Toxicological Effects of Electronic Waste (E-waste) on Microbial Flora and Radionuclides

Ocheoibo S. J. and Atuanya E. I.*
Department of Microbiology, Faculty of Life Sciences, University of Benin, Benin City, Nigeria.
* Corresponding author: ocheoibo@gmail.com; ernest.atuanya@uniben.edu

Abstract: This study was conducted to investigate the microbial, elemental levels and radionuclei concentration of three e-waste dumpsites with a view to establish the contamination status of these sites. E-waste soil samples were collected from Oluku and Osasogie in Benin, Edo state Nigeria while the third E-waste soil sample was obtained from Alaba, Lagos state Nigeria.The microbial analysis was done based on standard procedure. The mean bacterial counts on nutrient agar (NA) ranges between 9.00±2.646 cfu/g and 5.33±1.202 cfu/g, the former was for Oluku while the latter was for Osasogie. The highest fungal count was recorded in the control site (10.67±1.764 sfu/g). The isolated bacterial and fungal species included, *Bacillus* sp., *Clostridium* sp., *Pseudomonas* sp., *Yersinia* sp., *Serratia marcescens, Klebsiella* sp., *Providencia* sp, *Aspergillus* sp., *Geotrichum* sp., *Rhizopus* sp., and *Penicillium* sp. respectively, these microorganisms have been reported to possess the ability to biodegrade heavy metals. The physicochemical properties across the e-waste sites showed the available pH of the soil samples range from 6.83 - 8.45. Alaba soil sample recorded the highest amount of all the heavy metals analyzed, cadmium (Cd) was the only heavy metal that was not detected (ND) and it was not detected only in the control soil sample. The activity concentrations of natural radionuclides (^{40}K, ^{226}Ra, ^{323}Th). The highest mean values obtained for ^{226}Ra and ^{323}Th was in Alaba with (79.630±4.557 Bq/kg, 30.177±1.83 Bq/kg) respectively. The control was below detection limit (BDL) for both Ra and Th. The world average values of 412 Bq/kg, 35 Bq/kg and 30 Bq/kg for ^{40}K,^{226}Ra, and ^{323}Th, respectively. However, ^{226}Ra was higher than the accepted limit while ^{232}Th was at the recommended limit for Alaba e-waste site. Therefore, e-waste poses a radiological risk to the people living/working at Alaba e-waste site, but does not pose any immediate threat at the other two e-waste sites studied.
Key word: E-waste, heavy metal, microorganisms, dump sites, radionuclides

INTRODUCTION

Waste can be described as material(s) that has been abandoned by its owner and is no longer in use. “Each day, a vast amount of waste is produced, currently requiring immediate attention”. The remarkable advancements in contemporary times have unquestionably improved the standard of living for humanity (Chaurasia *et al.*, 2021). Numerous issues have arisen as a result of these issues, one of which is the prevalence of hazardous waste and other materials derived from electronic equipment, often referred to as "E-waste" or "Electronic-waste". Because digital devices contain hazardous and lethal substances, Getting rid of e-waste is becoming more of an ecological and public safety concern (Chaurasia *et al.*, 2021). It was anticipated that the total amount of garbage produced by broken down or outdated electrical and electronic equipment was 1,46,000 tons in 2005, 8,00,000 tons in 2012, 1.8 MT in 2016, and 5.2 MT in 2020 (Ideho, 2012; Chaurasia *et al.*, 2021). Hence, it is integral on an international scale to implement high-quality measures to curb the escalation of electronic waste, as projections indicate an attainable 50% increase over the next decade, leading to heightened environmental air pollution and health risks (Sanchari, 2021).

Electronic waste: can be described as used electronics that need to be recycled or disposed of appropriately (Mohammed *et al.*, 2013). Electronic waste, also known as Waste Electrical and Electronic Equipment (WEEE), is the term for unwanted electrical and electronic equipment that has been thrown, becomes obsolete, or reaches the end of its useful life (UNEP, 2005; Liu *et al.*, 2020; Alabi *et al.*, 2021). It contains more than a thousand amazing compounds that are divided into "hazardous" and "nonhazardous" categories. These resources often include metallic element such as copper (Cu), aluminum (Al), and valuable

metals like platinum (Pt), gold (Au), palladium (Pd), silver (Ag), and so on. (Malhotra and Jain, 2023). Factors including mercury, cadmium, hexavalent chromium, lead, arsenic, selenium, and flame retardants can have negative effects on the natural landscape and living things when their threshold levels are exceeded (Chaurasia *et al.*, 2021; Mophosa and Mophosa, 2020). Disposing of electronic waste poses a significant challenge in numerous areas worldwide, primarily due to concerns regarding the toxic and cancer-causing potential of certain substances when not adequately managed (Saoji, 2012).

