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Potential Phytoremediation of Designated Heavy Metal-contaminated Soils by Jute (*Corchorus capsularis*is) and Scent Leaf (*Ocimum gratissimum*)

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Abstract
The potentials of jute (Corchoruscapsularisis) and scent leaf (Ocimumgratissimum)for phytoremediation of three designated metal-contaminated soilswere investigated. Co, Sr, Cr, Mn, Zn, Cu, Ti, Al and Fe were detected in all the soil samples with Fe, Al and Cu being most prominent prior to planting.Based on their uptake factors, the vegetables studied were classified as hyperaccumulators, hypoaccumulators and isoaccumulators where uptake factors were greater than one, less than one and equal to one respectively. The leafy vegetables studied were hypoaccumulators for the removal of cobalt (Co) from the contaminated soils, and were hyperaccumulators for selective removal of Al, Cu, Zn, Cr and Sr. Generally, phytoremediation potentials of these leafy vegetablesdepended on both the nature of the plants and the type of soil. However, blends of these vegetables as a phytoremediation kitwould be more effective than single vegetables for contaminated soil phytoremediation.

Keywords: *Phytoremediation; heavy metals; hyperaccumulators; non-hyperaccumulators; plant uptake factor*

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I. Introduction

Accumulation of heavy metal in soil has rapidly increased over the past decades due to increased natural processes, industrial activities and urbanization, giving rise to global concerns (Suman*et al.*,2018; Ashraf *et al.*, 2019).Being non-biodegradable, heavy metals are persistent, toxic and carcinogenic; they bioaccumulate in the human body by finding their way into the human food chain through plants (Sarwar*et al.*, 2010;Suman et al., 2018).Their entry point into plants, which serve as meal for man, is soil – a universal nutrient facility to plants.

Soil is a prominent receiver and storage of heavy metalsgenerated from oil-based wastewater, metal mining and smelting, fossil fuel burning, sewage sludge, agricultural activities and electroplating (Neff *et al.*, 2011; Farahat and Linderholm, 2015; Chen *et al.*, 2016; Muradoglu*et al.*, 2015; Hamzah*et al.*, 2016; Rafique and Tariq, 2016; Iqbal *et al.*,2016).

Grouped as essential and non-essential, heavy metals such as Cu, Fe, Mn, Ni and Zn are essential for plant growth, when present in permissible proportion (Cempel and Nikel, 2006) whereas heavy metals such asPb, Cd, As and Hg are highly toxic with no known function in plants, even as low concentration (Fasani*et al.*, 2018; Clemens, 2006).

Considering the effect of heavy metals on both the ecosystem and human health, there is need to prevent them from entering into the ecosystem. Remediation approach is a versatile measure of restoring the quality of a contaminated soil, water and air (Gerhardt *et al.*, 2017; Hassan *et al.*, 2019) without losing these materials.Better than mechanical or physiochemical remediation techniques is phytoremediation, which is plant-based, eco-friendly, low cost, high recyclability and efficient low concentration (Sheoran*et al.*, 2011; Wuana and Okieimen, 2011; DalCorso*et al.*, 2019; Ali *etal.*, 2013;Berti and Cunningham, 200;Yan *et al.*, 2020). This is due to the uncommon potential of plants to absorb ionic compounds in the soil even at low concentrations through their root system(Ali *et al.*, 2013; Jacob *et al.*, 2018; DalCorso*et al.*, 2019).

Based on their phytoremediation potentials, plants have generally been classified as hyperaccumulators and nonhyperaccumulator; when plant uptake factor (PUF) is one or greater than one, the plant is classified as a hyperaccumulator (Zakka*et al.*, 2014), otherwise, it is a non-hypoaccumulator. While hyperaccumulators store heavy metals above ground parts, the non-hyperaccumulators store them below ground organs (Ghori*et al.*, 2015).Hyperaccumulation of heavy metals in plants depends on factors such as plant species, physicochemical properties of soil and the nature of heavy metals (Mwegoha and Kihampa, 2010; Chaudhary *et al.,* 2016).

The seeds of jute (*Corchoruscapsularis*is) and scent leaf (*Ocimumgratissimum*),were selected and grown on the samples of designated metal-contaminated soils to study their phytoremediation potentials.

