

Environmental effects of uncontrolled dumping of discarded mobile telecommunication technology equipment in Accra, Ghana

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Abstract

This study assessed the environmental impacts of discarded Mobile Telecommunication Technology equipment on soil quality and examined the health risks associated with heavy metals detected in soil samples from the Agbogbloshie e-waste dumpsite in Accra, Ghana. Heavy metal analysis of soils at the mobile electronic waste disposal site in Agbogbloshie, Accra was done to determine the concentrations of Fe, Hg, Ni, Cd, Cr, Cu, Zn, Pb and As to ascertain the metal or metals existing naturally. Forty-five (45) soil samples were collected at a depth of 8 cm at sites with heavy deposits of wastes and analyzed using the Atomic Absorption Spectroscopy (AAS). Results of the analysis indicated mean levels in mg/kg of heavy metals as; 14.92 (Fe), 0.53 (Hg), 11.77 (Ni), 1.2 (Cd), 6.85 (Cr), 11.01 (Cu), 1.67 (Zn), 6.22 (Pb) and 5.19 (As). Heavy metal level of Hg was above the threshold of 0.2mg/kg whilst that of Cd had reached the threshold of 1.2mg/kg set by the US EPA. Multivariate analysis of soil data showed that, only Fe occurs naturally whilst the others were associated with anthropogenic activities. Consequently, all the heavy metals analyzed may not pose any health risk to the public except Fe, Hg and Cd. Indeed, this suggests that, a research that consistently monitor quantitatively heavy metals in body fluids of residents in and around dumpsites should be initiated.

Keywords: *Heavy metals, Mobile telecommunication, E-waste, Dumpsite, Accra*

Introduction

Mobile Telecommunication Technology (MTT) has greatly enhanced the ability of individuals to communicate and has facilitated the dispatch of emergency medical, relief and security aid to persons in both urban and rural environments (Alabi, 2023; Oladele, 2024; Pervez *et al.*, 2018). MTT has improved efficiency in commerce, learning, health, governance, banking, agriculture, industry and even human rights (Emeana *et al.*, 2020; van Zanden, 2023). Other importance especially among the middle class population specified by Khusnullova *et al.*, (2017) include, to access jobs, to upload and download information, social networking and blogging, to send and receive e-mails, mobile money transactions among others. Such useful technological innovations can also be environmentally destructive especially when certain pre-

cautionary measures, quality standards, identified hazards to human health and safety are not considered seriously (Adanu *et al.*, 2020; Sun *et al.*, 2013). As heavy metals are non-biodegradable, their pollution are long-term, persistent and covert in nature, hence posing severe health risks (Ali, *et al.*, 2020). For instance, heavy metal contaminated soils often have restrictive physical, chemical and biological characteristics that hinder self-regenerating mechanisms and resistance to pollution (Kolesnikov, *et al.*, 2022). Indeed, the consequences of some environmental hazards are often temporally delayed and may not be limited to a specific geographical space (Muhammed, 2023). Global estimates predicts the total number of mobile devices in use to be over 18.2 billion by the end of 2025 (Radicati Group, 2021) with an estimated 4.6 billion people using the internet

(GSMA, 2024). Again, assessments on their rate of disposal reveal that, almost 1 billion tablets, cell phones and notebooks are discarded within five years of usage (Kumar *et al.*, 2017; Ilankoon *et al.*, 2018; Forti *et al.*, 2020). The National Communication Authority (NCA) of Ghana estimates that, there are 40.86 million mobile phone subscribers in Ghana as at December, 2019 (ITU, 2019). Actually, these figures provide useful information to researchers on the number of mobile phones, laptops and desktop computers that are expected to be disposed off over a specific period of time in Ghana. Considering the huge number and varieties of electrical and electronic equipment (EEE) in Ghana there is certainly the need for environmental measures on waste electrical and electronic equipment (WEEE). There are several definitions for the term “heavy metals”, however, the most appropriate for this study is the definition by Banfalvi (2011) which states that, “they are naturally occurring elements having high atomic weights and high densities which are five times greater than that of water. Again, Ali and Khan (2018) claim that, they are naturally occurring elements with a relatively high density existing in the ecosystem. Additionally Abraham and Susan (2017) explained that heavy metals exist in the form of oxides, carbonates and sulphides. Most heavy metals such as; As, Pb, Cd, Ni, Hg, Cr, Co, Zn, Fe and Cu among others are usually toxic even when present in trace quantities or in very low concentrations (Azeh Engwa, *et al.*, 2019). According to Rice *et al.* (2014) and He *et al.* (2019a) heavy metals originate from both natural and anthropogenic processes and sources, however, the authors further maintain that, environmental pollution is mostly resulting from human activities. According to Forti *et al.* (2020), WEEE or electronic waste (e-waste) are EEE or its end-of-life parts that have been rejected. EEE covers a wide variety of products, ranging from household appliances, equipment used in transport and energy generation, mechanical devices to highly complex integrated systems such as computers, fax machines and mobile phones (Ilankoon *et al.*, 2018). Specific assessment of EEE performed by Franz and Silva (2012) suggest that they consist of 69 elements of which some are precious metals, others are critical materials whilst others are non-critical materials. Consequently, WEEE contains both hazardous but valuable materials and therefore considered as one of the most important waste streams of the last decade and will continue to be so in the future (Ilankoon *et al.*, 2018; Baldé *et al.*, 2017). According to some researchers, the increase in WEEE worldwide is approxima-