The earth's habitability depends on the roles of soil microorganisms in cycling nutrients and supporting food chains. The marine ecosystems are also vulnerable to lasting environmental changes caused by human activities such as dumping electronic wastes. Microbes are vital for how ecosystems deal with pollutants, which affect nutrient cycles and food chains, and how microbes react to toxins in an ecosystem will largely influence the outcome of that ecosystem when the tolerance limit has not been reached (Aquastel, 2007). Numerous studies have demonstrated the negative effects of environmental pollution, including heavy metals and organic pollutants, on microbial metabolism, enzyme activity, soil microbial community resilience to additional perturbation, and microbial diversity (Jiang *et al.,* 2017). Furthermore, by enhancing the abundance of some species with exceptional adaptability or biodegradable properties and decreasing the population of other species, these contaminants alter the microbial makeup (Jiang *et al.,* 2017). Consequently, the microbial community in waste electronic disposal sites may be a good predictor of the ecological danger to the ecosystem and the quality of the soil. The effect of concentration patterns of hazardous metals and organic pollutants on microorganisms in electronic waste recycling facilities have garnered a lot of attention lately. Numerous laboratory investigations were carried out to investigate the ecotoxicological impacts of electronic waste pollution on microorganisms. It was discovered that urease, catalase, and saccharase were all toxically affected by the combination of Polybrominated Diphenyl Esters (PBDEs) and Cu (Jiang *et al.,* 2017). Pb and PBDEs hindered microbial basal respiration and decreased microbial biomass. (Jiang *et al.,* 2017).

Only very high concentrations of heavy metals in the soil have detrimental effect on how microorganisms respire and break down organic nitrogen in the soil. According to some research, low concentrations of heavy metals may even promote soil respiration and the buildup of organic matter. Nevertheless, other elements that affect the microbial community and interact with the heavy metals include pH level of the soil, organic matter in the soil, organic pollutants, and zinc (Salam and Varma, 2019). Heavy metals can also decrease the abundance and variety of microorganisms in the soil, and their toxicity varies according to the properties of the soil. However, another study discovered that soil specimens from three Nigerian waste electronic disposal sites contained more fungi and bacteria than a control sample, with *Aspergillus* sp. and *Bacillus* sp. being the most prevalent Taiwo *et al.,* 2018). This suggests that organic pollutant and heavy metal contamination can also favor resistant microbes that can degrade the contaminants (Salam and Varma, 2019).

More cases of leukemia in youngsters in the research location were associated with telomere shortening in the fetus and newborn. Workers at e-waste recycling facilities reported experiencing headaches, rash/itching, numbness in the hands and feet, blurred vision and hypertension. Electronic waste can cause prostate cancer in men and people who live near waste electronic disposal sites in Nigeria have problems with their reproductive and thyroid systems, especially children and adults who are exposed to dust containing PBDEs (Olukunle *et al.*, 2015). Additionally, a study at the Alaba e-waste dumpsite discovered

that scavengers' blood contained significant levels of the metals Pb and Mn (Popoola *et al.*, 2019). Furthermore, a recent study in waste electronic disposal site in Alaba, Nigeria, revealed notably elevated levels of Pb, Cd, Cr, and Ni in an adolescent scavenger's peripheral bloodstream (Alabi *et al.*, 2020). Therefore the objective of this study was to investigate the microbial, elemental levels and radionuclei concentration of three e-waste dumpsites with a view to establish the contamination status of these sites and its effects on public health.

