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DISTRIBUTION AND POTENTIAL RISK OF METALS AND METALLOIDS IN SOIL OF INFORMAL E-WASTE RECYCLING SITES IN LAGOS, NIGERIA

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ABSTRACT

Crude and haphazard informal e-waste recycling has resulted in environmental pollution with detrimental effects on human health. The present study assesses the levels of metals and metalloids (Pb, Mn, Fe, Zn, Co, Cd, Ni, Ag, Cu, As, Ba, Cr, Ca, Mg, K, and Na) in topsoil of informal e-waste recycling sites in Lagos, Nigeria. Topsoil samples (0-15 cm) were randomly collected at different informal e-waste recycling hubs in Lagos. Samples were digested and the levels of heavy metals and metalloids were determined using ICP-OES. Soil contamination indices, ecological and human health risks were evaluated using contamination factor, degree of contamination, geo-accumulation index, ecological risk index (RI), and human risk index (HI), respectively. There were variations in the concentrations of metals and metalloids in the soil, which ranged from 7.05-16,350 mg/kg Pb, 14.4-3,373 mg/kg Cu, ND-21.9 mg/kg Cd, and ND-166 mg/kg Ni. Lead had the highest mean concentration of 7394 ±7759 mg/kg in soil around the dismantling points at Ojota scrap market. Ojota scrap market also had the highest concentrations of all the metals except Co, Cd, As and Ba. Health risk index (HI) ranged from 3.93-183 in both children and adults populations. These calls for concern due to potential health risk associated with human exposure to toxic metals, some of which are also endocrine disruptors. There is need for proper management of e-waste in Nigeria to prevent human exposure to these toxic substances present therein.

Keywords: Electronic waste, environmental contamination, heavy metals, recycling, health risk, waste management

INTRODUCTION

Inventory and volume of outdated electronic equipment is constantly growing due to rapid innovation and technological advancement. These outdated equipment are eventually disposed of as electronic waste or e-waste (SOT, 2013). E-waste are discarded appliances that has or could enter the waste stream such as waste electronic goods (e.g., computers, televisions and mobile phones), which uses electricity before it reached its end-of-life and then becomes waste stream; and traditionally non-electronic goods such as refrigerators, ovens, washing machines, dryers, etc., home entertainment and stereo systems, toys, toasters, kettles and almost any household or business item with circuitry or electrical components with power or a battery supply (Robinson, 2009; Pérez-Belis et al., 2015). E-waste contains valuable metals such as Cu and platinum group elements that can be extracted as well as more than one thousand toxic substances including potential environmental contaminants such as Pb, Cd, Ni, etc., brominated flame retardants such as polybrominated diphenyl ethers (PBDEs), and polychlorinated biphenyls (PCBs) (Puckett and Smith, 2002; Araújo et al., 2012; Kiddee et al., 2013). The presence of halogenated compounds in e-wastes have been reported to results in the release of toxic, bio-accumulative and persistent organic pollutants such as dioxins and furans during recycling processes, which can jeopardize public health (Chakraborty et al., 2018). Burning e-waste may generate dioxins, furans, polycyclic aromatic hydrocarbons (PAHs), polyhalogenated aromatic hydrocarbons (PHAHs), and hydrogen chloride (Robinson, 2009; Steiner, 2004; Leung et al., 2006; Williams et al., 2008; Li et al., 2011; Luo et al., 2011; Atiemo et al., 2012; Amfo-Out et al., 2013; Song and Li, 2014; Tsydenova and Bengtsson, 2011). Some of these substances have also been reported to be endocrine disruptors due to their ability to mimic or antagonize the action of endogenous hormones, interfere with the synthesis, transport, metabolism, and excretion of natural hormones; and also alter the hormone receptor levels causing adverse effects in both humans and animals including aquatic organisms and wildlife (EC, 1999; Baker, 2001; Sheikh et al., 2017).

The growth of informal e-waste recycling sector in many developing countries including Nigeria has created an emerging environmental problems due to the non-stringent environmental laws and very weak enforcement (Bridgen et al., 2005; Chakraborty et al., 2018). E-waste recycling is a rapidly growing business globally and a major pollution sources with associated environmental and human health problems (Kaya and Sőzeri, 2009). Though, it can recover materials and other reusable components such as Cu and precious metals, however, it has resulted in environmental contamination with adverse effects on humans and animals. Due to high costs of labour, lack of facilities and stringent environmental laws and regulations, developed countries do not recycle e-wastes (Robinson, 2009; Perkins et al., 2014). These wastes are either landfilled or exported to developing countries as second hand electronic goods while the unserviceable and unrepairable ones are recycled. Developing countries lack the facilities and technical know-how to handle this category of waste. Thus, resulting in crude and haphazard recycling which resulted in contamination of environmental media and human health issues (Echegaray and Hansstein, 2016; Caravanos et al., 2011; Araújo et al., 2012).

Studies have shown a direct impact of crude and backyard recycling of e-waste on workers in Nigeria (Igharo et al., 2014; Igharo et al, 2015a, 2015b; Igharo et al., 2016); Ghana (Nukpezah et al., 2014; Asante et al., 2012; Caravanos et al., 2011); China (Chan et al., 2007; Zhao et al., 2008; Huo et al., 2008; Huo et al., 2007; Wang et al., 2009; Zheng et al., 2008); and India (Steiner,, 2004; Ha et al., 2009; Eguchi et al., 2012). Also, on plant (roots of onion bulbs) (Bakare et al., 2012; Bakare et al., 2013; Olafisoye et al., 2013). The danger posed by toxic substances in e-waste on human health has become a serious societal problem in recent time.

Generally, e-waste refurbishment, collection and recycling takes place in business clusters in Lagos such as Alaba International Market and Ikeja Computer village, which are involved in refurbishment, repairs and marketing of used electrical and electronic goods. Westminster and Lawanson Markets are also hubs for second-hand equipment (Manhart et al., 2011). Collection, dismantling, sorting and recycling of e-waste takes place at Ojota scrap market. This study therefore assesses the levels of metals and metalloids in topsoil of e-waste recycling hubs in Lagos, Nigeria where e-waste collection, recycling, refurbishing, repairs, dismantling and open burning were the major recycling processes. Soil contamination, ecological and human health risks were evaluated using contamination factor, degree of contamination, geo-accumulation index, ecological risk index, and human risk index (HI). Soil characteristics were also determined.

MATERIALS AND METHODS

Description of the study areas

Four major e-waste recycling hubs in Lagos were selected for this study. Alaba International Market is the largest market of used and new electrical and electronic goods in Africa. Ikeja Computer Village Market is active in the sales of second-hand products. Westminster Electronic Market is situated in Apapa Local Government Area of Lagos. Storing used electrical and electronics equipment before being redistributed to other markets or exported to neighbouring countries takes place therein (Adaramodu et al., 2012; Manhart et al., 2011). Ojota scrap market is known for the dismantling and sorting of solid wastes including electrical and electronics equipment (Figure 1).