tely three times faster than the world’s population (Jiang *et al.*, 2012; ITU, 2021). Others are of the view that, the increase in WEEE worldwide is approximately between 3% and 5% per annum (Kumar *et al.*, 2017; Jiang *et al.*, 2012; Chi *et al.*, 2011). It is further projected that, more than 50 million tons and 72 million tons of WEEE were discarded globally in 2009 and 2014 respectfully (Jiang *et al.*, 2012; ITU, 2019). Indeed, latest estimates suggest that, by 2030, the tons of WEEE that would be discarded globally will be 74 million (Jiang *et al.*, 2012; ITU, 2021). Specifically, global estimates conducted by the UN, suggest that 53.6 million tons of WEEE was disposed of in 2019 (UN, 2021). According to Forti *et al.* (2020), in 2019, the continent that generated the most WEEE was Asia with 24.9 million tons followed by America with 13.1 million tons, Europe with 12 million tons, Africa with 2.9 million tons and Oceania with 0.7 million tons. Although the developing countries do not generate much WEEE, it is estimated that 50% to 80% of WEEE from the developed world are exported to developing countries including Ghana (Daum, *et al.*, 2017; Wang, *et al.*, 2012). Consequently, WEEE recycling rates are not adequate to deal with the growing waste problems (ITU, 2021; Forti *et al.*, 2020; Agamuthu *et al.*, 2009; Hiramatsu *et al.*, 2009) and hence becoming a main challenge to modern societies (Aguiar *et al.*, 2021). These WEEE contain up to 60 different elements, many of which are valuable if recycled (Wang *et al.*, 2012). Again, the ITU (2013) specifies that, mobile phone contain over 20 rare metals which are valuable and therefore should be recycled. According to Chancerel, *et al.* (2016), the estimated fractions of Fe, Cu, Al, Au, Zn, Ni and other metals in WEEE are over 60%, with plastics accounting for about 30% whilst 2.7% comprise of hazardous pollutants. Others, including Vats and Singh (2015), were of the view that, mobile phones/laptops/computers consisted mostly of Cu, Pb, As, Ni, Hg, Ag, Li, Zn, Cd, Be, Ta, Pd, Sb and Au plating. Specifically, the printed circuit board (PCB) circuitry consists of Cu, Au, As, Be, Cd, Ni, Ag and Zn among others (ITU, 2013). Again, the liquid crystal display (LCD) contains Hg, the rechargeable batteries contain Cd, Ni, Zn and Cu whilst the charger also contains Cu, Au, Cd and brominated flame retardants (Forti *et al.*, 2020; ITU, 2013). However, most heavy metals eventually become hazardous and create public health concern by leaching from decomposing waste in landfills into surrounding soils, air or water bodies (Mohan and Joseph, 2021). For example, studies by Morhan and Joseph (2021) confirm that, heavy metals

like Cd, Cr, Pb, Zn, Cu, Ni and Fe were found in ground waters surrounding WEEE dumpsites. Conversely, resources such as precious metals contained in WEEE make them lucrative and therefore dismantle to salvage the useful components of the waste. Indeed, as a ton of Au ore yields just 5g of Au to a ton of used mobile phones which yields 400g of Au, therefore, the need for recycling (ITU, 2013). Also, the USGS (2014) maintains that, in 2013, 11% of the global gold production (2,770 tons) was obtained from mines while in 2014 almost 300 tons of gold was recovered from e-waste. For instance, in 2019, financial gains accrued from the sale of materials in WEEE amounted to US\$ 57 billion, with Au, Cu and Fe accounting for most of this amount (Forti *et al.*, 2020). Life cycle assessment of these devices and the possible health risks associated with their use as well as the manner in which they are handled during recycling raises concerns in developing countries (Wong *et al.*, 2007). The methods used for disposal and retrieving the useful components in developing countries such as Ghana are harmful to the environment and human health. The inappropriate management of WEEE over the years includes open burning and dumping at uncontrolled dumpsites, poses serious environmental problems and human health threats (Caetano *et al.*, 2019). The environmental and human health consequences of pollution by WEEE also affect other resources especially water bodies as leachate can seep into the ground and mix with groundwater up to 200m (Muyassar and Budianta, 2021; Nyiramigisha, 2021). Specifically, a desktop computer with accessories weighs 22kg, a laptop weighs 3.5kg and a mobile phone weighs 0.5kg as ascertained by (Hischier and Eugster, 2007). With these figures, the number of tons of mobile phones, desktop computers and laptops deposited in Ghana is estimated to be not less than 43,427 tons per annum. Other sources however, suggest an amount of 171,000 metric tons of WEEE being generated annually in Ghana (Amoyaw-Osei, *et al.*, 2011). The evaluation of environmental pollution by heavy metals performed in studies by Ali *et al.* (2020) maintain that, they are persistent, covert and long-term. Most of these sources of heavy metals that have effects on human life and the environment are attributed to anthropogenic activities (Christophoridis, *et al.*, 2019). The metal ions released in water become distributed into the surrounding areas by lateral and vertical movements in the ground (Kolesnikov, *et al.*, 2022). Once dispersed in the environment, heavy metals are only slowly removed by geological and biological processes such as being absor-

