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Environmental Assessment of Harmful Elements in Soil and Flora around Electrical and Electronic Equipment Waste Dumpsite in Rivers State, Nigeria

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ABSTRACT

The purchase of "tokumbo" electronics with very short life span in Nigeria has resulted in the disposal and burning of large quantity of e-waste in some cities in Nigeria. Thus, this study assessed soil and plant samples from e-waste dumpsite in Abuluoma, Rivers State, Nigeria. Soil samples were collected at 0-20, 21-40, 41-60, 61-80 and 81-100 cm depths at east (E), south (S), west (W), north (N) and center (C) of the e-waste dumpsite while plant samples (Pennisetum purpureum, Vernonia amygdalina and Amaranthus spinosus) were collected around the point soils with the exception of the center of the dumpsite. Soil and plant samples were analyzed for harmful elements (Pb, Cd, Cu, Hg and Cr). In soil, the value of Cd (1.43±0.21 mg/kg) was higher than the permissible limits of FAO/WHO. Pb (34.18±5.60 mg/kg) was higher than the accepted limit by FEPA and Hg (0.4767±0.03 mg/kg) was higher than the Dutch target value for soil. In plants, the values of Pb (2.70±0.10 mg/kg) and Cr (2.73±0.37 mg/kg) were higher than the permissible limit by FAO/WHO. Thus, e-waste released harmful elements in the soil and accumulated in plants. The implication is that man, including animals that relied heavily on these plant species for food and medicinal purposes will be exposed to bioaccumulation of harmful elements. Therefore, it is recommended that Rivers State government should carry out serious awareness campaign to dissuade people from accessing plants growing on or around e-waste dumpsite for food or medicine.

1. INTRODUCTION

Waste electrical and electronic equipment (WEEE) also known as electronic waste (e-waste) is chemically and physically distinct from other forms of municipal or industrial waste since it contains both valuable and hazardous materials that require special handling and recycling methods to avoid environmental contamination and detrimental effects on human health (Alani *et al*., 2020). E-waste includes discarded computers, office electronic equipment, entertainment device electronics, mobile phones, television sets, and refrigerators, used electronics that are destined for reuse, resale, salvage, recycling, or disposal (Yuan *et al*., 2007; Olafisoye *et al*., 2013).

The economic situation in a developing country like Nigeria has forced our able-bodied youth and men to be actively involved in e-waste scavenging. Their operations which include uncontrolled burning of electronic equipment in order to melt plastics and to recover metals can be deleterious to man and his environment. Solid materials in the form of smoke, dust and also vapour generated during e-waste recycling operations are usually suspended over a long period in the air. Fine particulate matter ($PM_{2.5}$) causes reduction in visibility, has an adverse influence on human health, and is known to be related to global climate change (Zhu *et al*., 2016; Wang *et al*., 2020; Ogbonna *et al*., 2020). Long-term exposure to air pollution particulate matter increases the risk of lung cancer, respiratory diseases and arteriosclerosis, and short-term exposure can exacerbate several forms of respiratory diseases, including bronchitis and asthma, as well as cause changes in heart rate variability (Liu *et al*., 2005; Garcon *et al*., 2006; Lu *et al*., 2007; Pope III *et al*., 2009; Peacock *et al*., 2011; Raaschou-Nielsen *et al*., 2011).

Since recycling activities like burning releases particles that escape into the atmosphere, the atmosphere is a pathway for transport of heavy metals and the major input of bio-available metals in the environment, which are potential threats to the health and survival of man (Ogbonna *et al*., 2018). For instance, the inhalation of cadmium (Cd) causes bronchitis, pneumonitis and inflammation of the liver (Mac Farland, 1979) but the effect becomes fatal and deleterious when up to 8 mg/m^3 of cadmium oxide fume is inhaled for about 5 hours (Ademoroti, 1996). Heavy metals are either deposited directly on plant surfaces such as leaves, flowers, branches, and stems or on soils, which are absorbed from the soil solution into plants via the roots (Ogbonna *et al*., 2018). Since herbivores largely depends on fodder plants for food and man also relied heavily on plants for nutrition and health benefits, heavy metal contamination of plants will constitute serious health risk to both man and animals residing around e-waste dumpsites.

The three plant species sampled in this study (*Vernonia amygdalina*, *Pennisetum purpureum* and *Amaranthus spinosus*) are important food, medicinal and fodder plant species in south east Nigeria. For instance, *Vernonia amygdalina* is of great importance in human diet because of the presence of vitamins and mineral salts (Sobukola and Dairo, 2007), treatment of schistsomiasis, skin infections such as ringworm, rashes and eczema and has anti-parasitic, anti-tumour, and bactericidal effect (Ogbonda *et al*., 2013). *Amaranthus spinosus* is used as vegetable and ornamental plants (Ganjare and Raut, 2019), treatment of various types of pain conditions (Taiab *et al*., 2011), antioxidant activity (Kumar *et al*., 2010), antidepressant activity (Kumar *et al*., 2014), possess immuno-modulatory effects (Lin *et al.* 2005), and for feeding of pigs. *Pennisetum purpureum* is an important feed and fodder crop in livestock production (Negawo *et al*., 2017), feeding fish (grass carp and tilapia) in Nepal (Shrestha and Yadav, 1998; Pandit *et al*., 2004) and Bangladesh (Shaha *et al*., 2015) while the young shoots were used as a cooked vegetable (Akah and Onweluzo, 2014). These varied uses provide an indication of the diversity of roles these three (3) promising plant species provide to mankind.

Quite a number of researches have been carried out in terms of polycyclic aromatic hydrocarbon in soil (Adeyi and Oyeleke, 2017), heavy metal contamination in sediment (Leung *et al*., 2006), soil and water (Olafisoye *et al*., 2013; Adewumi *et al*., 2017; Alani *et al*., 2020), vegetables (Luo *et al*., 2011; Olafisoye *et al*., 2013; Fosu-Mensah *et al*., 2017) and microorganisms (Sanusi, 2017) but none of these works was carried out in south-south geopolitical zone of Nigeria. Rivers State is an oil rich State relatively occupied by some wealthy Nigerians and expatriates. These wealthy men can afford to buy the latest models of electronic devices thereby discarding the previous devices for want of space. For instance, about 90% of homes in Nigeria possess obsolete electronic devices such as an outdated computer, printer or a mobile phone which are probably not in use but constitute e-wastes (Alani *et al*., 2020). Similarly, the relatively poor people in Rivers State might invest on “Tokumbo” electronic devices with very short life span. This, in turn, may result to generation of additional e-waste. Usually, these e-wastes are collected by the authority designated for collection and disposal of wastes and are dumped at Abuluoma in Rivers State where recycling or recovery activities are carried out via uncontrolled burning. As a result of land hunger occasioned by urbanization and housing development in the Southern part of Nigeria, farmers are constrained to farming on lands adjoined to sources of pollution without considering the health implications of consuming crops grown on such lands (Ogbonna *et al*., 2018). One of such adjoining sources of pollution is the e-waste dumpsites where electronic waste of various shapes, sizes and volumes are burnt over a period of time. Uncontrolled open burning of e-waste may be a possible route of entry of harmful elements and other organic pollutants in the environment. This study, therefore, is aimed to assess some harmful elements in soil and their accumulation in some plant species at e-waste dumpsite in Abuloma, Rivers State, Nigeria.

2. MATERIALS AND METHODS

2.1. Study Area

The study was carried out at e-waste dumpsite in Abuloma, Rivers State, Nigeria. Abuloma is located on Latitude 04°46' E and longitude 07°03' N. It is mainly a mangrove ecological zone and experiences two seasons namely, the dry and wet season. The dry season begin in December and ends in February while the wet season commence in March and end in November. It is surrounded by rivers linking to different communities such as Ojimba-ama, Kalio-ama, Okujagu-ama etc. Thus, many several companies are engaged in leasing/construction of marine vessels and equipment such as tugboats, barges, houseboats, dredger, amphibious excavators (swamp buggies), pay loaders, cranes in Abuloma. They also carryout pipeline constructions maintenance, supply of sand, stones, bitumen, transportation of products like diesel, kerosene and wood. The primary occupation of most inhabitants of Abuloma is fishing and subsistence crop production.

2.2. Sample Collection

A pre-survey was carried out prior to sample collection to determine wind direction, the terrain and plant species common in the study area.

2.2.1. Collection of soil samples

Soil samples was collected randomly from fifteen different sampling points at 0-20, 21-40, 41-60, 61-80 and 81-100 cm soil depth with well cleaned Dutch soil auger and 1 meter rule in four cardinal points (i.e., three sampling points each at north (N), south (S), east (E), west (W) and center (C) of the e-waste dumpsite in February (dry season) and June (wet season). The control sample was collected in a home garden about 3.2 km from the e-waste dumpsite where there was no visible source of contamination. Samples from each particular soil depth (e.g., 0-25 cm at N, S, E, W and C) was placed in cellophane bags (about 40 g), labelled well, sealed, placed in a wooden box and covered to avoid contamination from external sources. The samples in the wooden box was transferred to the laboratory for pre-treatment and analysis.

2.2.2. Collection of plant samples

Fresh leaves were sampled from different parts of three (3) plant species. The leaves of three species, *Vernonia amygdalina* (bitter leaf, Asteraceae), *Amaranthus spinosus* (pigweed, Amaranthaceae, and *Pennisetum purpureum* (elephant or napier grass, Poaceae) were randomly collected in February (dry season) and June (wet season) from each plant using well-cleaned stainless secateurs. The control sample was collected in a home garden about 3.2 km from the e-waste dumpsite where there was no visible source of contamination. These three plant species were collected because they are common among all sampling stations, thus, the plants were growing around the points where soil samples were collected from the e-waste dumpsite. Samples from each plant species was placed separately in large envelopes, labeled well, properly sealed, placed in a wooden box and covered to avoid contamination from external sources. The samples in the wooden box were transferred to the laboratory for pre-treatment and analysis.

2.2.3. Soil and plant digestion and analysis

Each bulked soil sample was freed from foreign objects such as stones, seeds, roots etc. and air-dried at room temperature until all moisture was completely eliminated. The samples were subjected to crushing and grinding and then homogenized using a porcelain pestle and mortar. The homogenized soil samples were sieved (<2 mm) and analyzed for heavy metals (Pb, Cd, As, Ni, Cr and Zn) using standard laboratory methods described in IITA (1979). The leaves were rinsed with deionized water to remove pollen particles, dust, sand and oven-dried at 30 °C for 120 hours. The dried leaves samples were milled to fine powder (<1 mm) in an agate mortar with pestle. The procedure of Raimi *et al.* (2019) was adopted for the analysis.

2.2.3.1. Determination of pH

The pH meter (Jenway pH meter, model 3510 USA) was used to determine the pH values of the soils.