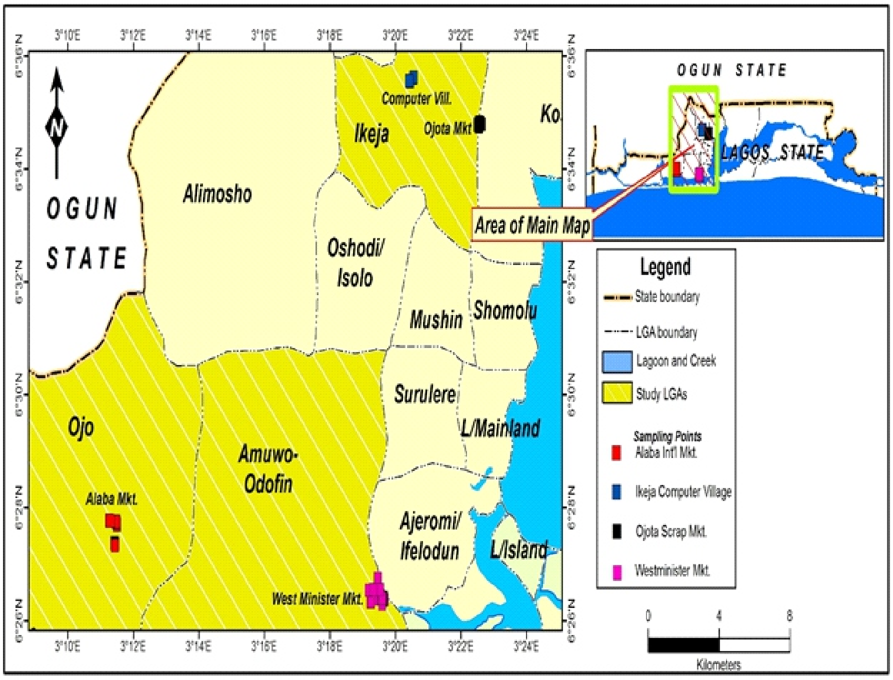

Figure 1: Map of Lagos showing the sampling locations

Sample collection and Treatment

Topsoil (0-15 cm) including sweeping were collected randomly at ten different locations and mixed together to form a composite at the selected e-waste recycling hubs in Lagos. Control soil sample was collected at the Botanical Garden, University of Ibadan, Ibadan. Since the study locations were all in Lagos and it was assumed that Lagos is more polluted than Ibadan due to anthropogenic activities going on all around Lagos, this informed the choice of Botanical Garden, University of Ibadan as the control site. Ten soil samples were collected at different points and mixed together to form a composite at that location in Alaba International market, Ojota scrap market and Westminster market. A total of 60 soil samples each were collected at Alaba International market, Ojota scrap market and Westminster market and composited. At Ikeja Computer Village, samples were collected at 5 different points and mixed together to form a composite at that location. A total of 30 samples were collected and composited. Samples were prepared in the laboratory by air drying, then pulverized and sieved using 2 mm sieve.

Sample analysis

The concentrations of toxic metals in the samples were determined using Inductively Coupled Plasma-Atomic Emission Spectrometry (ICP-AES, Perkin Elmer Optima 8000) after acid digestion of about 2 g of the dried and sieved soil samples using 20 mL of 2 M HNO_3. The resulting digestates were made up to mark using 0.1 mL HNO_3. Reagent blank and control samples were also digested (USEPA, 2007). Soil physicochemical characteristics were determined using standard analytical procedures (Walkey and Black, 1934)

Soil contamination, ecological risk and human health risk assessment

Quantification of Soil Contamination

Soil contamination was assessed using contamination factor, degree of contamination, geo-accumulation index, and ecological risk index.

1. Contamination factor (CF) and degree of contamination (DC)

The contamination factor and degree of contamination were used to evaluate the soil contamination (Adeyi and Torto, 2014). CF was defined according to four categories as follows: $C_f^i < 1$ low contamination; $1 \leq C_f^i < 3$ moderate contamination; $3 \leq C_f^i < 6$ considerable contamination; $6 \leq C_f^i$ very high contamination. Contamination factor (CF) was calculated using the expression

$$CF = Ci/Cn \quad (1)$$

The overall degree of contamination (DC) defines the quality of the environment and is expressed as:

$$DC = \sum_{i=1}^{n} CF \quad (2)$$

Where; CF = contamination factor; Ci = mean concentration of each metal in the soil; C_n = baseline or background value (concentration of each metal in the control sample was used); n = number of analysed elements; i = ith element (or pollutants). Modified formula of CF was used as reported by Adeyi and Torto (2014).

2. Geo-accumulation Index (I_{geo})

Geo-accumulation index shows the degree of anthropogenic pollution in the soil samples (Chai et al. 2014). It is expressed as

$$Igeo = Log_2(Cn/1.5Bn) \quad (3)$$

Where; Cn is the measured concentration of heavy metals; Bn is the geochemical background value in average shale of element n (Habes and Nigem, 2006) and 1.5 is the background matrix correction factor due to lithogenic effects. The geo-accumulation index (I_{geo}) of metals and their corresponding contamination strength was expressed in line with Forstner et al., 1993: <0, unpolluted; 0-1, unpolluted to moderately polluted; 1-2, moderately polluted; 2-3, moderately polluted to highly polluted; 3-4, highly polluted, 4-5, highly polluted to very highly polluted; >5, very highly polluted.

3. Potential Ecological Risk Index (RI)

The potential ecological risk index (RI) assess the level of metal pollution based on the toxicity of the metal and was able to evaluate the ecological risk caused by the toxic metals. The RI was calculated using the expression (Haciyakupoglu *et al.*, 2014):

$$Fi = Cs/Cr \quad (4)$$

$$Eir - Tir\ x\ Fi \quad (5)$$

$$RI = \sum_{i=1}^{n} Eir \quad (6)$$

Where; Fi is the single metal pollution index; Cs is the concentration of metal in the samples; Cr is the reference value for the metal; Eir is the monomial potential ecological risk factor; Tir is the metal toxic response factor according to Hakanson (1980), Zn = 1< Cr = 2 < Cu = Ni = Pb = 5 < As = 10 < Cd 30< Hg 40. RI is the potential ecological risk caused by the overall contamination categorized in the four classes as shown in Table 1. In this study, a simplified approach to risk assessment was used as reported by Adeyi and Torto (2014).

Table 1: Potential ecological risk factor and risk indices

Ei value	Level of ecological risk of metal	RI value	Ecological risk (RI) category
Ei< 40	Low risk	RI < 110	Low risk
40 ≤ Ei< 80	Moderate risk	110 ≤ RI < 200	Moderate risk
80 ≤ Ei< 160	Considerable risk	200 ≤RI <400	Considerable risk
160 ≤ Ei< 320	High risk	200 ≤RI <400	Very high risk
320 ≤ Ei	Very high risk	400 ≤ RI	

Human health risk assessment

Human beings are exposed to toxic chemicals via inhalation, ingestion and dermal contact. To assess the potential health effects of heavy metals and metalloids on the people around the e-waste recycling sites in Lagos, the following were estimated:

1. Daily intake via ingestion

The daily dose intake ([D(ing)] in mg/kg/day) of heavy metals and metalloids from soil and dust of the sites on infants and children through ingestion was determined using the expression:

$$D_{(ing)} = C(mg/kg)\ x\ \frac{IngR\ x\ EF\ x\ ED}{BW\ x\ AT}\ x\ 10^{-6} \quad (7)$$

Where; C is the concentration of the elements in the sample, IngR is the ingestion rate (mg/day), EF is the exposure frequency (d/y), ED is the exposure duration (years), BW the body weight (kg) and AT is the averaging time (days) (Table 2).