MATERIALS AND METHODS

Soil samples were collected from 3 major e-waste dumpsites, namely, Alaba (6°28'00" N 3°10'59" E) located in Ojo local government area, Lagos State, South Western part of Nigeria. It hosts the popular Alaba international market, the largest electronics market in West Africa. Oluku (6°43'05" N 5°59'32" E) a town in Benin city and Osasogie (6°33'52" N 5°61'69" E) is also a town in Benin city located in Ovia North-East local government area, Edo State, south-South Nigeria. The control soil sample was obtained at University of Benin (UNIBEN) (6°20'1.32 N" 5°36'0.53" E), Ugbowo campus free from e-waste dumpsite. Most of the wastes found at these 3 dumpsites are imported second-hand products which include electronics products such as communications, broadcasting, computers, televisions, videos, home appliances, refrigerators, video games, generators, satellite and so on. The scavengers or e-waste collectors indulged in burning and other crude recycling practices at the dumpsites without care for their health or environment, in an attempt to recover some useful parts/scrap from e-waste. Makeshift structures are also erected on the sites for accommodation.

Collection and preparation of soil samples: Soil sample were collected from Alaba International market e-waste dump site, Lagos state and e-waste dump site in Oluku and Osasogie, Edo state while the control soil was obtained from UNIBEN at a depth of 0-15 cm using a sterile soil auger. The samples were taken to the laboratory in a box containing ice for analysis. The soil samples were air-dried and sieved with a 2 mm mesh size to remove stones and other extraneous materials.

Chemical analysis of soil samples: The soil properties of the samples such as pH, moisture content and total nitrogen (N) were determined using methods described by Riegel *et al.* (2002), Oyeyiola (2004). Colorimetric determination for available Phosphorus and organic carbon were done using the method of Riegel *et al.* (2002), while AOAC, (2000) method was used to analyze calcium, magnesium, sodium and potassium concentrations of the soil samples.

Isolation of associated microorganisms: Total heterotrophic bacterial count (THBC) of the soil samples were analyzed using the method suggested by Akintokun and associates. Using the pour plate method, ten serially diluted samples, each measuring one milliliter, were inoculated onto sterile Plate Count Agar and incubated inverted for twenty-four hours at 37 ºC. After a day, colonies were enumerated and reported as colony forming units (cfu/g) (Akintokun *et al.*, 2017).

Total fungal count (TFC) were determined by inoculating 1 ml each of serially diluted (10) samples on sterile potato dextrose agar incorporated with 1 % (v/v) chloramphenicol using pour plate method and then incubated at 28ºC for 72 h. The 1% chloramphenicol was added to potato dextrose agar to inhibit bacterial growth. Colonies were counted and reported as the spore forming units per gram (SFU). After the incubation time, the colony forming units (CFU) for each plate was estimated using the formula:

$$CFU = \frac{\text{Number of colonies per plate x Dilution factor}}{Volume\ of\ aliquot\ used}$$

Purification of bacterial and fungal isolates: Discrete colonies on different media were isolated and purified on nutrient agar by repeated sub-culturing and pure cultures of the isolates were maintained on nutrient agar slants and stored at 4°C in the refrigerator for all bacterial isolates while the fungal colonies were purified and maintained on potato dextrose agar incorporated with 1% chloramphenicol and also stored at 4°C in the refrigerator for further analysis.

Identification and characterization of bacterial and fungal isolates: The bacterial isolates were characterized based on their morphological and biochemical characteristics (Cappuccino and Sherman, 2002) and examined and identified according to the Bergey's Manual of Determinative Bacteriology (Williams and Wilkins, 1984). Biochemical tests including catalase, citrate utilization capsule staining, Voges-Proskaeur, Methyl-red and sugar fermentation tests were carried out on the isolates. The fungal isolates were identified based on cultural and morphological characterization with reference to the work of de Hoog *et al.* (2000), Ellis *et al.* (2007).

Heavy metals content analysis of soil samples: The heavy metal content of the samples was determined as described by Taiwo and associates. Taiwo *et al*. (2018). The air-dried soil samples were passed through a 2 mm nylon sieve and digested by 1:2:2 (V: V: V) HNO: HCl:HClO . Iron (Fe), nickel (Ni), lead (Pb), zinc (Zn), copper (Cu), manganese (Mn), cadmium (Cd) and chromium (Cr) were measured by inductively coupled plasma atomic emission spectroscopy (ICP-AES, IRIS Intrepid II, Thermo Electron corporation, USA), to determine each of the above stated heavy metal content of the soil samples.

