UPTAKE OF HEAVY METALS BY PLANTS OBTAINED FROM ELECTRONIC-WASTE DUMPSITES

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ABSTRACT

The concentrations of Pb, Cd, Cr and Ni in the leaves, stems and roots of *Ipomea batatas* and *Eleusine indica* as well as in soil samples from three e-waste dumpsites in Lagos, Nigeria were investigated using Atomic Absorption Spectroscopy. The soil and plant samples were collected and digested using a mixture of nitric acid and perchloric acid. The concentrations of Pb, Cd, Cr and Ni ions at the dumpsites was found to range between 124.7±2.0 to 147.4±4.7, 36.6±0.6 to 49.4±0.3, 28.4±2.6 to 43.8±2.4 and 33.7±2.5 to 46.2±1.5 mg/kg respectively. The results showed that high concentration of Pb, Cd, Cr and Ni were found in the leaves, stems and roots of *I. batatas* and *E. indica* plants. Positive and negative correlation coefficients were displayed between metals in the soil with metals in the plants which inferred both common and uncommon sources of environmental pollution. Thus, plants grown in this area can be used to sequester heavy metals from the soil, thereby reducing the effects of heavy metals pollution in these areas.

Keywords: E-waste, Dumpsites, Plants, Pollution, Soil

INTRODUCTION

Industrialization and technological advancement are necessary to meet the basic requirement of people and are on the increase on daily basis. It is worthy to note that the environment is fast becoming fragile and environmental pollution is one of the side effects of this trend. Rapid product innovations and replacement, especially in Information and Computer Technology (ICT) and office equipment combine with the migration from analogue to digital technologies and to flat screen TVs and monitors are fuelling the increase in electronic-waste pollution [1]. E-waste is a term used to cover almost all types of electrical and electronic equipment (EEE) that has or could enter the waste stream from materials such as TVs, computers, mobile phones, entertainment and stereo systems, toys, and household items with circuitry or electrical components [1]. According to United Nation Union's study supporting the 2008 review of the Waste Electrical and Electronic Equipment (WEEE) Directive, 44% of e-waste is accounted for from fridges and other cooling and freezing appliances, combined with large household appliances [2]. E-waste also contains many valuable and precious materials in addition to hazardous materials [1]. For instance, a mobile phone contains over 40 elements among which are copper, gold, tin, silver, antimony, cobalt etc [1, 3].

Nigeria is the most populous country in Africa and accounts for approximately one-sixth of Africa's people with a population which is expected to be 156, 269,000 by the year 2015 [4]. Lagos State is the most populous, prosperous and busiest city in Nigeria with estimated population of 17.5 million people and the economic center of Nigeria. According to Basel Action Network study [6], Nigeria imports about 500, 000 used computers annually through the Lagos Port alone and about 25% of the imports are functional used computers while the remaining 75% is just junk or unserviceable [5]. Although, access to information and communication technology is pivotal to a country's economic and social development, the continuous importation of new, second hand or used TV sets, mobile phones, computers and other electronic appliances had contributed to the amount of WEEE [6]. According to the reports of Odeyingbo [7] and Ogungbuyi et al. [8], 70% of imported used EEE is functional and sold to consumers after testing while 70% of the non-functional share can be repaired and sold to consumers in major markets. Their study further revealed that 9% of the total imports of used EEE is non-repairable and is directly passed onto collectors and recyclers. Waste recyclers in developing countries like in Nigeria use several crude methods such as acid baths, open fires and broilers to extract precious components of EEE while the remaining scrap are dumped indiscriminately as waste [9]. These techniques pose dangers to poorly protected workers and the local community. These crude methods are mostly inefficient in terms of resource recovery as recycling in these instance usually focus on few precious elements or components while other parts are discarded and constitute environmental hazards. These various crude techniques coupled with the indiscriminate dumping of unused components lead to the discharge of toxic fumes, liquid waste and heavy metals into the environment and waterways thus constituting severe environmental degradation and health risks [10]. For example, personal computers (PCs) consist of printed wiring board (PWB) many of which contain heavy metals and brominated flame-retardants (BRFs) which are hazardous to human health and also to the environment [5, 11-12]. Also, a normal Cathode-Ray-Tube (CRT) in computer monitor contains cadmium which is used in rechargeable computer batteries and switches in older CRT monitors [1, 6]. When bio-accumulate, cadmium is carcinogenic, extremely toxic to humans, causing severe kidneys, bones and lungs damage and can also result in high blood pressure [6, 13]. Poly vinyl chloride (PVC) cabling which is used for printed circuit boards, plastic covers and cables when burnt can release harmful substances like dioxins which can damage the immune as well as the reproductive systems [8, 10]. Solders, CRTs and rechargeable EEE contain considerable amounts of lead and short term exposure can cause muscle pains, anorexia, headache, malaise, while long term exposure can result in nervous system impairment, brain damage and can lead to death on high level of exposure [6].

