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Heavy metals concentration and distribution in soils and vegetation at Korle Lagoon area in Accra, Ghana

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Abstract

The call for reclamation of land around Korle Lagoon in Accra, Ghana, where burning of E-waste and cultivation of vegetables takes place, make risk assessment of heavy metal contaminations important. This study aimed at evaluating the levels and risk of heavy metal contamination in soils and vegetation around the Korle lagoon area in Accra. Geoaccumulation index, enrichment factor and pollution load index were determined to assess the risk of contamination. The levels and distribution of nine heavy metals (Pb, Hg, Cd, As, Zn, Sn, Ni, Cu and Cr) in soil (0 – 20 cm) and common vegetation (*Panicum maximum, Imperata cylindrica*, *Lactuca sativa* and *Hibiscus sabdariffa*) from the area using Atomic Absorption Spectrometer (AAS) were assessed. The area was divided into five sites namely; the e-waste site (S1), gardens area (S2), recreational area (S3), reclaimed area (S4) estuary (S5), and the control (S6) which was about 700 m away. Soil analysis showed that the concentration of Pb (184.44 mg/kg), Cd (103.66 mg/kg), Cu (202.99 mg/kg), Ni (72.00 mg/kg) and Sn (705.32 mg/kg) at S1 exceeded their WHO/FAO thresholds for agricultural soils. Concentrations of heavy metals in soils from the e-waste site was significantly different ($p < 0.01$) from the other sites. High accumulations of heavy metals were also observed in the plants samples collected from the study sites, with the concentrations of Cu, Pb, Ni and Cd exceeding their acceptable limits. Laws against open burning of e-waste should be enforced and animals should be restricted from grazing on the forage.

Key word: Heavy metals; E-waste; pollution; Environment; health risks

1. Introduction

The fast technological change occurring with increase in demand for information technology has resulted in large volumes of e-waste globally (Wagner, 2009). E-waste contains many different substances that are classified as hazardous (Cd, Pb, As, Be, Cr, Hg, polycyclic aromatic hydrocarbons (PAHs), chlorofluorocarbons, polybrominated diphenyl ethers and dioxin-like compounds) and non-hazardous (Zn, Cu, Se, precious metals Ag, Au, Pt, among others.) which have significant harmful environmental impacts when not well disposed off (Lim, 2010; Tsydenova & Bengtsson, 2011). However, some non-hazardous chemicals such as Zn, Cu, and Se can become hazardous to humans and ecosystems depending on the dose and concentrations, and the target receptors (Musee, 2011; Tchounwou, Yedjou, Patlolla, & Sutton, 2012; Itai, et al., 2014).

In West Africa, the informal recycling of e-waste is becoming an emerging problem due to the high use of electric and electronic equipment (EEE) imported from the developed world (Feldt et al., 2014). Currently, West Africa serves as the major route in Africa, with Ghana and Nigeria serving as the main import hubs. It is estimated that about 215, 000 tons of new and used EEE were imported into Ghana and 129, 000 tons were generated in 2009 alone (E-waste Africa Programme, 2011). The methods mostly used in the recycling of these EEE include melting of electronic boards on open fire to extract metals and valuable chips, burning of cable wires to recover copper and open burning of residual waste materials (Feldt et al., 2014). These methods result in the emission of high concentration of toxins into the atmosphere there by polluting the environment, endangering the health of recycling workers and residents in the surrounding communities. Apart from a number of heavy metals and variety of organic toxins, like

polychorinated biphenyls (PCBs) and polybrominated dipenyls ethers (PBDEs), research has shown that PAHs constitute an important emission from informal e-waste recycling (Asante et al., 2012; Ma et al., 2009; Wang et al., 2012; Wang et al., 2010).

