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ENVIRONMENTAL ASSESSMENT OF HEAVY METAL CONTAMINATION IN SOIL, WATER AND VEGETABLES IN E-WASTE DUMPSITE

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Abstract
E-waste is regarded as one of the fastest-growing solid waste streams in the world, posing a 3–5% annual growth rate and it is expected to continue to increase. Developing countries particularly African countries are susceptible to increase in the generation of local e-waste. There is need to investigate soil, water and plants toxicity, this is critical in environmental monitoring and control, and in the design of health related policy or framework. Soil, water and plant samples were randomly collected from a major e-waste dumpsite in the study area, processed and analyzed for heavy metals. The result of the study indicates that Aluminum and Chromium had the maximum value for soil contamination; this is followed by iron and lead. Aluminum and Zinc had the maximum value for water contamination, and ranged between 130.30 to 393.55 mg/L, and 70.11 to 75.38 mg/L. The concentration of the heavy metals on the plants indicates that water melon had the maximum concentration of 1.16 mg/kg, 0.95 mg/kg, and 0.81 mg/kg of chromium, iron, and lead concentrations. Generally, it is observed that heavy metal concentrations are higher in water melon than other plants. Health policy to safe guard consumers will be appropriate measures.

Keywords: E-waste, E-Waste Dumpsite, Heavy metal contamination, Soil, Vegetables, Water

Introduction
Environmental deterioration due to industrialization, urbanization, and the rapid increase in the global population, has gained a lot of attention particularly in area of waste generation and management. Waste management is very vital to sustainable development goals (SDGs) such as "good health and well-being", "clean water and sanitation", "sustainable cities and communities", and "responsible consumption and production" (Liu et al., 2022). Amongst the various types of waste, e-waste has become a global issue due to increase in its generation and its associated health hazards with regards to improper handling, disposal, or recycling (Kuang et al., 2023). E-waste encapsulates all major electrical and electronic equipment and their parts which are deemed to be no longer valuable and as such discarded or recycled (Al-salem et al., 2022; Sengupta et al., 2022; Zhong et al., 2022). It is regarded as one of the fastest-growing solid waste streams in the world, constituting about 3–5% annual growth rate (Owusu-sekyere et al., 2022; Sengupta et al., 2022), and constituting 5% of the global solid

waste (Al-salem et al., 2022). Over a five-year period, the global generation of electronic waste (e-waste) increased by 21% with about 53.6 million metric tons (Mt) of e-waste generated in 2019 (Zhong et al., 2022). About 82.6% of that amount is usually dumped, traded, or informally recycled (Owusu-sekyere et al., 2022), while only 17.4% of that quantity is collected and properly recycled (Zhong et al., 2022). E-waste generation is expected to continue to increase, with projections indicating some 74 million metric tons (Mt) of e-waste to be generated by 2030 (Al-salem et al., 2022).

The substantial increase in e-waste can be linked to global industrialization and economic development which promotes the utilization of electronic devices and equipment (Zhong et al., 2022). People's daily activities now revolve around technology and the continuous use of personal computers, laptops, projectors, cables, televisions, printers, scanners, etc., among others (Brindhadevi et al., 2023). The enormous generation of e-waste can be attributed to the fixed lifespan of these products which make them obsolete at a certain point, in combination with other factors (technology up-gradation, easy availability of economical new designs, and increasing demand for ICTs) which encourage the discard of these products within their functional lifespan (Yadav et al., 2022).

The link between e-waste generation and industrialization makes developing countries, particularly African countries, susceptible to increase in the generation of local e-waste (Owusu-sekyere et al., 2022). This is a cause for environmental concern considering the fact that these countries lack appropriate treatment facilities and legislation, and the e-waste recycling sector is largely unregulated (Owusu-sekyere et al., 2022). Furthermore, these countries usually employ non-environmentally friendly methods which include manual disassembly, incineration, strong acid extraction, and landfilling to recycle large quantities of e-waste (Hang et al., 2022), hence exacerbating the problem further. E-waste has a wide range of environmental impact as it is the largest source of heavy metals and organic contaminants in municipal solid waste, hence their improper disposal can pose significant environmental damage (Zhong et al., 2022).