Phytoremediation is the direct use of green plants and their associated microorganisms to stabilize or reduce contamination in soils, sludge, sediments, surface water, or ground water [14]. Phytoremediation has become an effective and affordable technological solution used to extract or remove inactive metals and metal pollutants from contaminated soil [15]. This technology is environmentally friendly and very cheap [14]. It takes the advantage of the unique and selective uptake capabilities of plants roots systems together with the translocation, bioaccumulation and contaminant degradation abilities of the entire plant body [16]. Phytoremediation has been effectively applied in the removal of metals such as Pb, Zn, Cd, Cr, As, e.t.c. from soil and water [17]. Some of the plants which have been used to remove toxic metals from soil include *larrea tridentata* [18], *nicotiana plumbaginifolia* [19], *eleusine indica* [20], *ipomea batatas*, *laportea ovalifolia* [21], *fauna* and *flora* [22]. This research work is designed to quantify the amount of Pb, Cd, Cr and Ni in three selected dumpsites in Lagos state, Nigeria and to access the ability of *ipomea batatas* and *eleusine indica* to absorb these heavy metals from the landfills. This study will also verify if the dumping of e-waste in this area can increase the level of heavy metals in the soil and consequently in plants grown beside these landfills. The correlation of metals in soil with various plant parts will also be established.

MATERIAL AND METHODS

Sample location

Lagos state is one of the six states that make up Nigeria's South West geopolitical zone. Lagos has one of the highest populations of 17.5 million as reported by the Lagos state government [23-24]. It lies at latitude 6º27'// north and longitude 3º23'45'' east. Lagos is Nigeria's economic focal point, generating a significant portion of the country's GDP [24]. The Olusosun dumpsite is one of the largest in Africa and was established in 1992. It covers about 42 hectares of land and receives about 2,400 metric tons of waste every day. The Soluos dumpsites has a capacity of about 2,250 metric tons of waste with about 350 to 500 individuals involved in the picking of waste materials. Abule –Egba landfill site occupies a land of about 10.2 hectares in the western part of Lagos in Alimosho Local Government area and receives waste from the densely populated area. Figure 1 showed a schematic map of Lagos State with the study location sites as inscribed in numbers.

Fig.1: Map of Lagos State Showing the Study Area.

Where 1 = Soluos dumpsite, 2 = Abule-Egba dumpsite, 3 = Olusosun dumpsites.

Sample collection

Two plants namely *Ipomea batatas* (sweet potato) and *Eleusine indica* were collected at three dumpsites namely: Soluos dumpsite, Abule-Egba dumpsite and Olusosun dumpsites and thoroughly washed with distilled water to remove sand and other impurities. The leaves, stems and roots were separated in each case and cut into smaller pieces and thereafter dried in an oven at 110 ºC for 4 h. The dried samples were ground using mortar and pestle and then kept in air tight sample bottle prior to analysis. Top soil (0-15cm) samples were also collected from each dumpsite where the plants have been sampled, crushed and sun dried for 15 days followed by oven drying at 80 ºC for 4 h. The soil samples were ground into powdered from and kept in air tight sample bottles.