2.2.3.2. Determination of organic matter

Organic matter levels in the sieved soil samples were estimated indirectly from organic carbon (C) using the Walkley and Black procedure (Walkey and Black, 1934).

2.3. Experimental Design and Statistical Analysis

A factorial experiment was conducted in a randomized complete block design (RCBD) with four replications. Data generated from the experiment were subjected to one way analysis of variance (ANOVA) using statistical package for social sciences (SPSS) v. 17 and means were separated (Steel and Torrie, 1980) at $p<0.05$ using Duncan Multiple Range Test (DMRT) while Correlation analysis was used to determine the relationship between the means of the parameters analyzed.

3. RESULTS AND DISCUSSION

3.1. Chemical Properties of Soil

The values of pH, organic matter and harmful elements in soil of e-waste dumpsite and control site in the wet and dry season are summarized in Tables 1 and 2. The highest and lowest pH and organic matter values in soils were recorded at the control site and e-waste dumpsite, respectively. The high acidity of soil at e-waste dumpsite unlike the control site may be attributed to release of acidic substances from acid-containing waste such as Ni-Pb batteries. Lead batteries at e-waste site can cause soil acidity (Fosu-Mensah *et al.*, 2017). The soil pH of the study site ranged from 3.70 to 4.91 in the dry season which was more acidic than 3.82 - 5.04 in the wet season, and this may be attributed to the dilution effect of rainfall. In this study, it was observed that soil acidity increased with soil depth down the profile. Generally, most heavy metals do not exist in free form in the pH range of 6.0 - 9.0 (Adie and Etim, 2012). The pH for all e-waste soil samples analyzed in this study fell below this range (Tables 1 and 2). It therefore implies there would be leaching of metals from the surface soil (0-20 cm) towards sub soils (21-100 cm) as most of the metals would be dissolved in solution. Lower pH increases the solubility of metals and this may have contributed to the higher concentration of harmful elements in surface soil of e-waste dumpsite (Tables 1 and 2) (Gabriella and Anton, 2005; Ogbonna *et al.*, 2018).

The highest and lowest organic matter values in soils were obtained at the control site and e-waste dumpsite, respectively. The organic matter content in soil of e-waste site ranged from 0.11 to 2.10 % which is lower than 1.74 to 8.64 % recorded at the control site. The high organic matter in soil at the control site may be attributed to release of litter fall (i.e., leaves, flowers, pollens, twigs etc) by plants growing at the control site unlike the e-waste dumpsite where burning of e-waste materials generated high intensity of heat, resulting to poor population of plants, thus, reducing the build-up of organic matter on the site. The values of organic matter in the study site ranged from 0.21 to 2.10 in the dry season which was higher than 0.11 to 1.79 in the wet season. The results indicate that organic matter content in soil was higher in dry season than in wet season. The low organic matter content in soil during the wet season is attributed to leaching effect of rainfall (Ogbonna *et al.*, 2018). The results of this study also indicate that values of organic matter in soil decreases with depth down the profile. Organic matter content decreases with soil depth (Agboola and Fagbenro, 1985; Omenihu and Ojimgba, 2008) since the abundance and activity of microorganisms decline with soil depth (Andersen and Domsche, 1989; Ekklund *et al*., 2001; Taylor *et al*., 2002; Fang *et al*., 2005).

The concentration of the five (5) harmful elements (HEs) tested in soils collected at different soil depths from e-waste dumpsite in the dry season is summarized in Table 1. The result indicate that highest and lowest concentrations of harmful elements (Pb, Cd, Cu, Hg and Cr) were observed in soil samples from the e-waste dumpsite and control site, respectively. This show that anthropogenic activity via crushing and burning of phones, photocopying machines, printed circuit boards, air conditioners, cathode ray tubes, stabilizers at the e-waste dumpsite is the main source of metal contamination. Printed circuit boards, photocopying machines, lead capacitors and lead batteries, and cathode ray tubes contain some heavy metals (Wong *et al*., 2007; Tang *et al*., 2010; Kumar, 2014; Adesokan *et al*., 2016) that may be released during burning and crushing by scavengers. Some soil survey studies have shown that the concentrations of heavy metals are higher in soils adjoined to pollution sources than soil from control sites (Ogbonna *et al*., 2018, 2019, 2020). The constituents of the e-waste are implicated for the high values of harmful elements in soil in the dry season at e-waste dumpsite unlike the control site. The result also indicates that the concentrations of the HEs (Pb, Cd, Cu, Hg and Cr) decreased with increasing soil depth down the profile. This result is similar with the findings of Olafisoye *et al*. (2013) and Adesokan *et al*. (2016) who reported that the concentration of heavy metals in soil decreased as the depth of soil increased.

The highest values of Pb (34.18±5.60 mg/kg), Cd (1.43±0.21 mg/kg), Cu (38.33±1.40 mg/kg), Hg (0.4767±0.03 mg/kg) and Cr (69.74±6.42 mg/kg) in soils were observed at 0-20 cm soil depth and the values are significantly ($p<0.05$) higher than their (Pb, Cd, Cu, Hg and Cr) values in soils at 21-40 cm depth (22.08±1.87, 0.65±0.28, 17.90±2.07, 0.0800±0.07 and 43.19±2.78 mg/kg), its values at 41-60 cm soil depth (13.81±1.57, 0.24±0.33, 10.82±1.37, 0.0040±0.00 and 17.24±2.75 mg/kg) and 61-80 cm soil depth (6.46±1.37, 0.06±0.05, 2.40±0.90, 0.0004±0.00, and 6.41±1.52 mg/kg). Furthermore, the values of Pb, Cd, Cu, Hg and Cr at 0-20 cm soil depth is significantly ($p<0.05$) higher than its values at 81-100 cm soil depth (0.42±0.40, 0.00±0.00, 0.68±0.42, 0.0001±0.00 and 1.52±0.54 mg/kg) as well as the values of the control site at 0-20 cm depth (0.0004±0.01, 0.0002±0.00, 1.42±0.03, 0.0002±0.00 and 1.24±0.03 mg/kg), 21-40 cm soil depth (0.0001±0.00, 0.0001±0.00, 0.81±0.01, 0.0001±0.00, and 0.96±0.01 mg/kg), 41-60 cm soil depth (0.0000±0.00, BDL, 0.11±0.00, BDL and 0.12±0.00 mg/kg), 61-80 cm soil depth (<0.0000±0.00, BDL, 0.01±0.00, BDL and 0.0006±0.00 mg/kg) and 81-100 cm soil depth (BDL, BDL, <0.001, BDL and BDL). In this study, the concentrations of all HEs at 0-20 cm soil depth were higher than the values recorded in sub soils. It is assumed that the subsoil is considerably less influenced by soil-forming processes and anthropogenic supply than the top soil (Olafisoye *et al*., 2013).

Table 1: Concentration of harmful elements in soil during dry season

Depth (cm)	Pb	Cd	Cu	Hg	Cr	pH	OM
0-20	34.18^{a}±5.60	1.43^{a}±0.21	38.33a±1.40	0.4767^{a}±0.03	69.74^{a}±6.42	4.91^{c}	2.10^{c}
21-40	22.08^{b}±1.87	0.65b±0.28	17.90^{b}±2.07	0.0800^{b}±0.07	43.19^{b}±2.78	4.68^{c}	1.10^{c}
41-60	13.81^{c}±1.57	0.24^{c}±0.33	10.82^{c}±1.37	0.0040^{c}±0.00	17.24^{c}±2.75	4.09^{c}	0.76^{cd}
61-80	6.46^{d}±1.37	0.06^{c}±0.05	2.40^{d}±0.90	0.0004^{c}±0.00	6.41^{d}d±1.52	3.91^{cd}	0.52^{cd}
81-100	0.42^{e}±0.40	0.00^{c}±0.00	0.68^{d}±0.42	0.0001^{c}±0.00	1.52±0.54	3.70^{cd}	0.21^{d}
Control							
0-20	0.0004^{f}±0.01	0.0002^{d}±0.01	1.42^{d}±0.03	0.0002±0.00	1.24±0.03	6.89^{a}	8.64^{a}
21-40	0.0001^{f}±0.00	0.0001^{d}±0.00	0.81^{d}±0.01	0.0001±0.00	0.96±0.01	6.01^{a}	6.10^{ab}
41-60	0.0000^{f}±0.00	BDL	0.11^{d}±0.01	BDL	0.12±0.00	5.90^{ab}	4.14^{b}
61-80	<0.0000^{f}±0.00	BDL	0.01±0.00	BDL	0.0006±0.00	5.72^{ab}	2.18^{c}
81-100	BDL	BDL	<0.001	BDL	BDL	5.34^{ab}	1.96^{c}

Values were expressed as mean ± standard deviation of 3 replicates; ^{abc} *Means in a column with different superscripts are significantly different (P<0.05)*; BDL = Below detection limit

The highest values of Pb at 0-20 cm soil depth may be attributed to lead batteries and lead capacitors in the component of e-waste materials at the e-waste dumpsite that release Pb in soil. Perkins and Nxele (2014) opined that cathode-ray tubes, circuit boards, lead capacitors and lead batteries are part of the composition of e-waste. For instance, cathode ray tubes from television and computer monitors contains up to 400 mg/kg Pb (Menad, 1999; Adesokan *et al.*, 2016). The concentration of Pb (34.18±5.60 mg/kg) at 0-20 cm soil depth is 1.55, 2.48, 5.29, and 90.9 times higher than its values at 21-40, 41-60, 61-80 and 81-100 cm soil depths as well as 85450, 341800, 3418600 and 3418600 times higher than its values at the control site. The concentration of Pb in soil increased from 0.42±0.40 (at 81-100 cm depth) to 34.18±5.60 mg/kg (at 0-20 cm depth) and the values are below the permissible limit of 50 mg/kg (Pb) established by Codex Alimentarius Commission (FAO/WHO, 2001), Dutch target and intervention values of 85 and 530 mg/kg (Pb), respectively (Ogbonna *et al.*, 2020), accepted limit of 300 mg/kg (Pb) set by the European Union (EU, 2002) but well above 1.6 mg/kg (Pb) set by the Federal Environmental Protection Agency of Nigeria (FEPA, 1999) (Table 2). Similarly, the values of Pb (0.42 to 34.18 mg/kg) in this study is well below 629 to 7720 mg/kg in soil at e-waste site in Guangdong province in south China (Luo *et al.*, 2011), 693.3 to 1832.6 mg/kg in soil at e-waste site in India (Singh *et al.*, 2018), 183.66 mg/kg in soil at e-waste site in Accra, Ghana (Fasu-Mensah *et al.*, 2017), 64.90 mg/kg in soil at e-waste site in Lagos, Nigeria (Sanusi, 2015) and 15.9 to 22.5 mg/kg at e-waste site in Lagos, Nigeria (Adaramodu *et al.*, 2012). The low level of Pb in this study may be attributed to low-Pb containing e-waste at the dumpsite. The content of heavy metals in some electrical and electronic equipment (EEE) are too small to have an appreciable content in soil when soils are exposed to EEE (Adesokan *et al.*, 2016).