The lack of appropriate infrastructure and measures to effectively manage the disposal and recycling of e-wastes leads to the habitual contamination of the environments and a significant exposure of humans, including children, to toxic chemicals (Adenuga et al., 2022). Electrical and electronic products are made up of a wide range of heavy metals such as lead (Pb), cadmium (Cd), chromium (Cr), arsenic (As), copper (Cu), manganese (Mn), mercury (Hg), and nickel (Ni) (Hang et al., 2022). When these heavy metals exist in the environment in concentrations higher than their permissible level, they may constitute significant risk and hazards to human beings as well as the ecosystem (Chakraborty et al., 2022). As such, these metals are the most toxic substances found in e-waste and also make up its largest part by size and weight, constituting 40-60% of total e-waste (Al-salem et al., 2022). Furthermore, these toxic contaminants have the ability to percolate and leach into soil, water and air via processes such as rain washing, sewage irrigation, or atmospheric deposition (Brindhadevi et al., 2023; Li et al., 2022; Roy et al., 2022), with such condition posing severe health and environmental threats (Sengupta et al., 2022). Preliminary studies indicate that the major electronic waste in study area are obsolete computers, refrigerators, old tapes recorders, used batteries, monitors, television sets, cell phones, children's toys, printers, refrigerators, microwave ovens, rechargeable torch/lanterns, energy bulbs and fluorescence tubes and they pose serious threat to life of people within the area (Okoye et al., 2018)

The improper disposal of e-waste leads to the release of large amounts of these heavy metals and other contaminants to the soil, water, and atmosphere. Exposure to contaminants such as heavy metals can affect the health of residents in areas surrounding dumpsites and recycling plants (Hang et al., 2022). The exposure of humans to these toxic metals can occur in two ways. One, the introduction of these metals into the food chains and their subsequent transmission to humans, and two, direct contact with these harmful metals due to working in the e-waste industries (Kapoor et al., 2021). Such exposure through contaminated food chain or direct contact can cause significant damages to the human heart, kidney, brain, liver, birth capability and skeletal system (Roy et al., 2022).

For instance, mercury, which is found in obsolete computers and batteries, is linked to kidney and brain damage (Brindhadevi et al., 2023). Lead, which is found in cathode ray tube (CRT) monitors, is linked to the impairment of human neurological development, predominantly in youngsters (Brindhadevi et al., 2023; Canavati et al., 2022), resulting in health issues such as delayed development, inattentiveness, irritability, hyperactivity, stunted growth and brain damage (Chakraborty et al., 2022). Chromium uptake can also affect the neurodevelopment of young people (Chakraborty et al., 2022). Furthermore, extended exposure to cadmium can lead to the accumulation of cadmium in the kidneys, hence resulting in kidney disease (Canavati et al., 2022).

In addition to effect on human health, heavy metal contamination can also adversely affect physicochemical characteristics of the soil and subsequently plant health, with cadmium pollution in soil associated with low soil organic matter, high soil bulk density, and low crop production (Liang et al., 2022). Due to their slower metabolic rates in animals, these toxic metals can accumulate in animals and excreted out through milk, eggs, etc., hence reaching the human body via the consumption of such animals (Kapoor et al., 2021).

The soil for agricultural production of human food is a pathway for transmission of toxic chemicals to human. It is therefore critical to examine the various pathways through which sites contaminated with heavy metals, gain access to humans. Humans depend greatly on plants and water for survival and this puts them at great risk of consuming heavy metal contaminated food (Chakraborty et al., 2022). This study is critical, considering that there are scarce literatures in developing countries on the environmental impact of e-waste, to the best of the author's knowledge, there no studies on soil, water and vegetable assessment of e-waste in the study area.

In addition, previous studies considered the contamination of soil or water in isolation to the plant, this study therefore seeks to provide a holistic approach, by considering soil, water and the pathway to human transmission: the plant. In plants, vegetal tissues can accumulate metals in high concentrations when planting is done in a contaminated soil (Chakraborty et al., 2022). Since the concentration can vary with plants, this study seeks to consider several plants, and their toxicity in a typical developing country setting. This is critical in environmental monitoring and control, and in the design of health related policy or framework.