The Agbogbloshie slum is one of Ghana's largest E-waste dump sites. Obsolete electronic gadgets of no perceived value are disposed off in a large area on the edge of the e-waste market (also located in the Agbogboloshie slum) that is also used for the disposal of a wide range of other types of waste (Brigden, Labunska, Santillo, & Johnston, 2008). The north-eastern part of Agbogbloshie in Accra is where Korle lagoon is located, with the reclaimed site few meters away. Workers involved in the e-waste recycling, use open fire to extract metals, valuable chips and copper from electronic gadgets as well as cable wires. In addition, residents burn discarded electronic gadgets at a section of the Korle lagoon reclamation area to extract copper and other valuable metals. The fumes originating from the burning of the e-waste materials might contain heavy metals and other polyaromatic compounds which eventually end up in soils and vegetation of the reclaimed area. Furthermore, herds of cattle from neighbouring communities graze on the vegetation of the reclaimed waste land exposing them to heavy metals. Adjacent to the reclaimed area is a former dump site, which has been converted to an active vegetable garden by the urban poor in the vicinity. These vegetables and vegetation are likely to take up any heavy metals in the soil, hence, engendering the health of the consumers. Research shows that the presence of heavy metals in food and water in relatively high concentration has serious health implications. For example, mercury and cadmium are known to cause injury to the kidney or kidney dysfunction among others. The negative effect of heavy metal exposure in the environment, either through inhalation or ingestion of contaminated food is thus a major concern to researchers, governments and the general public because of its profound effects on humans and wildlife. Little is however

known about the extent of heavy metal pollution of soil and vegetation in the study area. This paper aims to assess the level of heavy metal pollution in soils and vegetation around the Korle lagoon reclamation area in Accra.

2. Materials and Methods

2.1. Study Area

This study was conducted at the Korle Lagoon area in Accra, Ghana. Korle Lagoon is a coastal wetland comprised of beautiful sand dunes, open lagoon, salt pans, marsh and scrubs. The lagoon also provides roosting and nesting grounds for various species of seabirds. It is 104 m above sea level with its coordinates at 5°33'0" N and 0°13'0" E. Accra is a coastal savannah zone which experiences bimodal rainfall. The average annual rainfall is about 730 mm, and ranges between 635 mm and 1140 mm. The mean temperature is about 28 ^{o}C with a minimum and maximum temperature of 25 ^{o}C and 35 ^{o}C respectively.

Figure 1. Map of the study area

2.2. Description of the sampling sites

The study area was divided into five (5) sites depending on the activity that was carried out during the time of the research. These comprised of E-waste area (S1) where burning of electronic waste, collected along the length and breadth of the capital are brought for burning in order to retrieve essential components for sale abroad; site 2 was the garden area (S2), where vegetables and plants are grown; site 3 was a reclaimed waste dump site (S3), site 4 a

recreational site (S4), and site 5 is the estuary area (S5) of the Korle Lagoon. Each site was about 300 m apart. The control (S6) was 700 m away.

2.3. Sample Collection

In each of the selected sites, six quadrats were marked. In each quadrat, four (4) core soil samples were collected randomly at depth 0-20 cm using a soil auger and put together to form a composite sample. The composite samples were well mixed and sub-samples taken (Qin et al., 2014). Six soil replicates were collected from each site, making a total of 36 soil samples from the study area. The soil samples were kept in zip-locked plastic bags, labelled and transported to the laboratory for further treatment and analysis. The soil samples were air dried at room temperature for 4 days, and ground to fine powder. They were then sieved with a 2 mm sieve to remove the coarse soil components. Sub-samples of the sieved soils were then taken for soil physico-chemical and heavy metals analysis.

In addition, twelve samples each of dominant plant species in each of the sites were collected for analysis. The plants samples collected were lettuce *(Panicum maximum, Imperata cylindrica*, *Lactuca sativa* and *Hibiscus sabdariffa)*. The plant samples were obtained by cutting at a height of 5 cm above the soil surface. The plant samples were freeze dried using the CHRIST Getriertrocknugsanlagen GmbH Freeze dryer at a temperature of 17 ˚C with a vacuum mbar of 6.110.