Table 2: Comparison with international and national standards

Source	Pb	Cd	Cu	Hg	Cr
[a]This study	0.05-34.18	0.00-1.43	0.18-38.33	0.00-0.4767	0.03-69.74
[a]Dutch criteria (target value) (mg/kg)	85	0.8	36	0.3	100
(Intervention value) (mg/kg)	530	12	190	10	380
[a]FAO/WHO 2001, 2006, 2007	50	0.1	100	2.0	100
European Union Standard (mg/kg)	300	3.0	140	NA	150
[a]NESREA standard 2011 (mg/kg)	NA	3	100	NA	100
[a]FEPA 1999	1.6	0.01	70-80	NA	NA
*Austria	100	1-2	60-100	NA	100
*Sweden	40	0.4	40	NA	60
*Luxembourg	50-300	1-3	50-140	NA	100-200
*France	100	2	100	NA	150
*Germany	70	1	40	NA	60
*UK	300	3	135	NA	400
*Netherlands	40	0.5	40	NA	30

**ECDGE (2010); [a] Ogbonna et al.* (2020); *NA = Not available*

The highest value of Cd (1.43±0.21 mg/kg) at 0-20 cm soil depth may be attributed to the burning of circuit boards, toner and ink containers at the e-waste dumpsite that released Cd that were complex at the surface soil by organic materials from the e-waste. Printed circuit boards contain substantial quantities of Cd and Pb (Lugon-Moulina *et al.*, 2006; Wong *et al.*, 2007; Tang *et al.*, 2010; Kumar, 2014). Furthermore, printer ink, toners, and photocopying machines contain some elements of Cd (Adewumi *et al.*, 2017). The values of Cd (1.43±0.21 mg/kg) at 0-20 cm soil depth were 2.2, 5.96, 23.83, and 1,430 times higher than its values at 21-40, 41-60, 61-80, and 81-100 cm soil depths at e-waste dumpsite as well as 7,150 and 14,300 times higher than its values at the control site. The values of Cd in soil increased from 0.00±0.00 (at 81-100 cm soil depth) to 1.43±0.21 mg/kg (at 0-20 cm soil depth) and the values are higher than the permissible limit of 0.1 mg/kg (Cd) established by Codex Alimentarius Commission (FAO/WHO, 2001), the target value of 0.8 mg/kg (Cd) described by Dutch criteria for soil (Ogbonna *et al.*, 2020), the accepted limit of 0.01 mg/kg (Cd) set by the Federal Environmental Protection Agency of Nigeria (FEPA, 1999) but lower than the accepted limit of 3 mg/kg (Cd) set by the European Union (EU, 2002) and 3 mg/kg (Cd) as described by National Environmental

Standards and Regulations Enforcement Agency (NESREA, 2011) of Nigeria for Cd (Table 2). Soil heavy metals naturally occur from erosion of rocks and minerals (Qu *et al.*, 2021) but human activities like e-waste crushing and burning enrich the soil ecosystem with harmful elements. The concentration of Cd in this study pose a serious concern because of its (Cd) toxicity, mobility and non-biodegradability. For instance, the Cd in the soil may be washed away by rainfall and end up in rivers and streams in proximity to the e-waste dumpsite. Heavy metals can contaminate groundwater through leaching especially under acidic conditions (Zheng *et al.*, 2013; Pradhan and Kumar, 2014; Wu *et al.*, 2014, Wu *et al.*, 2015) Similarly, the values of Cd (0.00 to 1.43 mg/kg) in this study is well below 82.0 to 230.6 mg/kg observed in soil at e-waste site in India (Singh *et al.*, 2018), 3.05 to 46.8 mg/kg obtained in soil at e-waste site in Guangdong province in south China (Luo *et al.*, 2011), , 103.66 mg/kg in soil at e-waste site in Accra, Ghana (Fosu-Mensah *et al.*, 2017) but higher than 0.32 mg/kg in soil at e-waste site in Lagos, Nigeria (Sanusi, 2015).

The highest value of Cu (38.33±1.40 mg/kg) at 0-20 cm soil depth may be associated with presence of electric (copper) wires and coils that are components of refrigerators, television and circuit boards that were burnt at the e-waste dumpsite. The burning of electronic gadgets at e-waste site contributes Cu to the soil (Fosu-Mensah *et al.*, 2017). The values of Cu (38.33±1.40 mg/kg) at 0-20 cm soil depth is 2.14, 3.54, 15.97, and 56.37 times higher than its values at 21-40, 41-60, 61-80, and 81-100 cm soil depths as well as 26.99, 47.32, 348.45, and 3,833 times higher than its values at the control site for 0-20, 21-40, 41-60, 61-80, and 81-100 cm soil depths, respectively. The concentration of Cu in soil increased from 0.68±0.42 (at 80-100 cm soil depth) to 38.33±1.40 mg/kg (at 0-20 cm soil depth) and the value is relatively higher than the target value of 36.0 mg/kg (Cu) as described by Dutch criteria for soil (Ogbonna *et al.*, 2020) but lower than the permissible limit of 100 mg/kg (Cu) established by Codex Alimentarius Commission (FAO/WHO, 2001), 70 to 80 mg/kg (Cu) set by the Federal Environmental Protection Agency of Nigeria (FEPA, 1999) and 100 mg/kg (Cu) as described by National Environmental Standards and Regulations Enforcement Agency (NESREA, 2011) of Nigeria (Table 2). Copper (Cu) is a micronutrient that can promote seed germination and seedling growth at low concentrations but its (Cu) concentration in this study is a serious concern. Non-biodegradable heavy metals in soil can cause long-term deleterious effects on ecosystem health as they can get absorbed by the root system and accumulate in different parts of plants, which affect plant physiological and metabolic processes (Qu *et al.*, 2021). Similarly, the values of Cu (0.68 to 38.33 mg/kg) in this study is well below 1,500 to 21,400 mg/kg in soil at e-waste site in Guangdong province in south China (Luo *et al.*, 2011), 915.3 to 13,646.6 mg/kg in soil at e-waste site in India (Singh *et al.*, 2018) and 202.66 mg/kg in soil at e-waste site in Ghana (Fosu-Mensah *et al.*, 2017). Copper is an essential element at trace level but can be toxic at when the threshold limit is exceeded.

Mercury recorded the lowest value among all the harmful elements tested in this study. The low concentration of Hg can be attributed to the fact that Hg easily evaporates into organo-mercury forms (Environmental Health and Safety Manual, 2000; Olafisoye *et al.*, 2013). The highest value of Hg (0.4767±0.03 mg/kg) occurred at 0-20 cm soil depth and was below detection level at other soil depths. The presence of Hg in surface soil (0-20 cm depth) may be attributed to release of mercury (Hg) from cathode-ray tubes and mercury lamps at the e-waste dumpsite. The values of Hg (0.4767±0.03 mg/kg) at 0-20 cm soil depth is 5.96, 119.18, 1191.8, and 4767 times higher than its values at 21-40, 41-60, 61-80, and 81-100 cm soil depth at the e-waste dumpsite as well as 2383.5 and 4767 times higher than its values at the control site for 0-20 and 21-40 cm soil depths, respectively. The values of Hg in soil increased from 0.0001±0.00 (at 81-100 cm depth) to 0.4767±0.03 mg/kg (at 0-20 cm depth) and the value is relatively higher than the target value of 0.3 mg/kg (Hg) as described by Dutch criteria for soil. Mercury is ranked third by the US Government Agency for Toxic Substances and Disease Registry of the most toxic elements or substances on the planet to arsenic and lead that continues to be dumped into waterways and soil, released into the atmosphere, and consumed in food and water (USDHHSPHS, 1999; Clifton, 2007). Studies in Hong Kong demonstrated that increased mercury levels were associated with infertility in both men and women (Dickman *et al.*, 1998). In males, mercury can have adverse effects on spermatogenesis (Boujbiha *et al.*, 2009), epididymal sperm count, and testicular weight (Rice *et al.*, 2014). Evidence also exists linking mercury with erectile dysfunction (Schrag and Dixon, 1985). In females, mercury has been shown to inhibit the release of follicle-stimulating hormone (FSH) and luteinizing hormone (LH) from the anterior pituitary which in turn can affect estrogen and progesterone levels leading to ovarian dysfunction, painful or irregular menstruation, premature menopause, and tipped uterus (Chen *et al*., 2006). There is good evidence linking mercury with menstrual disorders including abnormal bleeding, short, long, irregular cycles, and painful periods (Davis *et al*., 2001). Soil contaminated by mercury or the redistribution of contaminated water has the potential to enter the food chain through plant and livestock (Rice et al., 1997; Goldman and Shannon, 2001; Davidson et al., 2004) The values of Hg (0.0001 to 0.4767 mg/kg) in this study is relatively lower than 0.67 mg/kg and 0.60 mg/kg in soils at e-waste sites in Ghana (Fosu-Mensah *et al*., 2017).

The highest value of Cr (69.74±6.42 mg/kg) at 0-20 cm soil depth may be associated with the presence of switches at the e-waste dumpsite. The source of Cr in soil at e-waste site include hardener in plastics and dye in pigments of some switches of e-waste materials (Adewumi *et al*., 2017). The values of Cr (69.74±6.42 mg/kg) at 0-20 cm soil depth is 1.61, 4.05, 10.88, and 45.88 times higher than its values at 21-40, 41-60, 61-80, and 81-100 cm soil depths as well as 56.24, 72.65, 581.17, and 116233 times higher than its values at the control site for 0-20, 21-40, 41-60, 61-80, and 81-100 cm soil depths, respectively. The concentration of Cr in soil increased from 1.52±0.54 (at 80-100 cm soil depth) to 69.74±6.42 mg/kg (at 0-20 cm soil depth) and the value is lower than the target value of 100 mg/kg (Cr) as described by Dutch criteria for soil (Ogbonna *et al*., 2020), the permissible limit of 100 mg/kg (Cr) established by Codex Alimentarius Commission (FAO/WHO, 2001), the accepted limit of 150 mg/kg (Cr) set by the European Union (EU, 2002) and 100 mg/kg (Cr) as described by National Environmental Standards and Regulations Enforcement Agency (NESREA, 2011) of Nigeria (Table 2). Similarly, the values of Cr (1.52 to 69.74 mg/kg) in this study is below 0.00 to 268.6 mg/kg in soil at e-waste site in India (Singh *et al*., 2018), 23.6 to 122.0 mg/kg in soil at e-waste site in Guangdong province in south China (Luo *et al*., 2011) but higher than 56.0 mg/kg in soil at e-waste site in Accra, Ghana (Fasu-Mensah *et al*., 2017) and 0.54 mg/kg in soil at e-waste site in Lagos, Nigeria (Sanusi, 2015). The differences in the concentration of heavy metals in soil in this study from other research work on e-waste site may be attributed to age of the dumping site and the frequency of dumping waste at the site. Generally, the values of the harmful elements in soil during the dry season is: Cr>Cu>Pb> Cd>Hg.

