IOSR Journal of Environmental Science, Toxicology and Food Technology (IOSR-JESTFT)
e-ISSN: 2319-2402,p- ISSN: 2319-2399.Volume 12, Issue 3 Ver. III (March. 2018), PP 17-23
www.iosrjournals.org

Assesement of Some Heavy Metals in Soils and Plants Growth in Dumpsites

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Abstract: *This study was carried out to assess the heavy metal content (zinc, lead, chromium, cadmium and nickel) on soils and plants of dumpsites at Oluku, Iguomo and Ikhueniro in Benin City, Edo State. Soil samples were randomly collected from two depths (0-15 cm and 15-30 cm) from the dumpsite and control areas. Plant samples (Talinium triangulare) were also collected randomly from the dumpsite and control areas. Analysis of the soil and plant samples showed significant differences (P < 0.05) in heavy metal contents (especially zinc) between the control sites and the dumpsites. It was observed that the pollution index of the dumpsite soils were not high (<1) to readily cause harm. Although the transfer factor for zinc was >1 in the control and dumpsite areas, the other metals remained at <1 with the exception of cadmium which was >1 at the Iguomo dumpsite area.*

Keywords*: dumpsites, heavy metals, pollution, wastes.*

Date of Submission: 20-03-2018 Date of acceptance: 03-04-2018

I. Introduction

Waste materials which are generated from residential areas, markets, industries and hospitals are on the increase with increasing population and are disposed of in government approved and non-approved dumpsites in Benin City. In dumpsites, heavy metal such Cadmium (Cd) Copper (Cu, Chromium (Cr), Lead (Pb), Zinc (Zn) and Nickel (Ni) are also usually found due to remains from metals and other products (Shayley *et al*., 2009). These heavy metals are not only associated with pollution and toxicity but also include some elements which are essential for living organisms at low concentrations. Study of heavy metals in ecosystems has shown that many areas near urban complexes where waste is dumped contain high concentration of these heavy metals (Adelekan and Abegunde, 2011). The accumulation of these heavy metals above the threshold value in the soil or environment can lead to toxicity and this can be very dangerous to plants, animals including humans. The effects of these heavy metals include: destruction of ecosystem, destruction of marine biota, hindering of fisheries and other aquacultural operations, poisoning of sea food, contamination of surface and underground water, disturbances of soil function, reduction of plants productivity and chance of survival. Unlike organic contaminants, these heavy metals do not usually undergo microbial or chemical degradation through changes in their chemical forms.

Also, in developing countries, it is common to see crops grown around dumpsites due to the belief that these wastes are high in organic matter and thus can be used as manure and plants also tend to grow in these dumpsites and there is a high tendency for heavy metals to accumulate in the soil which is taken up by plants. Soils therefore are the major sink for heavy metals released in to the environment by dumping of refuse on land. Heavy metals occur naturally in the soil environment due to pedogenic processes of weathering of parent materials at levels that are regarded as trace (< 1000mg/kg) and rarely toxic (Anna and Piotr, 2014). These heavy metals become contaminants in the soil environment because their rate of generation via man-made cycles are rapid and also, the concentrations of these metals in discarded products are relatively high compared to those in the receiving environment. Interest has most recently been stimulated in researches at evaluating the levels of heavy metals around refuse dumpsite due to the growing concerns expressed by the government, regulatory agencies and the pubic over the large acres of land covered by the dumpsites. (Imasuen and Omorogieva, 2013). Heavy metal is often generally referred to as a silent killer and was defined by Harmsen (1977) as those having density greater than 5g cm^{-3}, but most often denote metals that are toxic such as lead (Pb), arsenal (As), mercury (Hg), nickel (Ni), and Selenium (Se). Therefore, heavy metal analysis form an important component tool needed to regulate environmental impact assessment in towns and cities (Asuen *et al*., 2005). Soil is very important in ecosystem research as it is where many types of interactions take place between minerals, air, water and biota. In the recent, the soil system has been subjected to physical stress by input of foreign substances such as heavy metals (Imasuen and Omorogieva, 2013). The presence of these heavy metals

in high levels due to dumping of wastes such as condemned batteries, engine oil amongst others could endanger the ecosystem, plants, animals and humans causing severe health problems (Amadi *et al.,* 2012).