bed by plants insidiously thereby concentrating along food chains and ultimately building up in consumers of such contaminated foods (Briffa, *et al.*, 2020). In contaminated foods, heavy metals pose a threat to both humans and animals, hence requiring the need to observe strict limits on their concentration (Muhammad, 2023). Other means by which humans are affected by heavy metal exposure include breathing in airborne dust and dirt, nonfood items, and the skin coming into direct contact with contaminated dust, soil and cosmetics (Khan *et al.*, 2015). Heavy metal such as Pb in air, water, or in mining effluents will persist and accrue in soil sediments (Wani *et al.*, 2015) and pollute the surrounding environment over years with the potential of damaging any human organ (Sable, *et al.*, 2024). Furthermore, Pb can cause anaemia, disruption of the biosynthesis of haemoglobin, brain damage, disruption of the nervous, reproductive and circulatory systems in humans (Chen, *et al.*, 2023). Even low levels of Pb absorption by pregnant women will lead to premature newborns, lower birth weight, problems of physical growth and mental development, or cause lower intelligence among children (Gudadhe *et al.*, 2024; Loh, *et al.*, 2016). Again, Briffa, *et al.* (2020) further cautioned that, the risks may increase when contaminated cereals are used for the production of baby foods. On Zn pollution, studies by Zheng *et al.* (2010) show that, free Zn^{2+} is a potent killer of neurons, glia, and other types of cells in humans. Indeed, ingestion of Zn salts have resulted in debilitating sequelae such as vomiting, diarrhea, red urine, icterus (yellow mucous membrane), anaemia, liver and kidney disorders and even deaths (Sankhla *et al.*, 2019; Zheng *et al.*, 2010). Similarly, Ni in groundwater has a potential to cause allergic reactions and also impairs the functions of the liver (Das *et al.*, 2008). Besides, Genchi *et al.* (2020) have argued that, Ni in inhaled air causes nasal and lung cancer, allergies, and kidney and cardiovascular diseases. Actually, it must be emphasized that, measures of association among health outcomes and risk factors for diseases, illnesses or injuries have been estimated primarily through epidemiological research. What should be stressed is that, the evidence on how structural conditions (culture and environment) and policy change influence the risk factors is still limited (Dow *et al.*, 2010). Furthermore, it is more convincing to consider factors that are more likely to modify the exposure-response relationships in such health impact assessments. For instance, cumulative impacts from the additive effects of unknown, new and existing exposures have been cited by (Pope and Dockery, 2006; Ma-

kria and Stilianakis, 2008). Particular population vulnerabilities (sensitivity to exposures, higher disease prevalence, poverty, unemployment, poor sanitation etc.) are also more likely to modify the exposure-response relationships (Pope and Dockery, 2006; Makria and Stilianakis, 2008). The current study seeks to assess the effects of uncontrolled dumping of discarded Mobile Telecommunication Technology devices on soils in Agbogbloshie e-waste dumping site in Accra and the potential health implications.

Materials and Methods

Description of study site

While e- waste and scrap workers in Agbogbloshie are mostly young males with an average age of 21 years, women sell water and work as food vendors on site (Amankwaa and Oteng-Ababio, 2014). Accra is located approximately between latitudes 05°47'30"N and 05°31'0"N, and also between longitudes 05°25'30"W and 0°3'30"W. The scrap yard has grown steadily into a popular recycling site and its Ghana's largest WEEE processing site covering a surface area of about 31.3 Ha (Amankwaa *et al.*, 2017). The settlement of Agbogbloshie (Old Fadama) consists of about 6,000 families or

30,000 people, situated on the left bank of the Odaw River in Accra (Amoyaw-Osei, 2011). Estimates done by Amankwaa and Oteng-Ababio (2014) suggest that, e-waste and scrap workers at Agbogbloshie are mainly males with an average age of 21 years, supported by women who sell food and water. Hundreds of tons of WEEE end up monthly at Agbogbloshie, where they are shattered apart to salvage Cu, Fe, Pb, Ni, Zn, Al and other metallic components using crude unsustainable technologies (Adanu *et al.*, 2020).

Sampling of Soil

The top soil was deemed as very appropriate for quantitative estimation or for soil analysis of heavy metals. This is because WEEE are deposited on backyard soils hence releasing or leaching heavy metals into water bodies and soils which are subsequently absorbed by plants. Sites A, B and C (Fig. 1) identified as sites for heavy deposits of used computers/laptops/mobile phones had soil samples collected at a depth of 8cm (Jarup, 2003). A Grid Cell Sampling Technique involving regular systematic sampling of grids was used to maintain experimental consistency (Franzen, 2011; Mylavarapu and Lee, 2011).

