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Ecological and Health Risk Assessment of Heavy Metals in Soil and Plant around E-Waste Dumpsite in Ijoko, Ogun State, Nigeria

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Abstract

The buildup of heavy metals in soil via e-waste has significantly impaired the physicochemical properties of soils and plants. The purpose of this study was to evaluate the ecological and health risk of heavy metals around e-waste dumpsite in Ijoko, Nigeria. Total of six Samples were taken from the research area (plant and soil) while the control samples (plant and soil) were collected at one kilometer away from the study site. The level of heavy metals (Cd, Cr, Cu, As, Ag, Zn and Pb) were determined using Inductively Coupled Optical Emission Spectrometry (ICP-OES). The metal content (mg/kg) in the soil samples were; 64.31-240.51, 240.21-1589.53, 4.86-42.86, 1092.76-3373.59 and 253.95-1247.62 for Cr, Cu, As, Zn and Pb, respectively, which were higher than USEPA and WHO soil guideline values. The metal content (mg/kg) in the plant samples were; 0.09- 5.80, 118.50-153.50, 21.16-39.88, 709.09-802.90 and 77.54-92.37 for Cr, Cu, As, Zn and Pb, respectively. Cd and Ag were not detected in both the soil and plant samples. The concentrations of all the metallic elements quantified in the soil samples exceeded both the control values and the permissible thresholds as advocated by WHO. The average dose ingestion of heavy metal concentrations varied at different sampling point. The results of the hazard quotient (HQ) and hazard index (HI) in this study were greater than 1 indicating pollution of the area. Cr, Cu, As and Zn have less adverse effect in both adult and children compared Pb which poses a significant cancer risk. Hence, there is need for appropriate management of e-waste in Ijoko and it environ to put an end to human exposure to these toxic metals.

Keywords: Dumpsite, e-waste, Health risk, Heavy metals, Plant, Soil.

Introduction

Waste disposal has been considered as one of the prominent factor of heavy metal (HMs) pollution in the society. Metallic elements such as cadmium, chromium, lead, arsenic, copper and zinc possessing a comparatively high density are often termed Heavy Metals. A distinct feature of these naturally occurring substances is their natural degradation resistance posing a significant environmental and health risk. [1]. These toxic

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metals from a number of origins, such as industrial effluents, lead in petrol, leaching of metal ions from the soils into rivers and lakes by acid rain, have density above 5 g/cm^3 and they lead to pollution of the environment. They pose a significant risk to public health and ecological systems even at low concentrations [2].

Electronic wastes (e-wastes) are solid waste from electronic and electrical equipment that is meant for recycling or disposing, it is a mixture of mobile used and discarded phones and all electronic equipment [3]. E-waste is not harmful; however, the presence of some components like heavy metals, metalloids, glass, plastics and organic compounds in e-wastes can be harmful [3,4]. Non-degradable of this heavy metals in the environment leads to disruption in the ecosystem's food chain [5]. The accumulation of these HMs in agricultural soils can significantly impair soil physicochemical properties and compromise plant health. For instance, cadmium (Cd) contamination in soil has been demonstrated to reduce soil organic matter content, increase soil bulk density, and ultimately lead to diminished crop yields [6]. Respiration, consumption and skin contact are the pathways by which human are exposed to heavy metals [7], thus, Exposure to heavy metals can result in a wide range of adverse health effects, including cancer, kidney damage, and brain disorders, blood emphysema, hepatic destruction, testicular tissue damage, and diseases of the red blood cells and bones, and can potentially be fatal [8].

Studies have shown that e-waste is one of the fast growing environmental problem in the world, it was reported that about 20-50 million tons of electronic-waste was produced annually for recycling and discarding [9]. However, there is need to investigate and address the pollution and health risk of heavy metals related to e-waste in soil and plant dumpsite in Ijoko, Ogun State, Nigeria.

Materials and Methods

Area of Study

Ijoko is situated in Ado-odo Ota, Ogun state, Nigeria. Its geographical coordinates are 6^o 45'0' North, 3^o 16' 0"East. Ijoko area is an urban settlement, where a different human activity takes place. The e-wastes dumpsite at Ijoko is surrounded by industries, schools, food market, and residential area. As a result of weak laws and regulations, heavy metals and other contaminants are suspected to be released into the environment in large quantities.

Sample Collection

The identified soil types were sampled using a hand trowel to collect core samples at 0-20 cm soil, kept in a plastic bag with proper identification. The plant samples; *Amaranthus hybidus*, also known as African spinach or Amaranth green were collected at designated points on the soil. The plants were uprooted and packed into a plastic bag with proper identification. The control samples (plant and soil) were collected at about 1 km away from the study

site. The control sample site is surrounded by industries, residential area and market area.