Moreover, the metal pollutants accumulated in soil and under some biogeochemical conditions may pass in the soil solution, and consequently become bio-available and absorbed by plants (Soraya *et al*., 2014). High concentration of pollutants from the dumps could affect plant growth by changing the biodiversity of vegetation because the sensitive plants to heavy metal stress are not able to survive. Also, long periods of exposure of plants to polluted soils could result in plants taking up and becoming tolerant to high amount of heavy metals by many mechanism and pathways such as: adsorption, detoxification, immobilization and accumulation.

Although nutrient-metals such as zinc is essential for good health, excess zinc can be in fact harmful (Nagajyoti*et al*., 2010). The free zinc ion in solution is highly toxic to plants, invertebrates and vertebrate fishes. Levels of zinc in excess in soil interfere with the ability of plants to absorb other essential metals such as iron and magnesium. Zinc (Zn) is an essential micronutrient that affects several metabolic processes of plants (Nagajyoti*et al*., 2010) and has a long biological half-life. The phytotoxicity of Zn is indicated by decrease in growth and development, metabolism and an induction of oxidative damage in various plant species such as *Phaseolus vulgaris* and *Brassica juncea* (Nagajyoti*et al*., 2010). Zn has also been reported to cause alternation in catalytic efficiency of enzymes in *Phaseolus vulgaris* and pea plants (Nagajyoti*et al.*, 2010). Concentrations of Zn found in contaminated soils frequently exceed to those required as nutrients and may cause phytotoxicity Excess Zn can also give rise to manganese (Mn) and copper (Cu) deficiencies in plant shoots. Such deficiencies have been ascribed to a hindered transfer of these micronutrients from root to shoot. This hindrance is due to Fe and Mn concentrations in plants grown in Zn-rich media been greater in the root than in the shoot (Nagajyoti*et al*., 2010). Another typical effect of Zn toxicity is the appearance of a purplish-red color in leaves, which is ascribed to phosphorus (P) deficiency (Nagajyoti*et al*., 2010).

Also, lead is released into soil, groundwater and surface water as lead oxides, hydroxides and lead-metal oxyanion complexes. The main sources of lead contamination are smelting works, application of waste water treatment sludges to soil, transportation, rain, snow and hail (Smirjakova *et al*., 2005).Lead (Pb) is one of the ubiquitously distributed most abundant toxic elements in the soil. It exerts adverse effect on morphology, growth and photosynthetic processes of plants. Lead is known to inhibit seed germination of *Spartiana alterniflora* (Nagajyoti, 2010). Inhibition of germination may result from the interference of lead with important enzymes. Lead also inhibited root and stem elongation and leaf expansion in *Allium species*, barley and *Raphanus sativas* (Nagajyoti, 2010). The degree to which root elongation is inhibited depends upon the concentration of lead and ionic composition and pH of the medium. A high lead level in soil induces abnormal morphology in many plant species. Lead administrated to potted sugar beet plants at rates of 100–200 ppm caused chlorosis and growth reduction. Higher lead concentrations are more likely to be found in leafy vegetables and on the surface of root crop.Most exposure to lead occurs through ingestion or inhalation and Lead can be ingested through fruits and vegetables contaminated by high levels of lead in the soils they were grown. Soil is contaminated through accumulation from lead pipes, lead paints, residual emissions and cans used to store lead chemicals which can be thrown in dumpsites.