Radionuclide analysis of soil samples: All the labeled soil samples were safely conveyed to the Radiation Laboratory of Physics Department, Federal University of Agriculture, Abeokuta, Ogun state, Nigeria. At the laboratory, the samples were dried to attain constant weight, pulverized and sieved using a 2 mm mesh sieve. One hundred and fifty grams (150 g) of each sample was subsequently measured using an electronic weighing balance (Scale Tec Analytical Balance, model: SAB-224CL, Serial number: N222112-223) and packed in plastic containers of diameter 6.6 cm to sit with good geometry on NaI (Tl) detector used for the measurements. The plastics were sealed with a tape and kept for 30 days in order to attain secular equilibrium between radium and its gaseous decay products, then examined using gamma ray spectrometer (Taiwo *et al.,* 2018). The activity concentration of a certain radionuclide, (Bq/kg), in the soil samples was calculated using the following equation (Dabayneh *et al.,* 2008).

$$Ca = \frac{\mathrm{C}}{£ \times Ieff \times Ms}$$

where,

'Ca' is the net gamma counting rate (counts per second) for a peak at energy

'£', Is the detected efficiency of a specific gamma-ray,

'I' Is the intensity of the gamma-line in radionuclides,

'M' Is the mass of the soil sample under consideration measured in kilograms.

Statistical Analysis*:* Data obtained were analyzed using Statistical Package for Social Sciences (SPSS) version 17.0 for Windows (SPSS, Chicago IL,-U.S.A). The mean, standard deviation (SD), median and ranges were calculated for continuous variables while proportions and frequency tables were used to summarize categorical variables. Means were separated and compared with standard error using Duncan's New Multiple Range Test (DMRT) where $P< 0.05$ implies significant difference between values obtained (Ogbeibu, 2019).

RESULTS AND DISCUSSION

Table 1 showed that the bacterial count was not significantly different across the sites. The mean bacterial counts on NA ranges between 9.00±2.646 cfu/g and 5.33±1.202 cfu/g, the formal was for Oluku while the latter was for Osasogie respectively and the

findings of the associated bacteria were not significantly different across the four locations, while the fungal counts showed a significant difference. The highest fungal count was recorded in the control site (10.67±1.764 sfu/g) and the lowest counts (3.33 ±0.882 sfu/g) was recorded at Alaba (Table 1).

Table 1: Total microbial count from the e-waste soil samples from different locations

Parameters	Control n= 3 $\bar{X}$±SE (min-max)	Oluku n= 3 $\bar{X}$±SE (min-max)	Alaba n= 3 $\bar{X}$±SE (min-max)	Osasogie n= 3 $\bar{X}$±SE (min-max)
HBC (NA) × 10,000,000 bacteria cfu/g (Mean)	7.33±1.764^{b}	9.00±2.646^{a}	5.00±0.577^{c}	5.33±1.202^{c}
HFC (PDA) × 200,000 fungi cfu/g (Mean)	10.67±1.764^{a}	7.33±1.856^{b}	3.33 ±0.882^{d}	6.00±1.000^{c}
HBC (MCA) × 20,000 bacteria cfu/g (Mean)	7.00±0.577^{a}	4.33±0.882^{c}	5.33±1.764^{b}	2.33±0.882^{d}

Key: HBC= Hetero-trophic bacteria count. HFC= Hetero-trophic fungal count. NA= Nutrient agar. PDA= Potato dextrose agar. MCA= MacConkey agar. The figure with dissimilar superscript alphabet are significantly different along the row.

Table 2: Distribution pattern of bacterial isolates across e-waste locations

	Soil sample locations											
Probable organism	Control 1	Control 2	Control 3	Oluku 1	Oluku 2	Oluku 3	Alaba 1	Alaba 2	Alaba 3	Osasogie 1	Osasogie 2	Osasogie 3
Bacillus sp	+	-	+	+	-	-	-	-	+	-	-	-
Bacillus cereus[1]	-	-	-	-	-	-	-	-	-	+	-	+
Yersinia sp [1]	+	-	-	-	-	-	-	-	-	-	-	-
Pseudomonas aeruginosa	-	+	-	-	-	-	-	-	-	-	-	-
Clostridium sp[1]	-	-	+	-	-	-	+	-	+	-	-	-
Bacillus subtilis	-	-	-	-	-	-	-	+	-	-	-	-
Bacillus cereus[2]	+	-	-	-	-	-	-		-	-	-	-
Serratia marcescens	-	-	-	+	-	+	-	-	-	-	-	-
Providencia sp	-	-	-	-	-	-	+	-	-	-	-	-
Yersinia sp[2]	-	-	-	-	-	-	-	-	-	+	-	+
Klebsiella sp	-	-	-	-	-	-	-	-	-	-	+	-
Bacillus cereus[3]	-	-	-	-	-	-	-	+	-	-	-	-
Clostridium sp[2]	-	-	-	+	-	-	-	-	-	-	-	-