Sample Analysis

The plant sample was washed and rinsed with distilled water to remove remains and insect, then oven dried at 60ºC for 10 hours and ground into powder using pestle and mortal. One (1 g) of the treated soil and plant samples were weighed into a beaker. The plants and soil samples was digested with 4 ml of 50% Nitric acid and 10 ml of 20% Hydrochloric acid in a fume hood at 900ºC for 1 hour. When the digestion has been completed, the digestate was filtered and diluted to 50 mL using ultra-pure deionized water for ICP-OES analysis. Environmental Protection Agency (EPA)3050B method was used for the digestion. Heavy metals (Cd, Cr, Cu, As, Ag, Zn and Pb) were determined from the filtrate using inductively couple plasma optical emission spectrometry (ICP-OES) Agilent 720 ICP-OES. By placing the electrode into each filtrate using a pH conductivity meter and a P713 meter, the pH of each soil sample was ascertained, and the results for each sample were noted

Ecological Risk Assessment

Contamination Factor (CF)

The CF is used to assess the rate of pollution by comparing the metal in the target location to the control point as suggested by [10]. Given as

$$CF = \frac{C_n}{B_n} \quad (1)$$

Where; C_n is the concentration of metals in the studied area and B_n is the metal concentration in the controlled area.

Degree of contamination (CD)

CD was calculated and applied by [11].

$$CD = \sum CF_n \quad (2)$$

Where: n is the number of HMs determined

Pollution load index (PLI)

Pollution load index gives information about hazardousness of metals gotten in the sample. Formula used was [11].

$$PLI = (CF_n \ x\ CF_n\ x\ CF_n)^{\frac{1}{n}} \quad (3)$$

Where; n is the number of elements.

Index of Geo-accumulation (Igeo)

Igeo values are used to rate pollution by HMs in surface soil samples, [12]. I_{geo} is calculated by equation

$$I_{geo} = Log^2\left(\frac{C_s}{1.5B_n}\right) \quad (4)$$

Where; Cs and Bn are the same as in CF. 1.5 is used as a results of possible variations of the background data due to lithological variations.

Ecological risk index (ERI) and Potential ecological risk index (PERI)

ERI is used to determine the environmental impact of HMs. ERI and PERI were determined based on [10]. The lethal level was based on the metal used which are Cr, Pb, Cu, Cd, Zn, Ag and As; 2, 5, 5, 30, 1, 30,10 respectively by [10, 11]. It is expressed mathematical

$$ERI = TrF\ x\ CF_n \quad (5)$$

Where; Trf is the lethal response factors, CF_n is the pollution factor of each metal

$$PERI = \sum ERI \quad (6)$$

Where; $\sum$ ERI is the total ERI determined

Enrichment Factor (EF)

Enrichment factor shows the degree the layers is affected by (natural and anthropogenic) with HMs concentrations above controlled background levels as proved by [11].

$$EF = \frac{\left(\frac{CM}{CX_{sample}}\right)}{\left(\frac{CM}{CX_{background}}\right)} \quad (7)$$

Where; CM is the composition of metal examined and CX is the composition of nonmobile element

For this research, iron (Fe) was used as a non-mobile element. The average reference values of Fe 216.3 mg/kg.

Transfer Factor (TF)

TF is used to measure the bio-movement of HMs from soil to plant. Using formula of [14].

$$TF = \frac{M_P}{M_S} \quad (8)$$

Where; M_p = Metal composition in plant (mg kg^{-1}) *and* M_s =metal composition in soil (mg kg^{-1}).

Health Risk Assessment

Average Dose Ingestion

The exposure of HMs in surface soil samples create a significant health hazard to the bodies of adults and children. The average dose intakes (ADI), the main pathway of HM exposure for this study is through ingestion. Average Dose Ingestion is calculated by [15].

$$AD_{ing} = \frac{C_{i\ X\ IingR\ X\ Exf\ X\ ED\ X\ CF}}{BW\ X\ AT} \quad (9)$$

Ci = mean of the metal level (mg/g) in surface soil samples and the other parameters are in accordance with those in Table 2.