Chromium (Cr) is the 17th most abundant element in the earth's mantle and naturally occurs as chromite ($FeCr_2O_4$) (Oliveira, 2012). Chromium from anthropogenic sources can be released to soils and sediments indirectly by atmospheric deposition, but releases are more commonly from dumping of Chromium bearing liquid or solid wastes such as chromate by-products ("muds"), ferrochromium slag, or chromium plating wastes. Such wastes can contain any combination of Cr (III) or Cr (VI) with various solubilities (Shadrack *et al*., 2013).Chromium exists in the environment in three stable oxidation states, Cr (0), Cr (III) and Cr (VI) which have different toxicities and transport characteristics (Papassipoi et al., 2009). Cr (0) is the metallic form, produced in industry and is a solid with high fusion point usually used for the manufacturing of steel and other alloys. Cr (VI) typically exists as the oxyanion chromate (CrO_4^{2-}), dichromate ($Cr_2O_7^{2-}$) and the trioxide (CrO_3) have a high solubility in soils and water and very mobile in the environment.Chromium (Cr) compounds are highly toxic to plants and are detrimental to their growth and development. Although some crops are not affected by low Cr (3.8-9- 10-4lM) concentrations (Nagajyoti, 2010), Cr is toxic to higher plants at 100 l kg-1 dry weight. Germination is the first physiological process affected by Cr and the ability of a seed to germinate in a medium containing Cr would be indicative of its level of tolerance to this metal (Peralta et al. 2001). Seed germination of the weed *Echinochloa colona* was reduced to 25% with 200lM Cr (Nagajyoti, 2010). Peralta *et al*. (2001) observed that 40ppm of Cr (VI) reduced by 23% the ability of seeds of Lucerne (*Medicago sativa* cv. Malone) to germinate and grow in the contaminated medium. Reductions of 32–57% in sugarcane bud germination were observed with 20 and 80 ppm Cr, respectively (Nagajyoti, 2010). The reduced germination of seeds under Cr stress could be a depressive effect of Cr on the activity of amylases and on the subsequent transport of sugars to the embryo axes. Protease activity, on the other hand, increases with the Cr treatment, which could also contribute to the reduction in germination of Chromium treated seeds. Decrease in root growth

is a well-documented effect due to heavy metals in trees and crops (Nagajyoti, 2010). Chromium stress is one of the important factors that affect photosynthesis in terms of CO_2 fixation, electron transport, photophosphorylation and enzyme activities (Nagajyoti, 2010) and can induce three possible types of metabolic modification in plants: (i) alteration in the production of pigments, which are involved in the life sustenance of plants (e.g., chlorophyll, anthocyanin) (Nagajyoti, 2010) (ii) increased production of metabolites (e.g., glutathione, ascorbic acid) as a direct response to Cr stress, which may cause damage to the plants and (iii) alterations in the metabolic pool to channelise the production of new biochemically related metabolites, which may confer resistance or tolerance to Cr stress (e.g., phytochelatins, histidine).

Cadmium is produced mainly as a by-product from mining, smelting and refining sulfidic ores of zinc also produced from dust generated by recycling iron and steel scrap. It is also used as a stabilizer for polyvinylchloride (PVC) in alloys and atomic compounds also, present as an impurity in detergent. It is an environmental hazard (Nagajyoti, 2010). Human exposure to environmental cadmium is mainly the result of fossil fuel combustion, phosphate fertilizers, municipal solid waste incineration and contamination of cadmium in food crops. The regulatory limit of cadmium (Cd) in agricultural soil is 100 mg/kg soil (Nagajyoti *et al*., 2010). Plants grown in soil containing high levels of Cd show visible symptoms of injury reflected in terms of chlorosis, growth inhibition, browning of root tips and finally death (Mohanpuria *et al*. 2007; Guo et al. 2008). The inhibition of root Fe (III) reductase induced by Cd lead to Fe(II) deficiency, and affects photosynthesis. In general, Cd has been shown to interfere with the uptake, transport and use of several elements (Ca, Mg, P and K) and water by plants (Nagajyoti, 2010). Cd also reduced the absorption of nitrate and its transport from roots to shoots, by inhibiting the nitrate reductase activity in the shoots (Nagajyoti *et al.*, 2010). Metal toxicity can affect the plasma membrane permeability, causing a reduction in water content; in particular, Cd has been reported to interact with the water balance and treatments have been shown to reduce ATPase activity of the plasma membrane fraction of wheat and sunflower roots (Nagajyoti, 2010). Also, cadmium produces alterations in the functionality of membranes by inducing lipid peroxidation and disturbances in chloroplast metabolism by inhibiting chlorophyll biosynthesis and reducing the activity of enzymes involved in CO_2 fixation (Nagajyoti, 2010).