2.4. Analysis of soil properties

The soil properties analysed were soil particle size distribution, pH, organic carbon, organic matter and exchangeable cations (K^+, $Ca^{2+,}$ Na^+ and Mg^{2+}). These characteristics were determined using the methods described by Wahabu, Fosu-Mensah, and Nyame (2015) and

Fosu-Mensah, Okoffo, Darko, and Gordon (2016). The amount of soil organic matter (SOM) was examined by multiplying the percentage carbon by the factor 1.724 (Walkley & Black, 1934). To determine Exchangeable sodium (Na^+), potassium (K^+), Ca^{2+} and Mg^{2+} the methods described by Wahabu et al. (2015) were followed.

2.5. Determination of heavy metals in soil and plant samples

Acid digestion of soil sample was done by weighing a 1.5 g of soil sample into a well labelled 100 mL polytetraflouroethylene (PTFE) Teflon bombs which was previously acid washed. Six (6) millilitre (mL) of 65 % nitric acid (HNO_3), 3 mL of 35 % hydrochloric acid (HCl) and 0.25 mL of 30 % hydrogen peroxide (H_2O_2) was added to each sample in a fume chamber. The samples were then loaded onto microwave carousel where they were irradiated for 26 minutes using milestone microwave lab station ETHOS 900, INSTR: MLS-1200 MEGA (Tiimub & Dartey, 2015; Adama, Esena, Fosu-Mensah, & Yirenya-Tawiah, 2016). Similarly, a 0.5 g plant sample was weighed in an acid washed Teflon bomb labelled "100 mL polytetraflouroethylene (PTFE)" and a similar procedure followed. Blanks were prepared to check for background contamination by the reagents used. The digested soil and plant samples were analysed for the heavy metals (Cd, As, Pb, Cu, Ni, Sn, Hg, Cr and Zn) using atomic absorption spectrophotometer (AA 240 FS, Varian) (Kumar, Singh, & Garg, 2012). All the readings were taken in five replicates.

2.6. Methods of Assessment of contamination in soils

In this study, geoaccumulation index (I_{geo}), enrichment factor (EF), and pollution load (PL) were calculated to assess the heavy metal contamination levels in soils from the study area.

2.6.1. Geoaccumulation Index (*I*geo)

The index of geoaccumulation (I_{geo}) is widely used in the assessment of contamination by comparing the levels of heavy metals obtained to background levels originally used with bottom sediments (Muller, 1969; Atiemo et al., 2011). It is calculated using the equation:

$$I_{geo} = log_2\left(\frac{C_n}{1.5B_n}\right)$$

Where C_n represents the measured concentration of the elements studied and B_n is the geochemical background value of the element in fossil argillaceous sediment (average shale) (Taylor & McLennan, 1985). The following classification is given for geoaccumulation index :<0 = practically unpolluted, 0-1 = unpolluted to moderately polluted, 1-2 = moderately polluted, 2-3 = moderately to strongly polluted, 3-4 = strongly polluted, 4-5 = strongly to extremely polluted and >5 = extremely polluted (Lu, Wang, Lei, Huang, & Zhai, 2009).

2.6.2. Enrichment factor (EF)

Enrichment factor (EF) of an element in the studied samples was based on the standardization of measured element against a reference element. Al was used as the reference element in this study. The EF is calculated using the equation:

$$EF_x = \frac{[C_x/C_{ref}]sample}{[B_x/B_{ref}]Background}$$

Where C_x is the concentration of the element of interest and C_{ref} is the concentration of reference element for normalization, B_x is the concentration of the element in the crust and B_{ref} is the concentration of the reference element used for normalization in the crust (Cevik, Göksu, Derici,

& Findik, 2009; Ato et al., 2010). Five contamination categories are assigned on the basis of the enrichment factor: EF<2=deficiency to minimal enrichment; EF=2-5 = moderate enrichment; EF=5-20 = significant enrichment; EF=20-40 = very high enrichment and EF>40 = extremely high enrichment (Yongming, Peixuan, Junji, & Posmentier, 2006).**2.6.3. Pollution Load Index (PLI)**

The Pollution index (PI) is defined as the ratio of element concentration in the study to the background content of the abundance of chemical elements in the continental crust. Pollution index and integrated pollution index are also commonly used to assess environments quality (dos Anjos et al., 2000). PLI for the soil samples was determined by the equation below, as proposed by Tomilson, Wilson, Harris, and Jeffrey (1980).