Key: + = positive**. - =**Negative

Table 3: The cultural and morphological characteristics of isolated fungal from contaminated e-waste soil samples

Cultural characteristics	Morphological characteristics				
Nature of colony	Hyphae	Spore type	Organism	Location	Plate
Powdery colonies with black spores and a yellow reverse side	Septate	Conidiophore	*Aspergillus niger*[1]	Control	1
Fluffy dark colonies with black spores and a yellow reverse side	Septate	Conidiophores	*Aspergillus niger*[2]	Control	2
Powdery colonies with black spores and a yellow reverse side	Septate	Conidiospore	*Aspergillus* sp	Control	3
Fluffy dry cream colonies with dark reverse side	Septate	Arthrospores	*Geotrichum* sp	Oluku	1
Fluffy dark colonies with brown reverse side	Sepate	Conidiophores	*Aspergillus* sp	Oluku	2
Fluffy black colonies with dark reverse side	Sepate	Conidiospore	*Aspergillus* sp	Oluku	3
Fluffy grayish brown colonies with a dark colour reverse side	Non-septate	Sporangiophores	*Rhizopus* sp	Alaba	1
Fluffy black colonies with dark reverse side	Septate	Conidiophores	*Aspergillus* sp	Alaba	2
Fluffy black colonies with dark reverse side	Septate	Conidiospore	*Aspergillus* sp	Alaba	3
Wooly greenish colonies with a yellow colour reverse side	Septate	Conidiospore	*Penicillium* sp	Osasogie	1
Dark colour colonies with entire margin	Sepate	Conidiospore	*Aspergillus* sp	Osasogie	2
Dark colour colonies with entire margin	Septate	Conidiospore	*Aspergillus* sp	Osasogie	3

Table 4: Physicochemical characteristics of the e-waste soil samples

Parameters	Control n= 3 $\bar{X}$±SE (min-max)	Oluku n= 3 $\bar{X}$±SE (min-max)	Alaba n= 3 $\bar{X}$±SE (min-max)	Osasogie n= 3 $\bar{X}$±SE (min-max)
Ca	1.013±0.009^{c}	1.273±0.043^{a}	1.127±0.009^{b}	1.340±0.010^{a}
Mg	0.560±0.010^{d}	0.757±0.012^{b}	0.640±0.006^{c}	0.817±0.007^{a}
Na	0.413±0.003^{c}	0.723±0.007^{a}	0.670±0.006^{b}	0.740±0.021^{a}
K	0.467±0.009^{b}	0.743±0.003^{b}	0.553 ±0.008^{b}	5.707±2.438^{a}
Phosphorus	19.04±0.147^{a}	10.23±0.027^{d}	11.26±0.063^{c}	14.19±0.038^{b}
Total Nitrogen	6.263±0.049^{a}	2.463±0.064^{c}	2.307±0.024^{d}	3.273±0.027^{b}
Organic Carbon	9.983±0.072^{d}	12.22±0.700^{c}	13.95±0.332^{b}	17.34±0.109^{a}
Moisture	9.533±0.120^{a}	8.087±0.060^{d}	9.377±0.055^{a}	8.523±0.223^{b}
pH	6.830±0.051^{c}	8.393±0.018^{a}	8.453±0.023^{a}	8.160±0.017^{b}

Key: The figure with dissimilar superscript alphabet are significantly different along the row

Table 5: Heavy metals concentration across e-waste soil sites (mg/kg)

Location	Pb	Zn	Cd	Ni	Cu	Cr	Mn	Fe
Control	0.002±0.001^{d}	0.008±0.001^{d}	ND	0.003±0.001^{c}	0.002±0.001^{c}	0.002±0.001^{d}	0.031±0.01^{c}	4.587±0.055^{d}
Osasogie	0.004±0.001^{c}	0.162±0.006^{b}	0.002±0.001^{b}	0.017±0.001^{b}	0.006±0.001^{b}	0.009±0.001^{b}	0.004±0.001^{d}	6.123±0.006^{c}
Oluku	0.006±0.001^{b}	0.044±0.001^{c}	0.001±0.001^{b}	0.016±0.001^{b}	0.002±0.001^{c}	0.006±0.00c	0.077±0.001^{b}	7.233±0.006^{b}
Alaba	0.029±0.001^{a}	2.833±0.006^{a}	0.033±0.006^{a}	2.453±0.006^{a}	1.453±0.006^{a}	0.103±0.006^{a}	5.123±0.006^{a}	64.833±0.058^{a}