2. Daily intake via dermal contact

$$D_{(derm)} = C(mg/kg) \times \frac{SA \times SL \times ABS \times EF \times ED}{BW \times AT} \times 10^{-6} \quad (8)$$

3. Daily intake via inhalation

$$D_{(inh)} = C(mg/kg) \times \frac{InR \times PEF \times EF \times ED}{BW \times AT} \times 10^{-6} \quad (9)$$

Where; C is the concentration of the elements in the sample, IngR is the ingestion rate, InR is the inhalation rate, SA is the exposure surface area (cm^2/day), SL is the skin adherence factor (mg/cm^2/day), ABS is the skin absorption factor, EF is the exposure frequency (d/y), ED is the exposure duration (years), PEF is the particulate emission factor, BW is the body weight (kg) and AT is the averaging time (days) (Table 2).

The risk of exposure to a particular toxicant (cancer risk) was calculated using the expression

$$Risk = DI \times SF \quad (10)$$

The risk of exposure to a particular toxicant (non-cancer risk) is the Hazard Quotient (HQ) and is given by:

$$HQ = \frac{DI}{RfD} \quad (11)$$

Where; Risk is a unitless probability of an individual developing cancer over a lifetime; SF is the slope factor, expressed in (mg/kg/day); DI is the daily intake by a given route of exposure; RfD is the reference dose (Table 3) (Atiemo et al., 2012; Adaramodu et al., 2012). It was assumed that heavy metals and metalloids have toxic additive effects, therefore the HQ values of each metal were summed together to generate the Hazard Index (HI) (Leung et al., 2008).

Table 2: Exposure parameters used for the estimation of health risk through different pathways

Parameters	Unit	Children	Adults
Body weight (BW)	kg	15	70
Exposure frequency (EF)	days/year	350	350
Exposure duration (ED)	years	6	30
Ingestion rate (IR)	mg/day	200	100
Inhalation rate (IN)	m^3/day	10	20
Skin surface area (SA)	cm^2	2100	5800
Soil adherence factor (AF)	mg/cm^2	0.2	0.07
Dermal Absorption factor (ABS)	none	0.1	0.1
Dermal exposure ratio (FE)	none	0.61	0.61
Particulate emission factor (PEF)	m^3/kg	1.3×10^9	1.3×10^9
Conversion factor (CF)	kg/mg	10^{-6}	10^{-6}
Average time (AT)	days		
For carcinogens		365 x 70	365 x 70
For non-carcinogens		365 x ED	365 x ED

(DEA, 2010)

Hazardous emission during burning of e-waste

E-wastes contains several heavy metals which are likely to be released during burning. Cadmium is emitted majorly during burning of printed wiring boards (PWBs) while Pb is released during burning of PWBs and capacitors. The tolerable daily intake (TD) of Cd is 7 ug/kg while Pb is 3.5 ug/kg (Steiner, 2004; WHO, 1987). Hazardous emission of Cd and Pb during e-waste burning were calculated using the expression:

$$\text{No Risk: } \frac{DI}{TDI} < 1 \text{ and Risk: } \frac{DI}{TDI} > 1 \quad (12)$$

The TDI is the daily intake, which should not lead to any chronic health impacts if the given amount is consumed daily during the whole life.

Table 3: Reference doses (RfD) in (mg/kg-day) and Cancer Slope Factors (CSF) for the different heavy metals

Heavy metals	Oral	Dermal	Inhalation	Oral CSF	Dermal CSF	Inhalation CSF
As[a]	3.00E-04	3.00E-04	3.00E-04	1.50E+00	1.50E+00	1.50E+01
Pb[a]	3.60E-03	-	-	8.50E-03	-	4.20E-02
Cd[a]	5.00E-04	5.00E-04	5.70E-05	-	-	6.30E+00
Cr[a]	3.00E-03	-	3.00E-05	5.00E-01	-	4.10E+01
Co[b]	2.00E-02	5.70E-06	5.70E-06	-	-	9.80E+00
Ni[a]	2.00E-02	5.60E-03	-	-	-	-
Cu[a]	3.70E-02	2.40E-02	-	-	-	-
Zn[a]	3.00E-01	7.50E-02	-	-	-	-

Note: [a] DEA, 2010; [b] USEPA, 2015

RESULTS AND DISCUSSION

Soil characteristics

The pH of topsoil of e-waste recycling sites in Lagos ranged from 6.9-9.2. The descriptive statistics of the soil physico-chemical characteristics is presented in Table 4. Soil samples collected at Alaba international market (burning points) had the highest pH while the lowest pH was obtained at dismantling and burning points, respectively at Ojota scrap yard. The mean concentration of soil pH at Alaba international market (burning and dismantling), Computer village (dismantling and dismantling with traces of burning), Westminster market (repair and dumping) and Ojota scrap yard (dismantling and burning) were 8.43±0.7 and 8.17±0.3; 7.70±0.4 and 7.93±0.5; 8.01±0.1 and 8.07±0.5; and 7.10±0.2 and 7.37±0.4, respectively while it was 6.6±0.1 in the control soil. The pH of soil samples collected at the burning points in all the selected e-waste recycling hubs were higher than what was obtained in other recycling activity points such as dumping and dismantling. Soil pH has been shown to correlate with the availability of nutrients to plant and also affects the mobility of heavy metals. (Gray et al., 1998; Amos-Tautua et al., 2014). Consequently, as pH decreases, the solubility and availability of metallic elements in soil increases (Oliver et al., 1998). Also, the optimal pH range for most plants is between 5.5 and 7.0. The values obtained in all the sites were higher than the optimal pH range for plant growth.

The soil organic matter ranged from 1.11-10.7 % at the burning and dismantling points at Ojota scrap yard. The mean concentrations of soil organic matter (%) at Alaba international market (burning and dismantling), Computer village (dismantling and dismantling with traces of burning), Westminster market (repair and dumping) and Ojota scrap yard (dismantling and burning) were 4.96±0.8% and 4.88±1.9%; 4.11±2.2% and 4.11±2.2%; 4.05±1.2% and 4.60±2.5%; and 7.78±3.2% and 5.84±4.1%, respectively while it was 3.75±1.3% in the control soil. Usually, most productive agricultural soils have organic matter between 3-6%. These contributes to soil productivity, binds soil particles into aggregates and improves water holding capacity of soil. Native top soil contains about 5% organic matter by weight (10% by volume). More than this will start causing problems for plants by providing nutrient levels that are too high (Bot and Benites, 2005). The soil organic matter in all the soils collected at the informal e-waste recycling sites in Lagos were within the values for productive soil except the soil collected at Ojota scrap yard. Increase in soil organic matter leads to an increase in pH in acidic soils

The soil samples collected at the informal recycling sites in Lagos were dominated by coarse particles of sand with the mean values which ranged from 88.5±1.3 - 97.4±0.6% at the Ikeja Computer Village and Alaba International Markets dismantling points, respectively. Generally, the percentage of sand in the soil was high. The high percentage of sand may pose the risk of pollutants leaching from the topsoil to the subsoil. The mean value of clay ranged from 0.07±0.1 - 7.83±1.5% at the Ojota scrap yard burning points and Computer Village, Ikeja dismantling points, respectively. When compared with the control soil samples, the mean value of sand in the soils collected at the informal recycling sites were higher than what was obtained in the control sample (89.8±1.4%) except Computer Village, Ikeja dismantling points (88.5±1.3%). The mean value of clay in the control samples (2.8±0.0%) was higher than the values obtained in the soils collected at all the informal recycling sites in Lagos except Computer Village, Ikeja dismantling points (7.83±1.5%) and dismantling points with traces of burning (5.33±0.8%), also at Computer Village in Ikeja. The soil particle distribution obtained at the recycling sites might be attributed to the different recycling activities going on at the sites.