Jute(*Corchoruscapsularis*)is a tall annual herb of 2-4m unbranched height. Its leaves are alternate, flowers are small and fruit of many seeded capsules. It thrives almost anywhere and can be grown all year round (Islam *et al.*, 2013).

Scent leaf (*Ocimumgratissimum)*belongs to the family *Lamiaceae*, scented shrub with lime green-leaves and widely distributed in the tropical Africa and Asia (Alexander, 2016). Literatures have revealed its uses for both medicinal and nutritional purposes (Alexander, 2016; Priyanka *et al.*, 2018).

The aim of this study was to investigate theuptake factors of jute (*Corchoruscapsularis*is) and scent leaf (*Ocimumgratissimum*)as a measure for their phytoremediation potentials of designated metal-contaminated soils.Based on their values of uptake factors, the plants shall be classified as either hyperaccumulators, hypoaccumulators or isoaccumulators. The choice of these tropical leafy vegetable was borne out of their underutilization, availability, ability to grow all year round, resistance to adverse growth conditions and eco-friendliness.

II. Materials And Methods

Sources of Materials

Metal-contaminated soil samples were obtained from three (3) designated areas in south-west Nigeria. All the vegetable seeds were obtained from a local farm in Ibadan, Oyo State were identified in the Department of Biological Sciences, University of Medical Sciences, Ondo-City as jute (*Corchoruscapsularis*) and scent leaf (*Ocinumgratissimum*). All the reagents used were of analar grade and were used as purchased.

Collection of Metal-Contaminated Soils

Three (3) different locations were designated for the collection of metal-contaminated soils, which were: ***Location1***(*Latitude* NS: 7^{o}11`67.209``; *Longitude* EW: 4$^{o}$82`64.668``): A metal dumping site at Sabo Market, Ondo-Ore Road, Ondo-West LGA, Ondo State (Figure 1); ***Location 2***(*Latitude* NS: 7^{o}09`19.894``, *Longitude* EW: 4$^{o}$82`81.425``):Refuse site at General Hospital vicinity, Ondo-West LGA, Ondo State (Figure 2); and ***Location 3***(*Latitude* NS: 7^{o}49`62.447``, *Longitude* EW: 4$^{o}$47`72.108``)**:**Iron and steel Smelting Industry, Modakeke, Ile-Ife, Osun State (Figure 3).Random samples of soils from the study locations were taken at uniform depth of 15 cm with the aid of a hand trowel that had been pre-cleaned with concentrated nitric acid in order to prevent heavy metal contamination prior to analysis (Oladebeye*et al.,* 2020).

Cultivation of Leafy Vegetables

The standard method of Intawongseand Dean (2006) was adopted for the cultivation of the seeds of jute (*Corchoruscapsularis*) and scent leaf (*Ocinumgratissimum*) with some modifications. The seedlings obtained for each vegetable after two (2) weeks of seed germination were transplanted into three (3) respective plastic pots loaded with 100 g each of the metal-contaminated soils, making a total of six (6) plastic pots for this study. The vegetables were grown under room temperature in a well ventilated and illuminated laboratory. They were allowed to grow for ten (10) weeks well irrigated using distilled water. Mature leafy vegetables harvested as whole plants were thoroughly washed with distilled water, packaged, labelled and stored at 4^{o}C prior to analysis.

Preparation of Vegetable Samples

The vegetable samples were first washed with tap water and subsequently, with de-ionized water to remove air pollutants. Moisture was removed from the samples by oven-drying them at 105 ^{o}C for 48 h. The dried samples were pulverized, using agate pestle and mortar, sieved (0.5 mm mesh size), labelled and stored in dry plastic containers that had been pre-cleaned with concentrated nitric acid to check heavy metal contamination prior to analysis (Oladebeye*et al.,* 2020).

Preparation of Soil Samples

The soil samples were air dried for 48 h, ground and sieved using 0.5 mm mesh size sieve tohave uniform particle size. Each sample was labelled and stored in a dry plastic container that had been pre-cleaned with concentrated nitric acid prior to analysis with X-ray fluorescence (XRF) spectrometer (Oladebeye*et al.,* 2020).