The objective of this study is to assess the degree of environmental toxicity or contamination in soil, water and vegetables in typical e-waste dumpsite, in the context of Nnewi city of Nigeria.

The Study Area

The study area is located in Anambra State of Nigeria. Nnewi, lies between Latitudes 6^{o} 16^{1} N and 6^{o} 10^{1} N, and Longitudes 6^{o} 91^{1}E and 6^{o} 55^{1} E. An average rainfall of 200 mm is experienced in the area with average

temperature of 27°C. The span of the city is over 2,789 km^2, with heavy rainfall between April to October. Low rainfall, low humidity and higher temperature characterize the months of November to February. The location of the study area is as shown in Figure 1.

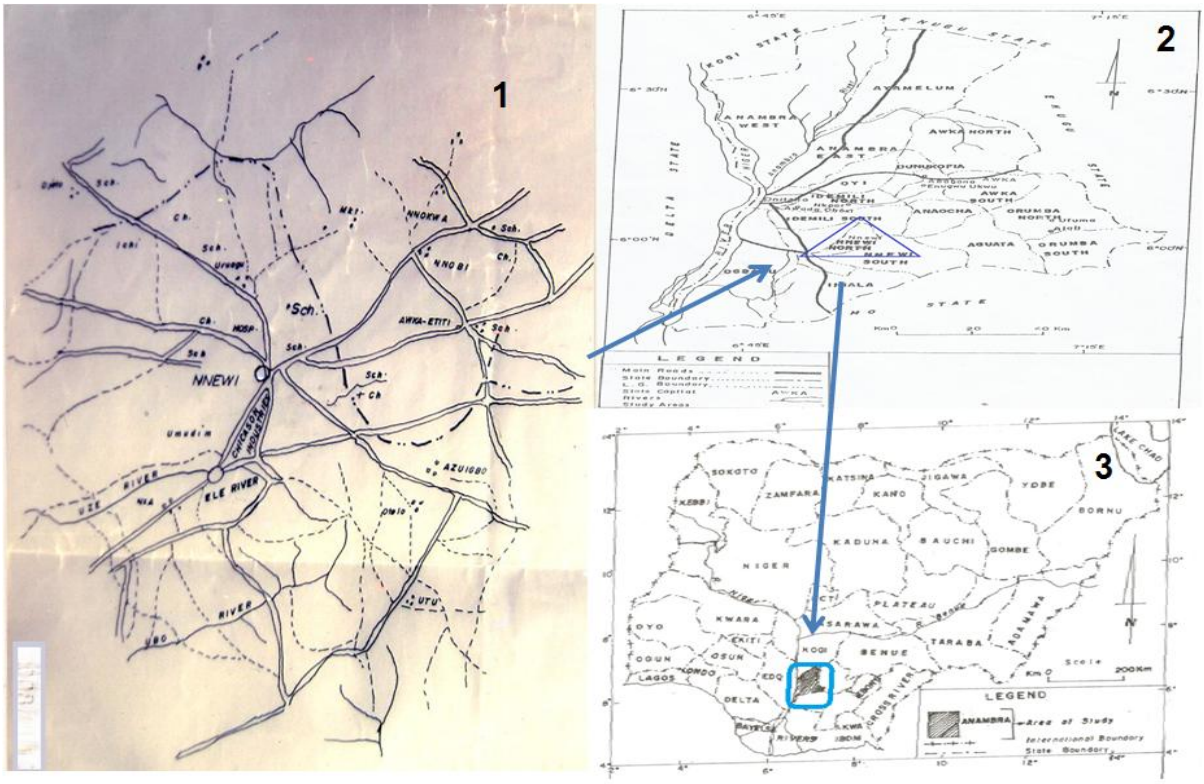


Figure 1: Map of Nnewi showing the study area (Map 1) in Anambra State (Map 2) of Nigeria (Map 3)

Materials and Methods

Soil and water samples were randomly collected in four stations from a major e-waste dumpsite in the study area, processed and analyzed for heavy metals using Atomic Absorption Spectrophotometer. The soil samples were collected within 0 to 10cm of the top soil, the water samples were collected with clean 1litre container, the samples were labeled, stored in cold environment and transported to the laboratory for analysis.