Table 4: Soil characteristics of informal e-waste recycling sites in Lagos, Nigeria

S/N	E- waste management sites/sample codes	pH	Particle Size Distribution (%)			Soil Organic Matter (%)
			Sand	Silt	Clay	
1.	**Alaba Intl' Market**					
	Burning points					
	AIMB1	8.1	96.6	2.3	1.1	5.22
	AIMB2	8.0	96.1	2.0	1.9	5.60
	AIMB3	9.2	87.6	10.3	2.1	4.07
	Mean ±SD	8.43±0.7	93.4±5.1	4.87±4.7	1.70±0.5	4.96±0.8
	Dismantling points					
	AIMD4	7.9	97.1	1.0	1.9	6.88
	AIMD5	8.2	96.9	1.0	2.1	4.71
	AIMD6	8.4	98.1	0.5	1.4	3.05
	Mean ±SD	8.17±0.3	97.4±0.6	0.83±0.3	1.8±0.4	4.88±1.9
2.	**Computer village, Ikeja**					
	Dismantling points					
	ICVD1	7.8	88.0	4.7	7.3	1.64
	ICVD2	7.3	90.0	3.3	6.7	5.75
	ICVD3	8.0	87.5	3.0	9.5	4.93
	Mean ±SD	7.70±0.4	88.5±1.3	3.67±0.9	7.83±1.5	4.11±2.2
	Dismantling points with traces of burning					
	ICVDB4	7.4	93.0	1.5	5.5	5.59
	ICVDB5	8.4	92.5	1.5	6.0	5.09
	ICVDB6	8.0	95.0	0.5	4.5	1.64
	Mean ±SD	7.93±0.5	93.5±1.3	1.17±0.6	5.33±0.8	4.11±2.2
3.	**Westminster market**					
	Repair points					
	WMR1	8.0	95.0	3.5	1.5	3.29
	WMR2	7.9	95.0	3.5	1.5	3.45
	WMRS3	8.1	96.0	3.0	1.0	5.41
	Mean ±SD	8.0±0.1	95.3±0.6	3.33±0.3	1.33±0.3	4.05±1.2
	Dumping points					
	WMD4	7.7	93.5	4.0	2.5	6.57
	WMD5	8.6	94.5	4.0	1.5	1.81
	WMD6	7.9	94.5	4.0	1.5	5.42
	Mean ±SD	8.07±0.5	94.2±0.6	4.00±00	1.83±0.6	4.60±2.5
4.	**Ojota scrap market**					
	Dismantling points					
	OJSD2	7.6	95.1	3.9	1.0	4.43
	OJSD3	6.9	96.4	2.4	1.2	8.21
	OJSD1	7.6	95.1	4.2	0.7	10.7
	Mean ±SD	7.37±0.4	95.5±0.8	3.50±1.0	1.0±0.3	7.78±3.2
	Burning points					
	OJSB4	7.1	96.1	3.9	0.0	8.12
	OJSB5	7.3	97.1	2.9	0.0	8.30
	OJSB6	6.9	96.6	4.2	0.2	1.11
	Mean ±SD	7.10±0.2	96.3±1.0	3.67±0.7	0.07±0.1	5.84±4.1
5.	**Control**	6.6±0.1	89.8±1.4	7.4±1.4	2.8±0.0	3.76±1.3

Heavy Metals and Metalloids Concentrations in the Soil

Heavy metals and metalloids are natural components of soil (Kabata-Pendias and Pendias, 2001). Their concentrations can be increased by human activities and thus, become a pollution concern affecting human health and the entire ecosystem. Some trace elements are required for healthy growth of organisms, but concentrations exceeding threshold can be toxic (Wade et al., 2008; Adeyi and Torto, 2014). The results of toxic metals and metalloids (Mn, Fe, Cr, Cu, Zn, Co, Cd, Pb, Ni, Ag, As, and Ba), and other elements (Na, Ca, K and Mg) determined in the soil samples are presented in Table 5. Ojota scrap yard is characterised by the dismantling of scrap metals and burning of e-wastes. The Westminster market exclusively deals with repair of used and obsolete electrical and electronic products.

Chromium concentrations in the topsoil ranged from ND-547 mg/kg at dismantling points at Alaba International market and Ojota scrap market, respectively. The highest mean concentrations was 209 ±293 mg/kg at the dismantling points at Ojota scrap market. This was followed by 118 ±141 mg/kg at the repair points, and 42.0 ±36 mg/kg at dumping points at Westminster market, respectively. The mean concentrations of Cr in all the soil samples were higher than what was obtained in the control samples, 2.88 mg/kg. Chromium can be readily absorbed by human body which might leads to health challenges such as irritation of skin, eyes and membrane, while chronic exposure could lead to DNA damage, cancer and permanent eye injury (Jaishankar et al., 2014). Zinc concentrations in soil samples collected at the selected informal e-waste recycling sites in Lagos were very high when compared to what was obtained in the control sample (Table 5). Zinc concentrations ranged from 45.1mg/kg at the dismantling point at Alaba International market to 4487 mg/kg at the dumping point at Westminster market. The highest mean concentrations of Zn was 2716 ±979 mg/kg at the burning points at Ojota scrap market. This was followed by 2334 ±2013 mg/kg at the dismantling points at Alaba International market. The high concentrations of Zn obtained at the sites compared to the control site (50.5 mg/kg) could be attributed to the release of Zn from Zn containing e-waste components and other materials such as cables, small motors, accumulators, batteries, screen coating and writing devices (Onwughara et al., 2010). Zinc is an essential element which is required by human body for healthy development but can be toxic at very high concentrations (Plum et al., 2010; Singh et al., 2011). However, exposure to zinc dust or fumes can cause a disease known as metal fume fever and its absorption can lead to abdominal pains, electrolyte imbalance, dehydration and vomiting (Udosen, 2000; Adaramodu et al., 2012; Wardhana and Datau, 2014).

The concentrations of cadmium in the topsoil sample collected at all the selected informal e-waste recycling sites ranged from ND in most of the sites to 21.9 mg/kg at the burning point at Ojota scrap market. In most cases, the concentrations of Cd in the soils of the informal e-waste recycling sites and the control were below the detection limit except burning points at Alaba International market and Ojota scrap market with mean concentrations of 2.14 ±3.7 mg/kg and 11.7 ±10, respectively. The level of Cd obtained at these sites may be as a result of the blazing of Cd containing e-waste components such as cathode ray tube screen, rechargeable Ni-Cd batteries, printer drum in photocopier, printer inks and tonners, etc. (Subburaman, 2012). Cadmium is carcinogenic and its inhalation in excess could damage the kidney, DNA and lungs (Singh et al., 2011; Jaishankar et al., 2014). High level of cadmium can also cause cognition, deficit in learning, behaviour and neuromotor skills in children (Thatcher et al., 1982; Rahimzadeh et al., 2017).