Determination of Elemental Compositions

The sample was oven-dried at 80 °C for 20 h, ground after cooling, sieved with 50 μm sieve-size and pellet with weight of 200 mg and diameter of 2.5 cm was made in a pellet-pressing machine under 15 ton of pressure. The pellet was irradiated with a primary radiation from a Cd-109 radioactive source for a period of 2500 s. Two irradiations were done; pure sample and sample with a molybdenum target on top. These two measurements were then used to calculate the absorption corrections. The characteristic x-rays emitted by the elements in the sample were detected by a liquid nitrogen cooled Si (Li) detector. To obtain optimum detection of elements, different filters of 0.05 mm Ti filter at applied voltage of 14-35 kV and 900 mA and 0.05 mm Fe filter at 37 kV and 45 mA current were used (Guerra*et al.,* 2014; Oladebeye*et al.,* 2020).

Plant Uptake Factor (PUF)

Here, PUFwas deduced mathematically by dividing the concentration of metal in the plant by the concentration of the same metal in the soil sample after cultivation (Kachenko*et al*., 2006; Tsafe*et al*.,2012; Rezapour*et al.,* 2019; Keeflee*et al.,* 2020).

Statistical Analysis

Simple Peasron's Correlations for the heavy metals was performed, using IBM SPSS 23.0 software (SPSS, Inc., Chicago, IL).

III. Results and Discussion

Heavy Metal Concentrations in Contaminated Soils and Vegetable Samples

Chromium (Cr), zinc (Zn), manganese (Mn), iron (Fe), aluminium (Al), copper (Cu), cobalt (Co), titanium (Ti) and strontium (Sr) are the heavy metals detected in the designated contaminatedsoils and the vegetables grown on them (Figures 4-6). In metal-dumping site, Fe is the most abundant (12.43 mg/kg), followed by Al (3.36mg/kg) and cobalt the least (0.06 mg/kg). The same trend is observed in other soil samples. Fe is an essential constituent for all plants and animals, which,at high concentration, causes tissues damage, anemia andneurodegenerative conditions in humans (Shah *et al.,* 2013). The WHO recommended level of iron in medicinal plants is 20 mg/kg while its dietary intake is 10–28 mg/day. The Fe concentration bioavailable in the soil and plant samples will not pose any health damage to both animals and humans. Cobalt (Co) and strontium (Sr) are found available at 0.03 mg/kg in refuse-site contaminated soil. Deficiency of cobalt leads to symptoms, which include loss of appetite, emaciation, anemia, weaknessand decreased production (González-Montaña*et al.,* 2020).RDA value for cobalt is 0.3mg/day (Gezahegn*et al*., 2017). Inorganic cobalt has no nutritional value, but sometimes is added to beer as an anti-foaming agent (Habschied*et al.,* 2020).

Figures 4-6 alsoshow that the most abundant metal in all the vegetable samples is aluminium (Al), ranging from 2.67 to 7.99 mg/kg. The WHO permissible limit of aluminum in the body ranges from 5 to 10 mg/kg (Ibrahim *et al.,* 2022). This research workshows that the peak concentrations of Al in jute (7.99 mg/kg) and scent leaf (6.28mg/kg) are within the permissible limit of WHO.

Correlation of Heavy Metals

Table 1 depicts the Pearson correlations coefficients, r among the heavy metals detected in the both the soil and vegetable samples studied ($P < 0.01, 0.05$). There are strong positive correlations ($P < 0.01$) between Cr and Mn (0.959), Fe (0.788) and Co (0.758); between Zn and Cu (0.841), Co (0.757), Ti (0.782) and Sr (0.852), between Fe and Co (0.927), and Ti (0.873); between Cu and Sr (0.816); between Co and Ti (0.822). Similarly, strong positive correlations ($P < 0.05$) exist between Zn and Fe (0.666), Mn and Fe (0.706), Mn and Co (0.625), and Ti and Sr (0.611). A strong negative correlation($P < 0.05$) exists between Al and Sr (-0.635).