$PLI = (CF_n \times CF_n \times CF_n \times CF_n \times CF_n \times CF_n)^{1/n}$.

The PI of each element is classified as either low ($PI \leq 1$), middle ($1 < PI \leq 3$) or high ($PI > 3$) (Chen et al., 2005).

2.7. Data Analysis

The data was analysed using SPSS 16.0. The Tukey test was used for pairwise comparison of means to identify significant differences of heavy metals among the sites.

3.0. Results and Discussion

3.1. Physicochemical properties of soil samples from the study area

Table 1 presents the summary of the physicochemical properties of soil samples from the study sites. The pH of the study sites ranged from 4.67 at S3 to 7.74 at S5 with a mean value of 6.93. The low pH (4.67) at site S3 might probably be due to the dumping of acid containing waste materials like batteries on the site as the site was once a dumping site. The OC content of the

soils ranged from 0.38 % at S5 to 0.85 % at S1 with a mean value of 0.50 %. Similarly, soil organic ranged from 1.13 % at S5 to 2.51 % at S1 with a mean value of 1.48 %. The exchangeable K^+ ranged from 0.58 cmol/kg at S6 to 1.52 cmol/kg at S1 and S3 with a mean value of 1.07 cmol/kg. In addition, the exchangeable Na^+ content of the soils analysed ranged from 2.01 cmol/kg at S6 to 6.15 cmol/kg at S1 with a mean of 3.86 cmol/kg. The exchangeable Ca^{2+} values ranged from 10.13 cmol/kg at S6 to 97.87 cmol/kg at S1 with a mean value of 30.65 cmol/kg. Site S6 recorded the lowest value (7.60 cmol/kg) of exchangeable Mg^{2+} with the highest (73.4 cmol/kg) recorded at S1.

Table 1. Summary of physicochemical analysis of soils at Korle Lagoon area in Accra

3.2. Heavy metal concentration of soils at the different sites in the study area

Table 2 presents the summary of the mean concentrations of heavy metals (Hg Pb, Cu, Zn, Cr, Cd, Ni, Sn, and As) analysed in the soil samples at the various sampling sites at Korle Lagoon area in the Greater Accra region of Ghana. Analysis of variance (ANOVA) revealed significant ($p < 0.05$) variation in the concentrations of the nine (9) elements among the sites (Table 2) which is an indication of the extent of metal pollution in the soils. The Tukey test revealed that the concentrations of most of the elements were significantly ($p < 0.01$) higher at the e-waste site (S1) compared to the other sites (Table 2). Site 2 generally had the lowest concentrations of most of the metals analysed except for Cr which was higher.

Mercury (Hg) was the least abundant metal recorded in the study area whereas Sn was the highest among the metals with a mean value of 705.32 mg/kg. Contrary to this finding, Xianjin et al. (2010) reported high concentration of Hg (654.1 mg kg^{-1}) and Sn (660.8 mg kg^{-1}) in simple household e-waste recycling workshop and large-scale e-waste recycling plants, respectively.

Mercury in the soil samples analysed ranged from <0.001 mg/kg at S2, S5 and S6 to 0.667 mg/kg at S1. The mean concentration of mercury recorded at the different sites were below the WHO/FAO (2001) limit of 2.00 mg/kg for soils. The low concentration of Hg can be attributed to the fact that Hg easily evaporates into organo-mercury forms (Environmental health and safety manual, 2000).

The concentrations of lead (Pb) in soil samples analysed ranged from 1.28 to 184.44 mg/kg with a mean value of 37.12 mg/kg. The E-waste site (S1) recorded the highest mean concentration of Pb whereas the garden area (S2) recorded the lowest mean concentration. Analysis of variance (ANOVA) showed significant differences ($p < 0.05$) in the mean concentration of Pb among the sites. The mean concentration of Pb at the e-waste zone (S1) was above the WHO/FAO (2001) permissible limit of 50.00 mg/kg for soils. The higher concentration of Pb recorded at the E-waste site (S1) could be attributed to the burning of electronic waste (such as refrigerator, used computers, cables, printers, photocopy machines, automobile tires, batteries, air condition among others). The mean value of Pb recorded in this study was however lower than the mean value of 2645.31 mg/kg reported by Pradhan and Kumar (2014) in an e-waste recycling site soil.