Furthermore, nickel is one of many trace metals widely distributed in the environment, being released from both natural sources and anthropogenic activity, with input from both stationary and mobile sources. It is present in the air, water, soil and biological material. Natural sources of atmospheric nickel levels include wind-blown dust, derived from the weathering of rocks and soils, volcanic emissions, forest fires and vegetation. Nickel finds its way into the ambient air as a result of the combustion of coal, diesel oil and fuel oil and the incineration of waste and sewage (Cempel *et al*., 2006).

However, Ni^{2+} concentration is increasing in certain areas by human activities such as mining works, emission of smelters, burning of coal and oil, sewage, phosphate fertilizers and pesticides (Nagajyoti, 2010). Ni^{2+} concentration in polluted soil may range from 20 to 30 fold (200–26,000 mg/kg) higher than the overall range (10–1,000 mg/kg) found in natural soil (Izosimova 2005). Excess of Ni^{2+} in soil causes various physiological alterations and diverse toxicity symptoms such as chalorosis and necrosis in different plant species (Rahman et al. 2005), including rice. Plants grown in high Ni^{2+} containing soil showed impairment of nutrient balance and resulted in disorder of cell membrane functions. Thus, Ni^{2+} affected the lipid composition and H-ATPase activity of the plasma membrane as reported in Oryza sativa shoots (Nagajyoti, 2010). Other symptoms observed in Ni^{2+}treated plants were related with changes in water balance. High uptake of Ni^{2+} induced a decline in water content of dicot and monocot plant species. The decrease in water uptake is used as an indicator of the progression of Ni^{2+} toxicity in plants (Gajewska *et al*. 2006).

Thus, the objectives of this work are to access the heavy metal content and levels (zinc, lead, chromium, cadmium and nickel) in the soils of the selected dumpsites and to access the level of heavy metal content of the vegetation around the dumpsite.

II. Materials And Methods

Description of study area

The study was conducted in Benin City. The City of Benin founded about 900AD is situated at an average height of 200m above sea level. Benin City, the capital of Edo State lies in the equatorial climate region between latitude 6° 47' and 7^{o} 15' and longitudes 5° 49' and 6° 14' in Edo State, of Nigeria (Ministry of Land and Survey, Edo State 2008) which is within the rainforest ecological zone of the South – South Nigeria with a mean annual rainfall of 1825mm. For purpose of this study, three (3) of the Government approved waste dumpsites were used and they are sited at: a) Oluku along the Benin-Ore road; Oluku is found in Ovia North East local government area of Benin and it lies between latitude 6° 27.766' N and longitude 5° 36.006' E. b) Iguomo is located along the Benin by-pass. c) Ikhueniro is located along the Benin-Abuja road. in Ikpoba Okha local government area of Benin and it lies between latitude 6° 20.174' N and longitude 5° 44.734' E.

Collection of samples

Three samples of soil at various depths (0-15 cm and 15-30 cm) were collected from the various dumpsite locations with a distance of 15 m^2 each and then bulked together to have a uniform distinguished collection of triplicates samples from the various depths. Six samples were also collected from opposite the dumpsites areas, at depth of between 0-15 cm, and 15-30 cm. Plant (*Talinium triangulare*) samples were also taken from each dumpsite and from areas opposite the dumpsites (control). Both plant and soil samples were packed in separate bags and taken to the laboratory for analysis.