Table 3 summarized the concentrations of the various harmful elements in the different soil depths during the wet season. The result indicates significant differences among the various HEs tested across the different soil depths. The highest values of the HEs (Pb, Cd, Cu, Hg and Cr) tested in soil during the wet season were observed at the 0-20 cm soil depth (24.14±0.92, 0.89±0.09, 22.12±2.00, 0.1133±0.02 and 50.37±0.55 mg/kg) and these values are significantly ($p<0.05$) higher than values recorded at 21-40 cm, 41-60 cm, 61-80 cm and 81-100 cm soil depths. The level of organic matter and soil pH at 0-20 cm depth during wet season is implicated for the high concentration of HEs in soil at 0-20 cm depth (Table 3). The values of Pb (24.14±0.92 mg/kg), Cd (0.89±0.09 mg/kg), Cu (22.12±2.00 mg/kg), Hg (0.1133±0.02 mg/kg) and Cr (50.37±0.55 mg/kg) in soil at 0-20 cm depth is 1.74, 2.73, 1.96, 3.09 and 1.49 times higher than its values at 21-40 cm depth as well as 2.45, 17.8, 3.25, 11330 and 3.93 times higher than its values at 41-60 cm depth, respectively. More so, the values of Pb, Cd, Cu, Hg and Cr in soil at 0-20 cm depth is 4.71, 89, 23.8, 1133 and 13.99 times higher than its values at 61-80 cm depth and 482.8, 890, 122.9, 11330 and 1679 times higher than its values at 81-100 cm depth, respectively. In furtherance of this, the values of HEs in soil at 0-20 cm depth at e-waste dumpsite is 241400, 89000, 34.56, 11330 and 66.28 times higher than values obtained in 0-20 cm depth at the control site for Pb, Cd, Cu, Hg and Cr, respectively. Generally, the order of abundance of HEs in soil at e-waste dumpsite in the wet season is: Cr>Pb>Cu>Cd>Hg.

In comparing the concentration of HEs in soil in both seasons, it was observed that the concentrations of Pb, Cd, Cu, Hg and Cr in soil were higher in dry season than in wet season. The low values of HEs in soil during the wet season may be attributed to leaching effect of rainfall that carried the HEs down the soil profile. This result is in conformity with the findings of Alloway and Ayres (1997), Chinwe *et al.* (2010) and Olafisoye *et al.* (2013). In this study, the values of Pb (0.42±0.40 to 34.18±5.60 mg/kg) in the dry season is higher than 0.05±0.05 to 24.14±0.92 mg/kg (Pb) in wet season but lower than 200.90±0.40 to 630.07±0.01 mg/kg (Pb) in wet and dry season (Olafisoye *et al*., 2013). The values of Cd (0.00±0.00 to 1.43±0.21 mg/kg) in the dry season is higher than 0.00±0.00 to 0.89±0.09 mg/kg (Cd) in the wet season but lower than 2.55±0.12 to 9.99±0.07 mg/kg (Cd) in wet and dry season (Olafisoye *et al*., 2013). The concentration of Cu (0.68±0.42 to 38.33±1.40 mg/kg) in the dry season is higher than 0.18±0.03 to 22.12±2.00 mg/kg in the wet season. Similarly, the values of Hg (0.0001±0.00 to 0.4767±0.03 mg/kg) in the dry season is higher than 0.0000±0.00 to 0.1133±0.02 mg/kg in the wet season. The values of Cr (1.52±0.54 to 69.74±6.42 mg/kg) in the dry season is higher than 0.03±0.02 to 50.37±0.55 mg/kg (Cr) in the wet season as well as 19.11±0.01 to 46.58±0.02 mg/kg (Cr) in wet and dry season (Olafisoye *et al*., 2013).

Table 3: Concentration of harmful elements in soil during wet season

Depth (cm)	Pb	Cd	Cu	Hg	Cr	pH	OM
0-20	24.14^{a}±0.92	0.89^{a}±0.09	22.12^{a}±2.00	0.1133^{a}±0.02	50.37^{a}±0.55	5.04^{b}	1.79^{d}
21-40	13.90^{b}±0.20	0.32^{b}±0.03	11.30^{b}±1.05	0.0367^{b}±0.03	33.70^{b}±0.52	4.80^{c}	0.82^{e}
41-60	9.84^{c}±0.55	0.05^{c}±0.01	6.80^{c}±0.61	0.0001^{c}±0.00	12.82^{c}±1.71	4.21^{c}	0.61^{e}
61-80	5.13^{d}±0.08	0.01^{c}±0.00	0.93^{d}±0.12	0.0000^{c}±0.00	3.60^{d}±0.40	4.01^{c}	0.46^{e}
81-100	0.05^{e}±0.05	0.00^{c}±0.00	0.18^{d}±0.03	0.0000^{c}±0.00	0.03^{e}±0.02	3.82^{d}	0.11^{ef}
Control							
0-20	0.0001^{f}±0.00	0.00001^{e}±0.00	0.64^{d}±0.01	0.00001^{c}±0.00	0.76^{e}±0.03	6.92^{a}	7.91^{a}
21-40	0.00001^{f}±0.00	BDL	0.02^{e}±0.00	BDL	0.09^{f}±0.01	6.20^{a}	5.42^{b}
41-60	BDL	BDL	BDL	BDL	0.05^{f}±0.00	5.96^{ab}	3.80^{c}
61-80	BDL	BDL	BDL	BDL	BDL	5.81^{ab}	1.90^{d}
81-100	BDL	BDL	BDL	BDL	BDL	5.40^{ab}	1.74^{d}

Values were expressed as mean ± standard deviation of 3 replicates; *[abc] Means in a column with different superscripts are significantly different (P<0.05)*

3.2. Concentration of Harmful Elements in Plants

The concentrations of harmful elements in different plant samples collected in the dry season is presented in Table 4. The results show that highest and lowest concentrations of the harmful elements were obtained in plant species from the e-waste dumpsite and control site, respectively. The result also indicates significant differences among the plant species sampled from the study site (i.e., e-waste dumpsite area). The high values of Pb, Cd, Cu, Hg and Cr in plant species sampled from the e-waste dumpsite may be attributed to the high concentrations of the harmful elements in soil at the e-waste dumpsite (Table 1) due to burning of electronic gadgets like batteries, toner, inkjet, cathode ray tubes, rechargeable lanterns, phones.

The highest values of Pb (2.70±0.10 mg/kg), Cd (0.087±0.03 mg/kg) and Cr (2.73±0.37 mg/kg) in the dry season were obtained in *Pennisetum purpureum* and the values are significantly (p<0.05) higher than its (Pb, Cd and Cr) values in *Vernonia amygdalina* (0.75±0.25, 0.005±0.00 and 0.95±0.10 mg/kg) and *Amaranthus spinosus* (0.16±0.08, 0.004±0.00 and 0.11±0.08 mg/kg) at the e-waste dumpsite as well as *Pennisetum purpureum* (0.0003±0.01, 0.0001±0.00 and 0.08±0.02 mg/kg), *Vernonia amygdalina* (0.0001±0.00, 0.0002±0.01 and 0.04±0.02 mg/kg) and *Amaranthus spinosus* (0.0001±0.01, 0.0001±0.01 and 0.01±0.00 mg/kg) from the control site. The high values of Pb, Cd and Cr in *Pennisetum purpureum* may be attributed to its inherent ability to uptake HEs from the soil via its network of fibrous root that traverse both the surface soil (0-20 cm depth) and sub soils (21-100 cm depth). The *P. purpureum* is a fast-growing perennial grass (FAO, 2013) with deep fibrous root system consisting of several main roots that branch to form a dense mass of intermeshed lateral roots (Kafle and Balla, 2008).

The values of Pb in plant samples collected from the e-waste dumpsite in the dry season increased from 0.16±0.08 to 2.70±0.10 mg/kg, which is lower than 37.25±0.11 to 86.35±1.28 mg/kg recorded in *Amaranthus caudatus* (spinach) at e-waste site in wet and dry season at Lagos, Nigeria (Olafisoye *et al*., 2013) and 36.72±0.57 mg/kg observed in *Panicum maximum, Imperata cylindrica*, *Lactuca sativa*, *Hibiscus sabdariffa* in Accra, Ghana (Fasu-Mensah *et al*., 2017) but higher than 0.11 to 1.3 mg/kg in *Pisum sativa* L., *Chrysanthemum coronarium* L., *Brassica rapa* L., *Lactuca sativa* L. var. romana Gars, *Raphanus sativus*, *Calocasia esculenta* (L) Schott, *Allium ascalonicum* L., *Brassica oleraceae* L. var. capitata L., *Lactuca* *sativa* L., *Daucus carota* L., *Oryza sativa* L., *Neyraudia arundinacea* (L) Henr., *Bidens pilosa* L. and *Echinochioa crusgailis* (L) Beauv at e-waste site in Guangdong province in south China (Luo *et al*., 2011). The concentration of Pb (0.16±0.08 to 2.70±0.10 mg/kg) in this study is well above the permissible limit of 0.3 mg/kg (Pb) established by the Codex Alimentarius Commission (FAO/WHO, 2006) (Table 5). The soil is implicated for the high concentration of Pb in plant species since its (Pb) concentration in soil is about ten (10) folds higher than in plants. Lead (Pb) is not an essential element for healthy growth and development of plants but will constitute serious health risk to animals and man that depend on these plant species (*Pennisetum purpureum*, *Vernonia amygdalina* and *Amaranthus spinosus*) for food and medicinal purposes. For instance, *P. purpureum* is an important feed and fodder plant in livestock production (Negawo *et al*., 2017) while its young shoots is used as a cooked vegetable (Akah and Onweluzo, 2014). Lead is of toxicological significance since it (Pb) has no known biological importance (Lenntech, 2009). Thus, livestock animals such as goat, sheep, cow that graze on the plant species growing on the e-waste dumpsite area are likely to accumulate the harmful elements that may expose them to serious health risks. Song and Li (2015) reported high rate of abortions, reduced birth weights as well as infant lengths in pregnant ladies exposed to heavy metals from EEE dumpsites. Deoxyribonucleic acid (DNA) damage in human peripheral blood lymphocytes due to exposure to e-waste pollutants have been reported in Nigeria and China (Alabi *et al*., 2012).