The mean concentration of copper recorded from the various sites ranged from 3.47 mg/kg at S2 to 202.99 mg/kg at S1with a mean value of 38.80 mg/kg. The mean concentrations of copper recorded were below the WHO/FAO (2001) permissible limit of 100 mg/kg for soils except at S1 (202.99 mg/kg) which was above the WHO/FAO (2001) permissible limit. The high concentration of Cu at S1 could be attributed to the burning of electronic gadgets as indicated earlier. This result is similar to the findings of Zhang, Wu, and Simonnot (2012) which recorded extremely high concentrations of copper at e-waste sites, which was beyond the acceptable agricultural soils limits of 50 mg/kg in China.

The mean concentration of zinc (Zn) ranged from 0.83 at S2 to 37.33 mg/kg at S5 with a mean value of 8.68 mg/kg. The maximum mean concentration of Zn recorded at the e-waste zone (S1) was below the WHO/FAO (2001) permissible limit of 300.00 mg/kg for soils. The presence of zinc in soil at the various sites could be attributed to the occurrence of dry cells in the municipal waste as reported by Thorpe and Harrison (2008) and the burning of e-waste materials in the area as indicated earlier. In a similar study, Li et al. (2011) reported a mean value of 3500 mg/kg for Zn in e-waste and municipal solid waste dump site in south China. Zinc is an essential microelement which plays a very essential catalytic role in enzyme reactions but its content varies with the type of soil (Knezevic, Stankovic, Krstic, Nikolic, & Vilotic, 2009). High concentration of Zn can however pose health threats to humans.

The concentration of chromium Cr ranged from 2.28 at S3 to 56.00 mg/kg at S1 with a mean value of 11.55 mg/kg. The high concentration of Cr recorded at S1 could be as a result of the recycling of E-waste such as refrigerator, used computers, cables, printers, photocopy machines, automobile tires and batteries at the site.

Similarly, the concentration of Cd ranged from <0.001 mg/kg at S3 to 103.66 mg/kg at S1 with a mean value of 18.64mg/kg. The mean concentrations of Cd recorded at all sites were above the WHO/FAO (2001) permissible limit of 3 mg/kg for soils except S3, S4 and S6 which recorded values that were below the WHO/FAO permissible limit. Cadmium is very much connected with non-residual fractions of heavy metals and thus makes them mobile and potentially bio-available for uptake by plants (Zhang et al., 2009).

The mean concentrations of nickel recorded in the soil samples ranged from 0.91 mg/kg at S2 to 72.00 mg/kg at S1 with a mean value of 13.60 mg/kg. The mean concentration of Ni recorded at

the various sites were below the WHO/FAO (2001) permissible limit of 50 mg/kg for soils except for S1 which recorded a mean value that was above the permissible limit.

On the other hand, the mean concentration of Sn at the sites ranged from 8.77 at S3 to 705.32 mg/kg at S1 with a mean value of 132.86 mg/kg. The mean concentration of Sn obtained at S1 was above the FAO/WHO (1984) permissible value for Sn. The concentration of arsenic (As) recorded in soils ranged from 0.04 mg/kg at (S6) to 3.67 mg/kg at (S1) with mean value of 1.09 mg/kg. The mean concentrations of As at all sites were below the WHO/FAO (2001) permissible limit of 20.00 mg/kg for agricultural soils. This result is in line with the finding of Pradhan and Kumar (2014) who reported the highest value of 17.08 mg/kg in E-waste dump site in south China.