Key: ND= Not Detected. In the column, values denoted by unique superscripts show statistically significant variations ($P < 0.05$)

Table 6: Radioactive emissions from the e-waste soil samples

Location	^{40}K	^{226}Ra	^{323}Th
Control	46.720±4.129^{c}	BDL	BDL
Oluku	85.660±4.150^{a}	27.257±2.240^{b}	17.063±1.280^{b}
Osasogie	75.667±4.928^{b}	6.333±0.830^{c}	9.567±1.387^{c}
Alaba	27.620±2.455^{d}	79.630±4.557^{a}	30.177±1.83^{a}
World range Limit (UNSCEAR, 2000)	400	35	30

Key: BDL = Below Detection Limit. In the column, values denoted by unique superscripts show statistically significant variations. ($P < 0.05$)

The tables 2 and 3 revealed the identity of isolated bacteria and fungi respectively. The e-waste soil samples and the control soil were found to contain bacterial and fungal species which included, *Bacillus* sp., *Clostridium* sp., *Pseudomonas* sp., *Yersinia* sp., *Serratia marcescens, Klebsiella* sp., *Providencia* sp, and *Aspergillus* sp., *Geotrichum* sp., *Rhizopus* sp., and *Penicillium* sp. respectively. Bacteria isolated fro soi samples were both Gram positive (*Bacillus* sp, and *Clostridium* sp) and Gram-negative (*Pseudomonas* sp. *Yersinia* sp.' *Serratia marcescens, Klebsiella* sp. and *Providencia* sp). The isolation of *Bacillus* sp, *Pseudomonas* sp, *Klebsiella* sp, *Aspergillus* sp from the soil samples was similar to a report by Sanusi (2015) and Taiwo *et al.* (2018) which reported similar microorganisms in soil collected from Alaba e-waste dump sites. However, all the microbial isolates identified from the soil samples, have been reported to be associated with waste biodegradation (Wade and Dave, 2006; Dabayneh *et al.*, 2008; Akintokun *et al.*, 2017; Taiwo *et al.*, 2018). *Aspergillus, Penicillium, Rhizopus* have also been previously reported to be associated with waste biodegradation (Adebisi *et al.*, 2014).

Physicochemical properties from the e-waste soil samples

The physicochemical properties across the e-waste sites are shown in Table 4. The pH of the soil samples range from 6.83 to 8.45. There was no significant pH difference between the pH of Alaba and Oluku, but there was significant difference between three e-waste soil and the control soil samples. The pH of Alaba was 8.45. This is similar to a report of a research done by (Jiang *et al.*, 2019) but (Taiwo *et al.*, 2018) observed a decreased pH of 6.40 at Alaba.

This may be due to different point of sample collection, variation in season when this analysis was carried out as water content and microbial activities mostly determine the pH of soil.

Concentration of heavy metals content across e-waste soil samples

There were significant differences in the heavy metals' concentrations across the soil samples. Alaba soil sample recorded the highest amount of all the heavy metals analyzed which includes, lead (Pb), zinc (Zn), cadmium (Cd), nikel (Ki), copper (Cu), chromium (Cr), manganase (Mn) and iron (Fe). The reason maybe that, Alaba e-waste dumpsite site was more of e-waste materials while the other two dumpsites is a combination of e-waste and municpal waste. This is similar to the findings of Popoola *et al* (2019) who reported a high concentration of blood Mn and Pb in scavengers at an e-waste dumpsite in Alaba. Also recently, Alabi *et al* (2020) showed significantly high concentrations of Pb, Ni, Cd, and Cr in the peripheral blood of teenage scavengers at e-waste dumpsites in Alaba international market, Nigeria. Cadmuim (Cd) was the only heavy metal that was below detection limit (BDL) at the control soil sample. The heavy metals analyses of the soil samples revealed that soil from e-waste dumpsites had a higher quantity of heavy metals in mg/kg than soil without e-waste (control). This finding agrees with the observation of Taiwo *et al.* (2018) who work on assessment of soil microorganisms, heavy metal levels and natural radionuclei concentrations of electronic waste dumpsites in Nigeria.