Table 4: Concentration of harmful elements in different plant species during dry season

Plant species	Pb	Cd	Cu	Hg	Cr
P. purpureum	2.70±0.10	0.087±0.03	0.55±0.17	0.19±0.05	2.73±0.37
V. amygdalina	0.75±0.25	0.005±0.00	7.10±0.95	0.40±0.30	0.95±0.10
A. spinosus	0.16±0.08	0.004±0.00	1.71±0.30	0.00±0.00	0.11±0.08
Control					
P. purpureum	0.0003±0.01	0.0001±0.00	0.06±0.00	BDL	0.08±0.02
V. amygdalina	0.0001±0.00	0.0002±0.01	0.04±0.02	BDL	0.04±0.02
A. spinosus	0.0001±0.01	0.0001±0.01	0.02±0.01	BDL	0.01±0.00

Values were expressed as mean ± standard deviation of 3 replicates

The values of Cd in plant samples collected from the e-waste dumpsite in the dry season increased from 0.004±0.00 to 0.087±0.03 mg/kg, which is lower than 0.13±0.13 to 1.21±0.01 mg/kg recorded in *A. caudatus* (Olafisoye *et al*., 2013), 1.64±0.12 mg/kg obtained in *P. maximum, I. cylindrica*, *L. sativa* and *H. sabdariffa* in Accra, Ghana (Fasu-Mensah *et al*., 2017) and 0.04 to 0.38 mg/kg in *P. sativa* L., *C. coronarium* L., *B. rapa* L., *L. sativa* L. var. romana Gars, *R. sativus*, *C. esculenta* (L) Schott, *A. ascalonicum* L., *B. oleraceae* L. var. capitata L., *L. sativa* L., *D. carota* L., *O. sativa* L., *N. arundinacea* (L) Henr., *B. pilosa* L. and *E. crusgailis* (L) Beauv at e-waste site in Guangdong province in south China (Luo *et al*., 2011). The concentration of Cd (0.004±0.00 to 0.087±0.03 mg/kg) in this study is lower than the permissible limit of 0.2 mg/kg (Cd) established by the Codex Alimentarius Commission (FAO/WHO, 2007) (Table 5). Cadmium is a non-essential element for growth and development of plants but may pose serious health challenges to animal and man that consume these promising plant species. Cadmium even at low concentration is toxic to all life, including plants, fish, birds, mammals (including humans), and microorganisms (Nordberg *et al*., 2007; ATSDR 2008). For example, *A. spinosus* is a vegetable that is widely utilized in Nigeria for preparation of soup, cooking of yam porridge, for making sauce. It (*A. spinosus*) is also offered to livestock animals such as goat and pigs in south east Nigeria for good growth and development. The *A. spinosus* is used as vegetable and for treatment of various types of pain conditions (Taiab *et al*., 2011).

The values of Cr in plant samples collected from the e-waste dumpsite in the dry season increased from 0.11±0.08 to 2.73±0.37 mg/kg, which is higher than 1.82±2.91 to 2.59±0.77 mg/kg recorded in *A. caudatus* (Olafisoye *et al*., 2013) and 1.56±0.12 mg/kg observed in *P. maximum, I. cylindrica*, *L. sativa* and *H. sabdariffa* in Accra, Ghana (Fosu-Mensah *et al*., 2017). The concentration of Cr (0.11±0.08 to 2.73±0.37 mg/kg) in this study is relatively higher than the permissible limit of 2.3 mg/kg (Cr) established by the Codex Alimentarius Commission (FAO/WHO, 2006) (Table 5). Chromium is an essential element for proper growth and development of plants at trace level but it (Cr) can be harmful to plants when the threshold is exceeded. Its (Cr) phytotoxicity include inhibition of seed germination or early seedling development, reduction of root growth, depressed biomass (Sharma *et al.*, 1995), chlorosis and necrosis in plants (Cervantes *et al.*, 2001). Seed germination and seedling growth are the most sensitive to soil chemical and physical conditions and can could produce severe toxicity symptoms which destroyed the antioxidant enzyme system in plants (Qu *et al.*, 2021). At high concentration, Cr reduces uptake of macronutrients in plants (Ghani, 2011). Thus, consumption of chromium-contaminated plants on sustained basis by animal and man living around the e-waste dumpsite may adversely affect their health. For instance, *V. amygdalina* is of great importance in human diet because of the presence of vitamins and mineral salts (Sobukola and Dairo 2007) and for the treatment of skin infections (Ogbonda *et al.*, 2013). Harmful elements adversely affect human health and ecosystem via the food chain. Hence, there is need for people to exercise caution on the use of plants growing around the e-waste dumpsite.

Table 5: Comparison with international and national standards source

	Pb	Cd	Cu	Cr	Hg
This study	0.02 – 2.70	0.001 – 0.027	0.46 – 4.23	0.04 – 1.12	0.00-0.13
Olafisoye *et al.* (2013)	37.25 – 86.35	0.13 – 1.21	NA	1.82-2.59	NA
Luo *et al.* (2011)	0.11 – 1.30	0.04 – 0.38	NA	NA	NA
FAO/WHO (2001), (2006), (2007)	0.3	0.2	40	2.3	NA
FEPA 1999	NA	NA	NA	NA	NA
NESREA 2011	NA	NA	NA	NA	NA

NA = Not available

The highest value of Cu (7.10±0.95 mg/kg) in the dry season was obtained in *V. amygdalina* and the value is significantly ($p<0.05$) higher than 1.71±0.30 mg/kg recorded in *A. spinosus* as well as 0.55±0.17 mg/kg observed in *P. purpureum.* The values of Cu in plants increased from 0.55±0.17 (in *P. purpureum*) to 7.10±0.95 mg/kg in (*V. amygdalina*) during the dry season. Copper plays a key function in CO_2 assimilation and ATP production (Marques *et al.*, 2018). It is the main constituent of diverse proteins like plastocyanin of photosynthetic system and cytochrome oxidase of electron transport chain (Zeng *et al.*, 2019). Cu concentration in plants beyond critical limits affects the plant growth, promotes leaf chlorosis and causes cytotoxicity (Saleem *et al.*, 2020), damaging plant roots, with symptoms ranging from disruption of the root cuticle and reduced root hair proliferation, to severe deformation of root structure (Sheldon and Menzies, 2005). According to the report of World Health Organisation (2017), excessive consumption of Cu in beverages and drinking water resulted in nausea, vomiting and diarrhoea in humans. Winge and Mehra (1990) documented that early-stage Cu poisoning causes weakness, lethargy and anorexia in humans and later on it damages the gastrointestinal tract and causes necrosis in the kidney (Barceloux and Barceloux, 1999). Desai and Kaler (2008) reported that Cu excess in human body results in mitochondrial damage, breaks in DNA, brain injury and various other neurological disorders (Kumar *et al.*, 2021).

The highest value of Hg (0.40±0.30 mg/kg) in the dry season was obtained in *V. amygdalina* but the value is statistically ($p>0.05$) the same with the value (0.19±0.05 mg/kg) observed in *P. purpureum* but significantly ($p<0.05$) different from 0.00±0.00 mg/kg recorded in *A. spinosus* during the dry season. The values of Hg in plants increased from 0.00±0.00 (in *A. spinosus*) to 0.40±0.30 mg/kg (in *V. amygdalina*) in the dry season. Release of mercury through burning of e-waste may lead to a progressive increase in the amount of atmospheric mercury, which enters the atmospheric-soil-plant distribution cycles where it can remain in circulation for years. Mercury reduced elongation of *Zea mays*' primary roots as well as an inhibition of the gravimetric response of the seedlings (Patra *et al.*, 2004). The major route of human exposure to methyl mercury (MeHg) is mainly via consumption of contaminated food and wildlife exposed to mercury through ingestion of contaminated lower organisms (Rice *et al.*, 2014). Its toxicity includes nervous system damage in adults and impaired neurological development in infants and children, induce oxidative stress and mitochondrial dysfunction (Lund *et al.*, 1993) which can result in alterations in calcium homeostasis and increased lipid peroxidation (Peraza *et al.*, 1998).

Table 6 shows the results of the concentrations of harmful elements tested in the different plant species during the wet season. The highest values of Pb (1.72±0.02 mg/kg), Cd (0.027±0.02 mg/kg) and Cr (1.12±0.16 mg/kg) in the wet season were obtained in *P. purpureum* and the values are significantly ($p<0.05$) higher than their (Pb, Cd and Cr) values in *V. amygdalina* (0.61±0.01, 0.001±0.00 and 0.30±0.10 mg/kg) and *A. spinosus* (0.02±0.02, 0.001±0.00 and 0.04±0.03 mg/kg). The values of Pb in plants during the wet season increased from 0.02±0.02 to 1.72±0.02 mg/kg. Similarly, the values of Cd in plants during the wet season increased from 0.001±0.00 to 0.027±0.02 mg/kg while the values of Cu in plants increased from 0.46±0.14 to 4.23±1.06 mg/kg in the wet season. The concentration of Hg in plants increased from 0.00±0.00 to 0.13±0.06 mg/kg in the wet season while the values of Cr in plants increased from 0.04±0.03 to 1.12±0.16 mg/kg in the wet season.

Table 6: Concentration of harmful elements in different plant species during wet season

Plant species	Pb	Cd	Cu	Hg	Cr
P. purpureum	1.72±0.02	0.027±0.02	0.46±0.14	0.03±0.01	1.12±0.16
V. amygdalina	0.61±0.01	0.001±0.00	4.23±1.06	0.13±0.06	0.30±0.10
A. spinosus	0.02±0.02	0.001±0.00	0.71±0.09	0.00±0.00	0.04±0.03
Control					
P. purpureum	0.00002±0.01	BDL	0.004±0.01	BDL	0.002±0.01
V. amygdalina	0.0000±0.01	BDL	0.001±0.02	BDL	0.001±0.01
A. spinosus	0.0000±0.01	BDL	0.001±0.01	BDL	0.001±0.00

Values were expressed as mean ± standard deviation of 3 replicates; ^{abc} *Means in a column with different superscripts are significantly different ($P<0.05$)*

In comparing the concentrations of HEs in plants in both seasons, it was observed that the concentrations of harmful elements in plants were higher in the dry season than in the wet season. This may be attributed to the soil since the concentrations of HEs were higher in soil during the dry season than the wet season. Similarly, the dilution effect of rainfall may have also contributed to the low concentrations of HEs during the dry season in the three (3) plant species tested in this study. The values of Pb in plants increased from 0.16±0.08 to 2.70±0.10 mg/kg in the dry season, which is higher than 0.02±0.02 to 1.72±0.02 mg/kg recorded in plants in the wet season but lower than 37.25±0.11 to 86.35±1.28 mg/kg reported for wet and dry season by Olafisoye *et al.* (2013). The values of Cd in plants increased from 0.004±0.00 to 0.087±0.03 mg/kg in the dry season, which is higher than 0.001±0.00 to 0.027±0.02 mg/kg recorded in plants in the wet season but lower than 0.13±0.13 to 1.21±0.01 mg/kg reported for wet and dry season by Olafisoye *et al.* (2013). The values of Cu in plants increased from 0.55±0.17 to 7.10±0.95 mg/kg in the dry season, which is higher than 0.46±0.14 to 4.23±1.06 mg/kg recorded in plants in the wet season. Similarly, the values of Hg in plants increased from 0.00±0.00 to 0.40±0.30 mg/kg in the dry season, which is higher than 0.00±0.00 to 0.13±0.06 mg/kg recorded in plants in the wet season. The values of Cr in plants increased from 0.11±0.08 to 2.73±0.37 mg/kg in the dry season, which is higher than 0.04±0.03 to 1.12±0.16 mg/kg recorded in plants in the wet season but higher than 1.82±2.91 to 2.59±0.77 mg/kg reported for wet and dry season by Olafisoye *et al.* (2013). From the results, it was observed that the values of harmful elements were affected by season.