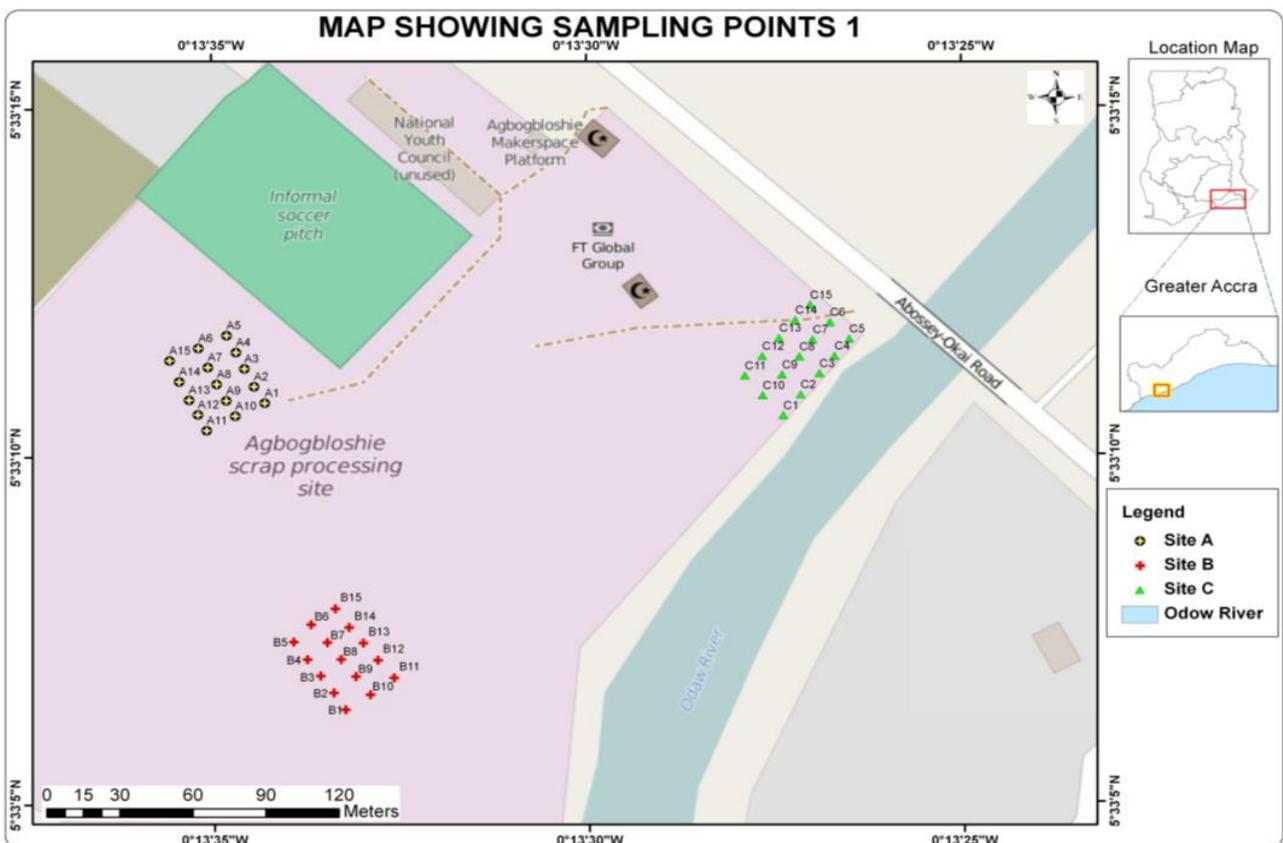


Figure 1. Map showing soil sampling points at “Agbogbloshie, Accra, Ghana”

Acid-Digestion method for soil analysis

The digestion method for heavy metal analysis was used in this study and has been used in several studies to determine the presence and levels of specific heavy metals in soil samples (Dalibo *et al.*, 2023; Nakayama & Wagatsuma, 2021). This method involved collecting and weighing 1.5g of soil sample from each sample point into a Teflon beaker. Six milliliters of HNO₃ (65%), 3ml of HCl (35%) and 0.25ml of H₂O₂ were added to each sample, covered tightly in Teflon bombs and loaded onto the rotor using the torque. The rotor with the Teflon bombs was placed in the ETHOS 900 Microwave Digester and Digested using the below microwave Program (Report Code: 308). The complete assembly was microwave irradiated for 21 minutes using the Milestone Microwave Labstation Ethos 900, MLS-1200 Mega. After digestion, the Teflon bombs mounted on the microwave carousel were cooled in a water bath to reduce internal pressure and allow volatilized material to re-stabilize. The digestate was diluted up to 20ml (nominal volume) with double distilled water and assayed for the presence of Fe, Hg, Ni, Cd, Cr, Cu, Zn, Pb and As. Reference Standards for the elements of interest, blanks and duplicates of the samples were digested under the same conditions and procedures as the actual samples were digested. These therefore served as internal positive controls. Quality Control and Quality Assurance measures employed for the analysis were; the use of *blanks* to check contaminations during sample preparation, the use of *duplicates* to check the reproducibility of the method; and, the use of *standards* to check the efficiency of the

equipment. Hence;

$$\text{Conc. (mg/kg)} = \frac{\text{Conc. (mg/L)} * (\text{Nominal Volume})}{\text{Sample weight (g)}} \quad [1]$$

where Sample weight=1.5g; Nominal Volume=20ml

Statistical analysis

There are several methods for assessing the contamination status and potential health risks of heavy metals in soil samples (Kamalha *et al.*, 2018). The statistical analysis for this study was done using Analysis of Variance (ANOVA), Pearson correlation analysis, Principal component analysis (PCA), Hierarchical cluster analysis (HCA) and Cluster analysis (CA) using IBM SPSS Statistics (version 20) software package.

Results

Specifically, nine (9) out of the over thirteen (13) heavy metals enumerated by Vats and Singh (2015) and ITU (2013) forming the components of mobile phones/ laptops/computers were analyzed. It was deemed relevant for the analysis to be quantitative as it is considered as the most preferred feature of any exposure assessment or estimation (MacIntosh and Spengler, 2000). Consequently a quantitative test for the presence of Fe, Hg, Ni, Cd, Cr, Cu, Zn, Pb and As at sites A, B and C (Fig. 2) was performed. Though permissible mean concentrations vary worldwide Carlon (2007) and Chen *et al.* (2018), this study compared the results obtained to the permissible mean concentrations of the