Hazard Quotient (HQ)

Is comparing the average dosage of HM level ingestion to determine the quantity of exposure in human health.

$$HQ = \frac{AD_{ing}}{RfD} \quad (10)$$

Where; RfD is the reference dose that is used for assessing the health risk of exposure to toxicants from non-carcinogenic effects

Hazard Index (HI)

Hazard index was used to determine non carcinogenic risk from average daily dose ingestion.

$$HI = \sum HQ \quad (11)$$

Table 1.0: WHO Permissible Limits for Heavy Metals in Soil and Plant

Metals	Acceptable limits in Soil (mg/kg)	Acceptable limits in plant (mg/kg)
Cd	0.8	0.02
Cr	100	1.30
Pb	85	2.0
Cu	36	10
As	NA	0.1
Ag	NA	NA
Zn	50	0.60

Note: NA –Not Available

Table 2.0: The Parameter values were employed in the Health Hazard Evaluation through Ingestion Exposure For Soil And Plant

Symbol	Parameter	Value
IngR	Ingestion Rate - for children	200mg/day [15]
	-for Adult	100mg/day [15]
ExF	Exposure Frequency	350 days [15]
ExD	Exposure Duration -for non-carcinogenic children	6 years [15]
	-for non-carcinogenic adult	24 years [15]
	-for carcinogenic	30 years [16]
BW	Average Body Weight -for children	15 kg [15]
	-for Adult	70 kg [15]
AT	Averaging time	365 x ExD children or adult [15]
CF	Conversion Factor	1 x 10-6 kg/mg
RfD	Reference Dose Cd	0.0013 $mg^{-1}kg^{-1}day$ [15]
	Cr	0.0033 $mg^{-1}kg^{-1}day$ [15]
	Pb	0.00035 $mg^{-1}kg^{-1}day$ [15]

Cu	0.03713 $mg^{-1}kg^{-1}day$ [15]
As	0.0003 $mg^{-1}kg^{-1}day$ [15]
Zn	0.33 $mg^{-1}kg^{-1}day$ [15]

Results and Discussion

Table 3.0: pH in Soil and Plant

Samples	CSS	MSS	ESS	NSS	WSS	SSS	PS	PCS
pH	6.82	5.78	6.31	6.48	6.08	6.42	6.82	7.31

Note: CSS = Control soil sample, MSS = Middle soil sample, ESS = East soil sample, NSS = North soil sample, WSS = West soil sample, SSS = South soil sample, PS = Plant sample, PCS = Plant control sample, ND = Not detected.

Table 4.0: Mean Concentration of Heavy metals in Soil and Plant ($mgkg^{-1}$)

	Cr	Pb	As	Cu	Zn
CSS	64.31	253.95	4.86	240.21	1092.76
MSS	240.51	391.39	18.56	722.19	1428.15
ESS	154.57	750.21	42.86	277.75	2029.89
NSS	177.88	1247.62	25.45	1589.83	3373.59
WSS	192.69	532.96	16.69	249.43	2323.63
SSS	128.42	347.07	14.50	295.48	1821.77
TMSS	159.73	587.20	20.49	562.49	2011.64
STDSS	60.09	366.81	12.83	535.76	769.67
PS	5.80	92.37	39.88	153.49	802.89
PCS	0.09	77.54	21.16	118.50	709.08
TMPS	2.95	84.96	30.53	136.00	755.99
STDPS	4.04	10.49	13.24	24.74	66.33

Note: TMSS= Total Mean of all Soil Sample, TMPS= Total Mean of all Plant Samples, STDSS= Standard Deviation of TMSS, STDPS= Standard Deviation of TMPS.

Table 5.0: Contamination Factor, Degree of Contamination (DC), Pollution Load Index (PLI), and Ecological Risk Index (ERI) of heavy metal in Ijoko, Ogun State (mg/kg)

Samples	Cr	Pb	Cu	As	Zn	CD	PLI	ERI
MSS	3.74	1.54	3.01	3.82	1.31	13.41	54.76	69.70
SSS	1.99	1.37	1.23	5.29	0.78	10.61	40.55	70.05
WSS	2.99	2.09	1.04	3.43	2.13	11.69	45.81	58.10
ESS	2.45	2.99	1.16	8.81	1.86	17.27	50.51	115.60
NSS	2.77	4.91	6.62	5.23	3.09	22.61	55.03	118.56
PS	60.37	1.19	1.40	1.89	1.13	65.87	58.04	153.34

Table 6.0: Geo- accumulation index (Igeo) and Enrichment Factor (EF) mg/kg

Symbol	MSS	SSS	WSS	ESS	NSS	PS
Cr	0.75,1.20	0.40,1.24	0.60,1.71	0.49,1.15	0.55,1.15	18.17,64.10
Pb	0.31,0.49	0.27,0.85	0.42,0.93	0.60,1.41	0.99,2.03	0.36,1.27
Cu	0.60,1.02	0.25,0.77	0.21,0.46	0.23,0.54	1.33,2.73	0.39,1.38
As	4.30,1.23	0.60,1.85	0.69,1.51	1.77,4.16	1.05,1.87	0.57,2.00
Zn	0.26,0.41	0.61,0.49	0.43,0.94	0.37,0.88	0.62,0.59	0.34,1.20