3.3. Pearson Correlation Relationship Between Harmful Elements in Soil During Wet and Dry Season

The Pearson correlation relationship between harmful elements concentration in soil during the wet and dry season is presented in Table 7. The results indicate very strong positive relationship between harmful elements in soil during wet and dry season. For instance, very strong positive relationship exists between Pb in the dry season and Pb in the wet season ($r= 0.971$, $p<0.01$), Pb in the dry season and Cd in the wet season ($r= 0.891$, $p<0.01$), Pb in the dry season and Cu in the wet season ($r= 0.948$, $p<0.01$) and Pb in the dry season and Hg in the wet season ($r= 0.886$, $p<0.01$). There was also very strong positive relationship between Cd in the dry season and Pb in the wet season ($r= 0.921$, $p<0.01$), Pb in the dry season and Cd in the wet season ($r= 0.930$, $p<0.01$), Cd in the dry season and Cu in the wet season ($r= 0.942$, $p<0.01$), Cd in the dry season and Hg in the wet season ($r= 0.958$, $p<0.01$), and Cd in the dry season and Cr in the wet season ($r= 0.932$, p<0.01). Very strong positive relationship exists between Cd and Pb in soil (r= 0.921, p<0.01), Cu and Pb (r= 0.961, p<0.01), Cu and Cd (r= 0.061, p<0.01) in the dry season.

Table 7: Pearson correlation coefficient showing the relationship between heavy metal concentrations in soil during dry (d) and wet (w) season

	Pb(d)	Cd(d)	Cu(d)	Hg(d)	Cr(d)	Pb(w)	Cd(w)	Cu(w)	Hg(w)	Cr(w)
Pb(d)	1									
Cd(d)	.921**	1								
Cu(d)	.961**	.961**	1							
Hg(d)	.848**	.921**	.934**	1						
Cr(d)	.959**	.933**	.976**	.893**	1					
Pb(w)	.971**	.921**	.978**	.875**	.971**	1				
Cd(w)	.891**	.930**	.968**	.961**	.957**	.933**	1			
Cu(w)	.948**	.942**	.990**	.911**	.982**	.983**	.964**	1		
Hg(w)	.886**	.958**	.945**	.975**	.912**	.888**	.951**	.921**	1	
Cr(w)	.968**	.932**	.973**	.867**	.994**	.971**	.943**	.977**	.905**	1

***. Correlation is significant at the 0.01 level (P<0.01)*

Similarly, very strong positive relationship occurs between Hg and Pb (r= 0.848, p<0.01), Hg and Cd (r= 0.921, p<0.01), Hg and Cu (r= 0.934, p<0.01) in the dry season. Furthermore, very strong positive relationship occurs between Cr and Pb (r= 0.959, p<0.01), Cr and Cd (r= 0.933, p<0.01), Cr and Cu (r= 0.976, p<0.01) and Cr and Hg (r= 0.893, p<0.01) in the dry season. There was also very positive relationship between Pb and Cd in soil (r= 0.933, p<0.01), Pb and Cu (r= 0.983, p<0.01), Pb and Hg (r= 0.888, p<0.01), Pb and Cr (r= 0.971, p<0.01) in the wet season. More so, very strong positive relationship exists between Cd and Cu (r= 0.964, p<0.01), Cd and Hg (r= 0.951, p<0.01) and Cd and Cr (r= 0.943, p<0.01) as well as Cu and Hg (r= 0.921, p<0.01) and Cu and Cr (r= 0.977, p<0.01) in the wet season. The very strong positive relationship between harmful elements in soil during the wet and dry season show that season was a strong factor that influenced the concentrations of HEs across soil depths.

3.4. Pearson Correlation Relationship Between Harmful Elements in Flora During Wet and Dry Season

The Pearson correlation relationship between harmful elements concentration in soil during the wet and dry season is presented in Table 8.

Table 8: Pearson correlation coefficient showing the relationship between heavy metal concentration in plants during dry (d) and wet (w) season

	Pb(d)	Cd(d)	Cu(d)	Hg(d)	Cr(d)	Pb(w)	Cd(w)	Cu(w)	Hg(w)	Cr(w)
Pb(d)	1									
Cd(d)	.900**	1								
Cu(d)	-.450	-.581	1							
Hg(d)	.215	-.027	.519	1						
Cr(d)	.984**	.897**	-.353	.224	1					
Pb(w)	.985**	.890**	-.333	.234	.986**	1				
Cd(w)	.843**	.624	-.550	.018	.775*	.797*	1			
Cu(w)	-.320	-.482	.955**	.715*	-.237	-.224	-.464	1		
Hg(w)	-.038	-.220	.765*	.883**	.028	.028	-.284	.849**	1	
Cr(w)	.980**	.946**	-.435	.214	.965**	.977**	.747*	-.306	-.025	1

***. Correlation is significant at the 0.01 level (P<0.01); *. Correlation is significant at the 0.05 level (p<0.05)*

The results indicate very strong positive relationship between harmful elements in plants during wet and dry season. For instance, very strong positive relationship exists between Pb and Cd in plants ($r= 0.900$, $p<0.01$), Pb and Cr ($r= 0.984$, $p<0.01$), Cd and Cr ($r= 0.997$, $p<0.01$) in the dry season. However, very strong positive relationship occurs between Pb (in the dry season with Pb in the wet season ($r= 0.985$, $p<0.01$), Pb in the dry season and Cd in the wet season ($r= 0.843$, $p<0.01$), Pb in the dry season with Cr in the wet season ($r= 0.980$, $p<0.01$), Cd in the dry season and Pb in the wet season ($r= 0.890$, <0.01), Cd in the dry season and Cr in the wet season (0.946, $p<0.01$).

4. CONCLUSION

The study show that harmful elements (Pb, Cd, Cu, Hg and Cr) were present in varying quantities in the soil and accumulated in plants growing at the e-waste dumpsite. The result indicates that values of harmful elements in soil and its concentrations in plants were affected by season. It also indicates that concentrations of HEs decreased with increase in soil depths. Of all the HEs tested in this study, the concentration of Pb (0.16±0.08 to 2.70±0.10 mg/kg) and Cr (0.11±0.08 to 2.73±0.37 mg/kg) pose varying degrees of toxicity to flora and fauna since it exceeds the FAO/WHO permissible limit. Hence, the utilization of the plant species by man and animals will result to serious adverse health impact. Therefore, it is recommended that effective monitoring of the e-waste area should be carried out on regular basis by the Rivers State government via sponsoring scientific research. More so, livestock owners should control their livestock to avoid consumption of contaminated plants at e-waste area since livestock will be a medium for bio-magnification of harmful elements.

5. CONFLICT OF INTEREST

There is no conflict of interest associated with this work.

REFERENCES

Adaramodu, A.A., Osuntogun, A.O., Ehi-Eromosele, C.O. (2012). Heavy metal concentration of surface dust present in E-waste components: The Westminster electronic market, Lagos Case Study. *Resources and Environment*, 2(2), pp. 9-13.

Ademoroti, C.M.A. (1996). *Heavy metals in air*. Foludex Press, Ibadan, Nigeria.

Adesokan, M.D., Adie, G.U. and Osibanjo, O. (2016). Soil pollution by toxic metal near e-waste recycling operations in Ibadan, Nigeria. *Research Journal of Health Pollution*, 11, pp. 26-33.

Adewumi, B., Akingunsola, E., Femi-Oloye, O.P. and Oloye, F.F. (2017). Evaluation of the heavy metals composition of soil at e-waste dumping sites. *Asian Journal of Environment and Ecology*, 5(4), pp. 1-8.

Adeyi, A.A. and Oyeleke, P. (2017). Heavy metals and polycyclic aromatic hydrocarbons in soil from e-waste dumpsites in Lagos and Ibadan, Nigeria. *Journal of Health Pollution*, 7(15), 71-84.

Adie, G.U. and Etim, E.U., (2012). Assessment of toxic heavy metal loading in topsoil samples within the vicinity of a limestone quarry in south western Nigeria. *African Journal of Environmental Science and Technology*, 6(8), pp. 322-330.

Agboola, A.A. and Fagbenro, J.A., (1985). *Soil organic matter and its management in the humid tropics with particular reference to Nigeria*. In: Proceedings. on soil fertility, soil tilth, and post clearing degradation in humid tropics, pp. 215-233.

Agency for Toxic Substances and Disease Registry (ATSDR) (2008). ATSDR Medical Fact Sheet; Division of Toxicology and Environmental Medicine ToxFAQs; Accessed November 19, 2010. http://www.atsdr.cdc.gov/tfacts5.pdf.

Akah, N. and Onweluzo, J. (2014). Evaluation of water-soluble vitamins and optimum cooking time of fresh edible portions of Elephant Grass (*Pennisetum purpureum* L. Schumach) shoot. *Nigerian Food Journal* 2014, 32, pp. 120–127.

Alabi, O.A., Bakare, A.A., Xu, X., Li, B., Zhang, X. and Huo, Y. (2012). Comparative evaluation of environmental contamination and DNA damage induced by electronic and waste in Nigeria and China. *Science of the Total Environment*, 423, pp. 62–72.

Alani, R., Ogunbanmwo, A., Nwude, D. and Ogbaje, M. (2020). Evaluation of the environmental impacts of electronic-waste management in Lagos using Alaba international market and Ikeja computer village as case studies. *Nigerian Journal of Environmental Science and Technology*, 4(2), pp. 283-297.

Alloway B.J. and Ayres D.C. (1997). *Chemical principles of environmental Pollution*. 2nd ed. Chapman and Hall, pp. 53-395.

Andersen, T.H. and Domsche, K.H. (1989). Ratios of microbial biomass carbon to total orgainic carbon in arable soils. *Soil Biology and Biochemistry*, 21(4), pp. 471-479.

Barceloux, D.G. and Barceloux, D. (1999). Copper. Journal of *Clinical Toxicology*, 3, pp. 217-230.