Heavy metal analysis of soil samples

The soil samples were air dried and sieved with a 2 mm sieve. 1 g of the sieved sample was weighed into a digestion flask. 20 ml of concentrated nitric acid was added and the mixture was digested using hot plate. After digestion, it was allowed to cool and 30 ml of distilled water was added and filtered with whatman filter paper. The digest was made up to 50 ml solution with distilled water. The digest was then read using unican 939 model of Atomic Absorption Spectrometer (AAS). The heavy metals read are zinc, chromium, lead, cadmium and nickel.

Heavy metal analysis of plant samples

The plant samples were oven dried to constant weight. The samples were then ground to powder. 1 g of the sample was weighed into the crucible and ash for 4 hrs at 600 $^{\circ}$C. It was then allowed to cool. 10% nitric acid was then added and filtered using whatman filter paper. The digest was made up to 50ml solution with distilled water and read using unican 939 model of atomic absorption spectrometer (AAS). The heavy metals read are zinc, chromium, lead, cadmium and nickel.

Pollution index and transfer factor

*T*his index is calculated by the ratio of metal concentrations in the soil based on the corresponding values suggested by Kloke (1979) and which correspond to tolerable levels in the soil: **PI= [(**Cd/3 + Cr/100 + Pb/100 + Zn/300 + Ni/50)] /5. The transfer coefficient was calculated by dividing the concentration of heavy metal in plant samples by the total heavy metal concentrations in the soil (Kachenko and Singh, 2006).

Statistical analysis

The data obtained were subjected to analysis of variance using Statistical Analysis Software (SAS) and significantly different treatment means were separated at 5% level of probability using LSD range test.

III. Result And Discussion

Heavy metal contents in soil of the three locations (mg/kg) and their pollution index (pi) is as shown on Table 1.

Table no 1: shows the heavy metal content of soils of the three locations and their pollution index.

Location	Depth(cm)	Zn	Cr	Pb	Cd	Ni	PI
Oluku control	0 – 15	6.63	0.07	0.9	0.07	0.42	0.01
	15 - 30	9.41	0.07	1.4	0.06	0.22	0.06
Oluku dumpsite	0 – 15	38.73	0.14	1.1	0.17	0.33	0.04
	15 – 30	16.31	0.10	1.1	0.05	0.32	0.22
Iguomo control	0 – 15	6.28	0.06	1.2	0.04	0.32	0.01
	15 – 30	14.51	0.06	1.1	0.07	0.21	0.09
Iguomo dumpsite	0 – 15	8.30	0.06	1.1	0.03	0.21	0.01
	15 – 30	15.29	0.09	1.1	0.12	0.31	0.03
Ikhueniro control	0 – 15	16.27	0.06	2.3	0.05	0.02	0.02
	15 – 30	7.30	0.06	1.3	0.04	0.31	0.01
Ikhueniro dumpsite	0 – 15	25.47	0.07	2.4	0.15	0.03	0.16
	15 - 30	9.86	0.07	1.6	0.06	0.26	0.02

Heavy metal content in plants at the three locations and their transfer factor, is as shown on Table 2

Table no 2: shows the heavy metal content in plant of the three locations and their transfer factor.

	LOCATIONS					
	Oluku control	Oluku dumpsite	Iguomocontrol	Iguomo dumpsite	Ikhueniro control	Ikhueniro dumpsite
Zn	110	146	176	287	155	170
TF	6.83	2.65	8.22	12.17	5.57	4.80
Cr	1.07	0.12	0.07	0.06	0.09	0.07
TF	7.2	0.5	0.6	0.4	0.8	0.5
Pb	0.1	0.1	0.3	0.2	0.1	0.1
TF	0.05	0.04	0.16	0.09	0.02	0.02
Cd	0.08	0.08	0.18	0.25	0.05	0.06