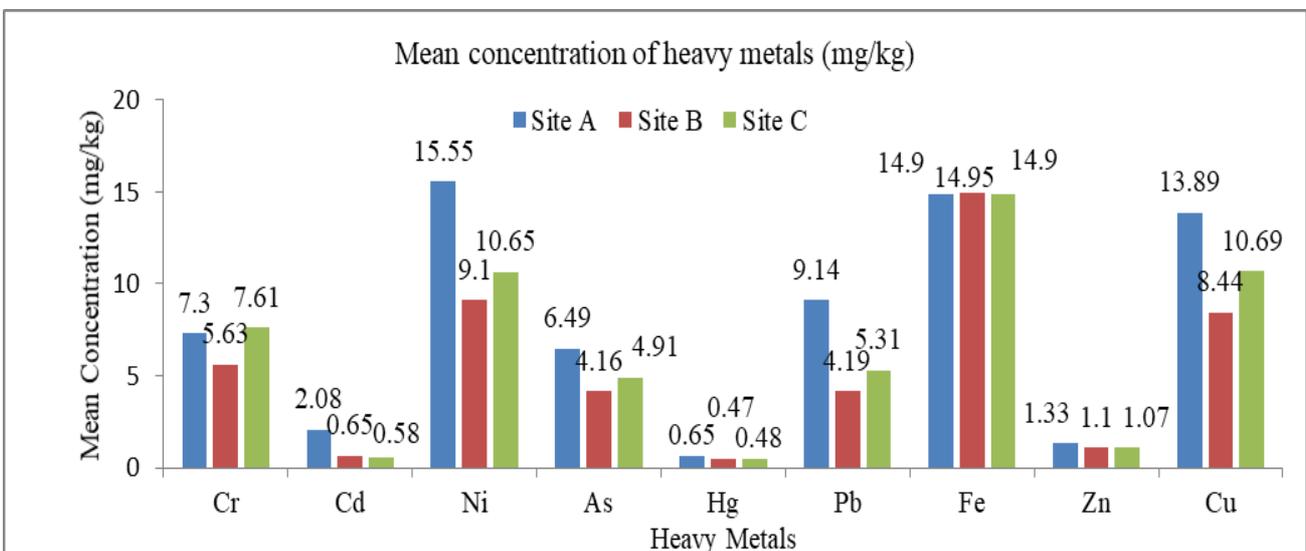


Figure 2. Mean levels of heavy metals at sites A, B and C

US EPA (2011). Quantitatively, the results revealed low levels of heavy metals, however, Hg has exceeded its threshold whilst Cd has reached its threshold as in Figures 3 and 4. This study can therefore predict that

Cd will exceed its threshold very soon as was detailed in studies conducted by Ghaida and Budianta (2023) in the majority of soil samples tested.

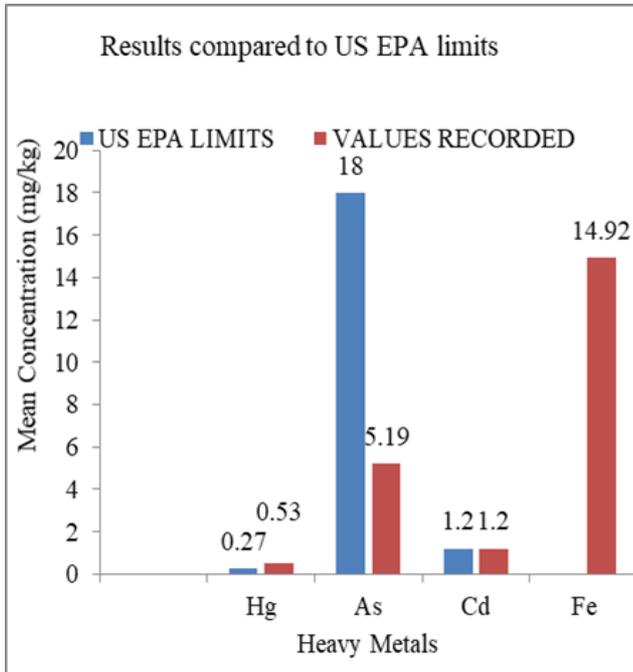


Figure 3. Results compared to US EPA limits

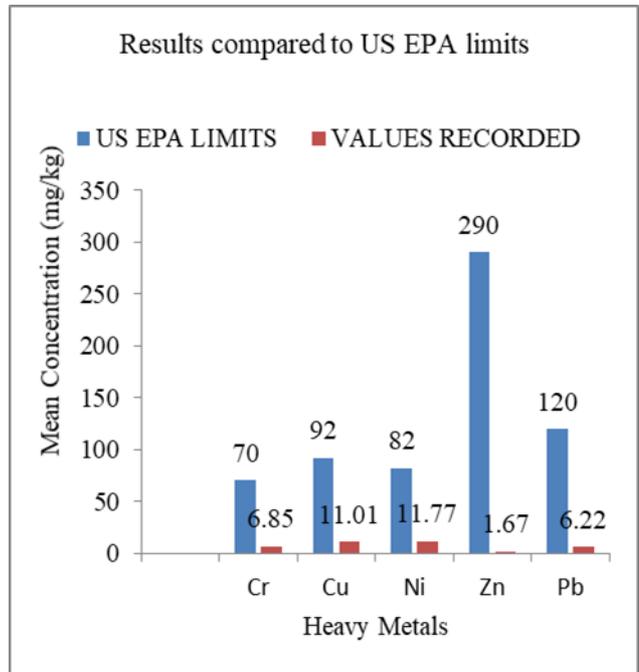


Figure 4. Results compared to US EPA limits

Discussion

The results therefore suggests that timely intervention procedures ought to be introduced. Again, since metal ions in water are distributed by lateral and vertical movements (Kolesnikov, *et al.*, 2022), and may affect surrounding lands and rivers (Muyassar and Budianta, 2021; Nyiramigisha, 2021; Nnorom and Osibanjo, 2008) or even groundwater surrounding dumpsites (Morhan and Joseph, 2021), the introduction of dumpsites cannot be supported by this research, as dumpsites do not have barriers to prevent leakage of leachates (Kiddee *et al.*, 2014).