Plant UptakeFactors (PUF)

Metal-Dumping Site Soil

PUF, a measure of the bioavailability of an element at a particular position in a species of plant, is mathematically expressed as the ratio of concentration of a metal in the plant to theconcentration of the same metal in the soil sample (Kachenkoand Singh, 2006; Tsafe*et al.,* 2012). Table 2 shows that the plant samples have significant differences in the uptake factors of metals relative to the availability of the same metals in the soil.

From the metal-dumping site soil in this study, jute leaf (*Corchoruscapsularis*)and scent leaf (*Ocinumgratissimum*) have less than one PUF value for Cr, Zn, Mn, Fe, Cu, Co, Ti and Sr, implying them as non-hyperaccumulators for these heavy metals. This arises from the poor translocation efficiency of the heavy metals through the xylem due to weak chelating affinity with the metal transporters in the plant (Chaudhary *et al.,* 2016). However, the same plants are hyperaccumulators for Al, having PUF values of 2.38 (jute leaf) and 1.28 (scent leaf). This implies high translocation efficiency of Al in the xylem of the plants.

Refuse-SiteSoil

Both jute leaf (*Corchoruscapsularis*) and scent leaf (*Ocinumgratissimum*) used in this study are hyperaccumulators for Cr, Cu and Sr detected in refuse-site soil, having exhibited PUF values greater than one (Table 2). Selective removal of Zn and Mn from the contaminated soil is possible with jute leaf and scent leaf respectively. Hyperaccumulation of Cu from the contaminated soil, which is twice in jute leaf compared to scent leaf, indicates the greater affinity between the chelation process and transportation of metals in the xylem (Chaudhary *et al.,* 2016).

Ironand Steel Smelting Industry Soil

From Table 2, the plant uptake factor in the Iron and SteelSmelting contaminated soil is found in the sequence ofCo (0.00) <Ti (0.05) <Fe (0.06) <Mn (0.08) <Cr (0.09) <Zn (0.15) <Al (0.69) <Sr (1.43) <Cu (5.50) by jute leaf, and Co (0.00) <Mn (0.04)<Fe (0.07) <Ti (0.09) <Cr (0.15)=Zn (0.15) <Sr (0.57) <Al (1.28) <Cu (5.50) byscent leaf. Itis observed that Cu has the same uptake factor of 5.50 by both plants, which is the highest among all the metals while the least uptake factor (0.00) is obtained for Co.Jute leaf is a hyperaccumulator for Sr and Cu and a non-hyperaccumulator for Cr, Zn, Mn, Fe, Al and Ti. On the other hand, scent leaf is a selective hyperaccumulator for the removal of Al and Cu from the soil, but a non-hyperaccumulator for the remediation of Cr, Zn, Mn, Fe, Sr and Ti in the contaminated soil from Iron and Steel Smelting Industry. These differences in hyperaccumulation depend on the different uptake factor values of the plants, which can be influenced by the soil type, metal type and the mechanism in the internal plant organs (Mwegoha and Kihampa, 2010; Chaudhary *et al.*, 2016),

IV. Conclusion

This study describes phytoremediation potentials of cultivated jute(*Corchoruscapsularis*) and scent leaf(*Ocimumgratissimum*)on their potentials as hyperaccumulators of Cr, Zn, Mn, Fe, Al, Cu, Co, Ti and Sr from contaminated soils obtained from different locations designated as metal dumping site, refuse contaminated soil and iron and steel smelting industry. Their potential as hyperaccumulators varies among the different contaminated soils examined. Jute leaf has been identified as a hyperaccumulator for Cu in both refuse site and iron and steel smelting contaminated soils. Both plants are suitable hyperaccumulators for Al in metal dumping site with major source of heavy metals from automobile spare parts and for Zn and Mn in refuse site with diverse municipal sources of heavy metals. Sr can selectively be removed from refuse site and iron and steel smelting contaminated soils by jute leaf. Harnessing the individual potentials of the plants studies into a composite may seem to perform better than the individual plants when used singly.

Statements and Declarations

Ethical Responsibility of Authors

All authors have read, understood, and have complied as applicable with the statement on "Ethical responsibilities of Authors" as found in the Instructions for Authors.