Boujbiha, M.A., Hamden, K., Guermazi, F., Bouslama, A., Omezzine, A., Kammoun, A. and Abdelfattah, E.F. (2009). Testicular toxicity in mercuric chloride treated rats: association with oxidative stress. *Reproductive Toxicology*, 28(1), pp. 81-89.

Cervantes, C., Campos-Garcia, J., Debars, S., Gutierrez-Corona, F., Loza-Tavera, H., Carlos-Tarres-Guzman, M. and Moreno-Sanchez, R. (2001). Interaction of chromium with microgenesis and plants. *FEMS Microbiology Reviews*, 25, pp. 335-347.

Chen, Y.W., Huang, C.F., Tsai, K.S., Yang, R.S., Yen, C.C., Yang, C.Y., Lin-Shiau, S.Y. and Liu, S.H. (2006). Methylmercury induces pancreatic beta-cell apoptosis and dysfunction. *Chemical Research in Toxicology*, 19(8), pp. 1080-1085.

Chinwe, U.O., Obinna, N.C. and Akeem, A. and Alo, B.I. (2010). Assessment of heavy metals in urban highway runoff from Ikorodu expressway, Lagos, Nigeria. *Journal of Environmental. Chemistry and Ecotoxicology*, 2 (3), p. 34.

Clifton, J.C. (2007). Mercury exposure and public health. *Pediatric Clinics of North America*, 54(2), pp. 237-269.

Davidson, P.W., Myers, G.J. and Weiss, B. (2004). Mercury exposure and child development outcomes. *Pediatrics*, 113(4 Suppl), pp. 1023- 1029.

Davis, B.J., Price, H.C., O'Connor, R.W., Fernando, R., Rowland, A.S. and Morgan, D.L. (2001). Mercury vapor and female reproductive toxicity. *Toxicological Sciences*, 59(2), pp. 291-296.

Desai, V. and Kaler, S.G. (2008). Role of copper in human neurological disorders. *American Journal of Clinical Nutrition*, 88(3), pp. 855S-858S.

Dickman, M.D., Leung, C.K. and Leong, M.K. (1998). Hong Kong male subfertility links to mercury in human hair and fish. *Science of the Total Environment*, 214, pp. 165-174.

Food and Agricultural Organization (FAO) of the United Nations (2013). Grassland species profiles: *Pennisetum purpureum*. Rome, Italy: FAO. http://www.fao.org/ag/AGP/AGPC/doc/Gbase/data/pf000301.htm.

Ekklund, F., Ronn, R. and Christensen, S. (2001). Distribution with depth of protozoa, bacteria and fungi in soil profiles from three Danish forest sites. *Soil Biology and Biochemistry*, 33(4-5), pp. 475-481.

European Commission Director General Environment, (ECDGE) (2010). Heavy Metals and Organic Compounds from Wastes Used as Organic Fertilizers. Final Rep., July. WPA Consulting Engineers Inc. Ref. Nr. TEND/AML/2001/07/20, pp. 73-74. http://ec.europa.eu/environment/waste/compost/pdf/hm_finalreport.pdf.

European Union, (EU) (2002). Directive 2002/96/EC of the European parliament and of the council of 27 January 2003 on waste electrical and electronic equipment (WEEE). In: Official Journal of the European Union (Ed.), L037:0024-39.

Environmental Health and Safety Manual. (2000). *Safe handling of mercury and mercury compounds*. Retrieved October 12, 2017, from https://iaomt.org/TestFoundation/safehandling.htm

Fang, C., Smith, P., Moncrieff, J.B.and Smith, J.U. (2005). Similar response of labile and resistant soil organic matter pools to changes in temperature. *Nature*, 433(7021), pp. 57-59.

FAO/WHO (2001). Food additives and contaminants. Joint FAO/WHO Food Standards Program, ALINORM 01/12A: 1-289.

FAO/WHO (2006). Guidelines for assessing Quality of Herbal Medicines with Reference to Contaminants and Residues, World Health Organization, Geneva, Switzerland.

FAO/WHO (2007). Joint FAO/WHO Food Standard Programme Codex Alimentarius Commission 13th Session. Report of the Thirty Eight Session of the Codex Committee on Food Hygiene. Houston, TX, ALINORM 07/30/13.

Federal Environmental Protection Agency (FEPA) (1991). Guidelines and Standards for Environmental Pollution in Nigeria.

Fosu-Mensah, B.Y., Addae, E., Yirenya-Tawiah, D. and Nyame, F. (2017). Heavy metals concentration and distribution in soils and vegetation at Korle Lagoon area in Accra, Ghana. *Cogent Environmental Science*, 3(1), pp. 1-14.

Gabriella, M.G. and Anton, A. (2005). Phytoremediation study; factors influencing heavy metal uptake of plants. *ActaBiologica*, 49(1-2), pp. 69-70.

Ganjare, A. and Raut, N. (2019). Nutritional and medicinal potential of *Amaranthus spinosus*. *Journal of Pharmacognosy and Phytochemistry*, 8(3), pp. 3149-3156.

Garcon, G., Dagher, Z., Zerimech, F., Ledoux, F., Courcot, D., Aboukais, A., Puskaric, E. and Shirali, P. (2006). Dunkerque city air pollution particulate matter-induced cytotoxicity, oxidative stress and inflammation in human epithelial lung cells (L132) in culture. *Toxicology in Vitro*, 20(4), pp. 519-528.

Ghani, A. (2011). Effect of chromium toxicity on growth, chlorophyll and some mineral nutrients of *Brassica juncea* L. *Egyptian Academic. Journal of Biological Sciences*, 2(1), pp. 9 – 15.

Goldman, L.R. and Shannon, M.W. (2001). American Academy of Pediatrics: Committee on Environmental Health. Technical report: mercury in the environment: implications for pediatricians. *Pediatrics*, 108(1), pp. 197-205.

International Institute of Tropical Agriculture, (IITA) (1979). Selected methods for soil and plant analysis, Manual series No.1: Nigeria p. 6.

Kafle, G. and Balla, M.K. (2008). Effectiveness of Root System of Grasses Used in Soil Conservation in Paundi Khola Sub Watershed of Lamjung District, Nepal. The Initiation, pp. 121-129.

Kumar, B.S.A., Kuruba, L., Jayaveera, K.N., Shekar, D.S., Nandeesh, R. and Velmurugan, C. (2010). Chemoprotective and antioxidant activities of methanolic activities of *Amaranthus spinosus* leaves on paracetamol induced liver damage in rats. *Acta Medica Saliniana*, 39, pp. 68-74.

Kumar ABS, Lakshman K, VelmuruganC, Sridhar SM, Gopisetty S. (2014). Antidepressant activity of methanolic extract of *Amaranthus spinosus*. *Basic Clinical Neuroscience*, 5(1), pp. 11-17.

Kumar, V., Pandita, S., Sidhu, G.P.S., Sharma, A., Khanna, K., Kaur, P., Bali, A.S. and Setia, R. (2021). Copper bioavailability, uptake, toxicity and tolerance in plants: a comprehensive review. *Chemosphere*, 262, pp. 1-25.

Lenntech, W.T. (2009). Chemical properties, health, and environmental effects of copper. Lenntech Water Treatment and Purification Holding B.V.

Leung, A., Cai, Z.W. and Wong, M.H. (2006). Environmental contamination from electronic waste recycling at Guiyu, southeast China. *Journal of Mater Cycles Waste Management*, 8, pp. 21–33.

Lin, B.F., Chiang, B.L. and Lin, J.Y. (2005). *Amaranthus spinosus* water extract directly stimulates proliferation of B lymphocytes in vitro. *International Immunopharmacology*, 5, pp. 711–722.

Liu, J., Curry, J.A., Rossow, W.B., Key, J.R. and Wang, X. (2005). Comparison of surface radiative flux data sets over the Arctic Ocean. *Journal of Geophysical Research*, 110, pp. 1-13.

Lu, S., Luan, Q., Jiao, Z., Wu, M., Li, Z., Shao, L. and Wang, F. (2007). Mineralogy of inhalable particulate matter (PM10) in the atmosphere of Beijing, China. *Water, Air and Soil Pollution*, 186(1-4), pp. 129-137.

Lugon-Moulina, L., Ryanb, L., Doninia, P. and Rossia, L. (2006). Cadmium content of phosphate fertilizers used for tobacco production. *Agronomy for Sustainable Development*, 26, pp. 151–155.

Lund, B.O., Miller, D.M. and Woods, J.S. (1993). Studies on Hg(II)-induced H_2O_2 formation and oxidative stress in vivo and in vitro in rat kidney mitochondria. *Biochemical Pharmacology*, 45(10), pp. 2017-2024.

Luo, C., Liu, C., Wang, Y., Liu, X., Li, F. and Zhang, G. et al. (2011). Heavy metal contamination in soils and vegetables near an e-waste processing site, south China. Journal of Hazard Materials, 186, pp. 481–490.

Mac Farland, H.N., (1979). *Pulmonary effects of cadmium*: In: Mennea, J.E. (ed), cadmium toxicity, Dekker.

Marques, D.M., Júnior, V.V., da-Silva, A.B., Mantovani, J.R., Magalh~aes, P.C. and de-Souza, T.C. (2018). Copper toxicity on photosynthetic responses and root morphology of *Hymenaea courbaril* L. (Caesal pinioideae). *Water Air Soil Pollution*, 229, p. 138.

Menad, N. (1999). Cathode ray tube recycling. *Resources*, *Conservation and Recycling* 26, pp. 143–154.

Negawo, A.T., Teshome, A., Kumar, A., Hanson, J. and Jones, C.S. (2017). Opportunities for Napier grass (*Pennisetum purpureum*) improvement using molecular genetics - A review. *Agronomy*, 7(28), pp. 1-22.

NESREA (2011). 1st Eleven Gazetted Regulations Federal Republic of Nigeria Official Gazette.

Nordberg, G. F., Nogawa, K., Nordberg, M., and Friberg, M. (2007). *Cadmium*. In: Handbook on the Toxicology of Metals (G. F. Nordberg, B. A. Fowler, M. Nordberg, and L. T. Friberg, Eds.), 3rd ed., pp. 446–486. Academic Press/Elsevier, Amsterdam and Boston.

Ogbonda, G., Echem, R. and Kabari, L.G. (2013). Heavy metal content in bitter leaf (Vernonia amygdalina) grown along heavy traffic in Port Harcourt. Agricultural Chemistry, Margarita Stoytcheva and Roumen Zlatev, IntechOpen,

Ogbonna, P.C., Nzegbule, E.C. and Okorie, P.E. (2018). Soil chemical characteristics in wet and dry season at Iva long wall underground mined site, Nigeria. *Nigerian Journal of Environmental Science and Technology*, 2(1), pp 96 – 107.