Analysis of heavy metals in soil samples

One way ANOVA. One-way ANOVA was conducted to determine whether there is a significant difference ($p \leq 0.05$) in the average concentration of the heavy metal depending on the sampling site. Two variables were therefore defined; the concentration of the heavy metal (dependent variable) and the sampling sites (grouping variable). Firstly, the normality of distribution and equality of variances which are the requirements for the application of ANOVA were accordingly tested. The assumption about distribution normality was also sat-

isfied, however Levene's test for equality of variances showed that this assumption was not justified for four heavy metals (Cr, Ni, Hg and Fe) and were accordingly excluded in the ANOVA analysis. The result from the one-way between-groups ANOVA (Table 1) with post-hoc test indicates that, there were significant differences in the average concentrations of Cd, As, Pb, Zn and Cu depending on the sampling site. Table 1. One-Way Between-Groups ANOVA for Heavy Metals Content and Sampling Sites as Grouping Variables For example, sampling site A significantly differs in the concentration of Cd and Pb from sampling sites B and C. However, there was no statistical significant difference between the concentrations of Cd and Pb from sampling sites B and C. Again, the total content of As and Cu from sampling site A was significantly different from those of sampling sites B and C. Nevertheless, the concentration of As and Cu from sampling site C did not differ significantly as compared to those of sampling sites A and B. Certainly, this research confirms similar observations which are of the opinion that, depending on the quantities deposited at a location most heavy metals leach from landfills into

Dependent Variable	Categorical Variable		Mean Difference (I-J)	Sig.
Cd	A1 - A15	B1 - B15	1.47400*	.028
		C1 - C15	1.73200*	.009
	B1 - B15	A1 - A15	-1.47400*	.028
		C1 - C15	.25800	.887
	C1 - C15	A1 - A15	-1.73200*	.009
		B1 - B15	-.25800	.887
As	A1 - A15	B1 - B15	2.33200*	.004
		C1 - C15	1.58467	.063
	B1 - B15	A1 - A15	-2.33200*	.004
		C1 - C15	-.74733	.522
	C1 - C15	A1 - A15	-1.58467	.063
		B1 - B15	.74733	.522
Pb	A1 - A15	B1 - B15	4.94667*	.005
		C1 - C15	3.82867*	.037
	B1 - B15	A1 - A15	-4.94667*	.005
		C1 - C15	-1.11800	.737
	C1 - C15	A1 - A15	-3.82867*	.037
		B1 - B15	1.11800	.737
Zn	A1 - A15	B1 - B15	.22933	.068
		C1 - C15	.25867*	.035
	B1 - B15	A1 - A15	-.22933	.068
		C1 - C15	.02933	.954
	C1 - C15	A1 - A15	-.25867*	.035
		B1 - B15	-.02933	.954
Cu	A1 - A15	B1 - B15	5.45133*	.002
		C1 - C15	3.19800	.086
	B1 - B15	A1 - A15	-5.45133*	.002
		C1 - C15	-2.25333	.283
	C1 - C15	A1 - A15	-3.19800	.086
		B1 - B15	2.25333	.283

Table 1
One-way between-groups ANOVA for heavy metals content and sampling sites as grouping variables

the surroundings (Wang *et al.*, 2012). Indeed sites A, B and C though were at “Agbogloboshie”, they were at different locations (see figure 1) and also had relatively different deposits of WEEE.

Correlation analysis. In order to quantitatively analyze and confirm the relationships among soil heavy metal contents, a Pearson’s correlation analysis was applied to the dataset. According to Kamalha *et al.* (2018), the relationships are relevant to determine the spatial patterns between the elements and the factors and sources of heavy metals. The Pearson correlation coefficients were calculated for each pair of variables (Table 2). The correlation between the metal pairs was positive and linear in all cases. The correlation coefficient between the metal pair As-Pb is 0.967, which indicates a very strong linear correlation at the 0.01 significance level and a common origin of these metals. Hg also exhibited a very strong correlation with Pb

(0.964) and As (0.939) suggesting they probably originated from a common source. Ni exhibited strong positive correlations with both Zn (0.834) and Cr (0.802). These high correlations between soil heavy metals may reflect the fact that these heavy metals had similar pollution levels and similar pollution sources. Moderate correlation was also observed between some of the metal pairs. Cd correlated moderately with Ni (0.694), Zn (0.640), Pb (0.584) and As (0.565). Additionally, Ni depicted a similar moderate correlation with As (0.620), Pb (0.617), Cu (0.652) and Hg (0.597). Furthermore, Cu correlated moderately with Pb (0.601), As (0.575) and Hg (0.565). Such elemental association may signify that each paired of elements has identical source or common sink in the soil samples. Fe exhibited the lowest correlation with majority of the elements studied. Very low correlation was observed between Fe with Cr, Cd and Ni. There was no signifi-

cant correlation between Fe and the heavy elements; As, Hg and Pb. The lack of significant correlation between Fe and these heavy metals suggests that, Fe had a different source from the other metals thus suggesting that, Fe occurs naturally at high levels and

not due to dumping of WEEE (Fig. 2). Indeed, this disclosure is compatible to studies suggesting that heavy metals originate from both natural and anthropogenic sources (Ali and Khan, 2018; He, 2005).