Ethical Approval

Not applicable to this article.

Authors' Contributions

All authors contributed to the study conception, design and execution. Material preparation, data collection and analysis were performed by Abraham OlasupoOladebeye, Janet Odunayo Adebayo, AdewaleFataiAdeyemi and Walter BankoleOsungbemiro. The first draft of the manuscript was written by Abraham OlasupoOladebeye and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

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Competing Interests

The authors have no competing interests to declare that are relevant to the content of this article.

Availability of Data and Materials

All the data and materials in this article originated from the research designed and carried out by the authors, and are available from the corresponding author on reasonable request.

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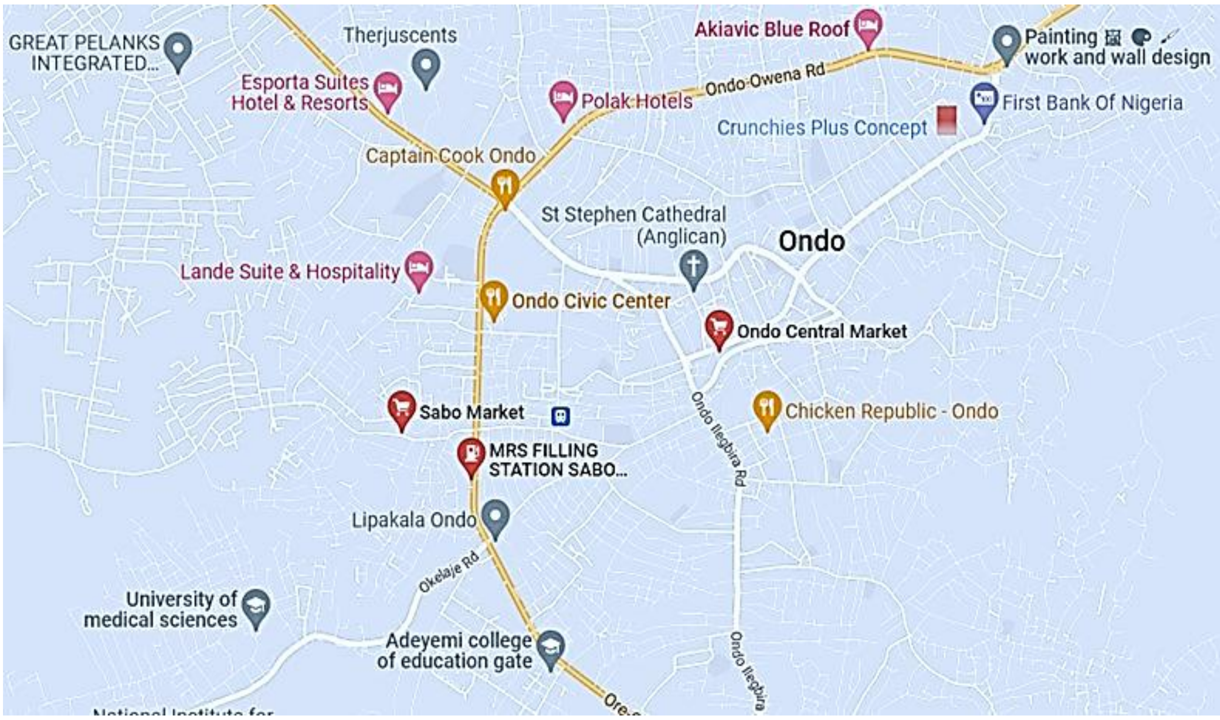

Figure 1. Map of metal-dumping site at Sabo Market, Ondo-Ore Road, Ondo-West LGA, Ondo State**(***Source:GoogleMaps***)**