Table 7.0: Transfer Factor (TF) mgkg^{-1}

	Cr	Pb	Cu	As	Zn	Cr	Pb	Cu	As	Zn
Samples										
	Control Plant Sample					Plant Sample				
CSS	1.4E-3	0.31	0.50	4.35	0.65	0.09	0.36	0.64	8.21	0.73
MSS	3.7E-4	0.20	0.16	1.14	0.50	0.02	0.24	0.21	2.15	0.56
WSS	4.7E-4	0.48	0.62	1.27	0.31	0.03	0.17	0.62	2.39	0.35
ESS	5.8E-4	0.10	0.43	0.50	0.35	0.04	0.12	0.55	0.93	0.40

NSS	5.1E-4	0.06	0.07	0.83	0.21	0.03	0.07	0.10	1.63	0.24
SSS	7.0E-4	0.22	0.40	1.46	0.39	0.05	0.27	1.52	2.75	0.44

Table 8.0: Average Dosage Ingestion of Heavy Metals Concentration for Adults and Children in Soil and Plant

	Cr	Pb	Cu	As	Zn
Samples	Adult/Children (mg kg^{-1} day^{-1})				
CSS	9.2E-5/1.8E-4	3.6E-4/7.3E-4	3.4E-4/6.9E-4	6.9E-6/1.4E-5	1.6E-3/3.1E-3
MSS	3.4E-4/6.9E-4	5.6E-4/1.1E-4	1.0E-3/2.0E-3	2.7E-5/5.3E-5	2.0E-3/4.1E-3
ESS	2.2E-4/4.4E-4	1.1E-3/2.1E-3	4.0E-4/8.0E-4	6.1E-5/1.2E-4	2.9E-3/5.8E-3
NSS	2.5E-4/5.1E-4	1.8E-3/3.6E-3	2.3E-3/4.5E-3	3.6E-5/7.3E-5	4.8E-3/9.6E-3
WSS	2.8E-4/5.4E-4	7.6E-4/1.5E-3	3.6E-4/7.2E-4	2.4E-5/4.7E-5	3.3E-3/6.6E-3
SSS	2.4E-4/3.7E-4	5.0E-4/10E-4	4.2E-4/7.4E-4	2.1E-5/4.1E-5	2.6E-3/5.2E-3
PS	8.3E-6/1.7E-5	1.3E-4/2.6E-4	2.2E-4/4.4E-4	5.7E-5/1.1E-4	1.1E-3/2.3E-3
PCS	1.3E-7/2.6E-7	1.1E-4/2.2E-4	1.7E-4/3.4E-4	3.0E-5/6.0E-5	7.0E-3/2.0E-3

Table 9.0: Hazard Quotient and Hazard Index (HI) for both Adult and Children in Soil and Plant

	Cr	Pb	Cu	As	Zn
Samples	Adult/Children (mg kg^{-1} day^{-1})				
CSS	0.03/0.05	1.03/2.09	9.2E-3/0.02	1.9E-4/3.8E-4	4.83/0.01
MSS	0.10/0.21	1.60/0.31	0.03/0.05	7.3E-4/1.4E-3	0.01/0.12
ESS	0.07/0.13	3.14/6.00	0.01/0.02	1.6E-3/3.2E-3	0.01/0.02
NSS	0.08/0.15	5.14/10.29	0.06/0.12	9.7E-4/1.9E-3	0.01/0.03
WSS	0.08/0.16	2.17/4.29	0.01/0.02	6.5E-4/1.3E-3	0.01/0.02
SSS	0.07/0.11	1.43/2.86	0.01/0.02	5.7E-4/1.1E-3	0.01/0.02
PS	2.4E-3/5.2E-3	3.7E-3/0.74	0.01/0.01	1.5E-3/3.0E-3	3.3E-3/0.01
PCS	3.9E-5/7.8E-5	0.31/0.63	4.6E-3/0.01	8.1E-4/1.6E-3	3.0E-3/0.01
HI	0.43/0.82	4.82/27.21	0.14/0.27	7.0E-3/0.01	0.06/0.24

Table 3.0 revealed that MSS was most acidic of the soil sample while the plant control sample had a pH 7.0. Table 4.0 showed that Cd and Ag were not detected in both plant and soil this is due to the type of electronics being dumped in the research area [22]. The highest concentration of metals are Zn, Cu and Pb (3373.59, 1589.84 and 1247.62 $mgkg^{-1}$) respectively at point NSS. Zn (2323.64 mgkg-1), Pb (532.96 $mgkg^{-1}$) and Cu (249.44 $mgkg^{-1}$) at point WSS. At point ESS Zn, Pb and Cu had a concentration of 2029.89 $mgkg^{-1}$, 750.21 $mgkg^{-1}$ and 277.76 $mgkg^{-1}$, respectively.