TF	0.6	0.4	1.6	1.4	0.6	0.3
Ni	0.17	0.17	0.16	0.17	0.15	0.11
TF	0.25	0.26	0.31	0.33	0.46	0.33

- TF – transfer factor

IV. Discussion

The result of the study showed the physical and chemical properties of the different control areas as well as the dumpsite areas. The soils of each control showed a pH range of 5.1 to 5.2 at depth 0-15cm which is strongly acidic, at 15-30cm, pH range from 5.1 to 5.2 which is strongly acidic. The control of each location at both depths showed strong acidity according to the USDA Soil Survey Staff (1951) (shown in table 2 of appendix). Soil texture of the control soils of each location at both depth showed that soils present is sandy loam except for Ikhueniro at 0-15cm which showed sandy clay loam and Iguomo at 15-30cm which showed sandy clay loam. The result also showed the soils at each control were low in organic carbon and organic matter as compared to the dumpsites locations; this could be as a result of the waste present in dumpsites which microorganisms break down. This phenomenon is in agreement with reports by Osazee et al., (2013) which reported that the microbial bio load recovered from control soil was comparatively less than that recorded for the soils collected from the dump sites and that the phenomenon might be the result of the increased availability of biodegradable organic and inorganic substrates from the variety of municipal wastes continuously being dumped at dumpsites. ECEC was higher in the control soil than the dumpsites; this could be as a result of degradation of the dumpsite land by heavy metals Also, the critical heavy metal concentration in the soil is defined as the value above which toxicity is possible. Results obtained show that metal concentrations are not above the critical level in the three locations according to Alloway B.J (1995). The pollution index (PI) which is a criterium for assessing the toxicity of a soil also identifies a phased array type contamination in soil samples (Chon et al., 1998). In this study, the pollution index for the different control locations was less than 1and thus showed that there was little or no heavy metal toxicity. The presence of heavy metals in soil significantly changes the plant composition of sites. The presence of vegetation species in their sites means that species supports excessive levels of metals and are tolerant to heavy metals. Plant heavy metal mean contents range from 110 mg/kg (Oluku) to 176 mg/kg (Iguomo) to 155 mg/kg (Ikhueniro) for Zn, from 1.07 mg/kg (Oluku) to 0.07 mg/kg (Iguomo) to 0.09 mg/kg (Ikhueniro) for Cr, from 0.1 mg/kg (Oluku) to 0.3 mg/kg (Iguomo) to 0.1 mg/kg (Ikhueniro) for Pb, from 0.08 mg/kg (Oluku) to 0.18 mg/kg (Iguomo) to 0.05 mg/kg (Ikhueniro) for Cdand from 0.17 mg/kg (Oluku) to 0.16 mg/kg (Iguomo) to 0.15 mg/kg (Ikhueniro) for Ni. The transfer factor for metal accumulation in plant was calculated for control and dumpsite locations. Heavy metal accumulation in plants depends upon plant species, soil properties, and the efficiency of different plants in absorbing metals which is evaluated by plant uptake or soil to plant transfer factors of the metals (Rattan et al., 2005). The results obtained shows that the plants had more of the heavy metals than the soil and this phenomenon is in agreement with Aktaruzzaman et al., (2013) which reported that the uptake of heavy metals in vegetables is likely to be higher than soils and that the accumulation of these toxic metals in humans creates great concern. The transfer factor for each metal is as follows: 6.83 (Oluku) to 8.22 (Iguomo) to 5.57 (Ikhueniro) for Zn, 7.2 (Oluku) to 0.6 (Iguomo) to 0.8 (Ikhueniro) for Cr, 0.05 (Oluku) to 0.16 (Iguomo) to 0.02 (Ikhueniro) for Pb, 0.6 (Oluku) to 1.6 (Iguomo) to 0.6 (Ikhueniro) for Cd, 0.25 (Oluku) to 0.31 (Iguomo) to 0.46 (Ikhueniro) for Ni. All control locations had TF less than 1 for each metal except for Zn at Oluku, Iguomo and Ikhueniro and Pb at Iguomo which means that plants in such areas should not be consumed. The soils of each dumpsite showed a pH range of 6.1 to 6.3 at depth 0-15cm which is slightly acidic, at 15-30cm, pH ranged from 6.1 to 6.2 which is also slightly acidic. The dumpsite of each location at both depths showed slight acidity according to the USDA Soil Survey Staff (1951) (shown in table 2 of appendix). Also, control soils of each location at both depths showed that the texture of the soils were sandy loam except for Iguomo at 0-15cm which showed sandy clay loam. The results also showed the soils at each dumpsite were higher in organic carbon and organic matter than the control. This may be due to the poor drainage of these waste dumpsites which inhibits the activities of microorganisms that decomposes organic residues, leading to accumulation of organic matter. ECEC was lower in the dumpsite soil than the control; this could be as a result of degradation of the dumpsite land by heavy metals Results obtained showed that the metal concentrations were not above the critical level in the three locations. The pollution index calculated for the different locations at the two depths were less < 1. The transfer factor for each metal in the plant was calculated all dumpsites locations had TF less than 1 for each metal except for Zn at Oluku, Iguomo and Ikhueniro and Cd at Iguomo. According to the concentrations of heavy metals in plants and soils and critical concentrations in plant and soils adapted from B.J. Alloway (1995), (shown in table 1 in appendix), zinc concentrations in plant and soil samples of the three dumpsites showed that zinc is critical and toxicity is likely. Chromium, lead, cadmium and nickel concentrations showed normal range in both plant and soil samples of the three dumpsites.