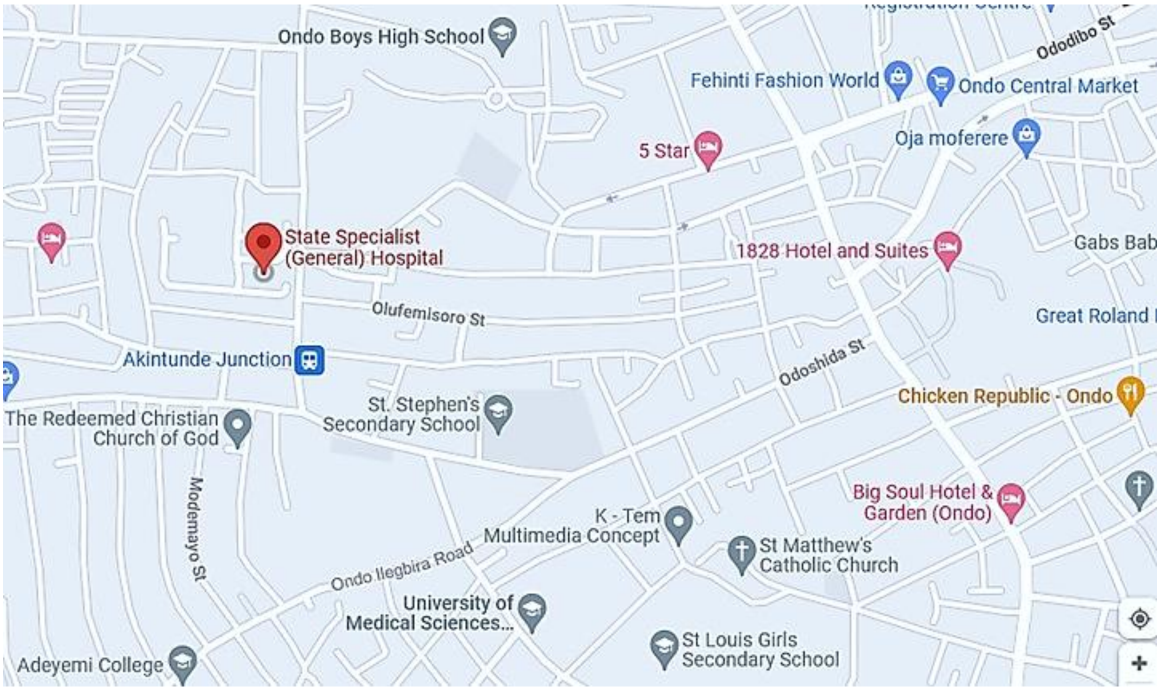

Figure 2. Map of Refuse site at General Hospital vicinity, Ondo-West LGA, Ondo State**(***Source:GoogleMaps***)**

Figure 3. Map of Iron and steel Smelting Industry, Modakeke, Ile-Ife, Osun State**(***Source:GoogleMaps***)**