Vegetables that are considered staple in the region were identified within the e-waste dumpsite, the vegetables include garden egg (s.macrocarpon), water melon (citrullus lanatus) and cucumber (cucumis sativus). The concentration of heavy metals in the vegetables is an indicator of bio-accumulation and also an indicator of potential health risks. Samples of the vegetables were cleansed through washing and were carefully oven dried for a day at 70°C. 200 grams of each sample were ground, and digested with acids. The samples were further digested for 4 hours at 93°C in a hot plate, till a whitish brown mass precipitated. Extraction was achieved using acid medium (HCI), and the product was filtered through whatman filter paper.

The sample obtained was subjected to heavy metal content evaluation using AAS (GBC 932AA). The means, standard deviations and actual concentrations were calculated for the heavy metals in the vegetables. Statistical significance of the difference of the mean

values between different groups was determined by applying the F-test with the level of significance at P>0,5.

Result and Discussion

The result of analyzing the soil and water obtained from the e-dumpsite is discussed below.

E-waste heavy metal contamination in water and soil

Exposure of humans to heavy metals in soil, water and in the air through various routes has been established (Garlapati, 2016). The need for constant environmental monitoring and control is critical for human sustenance. Table 1 presents the result of heavy metal contamination of soil and water samples from the study area.

Table1a: Heavy metal contamination in water and soil in the study area

Elements										
	Lead		Zinc		Copper		Cadmium		Iron	
Sample	Water mg/L	Soil mg/kg	Water mg/L	Soil mg/ kg	Water mg/L	Soil mg/ kg	Water mg/L	Soil mg/ kg	Water mg/L	Soil mg/ kg
1	22.43	111.40	72.00	110.00	11.21	100.17	2.80	12.20	20.88	160.80
2	24.31	110.26	70.11	112.17	10.41	110.51	2.10	11.31	20.68	164.20
3	22.11	110.42	75.38	99.43	9.88	96.38	1.98	11.84	19.96	159.80
4	22.94	111.23	72.50	107.2	10.51	102.35	2.29	11.78	20.51	161.6
Ave	22.95	111.4	72.52	107.3	10.54	102.37	2.31	11.79	20.55	161.70

Table 1a shows the value of lead, zine, copper, cadmium and iron contamination in the study area from four sample stations. The result shows that iron and lead has the maximum value for soil contamination among the five heavy metals, with an average value of 161mg/kg and 111.4 mg/kg respectively. The heavy metal concentration of the soil was generally above 100 mg/kg for all the five heavy metals with the exception of cadmium that had an average value of 11.79 mg/kg. The value of the contamination of the water was generally low when compared with the soil, zinc and lead had the highest concentration value of 72.52 mg/L and 22.95 mg/L respectively. The values of heavy metal concentration in this study are lower, when compared to a similar e-waste dumpsite in China, the study reported that the concentration of copper and lead are 513 mg/kg, lead 198 mg/kg respectively; the value of cadmium was 0.52 mg/kg, this is however lower compared to the value of 11.79 mg/kg observed in this study (Wu et al., 2015).

Another study that investigated e-waste dumpsite in India, observed that the lead, iron, copper, cadmium concentration ranged between 125.86–577.64 mg/ kg, 1238.33–12987.56 mg/ kg, 505.58–1156.18 mg/ kg, 17.37–178.97 mg/kg (Dutta et al. 2022), the values from this study are well above the values obtained in the study area.

Considering the allowable limit as stipulated by international standard, the value of heavy metal concentration of lead, zinc in the soil samples is within the allowable limits 300 mg/kg and 200 mg/kg respectively, based on USEPA standard. However, the concentration of copper and cadmium are above the USEPA standard of 50 mg/kg and 3 mg/kg respectively; the concentration of copper is twice above the allowable limit with an average value of 102.37 mg/kg, while the concentration of cadmium is thrice, with an average value of 11.79 mg/kg. This is an indicator that the negative health impacts of these heavy metals should be further investigated in the study area to avert any

consequences linked with the unregulated disposal of e-waste in the region. Essentially, kidney failure and related disease should be further investigated within the region to establish if this is linked to the impact of the e-dump site (Canavati et al., 2022).