	Cr	Cd	Ni	As	Hg	Pb	Fe	Zn
Cd	.537**							
Ni	.802**	.694**						
As	.572**	.565**	.620**					
Hg	.547**	.476**	.597**	.939**				
Pb	.550**	.584**	.617**	.967**	.964**			
Fe	.459**	.327*	.461**	0.162	0.215	0.228		
Zn	.745**	.640**	.834**	.499**	.464**	.479**	.331*	
Cu	.521**	.481**	.652**	.575**	.565**	.601**	.395**	.497**

Table 2
Pearson's Correlation Matrix of Heavy Metals in the Soils, ** Indicates Correlation is Significant at the 0.01 Level (2-Tailed)

Factor Analysis - Principal Component Analysis (PCA). For PCA, the value of KMO (Kaiser-Meyer-Olkin) measure of sample adequacy was 0.801, which meets the limit of 0.600 conventionally held as a critical value. Bartlett's test of sphericity showed that PCA could be applied to the data at the $p < 0.001$ level. Two principal components (PCs) were identified using Varimax with Kaiser Normalization for the seven variables (Table 3). The PCs accounted for 67.45% of the total variance in the variable set. PCA was performed

on normalized data sets which enhanced the identification of different groups of metals that correlate and hence can be considered as exhibiting a similar behaviour and also from a common origin. Indeed, Kamalha et al. (2018), have stressed that, the identifications are relevant to determine the spatial patterns between the elements and the factors and sources of heavy metals. The eigenvalue-one criterion indicates that PCs with eigenvalues >1 are regarded as significant when the correlation matrix is used in the analysis. According to these results (Table 3), the eigenvalues of the two extracted components are greater than those before and after the matrix rotation. Consequently, heavy metals could be grouped into a two-component model that accounts for 67.45% of all the data variation. In the rotated component matrix, the first principal component (PC₁) had an eigenvalue of 4.61, accounting for 51.24% of the total variance. It had strong positive loadings on As, Pb, Hg, Ni, Cr, Zn and Cu. However, PC₁ was mainly dominated by four of the afore-mentioned heavy elements (As, Pb, Hg and Ni) reflecting the anthropogenic contamination in the soil samples. This implies that these heavy metals in the soil may have originated from similar pollution sources at the Agboglobloshie site. The second principal component (PC₂) had an eigenvalue of 1.46 and accounts for 16.21% of the total variance. It is constituted by only Fe suggesting a possible natural source in the soil. PC₁ with 51.24% variance is heavily loaded on As, Pb, Hg and Ni and can be defined as anthropogenic component which confirms the claim on the components

Table 3. Principal component loadings (Varimax-Normalized) for heavy metals in the soil samples

Variables	Rotated Components	
	PC ₁	PC ₂
Cr	0.689	
Cd	0.568	
Ni	0.802	0.308
As	0.885	-0.338
Hg	0.827	-0.448
Pb	0.862	-0.377
Fe		0.711
Zn	0.698	0.425
Cu	0.682	0.348
Eigen Value	4.611	1.459
Total Variance (%)	51.238	16.209
Commutative Variance (%)	51.238	67.447

of mobile phones/laptops/computers as the major sources of heavy metal pollution (Vats and Singh, 2015). PC₂ on the other hand is heavily depended on Fe with a total variance of 16.21%. Fe being the only component in PC₁ confirms that, it is weakly correlated; thus, different from the other heavy metals regarding their correlation coefficient analysis and PCA. This separation between Fe and the other heavy metals may suggest that, Fe originated from local natural sources, as pointed out that, heavy metals could originate from natural sources by studies performed by (Ali and Khan, 2018; He, 2005). From this study, it can be suggested that, the unregulated recycling techniques (open-pit acid baths, heating, burning, chipping and melting etc.) at sampling sites as mentioned by Adanu *et al.* (2020), Sun *et al.* (2013) and Nnorom and Osibanjo (2008) have contributed to the elevated heavy metal content. Considering this, it seems reasonable to conclude that PC₁ constitute an anthropogenic component, whereas PC₂ appears to be within the parent rock (natural source) as reiterated by (Ali and Khan, 2018; He, 2005).

Hierarchical Cluster Analysis (HCA). Performing HCA on variables rather than on cases is preferred and comparable to most research studies (Kaufman and Rousseeuw, 1990). HCA was developed in the present study on soil samples in order to identify similarities in metal contents between the analyzed soil samples. This approach was selected instead of trying to discriminate between the different sources of metals as already accounted for by PCA. Thus, the aim in performing HCA was to identify the samples which represented different areas where metal content followed a similar pattern. This different approach was also considered since the results obtained by both the HCA and PCA are complementary. PCA helped to group metals according to their different origin (Ward, 1963). Once this information is known, HCA allowed clustering the areas affected by the different metals, that is, affected or not affected by anthropogenic activities. Three main clusters were distinguished in the dendrogram (Fig. 5), and analyzed with the Ward Linkage Method (1963), which uses the squared Euclidean distance as a similarity measure. Cluster 1 includes fourteen soil samples (sample IDs; A1, A4, A11, A15, B1, B2, B3, B8, B9, B12, C3, C4, C10 and C11) affected by higher Cu and Fe contents. Soils associated with this cluster had a local natural origin as the predominant source. Cluster 2 soil samples are the least contaminated and comprises of twelve soil samples (sample IDs: A8, B4, B5, B7, B10, B13, B15, C1, C2, C12, C13, and C14). This cluster contains the lowest contents of all the heavy metals under investigation. Soil samples (sample IDs; A2, A3, A5, A6, A7, A9, A10, A12, A13, A14, B6, B11, B14, C5, C6, C7, C8, C9, and C15) belonged to clusters 3. The soils in this cluster contain the highest concentrations of all the nine heavy elements under study. Cluster 3 soil samples were the most polluted with the heavy metals. These clusters are a clear indication that, various human activities or processes lead to different levels of pollution as explained by (Ali and Khan, 2018; He, 2005). This study, though, supports critical monitoring, it considers the adoption of the EU Directive 2002/96/EC on WEEE which imposes recovery, reuse and recycling as a reliable long-term option.