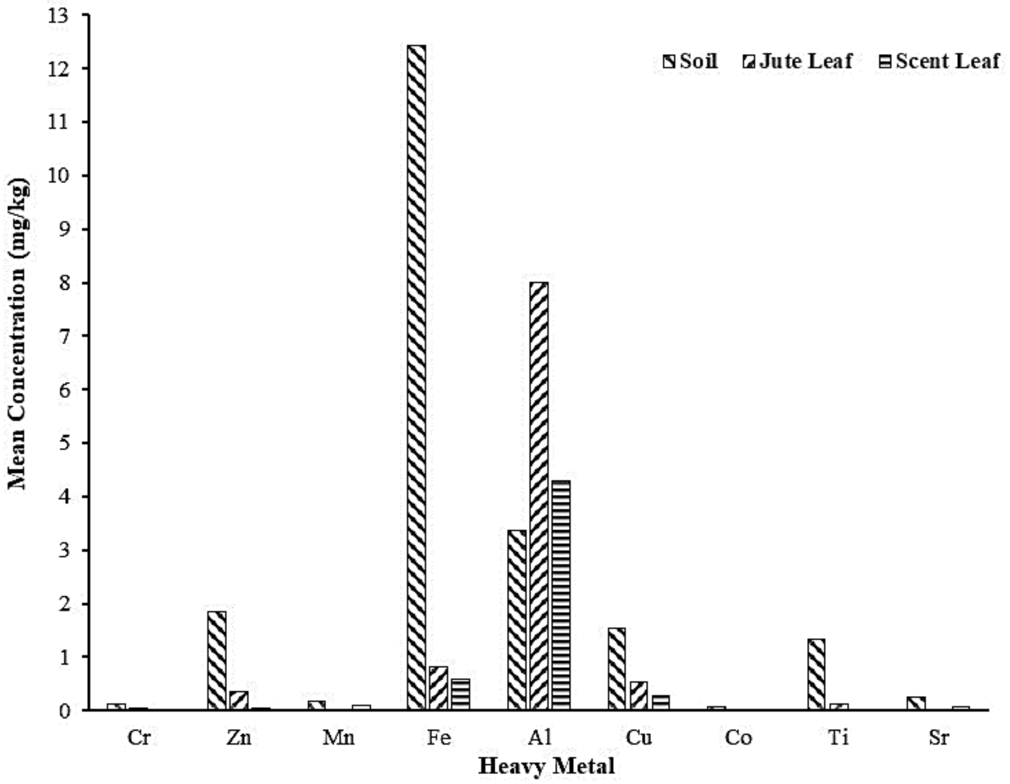

Figure 4. Mean heavy metal concentrations in metal-dumping site soil and cultivated plants

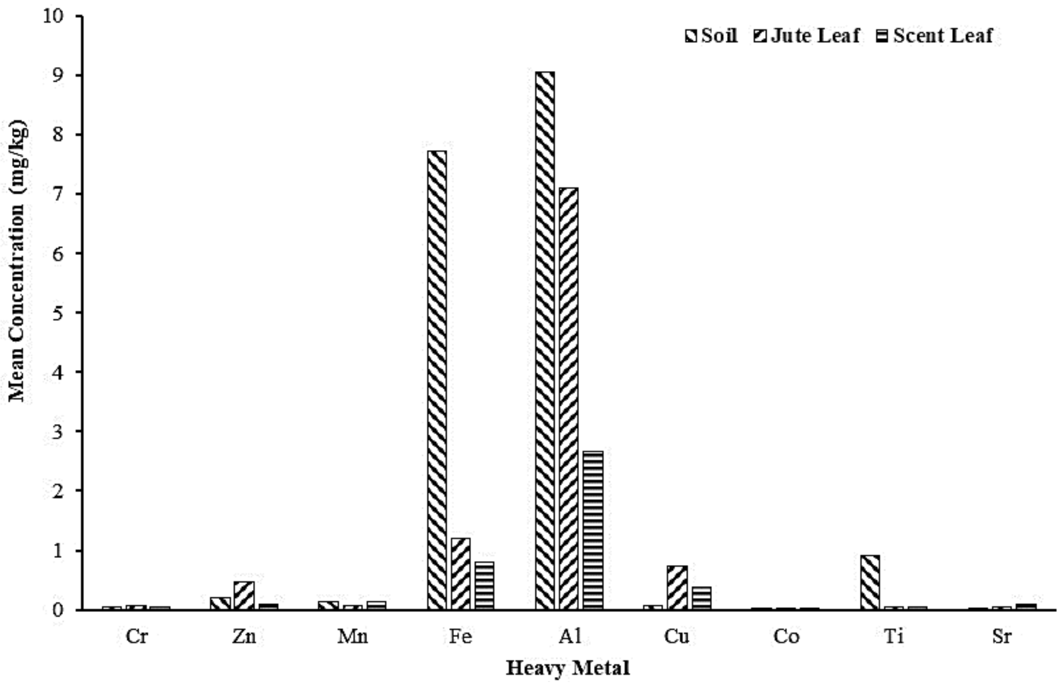

Figure 5. Mean heavy metal concentrations in refuse-site soil and cultivated plants