Point MSS had a concentration of 1428.16mg/kg, 722.19 mg/kg and 391.39 mg/kg for Zn, Cu and Pb, respectively. These results obtained could be due to the anthropogenic activities (disposal of electronic waste) carried out on the dumpsite. The mean variation in concentration at different locations is in line with the results reported in literature [17]. In PS and PCS, Zn had the highest concentrations of 802.89 mg/kg and 709.10 mg/kg while Cr had the least concentration of 5.80 $mgkg^{-1}$ and 0.09 $mgkg^{-1}$, respectively, this could be as result of accumulation of metals concentration in the soil. Thus, these values are higher than the one reported in similar work [18] and also above the recommended and tolerable limits by WHO except Cr in PCS. This high values of Heavy Metals shows a threat to the plants and human health [23]

Results of contamination factor as presented in Table 5.0 ranged from 1.03 – 8.81 mg/kg in soil sample. The order of decreasing contamination by the heavy metals are in ESS (8.81mg/kg) > NSS (6.62mg/kg) > SSS (5.29mg/kg) > MSS (3.82mg/kg) > WSS (3.43mg/kg). As had the highest contamination level in all the location except at point NSS where Cu had the highest contamination factor. According to [10], ESS and NSS have a very high contamination while SSS, MSS and WSS are considerably contaminated based on the following grouping CF≥ 6 (high contamination); < 6 (considerable contamination); < 3 (moderate contamination); < 1 (low contamination). In the plant sample, Cr had a very high contamination while Pb was considerably contaminated. Degree of contamination (DC) in MSS, SSS, and WSS showed moderate risk, ESS and NSS showed considerable risk while in plant sample (PS) it showed very high risk. From this study, PLI in all the soil samples and plant sample were extremely polluted according to [11]. Ecological risk, for MSS, SSS, WSS and PS were considered to be moderately risky ($Er\ 40 \leq Er < 80$) while ESS and WSS were revealed to be considerable according to the grouping of [10].

In Table 6.0, the results of the Igeo revealed that; Cr, Pb, Cu and Zn moderately contaminated in all the soil samples except for As which was extremely contaminated. In the plant sample, Pb, Cu, As and Zn were moderately contaminated except Cr which was extremely contaminated according to the classification of [11]. All the

metals were minimal to moderately enriched in all soil samples but Cr was extremely high enriched in the plant sample based on the classification of [13]. TF in Table 7.0 show that As is the most transferred from the soil to plant and Cr is the least transferred in both PCS and PS. This is in contrasts to the study of [21] and this is due to the e- waste present in the location for this study

Table 8.0 showed that both adult and children ingested below the tolerable limits [15] of zinc in all soil and plant samples. Cr, Cu, As and Zn have less adverse effect in both adult and children compared with Pb which shows extreme adverse effect. Zn was required by the plant for its hormonal regulation and needed for human growth but its deficiency affects plant development, low memory and pneumonia in children [19]. Pb poisoning can cause liver malfunction, reproductive, brain, kidney and also death even at low concentration [20]. From Table 9.0, the total HI for all the metals found in adults and children were 15.46 and 28.55 mg kg^{-1} day^{-1} respectively, which is in agreement with US Environmental Protection Agency [16] which says HI>1 have toxic adverse effects making Pb pose a significant cancer risk in both adults and children, in which children are more prone to attack.

Conclusion

This study investigated the ecological and health risk of heavy metals around e-waste dumpsite in Ijoko, Ogun State. Concentration and distribution of heavy metals varies at different locations, which gives insight of metals mobility trend in the study area. The CF and the CD ranged from low to moderate contamination. As is the most transferred metal from soil to plant. All these revealed that children are prone to accumulate more heavy metals than adults, hence, they are at higher cancer risk, due to the e-waste dumpsite in Ijoko. It is recommended that the government at federal, state and local government, environmental bodies/agencies to take proper actions on mismanagement of indiscriminate disposal of e- waste.

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