In general, the E-waste site (S1) recorded the highest concentration of heavy metals in soil samples as compared to the other sites. The burning of the E-waste materials results in the emission of toxins such as heavy metal in high concentration, thus exposing the recycle workers and the communities around to health risk. Li, Duan, and Shi (2011) reported that high concentration of heavy metals is recorded at pollution source.

Table 2 Summary of mean of Heavy metal concentration of soils within 0–20 cm depth in different sites in Korle Lagoon area in Accra

Table 3 presents comparison of heavy metal concentrations in E-waste dump sites of some cities of the world with data from E-waste site at the Korle Lagoon area in Accra. From the results, it was observed that heavy metal such as Hg, Pb, Zn, Cr, As and Ni were the most prominent heavy metals in the E-waste recycling site compared to Sn and Cu. In the current report, the mean

concentration of Pb, Zn, Cr, and Ni at the E-waste zone were below the concentration levels of metals reported in other literature (Tang et al., 2009; Ha et al., 2009; Li et al., 2011; Ofudje, Alayande, Oladipo, Williams, & Akiode, 2014; Timothy & Olajumoke, 2014; Quan et al., 2015). However, the average concentration of Cd (103.66 mg kg^{-1}) was higher than those (0.478) reported by Ha et al. (2009) in Bangalore, India and 1.21 mg kg^{-1} in Guiyu in Guangdong province by Li et al. (2011). The average mean (0.65 mg kg^{-1}) of Hg was higher than the value reported by Ha et al. (2009) in Bangalore, India. While Cd was higher than those reported by Tang et al. (2009), Li et al. (2011), Ofudje et al. (2014), Quan et al. (2015).

Table 3: Comparison of heavy metal concentration in E-waste dumpsites of some cities of the world with data from E-waste site at the Korle Lagoon area in Accra.

3.3. Index of Geoaccumulation (Igeo)

Soil quality was measured using the I_{geo} index of classification proposed by Muller (1981) (Table 4). The results of I_{geo} analysis indicated that, S1 and S2 were practically uncontaminated by Hg, Zn, Cr, Ni and As, while S1 was strongly polluted by Pb and extremely polluted by Cd and Sn which are the major constituents of e-waste (Pradhan & Kumar, 2014). In S3, S4, S5 and S6, only Sn showed moderate contamination with S3 showing strong contamination. The rest of the elements exhibited no pollution at the various sites. This might be due to the absence of e-waste activity and horizontal spread of metal pollutants in these areas.

Table 4 Values of geoaccumulation index for heavy metals at different sites from the Korle Lagoon area in Accra

3.4. Enrichment factor (EF) and Pollution Load Index (PLI)

Table 5 presents results of enrichment Factor (EF) and pollution load index of all the heavy metals analysed in the sampled soil at the different sites. From Table 5, S1 exhibited extremely high enrichment of Hg, Cd, and Sn, while the same site also showed significant enrichment of Pb and As. The EF for S2, S3, S4, S5 and S6 showed deficiency to minimal enrichment of Pb, Cu, Zn, Cr, and Ni while S2 showed extremely high enrichment for Cd and Sn. Similarly, S3 showed very high enrichment of Hg and extremely high enrichment of Cd and Sn while S4 showed moderate enrichment of As, very high enrichment of Sn and extremely high enrichment of Hg. Site 5 and 6 showed very high enrichment of Sn. A comparison among different sampling sites of the study area based on EF's of elements showed that S1 is the most contaminated site with the other remaining sites having almost similar EF's. From the results presented, EF's showed that the presence of heavy metals was extremely high in soils of e-waste recycling sites compared to the remaining sites.

The PLI values of Cu, Zn, Cr, As and Ni fell within the PLI ≤ 1 category. This means that the presence of these heavy metals in the earth crust was low (Pradhan & Kumar, 2014) and their pollution in the soil is very minimal. On the other hand, Hg and Pb belong to $1 < \text{PLI} \leq 3$ category which means that their presence in the study area fell between low to high pollutants in the soil. However, Cd and Sn were within the high category with PLI > 3. This meant that the presence of Cd and Sn was high in the study area.

