to plants which could provide valuable information for safe food production (21). Money plants can be used as an accumulator of trace metals and other anionic contaminants such as chloride and sulfate, more than 50% of fluoride is accumulated in the leaf and leaf attachments of the plant (22). The current pilot study demonstrates that common plant species can be employed for controlled e-waste management through phytoremediation. After a ten-year cultivation period, it was observed that Printed Circuit Boards and other components had degraded, leaving primarily plastic and a few metal elements, which can be readily recycled. Plants can be cultivated on e-waste materials, utilizing concrete ponds to contain large volumes of various e-waste components. Continuous monitoring of leachate management is critical throughout the process.

CONCLUSION:
E-waste management continues to pose a substantial challenge. This two-decade pilot study demonstrated that common plants can extract toxic metals such as Cu, Pb, and Zn from e-waste, effectively preventing their leaching into the soil. The plants were able to accumulate these metals without showing signs of harm and may potentially utilize them. However, further research is necessary to fully understand the long-term fate of these metals as the plants reach maturity.

Limitations:
This pilot study is innovative, with the second-decade review scheduled for next year; thus, only the results from the first decade are currently available. E-pots require protection from rainfall to prevent leaching. The study was conducted on a limited number of plant species, which showed promising outcomes. However, further observation is needed to determine whether these trees can utilize phytoaccumulated heavy metals without adverse effects. More detailed, controlled studies are necessary before developing comprehensive guidelines for future applications.

Table – 1 Mean values of Heavy Metal in Plant Leaves (2005-2015)

Name of the Plant Species	Copper (Before)	Copper (After)	Lead (Before)	Lead (After)	Zinc (Before)	Zinc (After)	Remarks
Ficus bengalensis	1.09	2.03*	0.14	1.85*	28.09	28.1#	Plant is Healthy
Ficus religiosa	4.74	5.00#	0.09	1.99*	18.32	20.01#	Plant is Healthy
Adenium obesum	0.87	1.21*	0.57	1.63*	12.04	15.77*	Plant is Healthy
Ficus microcarpa	0.97	1.66#	0.66	2.0*	27.2	28.11#	Plant is Healthy
Epiprenum aureum	0.13	1.26*	0.12	0.43#	14.21	16.02*	Plant is Healthy

Not Significant, * Significant $p < 0.05$

Declarations:
Ethical Approval
Not applicable on this work.

Conflict of Interest
This manuscript does not include conflict of interest.

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Availability of data
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Declaration Of Competing Interest

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Figure 1&2- Adenium obesum (2015)

Figure 3 Ficus microcarpa (2015)

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