Ogbonna, P.C., Nzegbule, E.C. and Okorie, P.E. (2019). Determination of Heavy Metal and Macronutrients in *Hyperiodrilus africanus* (Earthworm) and *Scolopendra cingulata* (Centipede) at Coal Mining Sites in Enugu State, Nigeria. *Nigerian Research Journal of Engineering and Environmental Sciences*, 4(1), pp. 341-351.

Ogbonna P.C., Osim O.O. and Biose E. (2020). Determination of heavy metal contamination in soil and accumulation in Cassava (*Manihot esculenta*) in automobile waste dumpsite at Ohiya mechanic village. *Nigerian Journal of Environmental Sciences and Technology*, 4(1), pp. 54-69.

Olafisoye, O.B., Adefioye, T. and Osibote, O.A. (2013). Heavy metals contamination of water, soil, and plants around an electronic waste dumpsite. *Polish Journal of Environ Studies*, 22(5), pp. 1431-1439.

Olalekan, R.M., Adedoyin O.O., Adedotun, A.T., Oluwaseun, O.E. and Anu, B. (2019). An analysis of Bayelsa State water challenges on the rise and its possible solutions – a review. *Acta Scientific Agriculture*, 3(8), pp. 110-125.

Omenihu, A.A. and Ojimgba, A., (2008) Organic matter status of "acid sands" of southeastern Nigeria and its agricultural implications. *Journal of Food and Fibre Production*, 1, pp. 79-85.

Pandit, N.P., Shrestha, M.K., Yi, Y., Diana, J.S. and Rampur, C. (2004). Polyculture of grass carp and Nile tilapia with Napier grass as the sole nutrient input in the subtropical climate of Nepal. In Proceedings of the 6th International Symposium on Tilapia in Aquaculture, Manila, Philippines, 12–16 September 2004; pp. 12–16.

Patra, M., Bhowmik, N., Bandopadhyay, B. and Sharma, A. (2004). Comparison of mercury, lead and arsenic with respect to genotoxic effects on plant systems and the development of genetic tolerance. *Environmental and Experimental Botany*, 52(3), pp. 199–223.

Peraza, M.A., Ayala-Fierro, F., Barber, D.S., Casarez, E. and Rael, L.T. (1998). Effects of micronutrients on metal toxicity. *Environmental Health Perspectives*, 106 Suppl 1, pp. 203-216.

Pradhan, J.K. and Kumar, S. (2014). Informal e-waste recycling: environmental risk assessment of heavy metal contamination in Mandoli industrial area, Delhi, India. *Environ Science and Pollution Research*, 21, pp. 7913–7928.

Peacock, J.L., Anderson, H.R., Bremner, S.A., Marston, L., Seemungal, T.A., Strachan, D.P. and Wedzicha, J.A. (2011). Outdoor air pollution and respiratory health in patients with COPD. *Thorax*, 66(7), pp. 591-596.

Perkins, B.D. and Nxele, S. (2014). E-waste: a global hazard. Annals of Global Health. Articl and Rev, 80, pp. 286-295.

Pope III, C.A., Burnett, R.T., Krewski, D., Jerrett, M., Shi, Y., Calle, E.E. and Thun, M.J. (2009). Cardiovascular mortality and exposure to airborne fine particulate matter and cigarette smoke: shape of the exposure response relationship. *Circulation*, 120(11), pp. 941-948.

Qu, T., Peng, Y., Chengxi, Y., Du, X., Guo, W. and Zhang, J. (2021). Single and combined effects of cadmium and lead on seed germination and early seedling growth in Rhus typhina. *Polish Journal of Environmental Studies*, 20(1), pp. 823-831.

Raaschou-Nielsen, O., Andersen, Z.J., Hvidberg, M., Jensen, S.S., Ketzel, M., Sørensen, M., Loft, S., Overvad, K. and Tjønneland, A. (2011). Lung Cancer Incidence and Long- Term Exposure to Air Pollution from Traffic. *Environmental Health Perspectives*, 119(6), pp. 860-865.

Raimi, M.O., Sawyerr, H.O., Adeolu, A.T. and Odipe, O.E. (2019). Measures of harm from heavy metal pollution in battery technicians' workshop within Ilorin metropolis, Kwara State, Nigeria. *Communication, Society and Media*, 2(2), pp. 73-89.

Rice, G.E., Ambrose, R.B. Bullock, O.R. and Smawtout J. (1997). Mercury study report to Congress. Durham: US Environmental Protection Agency, p. 1.1-6.30.

Saleem, M.H., Kamran, M., Zhou, Y., Parveen, A., Rehman, M., Ahmar, S., Liu, L. (2020). Appraising growth, oxidative stress and copper phytoextraction potential of flax (Linum usitatissimum L.) grown in soil differentially spiked with copper. *Journal of Environmental. Management*, 257, 109994.

Sanusi, A.I. (2015). Impact of burning e-waste on soil physicochemical properties and soil microorganisms. *British Microbiology Research Journal*, 8(2), pp. 434-442.

Schrag, S.D. and Dixon, R.L. (1985). Occupational exposures associated with male reproductive dysfunction. *Annual Review of Pharmacology and Toxicology*, 25, pp. 567-592.

Shaha, D.C.; Kundu, S.R.; Hasan, M.N. (2015). Production of organic grass carp (Ctenopharyngodon idella) and GIFT tilapia (*Oreochromis niloticus*) using Napier grass, *Pennisetum purpureum. Journal of Fish Biology*, 2015, 3, pp. 233–238.

Sharma, D.C., Chatterjee, C. and Sharma, C.P. (1995). Chromium accumulation by barley seedlings (*Hordeum vulgare* L.). *Journal of Experimental Botany*, 25, pp. 241-251.

Sheldon, A.R. and Menzies, N.W. (2005). The effect of copper toxicity on the growth and root morphology of Rhodes grass (*Chloris gayana* Knuth.) in resin buffered solution culture. *Plant and Soil*, 278, pp. 341-349.

Shrestha, M. and Yadav, C. (1998). Feeding of Napier (*Pennisetum purpureum*) to grass carp in polyculture: A sustainable fish culture practice for small farmers. *Asian Fisheries Science*, 1998, 11, 287–294.

Singh, A., Dwivedi, S.P. and Tripathi, A. (2018). Study of the toxicity of metal contamination in soil samples collected from abandoned e-waste burning sites in Moradabad, India. Nature Environment and Pollution Technology, 17(3), pp. 973-979.

Sobukola O. P. and Dairo O. U. (2007). Modeling drying kinetics of fever leaves *(Ocimum viride*) in a convective hot air dryer. *Nigerian Food Journal*, 25(1), pp. 145-153.

Song, Q., and Li, J. (2015). A Review on human health consequences of metals exposure to e-waste in China. *Environmental Pollution*, 196, pp. 450-461.

Steel, R.G.D. and Torrie, J.H., (1980). *Principles and procedures of statistics: A biometric approach*, McGraw-Hill, New York, p. 633.

Taiab Md, J.A., Nazmul, Q., Asif, A.M., Md. Amran, H., Shams-Ud-Doha, K.M. and Apu Apurba, S. (2011). Analgesic activity of extracts of the whole plant of *Amaranthus spinosus* linn. *International Journal of Drug Development and Research*, 3(4), pp. 189-193.

Tang, X., Shen, C., Shi, D., Cheema, S.A., Khan, M.I. and Zhang, C. et al. (2010). Heavy metal and persistent organic compound contamination in soil from Wenling: an emerging e-waste recycling city in Taizhou area, China. *Journal of Hazard Materials*, 73, pp. 653–60.

Taylor, J.P., Wilson, B., Mills, M.S. and Burns, R.G. (2002). Comparison of microbial numbers and enzymatic activities in surface soils and subsoils using various techniques. *Soil Biology and Biochemistry*, 34(3), pp. 387-401.

United States Department of Health and Human Services, Public Health Service, (USDHHSPHS) (1999). Toxicological profile for mercury. Atlanta: US Department of Health and Human Services, pp. 1-600.

Walkey, A. and Armstrong Black, A.I. (1934). An examination of the DEGTJAREFF method for the determination of soil organic matter, and a proposed modification of the chromic acid titration method. *Soil Sciences*, 37, pp. 29-38.

Wang, Y., Zhang, H., Zhai, J., Wu, Y., Cong, L., Yan, G. and Zhang, Z. (2020). Seasonal variations and chemical characteristics of $PM_{2.5}$ aerosol in the urban green belt of Beijing, China. *Polish Journal of Environmental Studies*, 29(1), pp. 361-370.

Winge, D.R. and Mehra, R.K. (1990). *Host defenses against copper toxicity*. In: International Review of Experimental Pathology, Vol. 31. Academic Press, pp. 47-83.

Wong, C.S.C., Duzgoren-Aydin, N.S., Aydin, A. and Wong, M.H. (2007). Evidence of excessive releases of metals from primitive e-waste processing in Guiyu, China. *Environmental Pollution*, 148, pp. 62–72.

World Health Organisation, (WHO) (2017). Guidelines for Drinking-Water Quality, fourth ed. incorporating the first addendum, Geneva.

Wu, C., Luo, Y., Deng, S., Teng, Y. and Song, J. (2014). Spatial characteristics of cadmium in topsoils in a typical e-waste recycling area in southeast China and its potential threat to shallow groundwater. *Science of the Total Environment*, 472, pp. 556–561.

Wu, Q., Leung, J.Y.S., Geng, X., Chen, S., Huang, X., Li, H., Huang, Z., Zhu, L., Chen, J. and Lu, Y. (2015). Heavy metal contamination of soil and water in the vicinity of an abandoned e-waste recycling site: implications for dissemination of heavy metals. *Science of the Total Environment*, 506-507, pp. 217-225.

Yuan, C., Zhang, H.C., McKenna, G., Korzeniewski, C. and Li, J. (2007). Experimental Studies on Cryogenic Recycling of Printed Circuit Board. *International Journal of Advanced Manufacturing Technology*, 34, pp. 657–666.

Zeng, Q., Ling, Q.,Wu, J., Yang, Z., Liu, R. and Qi, Y. (2019). Excess copper-induced changes in antioxidative enzyme activity, mineral nutrient uptake and translocation in sugarcane seedlings. *Bulletin of Environmental Contamination and. Toxicology*, 103(6), pp. 834-840.

Zheng, J., Chen, K.H., Yan, X., Chen, S.J., Hu, G.C. and Peng, X.W., Yuan, J., Mai, B. and Yang, Z. (2013). Heavy metals in food, house dust, and water from an e-waste recycling area in South China and the potential risk to human health. *Ecotoxicology and Environmental Safety*, 96, pp. 205–212.

Zhu, L., Liu, J., Cong, L., Ma, W., Ma, W. and Zhang, Z. (2016). Spatiotemporal characteristics of particulate matter and dry deposition flux in the Cuihu wetland of Beijing. *Plos One*, 11(7), pp. 1-16.