Table 5 Enrichment factor (EF) of heavy metals for soil at different zones in Korle Lagoon area in Accra

3.5. Heavy metal concentration in plants at different sites from the Korle Lagoon area in Accra

Heavy metals with different concentration were detected in common plants in all sites under study. Table 6 presents the summary of the concentrations of nine heavy metals in plants samples collected in the study area. The control site (S6) recorded the least concentration of most of the elements. The trend in heavy metals in the plants samples was similar to what was observed in the soil. There was significant difference ($p < 0.01$) in the concentration of heavy metals among sites. ANOVA showed significant ($p < 0.01$) higher concentrations of most of the heavy metals (Sn, Cd, Cu, Zn, and Ni) in plant samples obtained from the e-waste site (S1) than the other sites. Among the heavy metal analyzed, Hg was not observed in any of the sampled plants while Pb was also not detected at S4. The non-detection of Hg in the plant samples could be attributed to the minimal or no usage of mercury in the activities undertaken at these zones. It might also be the fact that Hg can easily be transformed into other organic forms which are more poisonous (Clarkson, 1997; Boening, 2000). Hg is not essential for plant growth (Lange, Nobel, Osmond, & Ziegler, 2013). The ability of plants to accumulate essential metals equally enables them to acquire other nonessential metals (Djingova & Kuleff, 2000).

The concentration of Pb in plant samples ranged from <0.001 at S4 to 36.72 mg/kg at S1. Tukey test revealed significant differences ($p < 0.01$) in the mean values of Pb between S1 and the other sites. The mean values recorded at all sites except S4, were above the FAO/WHO (1984) acceptable value of 0.43 mg/kg in edible plants. The high concentration of Pb in plant from the E-waste site could be attributed to the burning of lead containing products like scrap metals and batteries in the e-waste site. Livestock that graze in the e-waste area are likely to be exposed to health risks with regards to lead toxicity through the consumption of forage grasses growing in

this area. Lead is reported to cause liver disorders in livestock especially in cattle. Khan, Khan, Hussain, Marwat, and Ashtray (2008) reported that lead causes both acute and chronic poisoning and thus, poses adverse effects on kidney, liver, vascular and immune system.

Cadmium concentrations recorded ranged from 0.25-1.64 mg/kg which was above the WHO/FAO (2007) permissible limit of 0.20 mg/kg for edible plants. Site S6 recorded the least concentration of Cd while the highest was recorded at S1. The high concentration of Cd at S1 might be as a result of the burning of e-waste containing cadmium-nickel batteries, pigments and paints. Significant concentration of Cd may have gastrointestinal effect and reproductive effect on livestock (Maobe, Gatebe, Gitu, & Rotich, 2012). Jabeen, Shah, Khan, and Hayat (2010) reported that cadmium causes both acute and chronic poisoning, adverse effect on kidney, liver, vascular and the immune system.

Similarly, the concentration of Cu ranged from 0.21 mg/kg at S3 and S6 to 95.56 mg/kg at S1. With the exception of S3 and S6 which recorded mean Cu values that were below the FAO/WHO (1984) permissible limit of 3.0 mg/kg, the other sites recorded values that were above the limit. This could be attributed to continuous dumping of copper-containing electrical gadgets. In a similar study, Pradhan and Kumar (2014) reported a range of Cu values from 11.08 to 23.07 mg/kg in a study conducted in China. According to Ullah et al. (2012) as cited in (Maobe et al., 2012), high levels of copper can cause metal fumes fever with flue like symptoms, hair and skin decolouration, dermatitis, irritation of the upper respiratory tract, metallic taste in the mouth and nausea.

Additionally, concentration of Zn ranged from 1.33 at S6 to 34.92 mg/kg at S1. However, all the sites recorded mean values of zinc that were below the FAO/WHO (1984) permissible limit of

27.3 mg/kg except for S1. Zinc is required nutrient and becomes toxic to plants only at high concentrations.

Similarly, the concentration of chromium ranged from 1.08 at S3 to 3.84 mg/kg at S4, which was within the critical range of 5.00 to 30.00 mg/kg stated by Radojevic and Bushkin (2008).