Radioactive emissions from the e-waste soil samples

There were statistical differences in the activity concentrations of natural radionuclides (^{40}K, ^{226}Ra, ^{323}Th) in all the soil samples. Soil sample from Oluku had the highest mean concentration (85.660±4.150 Bq/kg) for ^{40}K followed by Osasogie with (75.667±4.928 Bq/kg) and the lowest mean value was obtained in Alaba (27.620±2.455 Bq/kg). The highest mean values obtained for ^{226}Ra and ^{323}Th was in Alaba with (79.630±4.557 Bq/kg, 30.177±1.83 Bq/kg) while the lowest mean value, (6.333±0.830Bq/kg, 9.567±1.387Bq/kg) was obtained at Osasogie. However the control was below detection limit for both ^{226}Ra and ^{323}Th. The findings on the activity concentrations of natural radionuclides (^{40}K, ^{226}Ra, ^{323}Th) of the e-waste soils in this study showed that the values for Oluku (85.660±4.150 Bq/kg, 27.257±2.240 Bq/kg, 17.063±1.280 Bq/kg) and Osasogie (75.667±4.928 Bq/kg, 6.333±0.830 Bq/kg, 9.567±1.387 Bq/kg) respectively were below the world range reported by the international radioactivity levels by UNSCEAR (2000). Also the findings agrees with the works of Bello *et al* (2015) and Taiwo *et al.* (2018) who also reported similar results in their work in the analysis of the activity concentrations of natural radionuclides at different e-waste dumpsites in Nigeria. However the value for Alaba (27.620±2.455 Bq/kg, 79.630±4.557 Bq/kg, 30.177±1.83 Bq/kg), ^{40}K (27.620±2.455 Bq/kg) is below the world range limit, the value for ^{323}Th (30.177±1.83 Bq/kg) was at the world range limit but ^{226}Ra (79.630±4.557 Bq/kg) was above the world range reported by the International radioactivity levels by UNSCEAR, 2000. This implies that people living or working at Alaba e-waste dumpsite are at radiological and other health risk. This agrees with the report of Alabi *et al.* (2020). Radio-active emissions from e-waste dumpsites have been reported as one of the causes of natural radionuclides, (Bello *et al.*, 2015). The e-waste dumpsites in this study revealved that; Oluku and Osasogie soil does not pose any immediate radiological risk to the people working or living on the dumpsites and its environs but Alaba e-waste dumpsite pose radiological and other health risk to those living and working at the e-waste site. An urgent attention should be given to Abala ewaste dumpsite in other to reduce the radioactive emission and protect public health of people living in the environ.

CONCLUSION

The study has shown that e-waste significantly alters the composition and diversity of microbial flora as isolated organisms are those known to possess the ability to biodegrade heavy metal. The physicochemical properties across the e-waste sites showed the available pH of the soil samples range from 6.83 - 8.45. E-waste has demonstrated adverse effect on soil fertility as evidenced by altered nutrient level as nitrogen and phosphorus concentration was high in the control soil compared to the ewaste soil samples. Alaba soil sample recorded the highest amount of all the heavy metals analyzed.This disparity may be due to the prevalence of electronic waste materials at the Alaba waste electronic disposal site compared to the other two dumpsites. Alaba has the highest values of natural radio nucleotide ^{226}Ra and ^{323}Th, while the lowest was at Osasogie; the control was below detection limit. However, ^{226}Ra was higher than the accepted limit while ^{232}Th was at the recommended limit for Alaba e-waste site. Therefore, e-waste poses a radiological risk to the people living/working at Alaba e-waste site, but does not pose any immediate threat at the other two e-waste sites studied. A strict policies and procedures for the handling, recycling, and disposal of electronic trash should be enacted. This should involve taking precautions against the emission of radioactive materials and dangerous compounds. Promote the use of eco-conscious e-waste recycling techniques, including mechanical and biological approaches, to reduces the discharge of harmful chemicals into the environment, promote collaboration between governmental organizations, environmental agencies, academic institutions, and the commercial sector to create comprehensive solutions to address the complex problems associated with electronic waste that affect public health and the environment.

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