Table 5: Concentrations (mg/kg) of heavy metals and metalloids in soil of informal e-waste recycling sites in Lagos

S/N	E-waste recycling sites /activities	Mn	Fe	Cr	Cu	Zn	Co	Cd	Pb	Ni	As	Ag	Ba	Ca	Mg	K	Na
1.	**Alaba Intl.'Market (AIM)**																
	Burning points																
	AMB1	364	2793	5.10	238	428	ND	ND	166	12.0	NN	0.28	11.2	24103	1378	919	403
	AMB2	168	3988	16.1	2441	435	ND	6.43	521	20.4	ND	ND	146	24591	1638	934	474
	AMB3	57.6	1771	7.70	755	642	ND	ND	265	7.78	0.05	ND	23.0	80498	4684	769	1982
	Mean ± SD	197 ±155	2851 ±1110	9.63 ±5.7	1145 ±1152	502 ±122	-	2.14 ±3.7	317 ±183	13.4 ±6.4	0.02 ±0.03	0.09 ±0.2	60.1 ±75	43064 ±32420	2567 ±1838	874 ±91	953 ±892
	Dismantling points																
	AMD1	11.6	723	ND	14.4	45.1	ND	ND	7.05	ND	ND	0.05	ND	1380	140	50.3	35.3
	AMD2	238	5993	29.7	2721	3130	ND	ND	2377	89.6	ND	ND	57.9	13598	1329	385	221
	AMD3	231	5505	17.6	2756	3827	ND	ND	2309	78.0	ND	ND	77.3	15168	1268	421	267
	Mean ± SD	160 ±129	4074 ±2912	15.8 ±15	1830 ±1573	2334 ±2013	-	-	1564 ±1349	55.9 ±49	-	0.02 ±0.03	45.1 ±40	10049 ±7548	912 ±670	285 ±204	174 ±123
2.	**Computer village, Ikeja (ICV)**																
	Dismantling points																
	ICVD1	223	4863	13.3	20.1	235	ND	ND	67.2	2.35	ND	ND	ND	8576	795	392	ND
	ICVD2	242	5885	15.8	49.8	470	ND	ND	113	5.38	ND	ND	0.1	5783	669	480	15
	ICVD3	204	6205	21.5	298	301	ND	ND	136	3.45	0.08	ND	4.1	8103	668	540	29
	Mean ± SD	223 ± 19	5651 ±701	16.9 ±4.2	123 ±153	335 ±121	-	-	105 ±35	3.73 ±1.5	0.03 ±0.05	-	1.4 ± 2.34	7487 ±1495	711 ±73	471 ±74	14.7±15
	Dismantling points with traces of burning																
	ICVDB1	112	5183	12.7	124	523	ND	ND	64	14.5	ND	ND	1.2	12801	708	467	207
	ICVDB2	249	4868	12.6	25.5	302	ND	ND	33.7	2.48	ND	ND	ND	2571	300	296	34.5
	ICVDB3	226	4943	11.9	32.9	284	ND	ND	48.3	1.3	0.13	ND	ND	3523	351	726	ND
	Mean ± SD	196 ±73	4998 ±165	12.4 ±0.4	60.8 ±55	370 133±	-	-	48.7 ±15	6.09 ±7.3	0.04 ±0.08	-	0.4 ±0.7	6298 ±5652	453 ±222	496 ±216	81 ±111

Table 5 contd: Concentrations (mg/kg) of heavy metals and metalloids in soil of informal e-waste recycling sites in Lagos.

3.	**Westminster Market (WMM)**																
	Repair points																
	WMR1	101	4503	277	177	466	ND	ND	707	9.6	ND	ND	ND	5148	511	372	22
	WMR2	94	3945	8.95	27	264	ND	ND	46.7	5.25	ND	ND	6.33	3836	438	150	ND
	WMR3	11.2	986	67.6	15.2	64.3	ND	ND	25.5	0.4	ND	ND	ND	434	91.3	89	ND
	Mean ± SD	68.7 ±50	3145 ± 1890	118 ±141	73.1 ±90	265 ±201	-	-	260 ±387	5.08 ±4.6	-	-	2.11 ±3.7	3139 ±2433	347 ±224	204 ±149	7.33 ±13
	Dumping points																
	WMD1	48.9	1603	5.95	177	178	ND	ND	25	8.88	ND	ND	7.7	1966	192	70.5	ND
	WMD2	217	6252	41.8	1231	4487	152	ND	551	166	ND	ND	147	8571	2014	340	60.3
	WMD3	121	4845	78.3	121	589	ND	ND	241	13.8	ND	ND	ND	5541	860	409	ND
	Mean ± SD	129 ±84	4233 ± 2384	42.0 ±36	510 ±625	1751 ±2378	50.7 ±88	-	272 ±264	62.9 ±89	-	-	51.6 ±83	5359 ±3306	1022 ±922	273 ±179	20.1 ±35
4.	**Ojota Scrap Market (OJS)**																
	Dismantling points																
	OJSD1	435	5700	35.3	3223	1679	ND	ND	16350	49.5	ND	ND	3.33	16625	1966	614	447
	OJSD2	300	7685	547	3373	1771	ND	ND	3130	34	ND	ND	11.4	17833	1492	1159	166
	OJSD3	165	7922	44.6	1424	1880	ND	ND	2703	25.5	ND	ND	16.9	37948	1851	443	50.5
	Mean ± SD	300 ±135	7102 ±1220	209 ±293	2673 ±1085	1777 ±101	-	-	7394 ±7759	36.3 ±12	-	-	10.5 ±6.8	24135 ±11977	1770 ±247	739 ±374	221 ±204
	Burning points																
	OJSB1	159	6840	29.1	1844	1613	ND	1.25	4775	20.2	0.13	ND	22.1	50773	2661	524	594
	OJSB2	132	2478	19.8	1010	3055	ND	21.9	4740	38.1	ND	ND	66.5	68498	7561	529	530
	OJSB3	85.8	1765	20	1710	3480	ND	11.8	3325	23.8	ND	ND	21.3	66798	6716	488	637
	Mean ± SD	126 ± 37	3694 ±2747	23.0 ±5.3	1521 ±448	2716 ±979	-	11.7 ±10	4280 ±827	27.4 ±9.5	0.04 ±0.1	-	36.6 ±26	62023 ±9780	5646 ±2619	514 ±22	587 ±54
	Control	627	5208	2.88	9.60	50.5	ND	ND	12.7	0.35	ND	ND	ND	1137	27.3	375	46.8

Lead concentrations in the topsoil of informal e-waste recycling sites ranged from 7.05 mg/kg at the dismantling point at Alaba International market to 16,350 mg/kg at dismantling point at Ojota scrap market. The highest mean concentrations, 7394 ±7759 mg/kg, was obtained at dismantling points at Ojota scrap market, followed by 4280 ±827 mg/kg obtained at the burning points at Ojota scrap market, and 1564 ±1349 mg/kg obtained at the dismantling points at Alaba International market. When compared with what was obtained in the control sample (12.7 mg/kg) (Table 5), the soil samples collected at the informal e-waste recycling sites in Lagos, in most cases, were over 1,000 times higher than the concentration in the control soil. This may be linked to the burning and dismantling of Pb containing e-waste components such as rechargeable batteries, printed wiring boards and cathode ray tubes (Okorhi et al., 2017) with high levels of Pb. Exposure to Pb in a short-term could lead to convulsion or coma, vomiting, and diarrhea, while kidney and nervous damage, brain and blood disorder and death could result with long- term exposure (Jaishankar et al., 2014; Fu and Wang, 2011; Adeyi and Babalola, 2017; Okorhi et al., 2017). The order of Pb concentrations in the topsoil of informal e-waste recycling sites was repair < dumping < burning < dismantling.