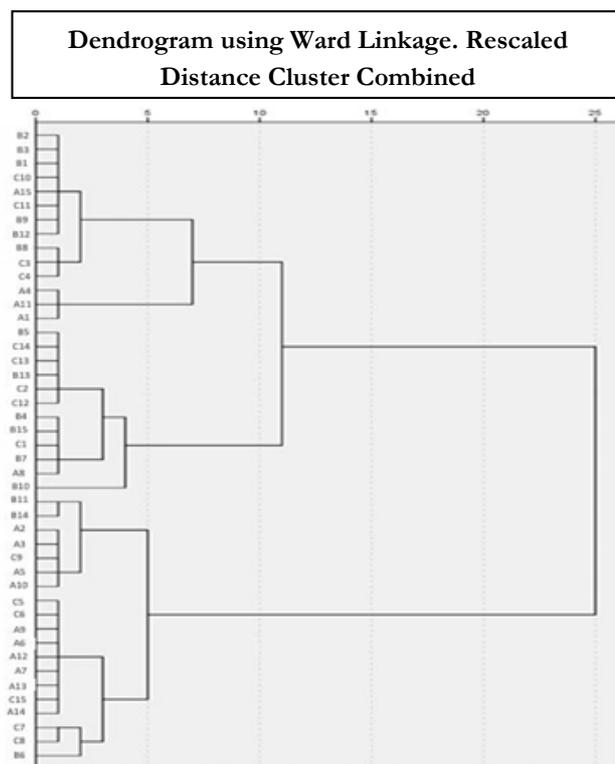


Figure 5. Dendrogram obtained by HCA for heavy metal contents in soil samples (Ward linkage method, 1963).

ster contains the lowest contents of all the heavy metals under investigation. Soil samples (sample IDs; A2, A3, A5, A6, A7, A9, A10, A12, A13, A14, B6, B11, B14, C5, C6, C7, C8, C9, and C15) belonged to clusters 3. The soils in this cluster contain the highest concentrations of all the nine heavy elements under study. Cluster 3 soil samples were the most polluted with the heavy metals. These clusters are a clear indication that, various human activities or processes lead to different levels of pollution as explained by (Ali and Khan, 2018; He, 2005). This study, though, supports critical monitoring, it considers the adoption of the EU Directive 2002/96/EC on WEEE which imposes recovery, reuse and recycling as a reliable long-term option.

Potential health implications of heavy metals found in soil samples at Agbogbloshe e-waste dumpsite. The results as shown by this research has confirmed that, possibly, soils and water bodies at “Agbogbloshe” predispose the public to the health implications of especially Hg and Cd. This is compatible to several studies which have demonstrated significant levels of health implications at e-waste recycling sites (Wu, et al., 2019; Kiddee and Decharat, 2018). According to Berry and Ralston (2009), Hg disrupts the functioning of the pituitary, thyroid and adrenal glands even at low-level exposures. Studies by Singh and Shar-

ma (2024) reveal that, a variety of disturbances primarily in the sensory and motor nerves are connected to Hg contamination. Further reports by Rice *et al.* (2014) indicate that, the chronic absorption of Hg leads to an irreversible damage of the central nervous system and that Hg can further be described as mutagenic, teratogenic and carcinogenic. Also, the accumulation of both organic and ionic forms of Hg in the heart can cause hypertension, tachycardia and ventricular arrhythmias (Posin *et al.*, 2023). In general, minute exposures to Hg can cause severe health challenges in fetus and during infancy, childhood, and early intermediate adolescence periods (Posin *et al.*, 2023). Studies have revealed that, exposure to Cd in human leads to a 31% rise in the risk of lung cancer (Farahmandian *et al.*, 2024). According to Marchetti (2014) Cd causes cramps, nausea, vomiting and diarrhea and is also associated with renal and arterial hypertension as well as damage to the central nervous system. The naturally occurring high levels of Fe revealed by this study is considered interesting as Fe is the fourth most prevalent element on the planet and again consistent to findings by numerous studies (Wang and Astruc, 2017). The presence of Fe in water changes the colour and taste of groundwater (Chen and Khan, 2021) and ingestion of large quantities of Fe results in haemochromatosis, diabetes, nausea and can harm the liver, pancreas and heart (Regan, 2009).

Conclusions

This research focused on the presence of heavy metals as they are bio-accumulative, persistent and can virtually damage any organ. All the heavy metals analyzed were detected at low levels, except Hg which has exceeded its threshold while Cd has also reached its threshold and may possibly pose health risk to the public. This confirms the claim by Tellez-Plaza *et al.* (2013), UNEP (2013) and Obiri *et al.* (2010) that, there is increasing evidence linking toxicants such as Hg, Pb, As, and Cd to the incidence of cognitive impairments and cancers of all sorts, especially in children as they are at high risk (Loh *et al.*, 2016). The high levels of Fe at all the sampling sites confirms studies by Wang and Astruc (2017), that pointed to Fe as the fourth most prevalent element on the planet. Though Fe recorded high values in the soil samples, the statistical analysis performed suggested that, only Fe occurred naturally and is hardly affected by human activities. Indeed, the application for EPA permit requires the performance of EIA to avert any detrimental effect to the environ-

ment, the guidelines failed to highlight the holistic and credible management of WEEE. Considering the diverse significant importance of the MTT to individuals and the society at large, it is therefore necessary to have regulations and practices that are relevant to encourage all stakeholders to voluntarily improve upon their environmental performance.

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