Sample treatment and metal analysis

The method described by Afzal et al [25] was adopted and modified. Briefly, a homogeneous solution of nitric acid and perchloric acid in the ratio 2:1 strength was prepared. About 1 g of the dried powdered samples of each plant parts was added to this solution in a conical flask. The contents of the flask were heated on a hot plate at 130 ºC until the volume was reduced to 3 mL. The solution was cooled and filtered with Whatman No. 42 filter paper. The filtrate was there after diluted up to the mark in a volumetric flask. The soil samples were digested in the same way. All the sample solutions were analyzed for the presence of Pb, Cd, Cr and Ni using Buck Scientific model 210 VGP Atomic Absorption Spectrophotometer. The samples were analyzed in triplicate. The mean together and their respective standard deviations were recorded.

RESULTS AND DISCUSSION

The concentration of Pb, Cd, Cr and Ni in various plant parts obtained from Olusosun, Soluos and Abule-Egba dumpsites are presented in Tables 1 to 3, while that of the soil samples where the plants were sampled are presented in Table 4.

Lead

Table 1: Heavy Metal Concentration of Various Plant Parts at Olusosun Dumpsites.

	Ipomea batatas			***Eleusine indica***		
Metals	**Leaves (mg/kg)**	**Stems (mg/kg)**	**Roots (mg/kg)**	**Leaves (mg/kg)**	**Stems (mg/kg)**	**Roots (mg/kg)**
Pb	9.3±0.3	8.3±0.9	6.4±0.6	5.6±0.7	4.5±0.4	2.2±0.8
Cd	4.5±0.3	2.0±0.5	1.8±0.6	7.4±0.5	5.3±0.3	3.1±0.8
Cr	10.5±1.5	8.4±0.4	5.1±0.2	9.5±0.3	6.8±0.2	4.4±0.6
Ni	8.4±3.3	6.5±2.6	4.6±0.9	6.3±2.4	4.5±0.6	2.7±1.8

The concentration of Pb in *I. batatas* collected at Olusosun dumpsite was found to be 9.2±0.3 (leaves), 8.4±0.6 (stems) and 6.4±0.6 (roots) mg/kg while that of *E.indica* was found to be 5.6±0.7 (leaves), 4.5±0.4 (stems) and 2.2±0.8 (roots) mg/kg as shown in Table 1. The lead concentration at *I. batatas* at Soluos dumpsite showed 6.3±0.6 (leaves), 4.4±0.2 (stems) and 1.3±0.4 (roots) mg/kg and 7.1±0.6, 5.2±1.2 and 3.0±0.5 mg/kg for the leaves, stems and reoots as indicated in Table 2. Analysis of the *I. batatas* and *E. indica* at Abule-Egba landfill showed their leaves, stems and roots contained 4.1±0.2, 3.6±0.4, 5.3±0.6, 4.0±0.2, 6.3±0.4, and 8.1±0.6 mg/kg respectively as presented in Table 3. Soil samples collected from Olusosun, Soluos and Abule-Egba dumpsites were found to contain lead in concentration range of 128.4±5.8 to 136.1±11.8, 141.2±5.8 to 147.2±4.7 and 124.7±2.0 to 133.6±5.2 mg/kg respectively which is presented in Table 4. The highest concentration of lead was observed in the leaves of *I. batatas* at Olusosun landfill while the least value was observed in the root of *E. indica* at Abule-Egba landfill. Generally, the *I. batatas* contained more Pb than the *E. indica*. The trend of lead level in plant parts was in the order of leaves > stems > roots. The level of Pb in the soil as well as in the various plant parts fall below the limit of 300 mg/kg proposed by USEPA [26] and within the range of 2-200 mg/kg reported by Ebong *et al*. [27] and Vacera *et al*. [28]. The results bear similarities with the findings of Abdallah *et al*. [20] and Ogbemudia and Mbong [21]. The high level of Pb in the soil may be as a result of the leaching of Pb from Pb containing e-waste substances such as cathode ray tubes, batteries and solders which were evident at the dumpsite. Long-term exposure to Pb and Pb containing substances can result in anemia, abdominal pains, vomiting [29], while prolonged exposure may also result in kidney damage, severe headache, coma and death [30-32].