Copper concentrations in the topsoil samples collected at the selected informal e-waste recycling sites in Lagos ranged from 14.4 --3,373 mg/kg at the dismantling points at Alaba International market and Ojota scrap market, respectively (Table 5). The highest mean concentration of Cu was 2673 ±1085 mg/kg obtained at dismantling points at Ojota scrap market, followed by dismantling points at Alaba International market (1830 ±1573 mg/kg), and 1521 ±448 mg/kg at the burning points at Ojota scrap market. The concentrations of copper in all the soil samples collected were higher than the concentration (9.60 mg/kg) obtained in the control sample. The high Cu content of the soil may be attributed to e-waste recycling activities at the sites. Copper is an essential trace element, the human body contain copper at a level of about 1.4 to 2.1 mg/kg of the body mass (Bost et al., 2016). Accumulation of copper in human body can cause several ailments and health problems such as vomiting, diarrhea, irritations of eyes, nose and skin, dizziness, headache, damage of the liver and kidney, and can also lead to death (Bost et al., 2016). The order of Cu concentrations in the topsoil was dismantling > burning > dumping > repair. Nickel concentrations in the topsoil of the selected informal e-waste recycling sites in Lagos ranged from ND at the dismantling point at Alaba International market to 166 mg/kg at dumping point in Westminster (Table 5). The nickel concentrations in the topsoil samples collected at the control site was 0.35 mg/kg, which was lower than what was obtained in all the recycling sites. Dismantling points at Computer village, Ikeja had the lowest mean concentration of Ni, 3.73 ±1.5 mg/kg while the highest mean concentration, 62.9 ±89 mg/kg, was obtained in the topsoil collected at the dumping points at Westminster market (Table 5). Nickel concentrations in the topsoil was in the order: dismantling > burning > dumping > repair.

Iron concentrations in the topsoil of informal e-waste recycling sites in Lagos ranged from 723 mg/kg at the dismantling point at Alaba International market to 7922 mg/kg at the dismantling point at Ojota scrap market. The highest mean concentration of Fe was 7102 ±1220 mg/kg obtained at dismantling point at Ojota scrap yard (Table 5). This was followed by 5651 ±701 mg/kg at the dismantling points and 4998 ±165 mg/kg at the dismantling points with traces of burning both at Computer village, Ikeja. The lowest mean concentrations of Fe, 2851 ±1110 mg/kg, was obtained at burning points at Alaba International Market. The order of mean concentrations of Fe was dismantling > dumping > burning > repair. The level of Fe found in this study could be attributed to the metal scraps being continuously dismantled in the study sites.

The mean concentrations of silver in the topsoil samples collected at all the informal e-waste recycling hubs in Lagos and the control sample were below the detection limit of the instrument except 0.09 ±0.2 mg/kg and 0.02 ±0.03 mg/kg obtained at the burning and dismantling points at Alaba International Market. Similarly, cobalt concentration in all the samples collected at the study sites and the control were below the detection limit. However, 50.7 mg/kg was obtained at Westminster market dumpsite. Arsenic concentrations in all the e-waste recycling sites were below the detection limit except 0.02 ±0.030 mg/kg and 0.04 ±0.1 mg/kg obtained at the burning points at Alaba International Market and Ojota scrap yard, respectively, and 0.04 ±0.08 mg/kg at the dismantling points with traces of burning at Computer village, Ikeja. The concentrations of manganese (Mn) in the topsoil samples ranged from 11.2 mg/kg obtained at Alaba International Market to 435 mg/kg at Ojota scrap market. The order of Mn concentrations in the topsoil of informal e-waste recycling sites in Lagos was dismantling > burning > dumping > repair.

The concentrations of other elements (Ca, Mg, K, and Na) in the topsoil of informal e-waste recycling sites in Lagos occurred in decreasing order: Ca > Mg > K > Na. These elements are part of the most common elements in the earth's crust. There were variations in the concentrations of these elements in the topsoil of the informal e-waste recycling sites in Lagos. The order of these metals in the topsoil samples based on the recycling activities were:
Ca: burning > dismantling > dumping > repair
Mg: burning > dismantling > dumping > repair
K: dismantling > burning > dumping > repair
Na: burning > dismantling > dumping > repair.

Results of soil contamination indices and risk assessment

The geo-accumulation index (Igeo) of heavy metals in the top soil are presented in Table 6. Lead had the highest Igeo values at dismantling points at Ojota scrap market (strongly/heavily to extremely contaminated), followed by burning points at the same scrap market (strongly/heavily to extremely contaminated), and dismantling points at Alaba International market (strongly/heavily to extremely contaminated). Copper, Zn, and Cd also had high Igeo values while all the other elements had values below one which signified that the soil were unpolluted by Mn, Fe, Cr, Co, Ni, As, Ag and Ba.

Contamination factor (CF) and degree of contamination (DC) values are presented in Table 7. Manganese, Fe, Ni, Cr, As, Ag and Ba have CF below 1, which indicated low contamination. Lead had the highest CF (462) at dismantling points at Ojota scrap market. This was followed by Cu and Zn in all the recycling sites. The degree of contamination (DC) ranged from 7.16-516, suggesting very high contamination. This showed that the ecosystem is vulnerable to a very high degree of contamination. It is crucial to note that the DC values in the samples collected at the informal e-waste recycling sites were higher than the control site linking the contamination of the sites to the haphazard and informal e-waste recycling activities, using crude methods. The order of the overall degree of contamination at the sites was dismantling points at Ojota scrap market > burning points at Ojota scrap market > dismantling points at Alaba International Market > burning points at Alaba International market > dumping points at Westminster > repair points at Westminster > dismantling points at Computer village, Ikeja > dismantling points with traces of burning at Computer village, Ikeja. In all the informal e-waste recycling sites, dismantling points had the highest overall degree of contamination when compared to the other e-waste recycling activities such as burning, dumping and repairing going on at the sites.