Table 1b is the continuation of the heavy metal concentration for barium, nickel, chromium, aluminum and silver. The concentration of aluminum in the water sample is noteworthy, the average value is about 137.74 mg/L, and this is the highest concentration among all the water samples. The concentration of heavy metals in the water samples were above the recommended allowable limits; for nickel, the recommended limit based on USEPA and Dutch Standard is 0.05 mg/L and 0.2 mg/L respectively. The average value of nickel for this study is 1.27 mg/L, this is obviously above the recommended allowable limits. Similarly chromium exceeded the allowable limit, this suggest that neurodevelopment of young people within the region could be at risk (Chakraborty et al., 2022).

Table 1b: Heavy metal content in soil and water (continued)

	Elements									
	Barium		Nickel		Chromium		Aluminum		Silver	
Sample	Water mg/L	Soil mg/kg	Water mg/L	Soil mg/kg	Water mg/L	Soil mg/kg	Water mg/L	Soil mg/kg	Water mg/L	Soil mg/kg
1	1.03	2.83	1.09	6.14	20.88	160.80	139.36	1119.8	1.03	2.83
2	1.41	2.66	1.26	6.23	20.68	164.20	143.17	965.43	1.41	2.66
3	1.38	3.14	1.15	6.62	19.96	159.80	130.30	1032.4	1.38	3.14
4	1.27	2.89	1.17	6.33	20.51	161.6	393.55	168.93	1.27	2.89
Ave	1.39	2.89	1.27	6.43	20.55	161.70	137.74	393.65	1.39	2.89

The Table 1b also indicates that aluminum and chromium has the maximum value for soil contamination among the five heavy metals, with an average value of 393.65 mg/kg and 161.70 mg/kg respectively. The heavy metal concentration of the soil was generally below 10 mg/kg for other heavy metals.

Heavy metal contamination of vegetables

Three different types of vegetables, water melon (citrullus lanatus), garden egg leave (s.macrocarpon), and cucumber (cucumis sativus) were analyzed for heavy metals content. Differences in metal concentration in vegetables seem to imply that different types of vegetables have different abilities to accumulate metals. Different types of vegetable species accumulate different metals depending on environmental conditions, metal species and plant available for heavy metals (Onwuemesi, 2018). Table 2 shows the concentration of heavy metals in the three vegetables assessed in the study. The table also shows the recommended allowable limit stipulated by FAO. Water melon is a major stable crops in the region, and is a major food crops in the region. Garden egg is another major staple crop, and is served in major occasions or public gather in the region; it generally serves as a symbol that a visitor or guest is welcome. The concentration of Pb in water melon and garden egg were more than the maximum limit recommended by (FAO, 2010), with 0.81ppm of dry sample.

The mean, standard deviation, maximum and minimum values of heavy metals in the vegetables from the study e- dumpsite are presented in Table 3.

Table 2: Concentration of heavy metals in the three vegetables assessed in the study

S/N	Element	Type of vegetable	Nnewi	FAO STD 2010
1	Pb	Water melon	0.81	0.62
		Garden egg leaves	0.72	0.89
		Cucumber	0.29	0.05
2	Cr	Water melon	1.16	0.18
		Garden egg leaves	0.13	0.14
		Cucumber	0.33	0.12
3	Ag	Water melon	0.17	1.27
		Garden egg leaves	0.25	2.08
		Cucumber	0.35	2.05
4	Cd	Water melon	0.18	0.15
		Garden egg leaves	0.15	0.13
		Cucumber	0.16	0.10
5	Ni	Water melon	0.34	2.06
		Garden egg leaves	0.21	2.04
		Cucumber	0.17	2.02
6	Al	Water melon	0.05	0.22
		Garden egg leaves	0.39	0.27
		Cucumber	0.46	0.31
7	Fe	Water melon	0.95	0.72
		Garden egg leaves	0.76	0.89
		Cucumber	0.27	0.05
8	Ba	Water melon	0.05	0.45
		Garden egg leaves	0.22	0.34
		Cucumber	0.37	0.23
9	Zn	Water melon	0.163	0.132
		Garden egg leaves	0.147	0.111
		Cucumber	0.027	0.140
10	Cu	Water melon	0.05	0.01
		Garden egg leaves	0.02	0.01
		Cucumber	0.03	0.02

Table 3: Concentration of heavy metal in vegetables obtained from Nnewi E-waste dump site, Anambra State.