Chromium

The amount of Cr determined in *I. batatas* plant from Olusosun was 10.5±1.5 (leaves), 8.4±0.4 (stems) and 5.1±0.2 (roots) mg/kg while that of the *E. indica* was 9.5±0.3 (leaves), 6.8±0.2 (stems) and 4.4±0.6 (roots) mg/kg as reported in Table 1. From Soluos landfill, the level of Cr in the leaves, stems and roots of *I. batatas* and *E. indica* was found to be 20.0±1.4, 17.3±2.8, 13.8±1.4 mg/kg and 22.6±3.4, 19.6±1.9, 16.5±1.3 mg/kg respectively as indicated in Table 2. The amount of Cr in the leaves, stems and roots of *I.batatas* from Abule-Egba site was 4.4±0.8, 3.6±0.5 and 7.6±0.4 mg/kg, while that of *E. indica* was found to be 5.2±1.2, 3.5±0.9 and 3.3±0.3 mg/kg as shown in Table 3. The level of Cr in the soil samples from Olusosun, Soluos and Abule-Egba dumpsites was found to range between 28.4±2.6 to 36.4±2.0, 39.9±2.8 to 42.9±1.9 and 40.4±4.1 to 43.8±2.4 mg/kg as presented in Table 4. The highest level of Cr in the soil samples was obtained at Abule-Egba dumpsites while the least value was observed at Olusosun landfill. Generally the increasing order of Cr level in the plant parts is leaves > stems > roots.

Table 2: Heavy Metal Concentration of Various Plant Parts at Soluos Dumpsites.

	Ipomea batatas			*Eleusine indica*		
Metals	**Leaves (mg/kg)**	**Stems (mg/kg)**	**Roots (mg/kg)**	**Leaves (mg/kg)**	**Stems (mg/kg)**	**Roots (mg/kg)**
Pb	6.3±0.6	4.4±0.2	1.3±0.4	7.1±0.6	5.2±1.2	3.0±0.5
Cd	4.6±0.8	1.9±0.4	1.4±0.5	6.0±2.2	2.5±0.7	2.4±0.2
Cr	20.0±1.4	17.3±2.8	13.8±1.4	22.6±3.4	19.6±1.9	16.5±1.3
Ni	7.0±0.1	6.3±0.6	4.5±0.3	6.7±0.8	4.2±1.8	3.0±0.4

The results from this study are in agreement with the reports of Abdallah *et al*. [20] and Okunola *et al.* [33]. The amount of Cr in the soil samples was found to fall within the normal range of 2 to 100 mg/kg in soil [28] and 5 to 30 mg/kg in plant [29]. The high level of Cr in the soil and plants part may be attributed to the released of Cr from Cr containing e-waste substances such as hardeners in plastics and dyes pigment switches, flat screen and batteries [6] among others which were visible at these dumpsites. Exposure to Cr could result in lung cancer [6, 34] and can as well damage the DNA [6].