Table 6: Geo-accumulation Index (Igeo) of heavy metals in topsoil of informal e-waste recycling sites in Lagos

E-waste recycling sites	Mn	Fe	Cr	Cu	Zn	Co	Cd	Pb	Ni	As	Ag	Ba
Alaba Intl' Market (AIM)												
Burning points	-2.93	-4.72	-4.96	3.45	1.34	-	3.25	3.72	-3.16	-8.55	-0.74	-2.64
Dismantling points	-3.23	-4.2	-4.25	4.12	3.56	-	-	6.03	-1.1	-	-2.91	-3.06
Computer village, Ikeja (ICV)												
Dismantling points	-2.75	-3.73	-4.15	0.23	0.76	-	-	2.13	-5.01	-7.97	-	-8.07
Dismantling points with traces of burning	-2.94	-3.91	-4.6	-0.79	0.9	-	-	1.02	-4.3	-7.55	-	-9.87
Westminster Market (WMM)												
Repair points	-4.45	-4.58	-1.35	-0.52	0.42	-	-	3.44	-4.56	-	-	-7.47
Dumping points	-3.54	-4.15	-2.84	2.28	3.14	-	-	3.5	-0.93	-	-	-2.86
Ojota Scrap Market (OJS)												
Dismantling points	-2.32	-3.4	-0.52	4.67	3.17	-	-	8.27	-1.72	-	-	-5.16
Burning points	-3.57	-4.34	-3.71	3.86	3.78	-	5.7	7.48	-2.13	-7.55	-	-3.36
Control	-1.26	-3.85	-6.7	-3.45	-1.97	-	-	-0.918	-8.42	-	-	-

Note: - mean concentrations were below the detection limit

Table 7: Contamination Factors (CF) and Degree of Contamination (DC) of heavy metals in topsoil of informal e-waste recycling sites in Lagos

E-waste recycling sites	CF												DC
	Mn	Fe	Cr	Cu	Zn	Co	Cd	Pb	Ni	As	Ag	Ba	
Alaba Intl' Market (AIM)													
Burning points	0.20	0.06	0.05	16.4	3.80	-	14.3	19.8	0.17	0.004	0.9	0.24	55.9
Dismantling points	0.16	0.08	0.08	26.14	17.7	-	-	97.8	0.70	-	0.2	0.18	143
Computer village, Ikeja (ICV)													
Dismantling points	0.22	0.11	0.08	1.76	2.54	-	-	6.56	0.05	0.01	-	0.01	11.3
Dismantling points with traces of burning	0.20	0.10	0.06	0.87	2.80	-	-	3.04	0.08	0.01	-	0.002	7.16
Westminster Market (WMM)													
Repair points	0.09	0.06	0.59	1.04	2.01	-	-	16.3	0.06	-	-	0.01	20.1
Dumping points	0.13	0.08	0.21	7.29	13.3	0.22	-	17	0.79	-	-	0.21	39.2
Ojota Scrap Market (OJS)													
Dismantling points	0.30	0.14	1.05	38.2	13.5	-	-	462	0.45	-	-	0.04	516
Burning points	0.13	0.07	0.12	21.7	20.6	-	78	268	0.34	0.008	-	0.15	389
Control	0.63	0.1	0.01	0.14	0.38		-	0.79	0.004	-	-	-	2.05

Note: - means concentration was below detection limit

The results of ecological risk factor (Eir) and (RI) are presented in Table 8. The monomial potential ecological risk factor (E^i_r) was lower than 40 for Cr, Ni and Zn across all the recycling sites indicating that these elements pose a low ecological risk. However, Cd, Cu and Pb had moderate to considerable risk at Alaba International Market while Pb had considerable risk at Westminster market; Cu and Pb had considerable to high risk at Ojota scrap market. However, the values of ecological risk index (RI) across all the informal e-waste recycling sites in Lagos ranged from 22.9-2,519. Ojota scrap market dismantling points and burning points, and dismantling points at Alaba International Market had ecological risk index above 400. This indicated that the ecosystem is susceptible to a very high risk. The ecological risk index of informal e-waste recycling sites at Computer village, Ikeja and Westminster had considerable to moderate risks. The monomial potential ecological risk factor (E^i_r) and ecological risk index (RI) of all the informal e-waste recycling sites in Lagos were higher than what was obtained in the soil of the control site linking the ecological risk to the e-waste recycling activities at these sites.

The cancer risk of heavy metals in topsoil of informal e-waste recycling sites in Lagos ranged from 3.93-183 in both children and adults populations (Table 9). The average carcinogenic risk index of As, Pb, Cd, Ni, Cu, Cr, Zn, Co and Ba across the informal e-waste recycling sites under the three exposure pathways was higher than the safe limit (0.0001), suggesting that the various e-waste recycling activities posed an unacceptable health risk to both children and adults around the sites. Chromium was the major contributor to the risk in all the sites except dismantling points at Alaba International Market and burning points at Ojota scrap market, where Pb was the dominant contributor to the risk. In addition, the exposure pathways were in the order: ingestion >> inhalation > dermal contact. Generally, children were more exposed to the risk than adults.

Hence, children around these sites were more susceptible to carcinogenic risk. Furthermore, the level of risk recorded at the control site was far lower than that of the recycling sites, revealing that the risk might be due to improper e-waste recycling at the sites. The hazardous emission of Cd and Pb through burning of e-waste ranged from 224-2,066 and 1,720-151,179, respectively in both children and adults populations around the informal e-waste recycling sites where e- waste burning is prevalent (Table 10). E-waste burning posed major health risk to the populations in all the selected sites since the values are greater than 1, which can lead to chronic health impacts.

Table 8: Potential Ecological Risk Index of heavy metals in topsoil of informal e-waste recycling sites in Lagos

E-waste recycling sites	**Eir**							**R.I**
	Cr	**Cu**	**Zn**	**Cd**	**Pb**	**Ni**	**As**	
Alaba Intl' Market (AIM)								
Burning points	0.1	81.8	3.8	142.67	99.1	0.84	0.04	**328**
Dismantling points	0.16	131	17.68	-	489	3.49	-	**641**
Computer village, Ikeja (ICV)								
Dismantling points	0.17	8.79	2.54	-	32.8	0.23	-	**44.5**
Dismantling points with traces of burning	0.12	4.34	2.8	-	15.2	0.38	-	**22.9**
Westminster Market (WMM)								
Repair points	1.18	5.22	2.01	-	81.3	0.32	-	**90**
Dumping points	0.42	36.4	13.3	-	85	3.93	-	**139**
Ojota Scrap Market (OJS)								
Dismantling points	2.09	191	13.5	-	2311	2.27	-	**2519**
Burning points	0.23	109	20.6	-	1338	1.71	-	**1469**
Control	0.03	0.69	0.38	-	3.97	0.02	-	**5.09**

Table 9: Cancer risk of heavy metals in topsoil of informal e-waste recycling sites in Lagos