In all, there is a clear indication that waste dumpsite has higher concentration of microorganisms and heavy metal than control site and the concentration is higher at 0-15cm depth than depth 15-30cm depth.

V. Conclusion

This study showed that the dumpsites areas investigated contained heavy metals which when in high amounts are toxic to plants, animals and humans causing various infections. Also, based on the results of this study, heavy metal concentration is generally higher at 0-15cm depth than 15-30cm depth.It was observed that the pollution index of the dumpsite soils were not high (<1) but have the tendency to increase and cause toxicity to life around the areas if not properly managed. The transfer factor (TF) of heavy metals in plant samples was >1 for cadmium in Iguomo dumpsite area. It is therefore recommended that waste pickers and town refuse control workers should take precautionary measures when working at waste dump sites. Furthermore, reclaimed waste dump sites areas should not be considered for use as market places and other such establishments where human activities would have direct contact with the soil.

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APPENDIX

Table 1: Concentrations of heavy metals in plants and soils and critical concentrations in plant and soils

Metal	Normal range in plants ($mgkg^{-1}$)	Critical plant concentration A ($mgkg^{-1}$)	Critical plant concentration B ($mgkg^{-1}$)	Normal range in soils ($mgkg^{-1}$)	Critical soil concentration ($mgkg^{-1}$)
As	0.02-7	5-20	1-20	0.1-40	20-50
Cd	0.1-2.4	5-30	4-200	0.01-2.0	3-8
Co	0.02-1	15-50	4-40	0.5-65	25-50
Cr	0.03-14	5-30	2-18	5-1500	75-100
Cu	5-20	20-100	5-64	2-250	60-125
Hg	0.005-0.17	1-3	1-8	0.01-0.5	0.3-5
Mn	20-1000	300-500	100-7000	20-10000	1500-3000
Mo	0.03-5	10-50	-	0.1-40	2-10
Ni	0.02-5	10-100	8-220	2-750	100
Pb	0.2-20	30-300	-	2-300	100-400
Sb	0.00001-0.2	-	1-2	0.2-10	5-10
Se	0.001-2	5-30	3-40	0.1-5	5-10
Sn	0.2-6.8	60	63	1-200	50
V	0.001-1.5	5-10	5-13	3-500	50-100
Zn	1-400	100-400	100-900	1-900	70-400

A: concentrations above which toxicity is likely, **B:** concentrations likely to cause a 10% yield
Adapted from B.J. Alloway (1995)

Orji, O. A. " Assesement of Some Heavy Metals In Soils And Plants Growth In Dumpsites." IOSR Journal of Environmental Science, Toxicology and Food Technology (IOSR-JESTFT) 12.3 (2018): 17-23.