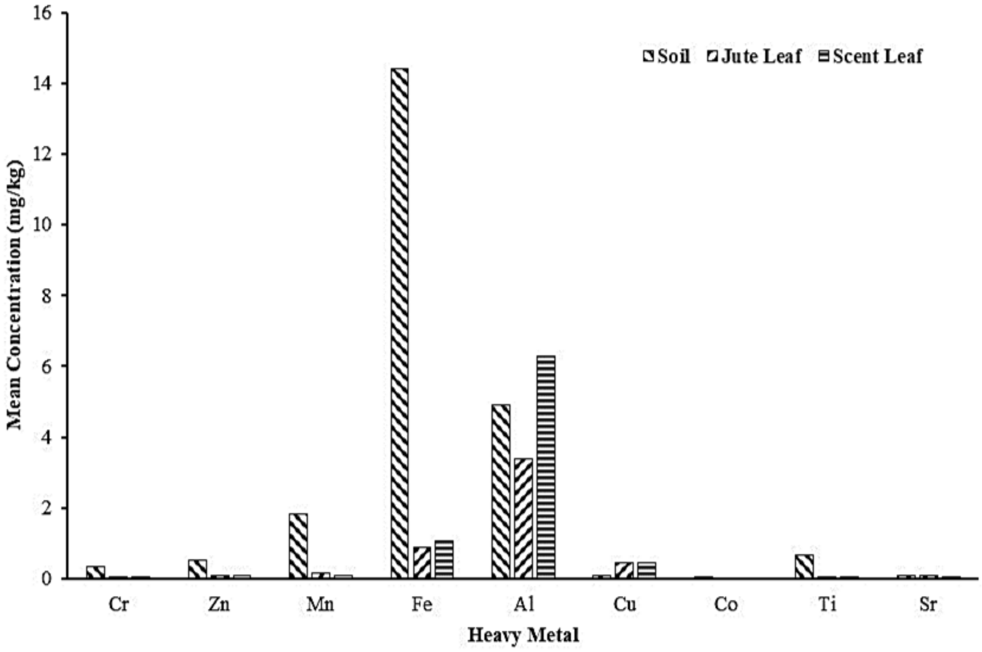

Figure 6. Mean heavy metal concentrations in iron and steel smelting industry soil and cultivated plants

Table 1. Pearson Correlations

Heavy Metals	Heavy Metals								
	Cr	**Zn**	**Mn**	**Fe**	**Al**	**Cu**	**Co**	**Ti**	**Sr**
Cr	1	.346	.959**	.788**	-.121	-.083	.758**	.400	.149
Zn	.346	1	.115	.666*	-.207	.841**	.757**	.782**	.852**
Mn	.959**	.115	1	.706*	-.136	-.330	.625*	.277	-.008
Fe	.788**	.666*	.706*	1	-.058	.173	.927**	.873**	.477
Al	-.121	-.207	-.136	-.058	1	-.298	-.083	.047	-.635*
Cu	-.083	.841**	-.330	.173	-.298	1	.313	.400	.816**
Co	.758**	.757**	.625*	.927**	-.083	.313	1	.822**	.525
Ti	.400	.782**	.277	.873**	.047	.400	.822**	1	.611*
Sr	.149	.852**	-.008	.477	-.635*	.816**	.525	.611*	1

***Correlation is significant at the 0.01 level (1-tailed)*

**Correlation is significant at the 0.05 level (1-tailed)*

Table 2. Uptake factors of cultivated plants

Soil Location	Vegetable Sample	Uptake Factor/Heavy Metal								
		Cr	**Zn**	**Mn**	**Fe**	**Al**	**Cu**	**Co**	**Ti**	**Sr**
Metal-Dumping Site	**Jute Leaf**	0.42	0.19	0.17	0.07	2.38	0.35	0.33	0.08	0.12
	Scent Leaf	0.17	0.03	0.50	0.05	1.28	0.18	0.17	0.01	0.27
Refuse Site	**Jute Leaf**	2.00	2.24	0.50	0.16	0.78	12.33	0.67	0.04	1.67
	Scent Leaf	1.25	0.43	1.00	0.10	0.29	6.50	0.67	0.04	3.00
Iron and Steel Smelting Industry	**Jute Leaf**	0.09	0.15	0.08	0.06	0.69	5.50	0.00	0.05	1.43
	Scent Leaf	0.15	0.15	0.04	0.07	1.28	5.50	0.00	0.09	0.57

Abraham Olasupo Oladebeye, et. al. “Potential Phytoremediation of Designated Heavy Metal-contaminated Soils by Jute (Corchoruscapsularisis) and Scent Leaf (Ocimumgratissimum)."*IOSR Journal of Environmental Science, Toxicology and Food Technology (IOSR-JESTFT)*, 17(1), (2023): pp 01-09.