Heavy metal	Sample of vegetable		
	Water mellow	**Cucumber**	**Garden eggs**
Lead mg/kg	$2.43^{-e} \pm 0.04$	$2.33^{d} \pm 0.00$	$1.45^{e} \pm 0.03$
Zinc mg/kg	$57.56^{b} \pm 001$	$57.55^{b} \pm 0.002$	$22.94^{r} \pm 0.06$
Copper mg/kg	$3.85^{-a} \pm 0.02$	$2.90^{e} \pm 0.05$	$1.89^{g} \pm 0.10$
Cadmium mg/kg	0.14 ± 0.02	$0.17^{d} \pm 0.06$	$0.22^{b} \pm 0.01$
Silver mg/kg	$0.17^{b} \pm 0.00$	$2.84^{e} \pm 0.01$	$2.00^{e} \pm 0.01$
Barium mg/kg	$0.18^{b} \pm 0.001$	$2.88^{c} \pm 0.02$	1.33 ± 0.01
Nickel mg/kg	$0.25^{-a} \pm 0.001$	$0.50^{a} \pm 0.01$	$0.21^{e} \pm 0.01$
Chromium mg/kg	$2.05^{-e} \pm 0.06$	$2.51^{d} \pm 0.01$	$3.28^{e} \pm 0.00$
Aluminum mg/kg	$211^{e} \pm 0.01$	$2.11^{e} \pm 0.01$	$2.01^{e} \pm 0.01$
Iron mg/kg	$3.85^{-a} \pm 0.02$	$2.90^{e} \pm 0.05$	$1.89^{g} \pm 0.10$

Table 3 shows that the mean concentration of Cu at vegetable samples collected from the study area was observed to be high with 101.62mg/kg. Cd was observed to be high with 142.27mg/kg. Cr was present in all samples. In Nnewi samples, mean concentration was 3.14

± 3.76 which ranged from 0.30 to 10.62mg/kg. In cucumber samples, mean concentration was 1.36 ± 1.21, ranging from 0.2 to 6.4 mg/kg and, in garden egg samples, it was 0.62 ± 1.31 with the range from 0.28 to 5.10 mg/kg. Considering the mean values, order of Cr concentration was Nnewi> Cucumber> garden eggs. Like Cd, Ni was present in some of the samples. The high concentration of these vegetables in the selected samples shows that the consumption of these vegetables without proper washing remains a serious health problem to the consumer. Most of these vegetables are not cooked before consumption, hence, the heavy metals are transferred to the consumer directly which results to organ failures.

Conclusion

E-waste encapsulates all major electrical and electronic equipment and their parts which are deemed to be no longer valuable. E-waste has a wide range of environmental impact as it is the largest source of heavy metals and organic contaminants in municipal solid waste, hence their improper disposal can pose significant environmental damage. This study assessed the degree of environmental toxicity or contamination in soil, water and vegetables in typical e-waste dumpsite, in the context of Nnewi city of Nigeria. The result of the study indicates that Aluminum and Chromium had the maximum value for soil contamination; this is followed by iron and lead. Aluminum and Zinc had the maximum value for water contamination, and ranged between 130.30 to 393.55 mg/L, and 70.11 to 75.38 mg/L. The concentration of the heavy metals on the plants indicates that water melon had the maximum concentration of 1.16 mg/kg, 0.95 mg/kg, and 0.81 mg/kg of chromium, iron, and lead concentrations. Generally, it is observed that heavy metal concentrations are higher in water melon than other plants. Health policy to safe guard consumers will be appropriate measures.

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