Cadmium

The Cd in the plant parts of *I. batatas* at Olusosun dumpsite was found to be 4.5±0.4 (leaves), 2.0±0.5 (stems) and 1.8±0.6 (roots) mg/kg while the concentration of Cd in *E. indica* was found to be 7.4±0.5 (leaves), 5.3±0.3 (stems) and 3.1±0.8 (roots) mg/kg which is presented in Table 1. The analysis of the *I. batatas* parts at Soluos dumpsite revealed that leaves, stems and roots contained Cd concentration of 4.6±0.8, 1.9±0.4 and 1.4±0.5 mg/kg while, and that of the *E. indica* contained 6.0±2.2, 2.5±0.7 and 2.4±0.2 mg/kg as shown in Table 2. Similarly, the Cd analysis of *I. batatas* parts at Abule-Egba dumpsite showed that the leaves, stems and roots contained 2.4±0.3, 1.8±0.3 and 1.5±0.6 mg/kg, while that of *E. indica* contained 2.5±1.2, 2.0±0.8 and 1.7±0.2 mg/kg as indicated in Table 3. The analysis of the soil samples at Olusosun, Solous and Abule-Egba landfills revealed that the concentration of Cd range between 46.3±1.4 to 49.4±0.3 mg/kg, 40.8±1.9 to 43.4±1.8 mg/kg and 36.6±0.6 to 38.4±2.6 mg/kg respectively.

Table 3: Heavy Metal Concentration of Various Plant Parts at Abule-Egba Dumpsites.

	Ipomea batatas			***Eleusine indica***		
Metals	**Leaves (mg/kg)**	**Stems (mg/kg)**	**Roots (mg/kg)**	**Leaves (mg/kg)**	**Stems (mg/kg)**	**Roots (mg/kg)**
Pb	4.1±0.6	3.6±0.4	5.3±0.6	4.0±0.2	6.3±0.4	8.1±0.6
Cd	2.4±0.3	1.8±0.5	1.5±0.6	2.5±1.2	2.0±0.8	1.7±0.2
Cr	4.4±0.8	3.6±0.5	7.6±0.4	5.2±1.2	3.5±0.9	3.2±0.3
Ni	8.6±0.5	4.2±0.8	3.0±1.8	6.1±0.3	2.2±1.5	2.9±0.3

Table 4: Heavy Metal Concentration of Soil Samples at Various Dumpsites.

	Olusosun Dumpsite		**Soluos Dumpsite**		**Abule-Ebga Dumpsite**	
Metals	**Site 1 (mg/kg)**	**Site 2 (mg/kg)**	**Site 1 (mg/kg)**	**Site 2 (mg/kg)**	**Site 1 (mg/kg)**	**Site 2 (mg/kg)**
Pb	128.4±5.8	136.1±11.8	141.2±5.8	147.4±4.7	133.6±5.2	124.7±2.0
Cd	49.4±0.3	46.3±1.4	43.4±1.8	40.8±1.9	36.6±0.6	38.4±2.6
Cr	36.4±2.0	28.4±2.6	42.9±1.9	39.9±2.8	43.8±2.4	40.4±4.1
Ni	40.5±4.3	36.1±2.0	45.3±3.4	46.2±1.5	37.1±3.3	33.7±2.5

The level of Cd concentration in the soil from this study falls within the normal value of 2 to 200 mg/kg [30]. The concentration of Cd from this study is high which might be as a result of the high level of Cd containing e-waste at this site. Major sources of Cd in e-waste include batteries, aviation corrosion resistant and light sensitive resistors as well as PVC [6, 10]. Cadmium is a potentially long-term cumulative poison which is toxic to human body particularly the kidneys [34]. The concentration of Cd in this study agree with our earlier findings [35], the report of Abdallah *et al.* [20], Ogbemudia and Mbong [21] but lower than 0.009 and 0.42 mg/kg, 0.04 to 0.08 mg/kg reported by Umoh and Etim [36].