Alaba International Market (AIM)										
Burning points										
PATHWAY	Pb	Ni	Zn	Cd	Cr	Cu	As	Ba	Co	HI
	Children									
Ingestion	2.9529	0	0	0	5.2767	0	0.0329	0	0	8.2625
Dermal	0	0	0	0	0	0	0.0042	0	0	0.0042
Inhalation	1.12E-10	0	0	1.14E-10	3.30E-08	0	2.53E-11	0	0	3.35E-08
HI										8.27
	Adults									
Ingestion	1.5819	0	0	0	2.8268	0	0.0176	0	0	4.4263
Inhalation	6.01E-11	0	0	6.09E-11	1.78E-08	0	1.35E-11	0	0	1.8E-08
Dermal	0	0	0	0	0	0	0.0044	0	0	0.004362
HI										4.43
Dismantling points										
	Pb	Ni	Zn	Cd	Cr	Cu	As	Ba	Co	HI
	Children									
Ingestion	14.57	0	0	0	8.66	0	0	0	0	23.23
Dermal	0	0	0	0	0	0	0	0	0	0
Inhalation	5.54E-10	0	0	0	5.46E-08	0	0	0	0	5.52E-08
HI										23.2
	Adults									
Ingestion	7.8	0	0	0	4.64	0	0	0	0	12.44
Dermal	0	0	0	0	0	0	0	0	0	0
Inhalation	2.97E-10	0	0	0	2.93E-08	0	0	0	0	2.96E-08
HI										12.4
Computer village, Ikeja (ICV)										
Dismantling points										
	Pb	Ni	Zn	Cd	Cr	Cu	As	Ba	Co	HI
	Children									
Ingestion	0.98	0	0	0	9.26	0	0.05	0	0	10.3
Dermal	0	0	0	0	0	0	0.01	0	0	0.01
Inhalation	3.72E-11	0	0	0	5.84E-08	0	3.79E-11	0	0	5.85E-08
HI										10.3
	Adults									
Ingestion	0.52	0	0	0	4.96	0	0.03	0	0	5.51
Dermal	0	0	0	0	0	0	0.01	0	0	0.01
Inhalation	1.99E-11	0	0	0	3.13E-08	0	2.03E-11	0	0	3.13E-08
HI										5.52
Dismantling points with traces of burning										
	Pb	Ni	Zn	Cd	Cr	Cu	As	Ba	Co	HI
	Children									
Ingestion	0.45	0	0	0	6.79	0	0.07	0	0	7.32
Dermal	0	0	0	0	0	0	0.01	0	0	0.01
Inhalation	1.72E-11	0	0	0	4.29E-08	0	5.06E-11	0	0	4.29E-08
HI										7.32
	Adults									
Ingestion	0.24	0	0	0	3.64	0	0.04	0	0	3.92
Dermal	0	0	0	0	0	0	0.01	0	0	0.01
Inhalation	9.24E-12	0	0	0	2.30E-08	0	2.71E-11	0	0	2.30E-08
HI										3.93

Table 9 contd: Cancer risk of heavy metals in topsoil of informal e-waste recycling sites in Lagos

Westminster Market (WMM)										
Repair points										
	Pb	Ni	Zn	Cd	Cr	Cu	As	Ba	Co	HI
	Children									
Ingestion	2.42	0	0	0	64.66	0	0	0	0	67.08
Dermal	0	0	0	0	0	0	0	0	0	0
Inhalation	9.21E-11	0	0	0	4.08E-07	0	0	0	0	4.08E-07
HI										67.1
	Adults									
Ingestion	1.3	0	0	0	34.64	0	0	0	0	35.94
Dermal	0	0	0	0	0	0	0	0	0	0
Inhalation	4.93E-11	0	0	0	2.18E-07	0	0	0	0	2.19E-07
HI										35.9
Dumping points										
	Pb	Ni	Zn	Cd	Cr	Cu	As	Ba	Co	HI
	Children									
Ingestion	2.53	0	0	0	23.01	0	0	0	0	25.55
Dermal	0	0	0	0	0	0	0	0	0	0
Inhalation	9.63E-11	0	0	0	1.45E-07	0	0	0	4.19E-09	1.50E-07
HI										25.6
	Adults									
Ingestion	1.36	0	0	0	12.33	0	0	0	0	13.69
Dermal	0	0	0	0	0	0	0	0	0	0
Inhalation	5.16E-11	0	0	0	7.78E-08	0	0	0	2.24E-09	8.01E-08
HI										13.7
Ojota Scrap Market (OJS)										
Dismantling points										
	Pb	Ni	Zn	Cd	Cr	Cu	As	Ba	Co	HI
	Children									
Ingestion	68.88	0	0	0	114.52	0	0	0	0	183.4
Dermal	0	0	0	0	0	0	0	0	0	0
Inhalation	2.62E-09	0	0	0	7.22E-07	0	0	0	0	7.25E-07
HI										183
	Adults									
Ingestion	36.9	0	0	0	61.35	0	0	0	0	98.25
Dermal	0	0	0	0	0	0	0	0	0	0
Inhalation	1.40E-09	0	0	0	3.87E-07	0	0	0	0	3.88E-07
HI										98.3
Burning points										
	Pb	Ni	Zn	Cd	Cr	Cu	As	Ba	Co	HI
	Children									
Ingestion	39.87	0	0	0	12.6	0	0.07	0	0	52.54
Dermal	0	0	0	0	0	0	0.01	0	0	0.01
Inhalation	1.52E-09	0	0	6.21E-10	7.95E-08	0	5.06E-11	0	0	8.17E-08
HI										52.6
	Adults									
Ingestion	21.36	0	0	0	6.75	0	0.04	0	0	28.14
Dermal	0	0	0	0	0	0	0.01	0	0	0.01
Inhalation	8.12E-10	0	0	3.33E-10	4.26E-08	0	2.71E-11	0	0	4.38E-08
HI										28.2

Table 9 contd: Cancer risk of heavy metals in topsoil of informal e-waste recycling sites in Lagos

	Control									
	Pb	Ni	Zn	Cd	Cr	Cu	As	Ba	Co	HI
	Children									
Ingestion	0.12	0	0	0	1.58	0	0	0	0	1.7
Dermal	0	0	0	0	0	0	0	0	0	0
Inhalation	4.50E-12	0	0	0	9.95E-09	0	0	0	0	9.96E-09
HI										1.7
	Adults									
Ingestion	0.06	0	0	0	0.85	0	0	0	0	0.91
Dermal	0	0	0	0	0	0	0	0	0	0
Inhalation	2.41E-12	0	0	0	5.33E-09	0	0	0	0	5.33E-09
HI										0.91

Table 10: Hazardous emission during burning of e-waste at informal e-waste recycling sites in Lagos

Sites	Cd				Pb			
	DI (mg/kg/day)		**Hazardous emission**		**DI DI (mg/kg/day)**		**Hazardous emission**	
	Children	**Adults**	**Children**	**Adults**	**Children**	**Adults**	**Children**	**Adults**
AIMB	2.65	1.57	379	224	391.8	232.2	11,194	6,634
ICVDBS	-	-	-	-	60.21	35.67	1,720	1,019
OJSB	14.46	8.57	2,066	1,224	5291.25	3135.02	151,179	89,572
Control	-	-	-	-	15.70	9.30	448	266

CONCLUSION

Informal e- waste recycling activities released high level of heavy metals and metalloids into the environment (soil, water, and air). In most cases, metals and metalloids concentrations in the topsoil of the selected informal e-waste recycling sites in Lagos was in the order: dismantling > burning > dumping > repair. E-waste dismantling and burning contributed significant metals and metalloids concentrations into the topsoil of the selected informal e-waste recycling sites in Lagos. This can have detrimental effects on the entire ecosystem and in particular human health via the different exposure pathways such as ingestion, dermal and inhalation routes. The different e-waste recycling activities posed an unacceptable human health risk to both children and adults. Hazardous emission of Cd and Pb during e-waste burning also showed cancer risk. Due to poverty and weak enforcement of regulations, different categories of people including the vulnerable groups such as children and women are exposed to different hazardous substances present in e-waste during crude and haphazard e-waste recycling in Lagos. Need for proper enlightenment of the people involved in crude e-waste recycling through understanding of the hazards of e-waste, the impacts of its disposal, and the dangers of informal or crude recycling is recommended.

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