Nickel

The concentration of Ni in leaves, stems and roots of *I. batatas* collected at Olusosun dumpsite was found to be 8.4±3.3, 6.5±2.6 and 4.6±0.9 mg/kg, while that of *E. indica* was found to 6.3±2.4, 4.5±0.6 and 2.7±1.8 mg/kg respectively as shown in Table 1. Analysis of the leaves, stems and roots of *I.batatas* at Soluos dumpsites revealed that Ni contained 7.0±0.1, 6.3±0.6 and 4.5±0.3 mg/kg, while that of *E. indica* contained 6.7±0.8, 4.2±1.8 and 3.0±0.4 mg/kg which is presented in Table 2. Similarly, Ni contents in the leaves, stems and roots of *I. batatas* and *E. indica* at Abule-Egba was 8.6±0.5, 4.2±0.8, 3.0±1.8 mg/kg and 6.1±0.3, 2.2±1.5 and 2.9±0.3

mg/kg respectively as shown in Table 3. The analysis of the soil samples showed the range of Ni to be 36.1±2.0 to 40.5±4.3 mg/kg (Olusosun), 45.3±3.4 to 46.2±1.5 mg/kg (Soluos) and 33.7±2.5 to 37.1±3.3 mg/kg (Abule-Egba). Nickel, an essential element can be harmful when inhaled in excess and is toxic, inducing carcinogenicity [37]. High exposure to nickel could cause damage to brain, kidney, brain, muscles and can as well lead to cancer [38-39]. The results of this study agreed well with our earlier findings of Gitimoni and Krishmna [38].

Correlation coefficient

Table 5 showed the statistical analysis of the correlation between metals in soil with metals in plants. The statistical correlation was performed at $\alpha = 0.05$ (two tail) and for $n = 5$. The results showed that Cd-plant displayed a strong positive correlation with Cd-soil, Pb-soil and Cr-soil while, a negative correlation was observed between Cd-plant and Ni-soil. A positive correlation was also observed between Pb-plant and Cd-soil and Cr-soil, while a negative correlation was observed between Pb-plant and Pb-soil and Ni-soil. Cr-plant displayed strong correlation with Cd-soil and mild positive correlation with Ni-soil but showed a negative correlation with Pb-soil and Cr-soil respectively. Finally, Ni-plant displayed a strong positive correlation with Pb-soil and Cr-soil, mild positive correlation with Cd-soil but negative correlation with Ni-soil. The positive correlation observed between the metals in soil and plants could indicate common sources of metal pollution and in this case, the e-waste. This inferred that with an increase in the amount of metals in the soil due to the leaching of metals from e-waste, the uptake of metals by plants will also increase. Similar observation was reported by Aksoy *et al*. [40], Abdallah *et al*. [20] and Amusan *et al*. [41]. On the contrary, the negative correlation may indicate different sources of metal pollution. This inferred that for negative correlation, there is no interaction between the metal in the soil and that in the plants. The natural concentration of individual metals in the soil as well as contaminant from other sources like mining activities, dust, and other industrial activities may be responsible.

Table 5: Correlation between the levels of metals in plants versus soil samples.

	Pb-soil	**Cd-soil**	**Cr-soil**	**Ni-soil**
Pb-plant	-0.24	0.71	0.68	-0.28
Cd-plant	0.82	0.94	0.86	-0.42
Cr-plant	-0.56	0.92	-0.21	0.57
Ni-plant	0.95	0.59	0.97	-0.23

Mechanism of metal uptake and FT-IR analysis of *I. batatas* and *E. indica* plants

Most previous research works on phytoremediation have focused mostly on either the adsorption by roots which require the total harvesting of the plant. The results of our study revealed the potentials of *I. batatas* and *E. indicca* to sequester heavy metals from contaminated soil through absorption via other plant parts such as leaves, stems and roots. Plants can tolerate toxic heavy metals by excluding the metals from sensitive sites by either synthesizing enzymes that would detoxify the heavy metals or by changing the metabolic pathways so as to prevent damage [42]. Two of the most common plants defensive mechanisms which allow plants to absorb and incorporate toxic metals into their tissues without causing death are their ability to synthesize phytochelatins [19] and the synthesis of metal-chelating proteins called metallothioneins [43]. During metal uptake, there is interaction between the metal and the various functional groups present on the plant cell surface which is mainly composed of polysaccharides, amino acids, proteins and lipids. These biomolecules have abundant metal binding groups such as alcohol, amine, carbonyl, sulphate, phosphate, unsaturated bonds and amino groups [44-45]. The various functional groups which are present in *I. batatas* and *E. indica* plants were evaluated by FT-IR spectra as presented in figure 2. The peaks observed between 3443 and 3458 cm^{-1} are indication of –NH groups, while those located between 3621 and 3695 cm^{-1} were assigned to –OH stretching. The band at 2921 cm^{-1} is ascribed to C-H stretching of aliphatic, while that at 2555 cm^{-1} is attributed to S-H stretching. The bands at 1745 and 1821 cm^{-1} are associated with C=O groups. The peak at 1561 cm^{-1} is attributed to N-H bending in primary amines, while the peaks at 1484 and 1479 cm^{-1} indicate NO asymmetric stretch in nitro groups. Peaks observed at 1242 cm^{-1} correspond to NO symmetric stretch in nitro groups. The peaks between 1105 and 1099 cm^{-1} are assigned to C-O bond. The stretching observed between 1130 and 1132 cm^{-1} is associated with –CN, while that which was observed from 711 to 875 cm^{-1} were attributed to C-H of aromatic ring. These functional groups such as alcohol, amine, carbonyl, nitro, cyano and amino groups [44-45] as observed in the FT-IR spectra could be responsible for the uptake of the heavy metals by these plants.

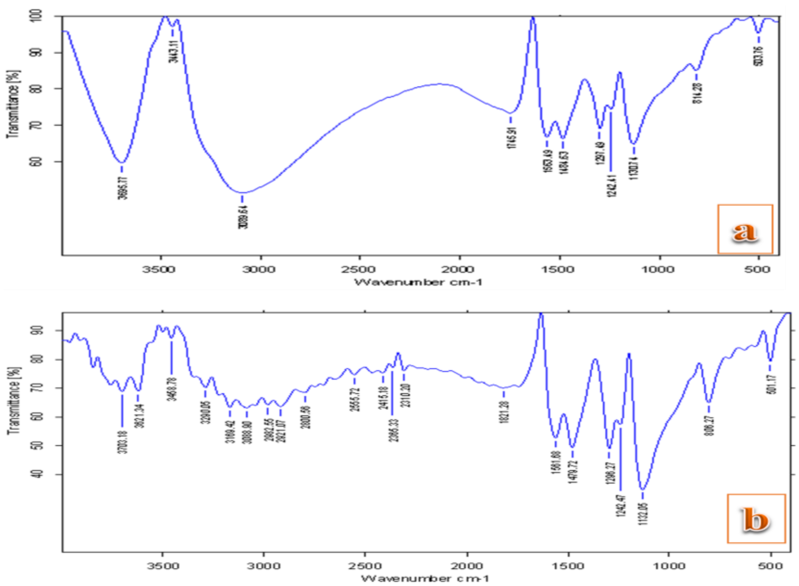

Fig. 2: FT-IR spectra of (a) *I. batatas* and (b) *E. indica* plants

CONCLUSION

This research work was designed to quantify the amount of Pb, Cd, Cr and Ni in three selected dumpsites in Lagos state, Nigeria and to access the ability of *ipomea batatas* and *eleusine indica* to absorb these heavy metals from the landfills. This study also verified the impact of dumping of e-waste in this area which showed an increased the level of heavy metals in the soil and consequently in plants grown beside these landfills. The correlations of metals in soil with various plant parts were also established. Thus, plants grown in this area can be used to sequester heavy metals from the soil, thus reducing the effects of heavy metals pollution in these areas.

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