The concentration of nickel also ranged from 0.59 at S6 to 6.80 mg/kg at S5. With the exception of S6, the remaining sites were above the WHO/FAO permissible limit of 1.63 mg/kg in edible plants. Nickel in plants could be attributed to cadmium-nickel batteries in the electrical gadgets and some paints used to polish the surfaces of the gadgets which might have spread to adjoining sites as it was also detected in the soil samples. High concentration of nickel can lead to health risks. According to Khan et al. (2008), Ni deficiency results in liver disorder.

The concentration of Sn ranged from 2.52 at S4 to 22.29 mg/kg at S6 which were all below the recommended FAO/WHO (1984) permissible limit of 200.00 mg/kg in edible plants.

Additionally, As ranged from below detection at S2 to 0.32 mg/kg at S1. The presence of As in the vegetation samples could be attributed to the recycling activities in the area. The concentration of As is in line with the findings of Pradhan and Kumar (2014) on Delhi informal re-cycling site. According to Luo et al. (2011) atmospheric deposition is a major factor for high metal accumulation in plant samples, and this could therefore be the cause of the As in the samples analysed.

The uptake of heavy metals by plants occur during the vegetative period (Knezevic et al., 2009; Krstić, Stanković, Igić, & Nikolic, 2007). The presence of toxic heavy metals in the soil results

in the bio-accumulation and bio-magnification of these toxins into plant tissues (Fagbote & Olanipekun, 2010; Suciu, Cosma, Todica, Bolboaca, & Jantschi, 2008).

Table 6. Summary heavy metal concentration in plants at the Korle Lagoon area in Accra

4. Conclusion

The soils and vegetation samples from the Korle lagoon reclamation area recorded significant levels of heavy metals, especially at the e-waste site (S1). The results showed that all the nine heavy metals (Hg Pb, Cu, Zn, Cr, Cd, Ni, Sn, and As) analysed were present in soil samples at the six sites. Similarly, eight heavy metals (except Hg) out of the nine analysed were present in vegetation sampled from the six sites. Generally, the E-waste site (S1) had higher concentration values of all heavy metals in both soil and vegetation samples than the other sites. Pollution assessment revealed high contents of heavy metals in soil samples collected from the e-waste recycling area compared to the other sites. Site S1 exhibited extremely high enrichment of Hg, Cd, and Sn, while the same site also showed significant enrichment of Pb and As. The results from the enrichment factor analysis showed that the presence of heavy metals was extremely high in soils from the e-waste recycling sites compared to the other sites. The geoaccumulation index showed that S1 was strongly polluted by Pb and extremely polluted by Cd and Sn, with S3 showing strong contamination by Sn. The values for pollution load index of heavy metals recorded low contamination except Hg and Pb which fell between low to high pollutants in the soil, and Cd and Sn which were within the high category which meant that the presence of Cd and Sn was high in the study soils. The contamination of the environment with heavy metals pose hazard to human and animal health, through bioaccumulation and bio-magnification as

animals sometimes graze around the area. The Informal recycling of e-waste also has the potential to pollute the environment and nearby communities. The need for periodic monitoring of toxic metals in this area is crucial to protect human health and the environment.

5. Recommendation

The Environmental Protection Agency of Ghana and the Ghana Customs Excise and Preventive Service (CEPS) should collaborate to educate the public on e-waste separation at the various entry points. The Accra Metropolitan Assembly must enforce laws on open burning and hasten the Korle Lagoon Reclamation Project in order to curtail the activities of these e-waste dealers and the burning of e-waste at the reclamation area. E-waste workers should be educated occasionally to create awareness on the potential health risks they are exposed to. Herds of cattle crossing from nearby communities should be restricted from grazing on the forage grasses in the study area. Children should be restricted from playing within the recreational area since some levels of heavy metals were found in both the plant and soil sampled from the area. Farmers cultivating vegetables along the borders of the reclamation zones should be educated on the health risk consumers are expose to by consuming vegetable grown as the plants are likely to pick heavy metals from the polluted soil.

Competing interests

All authors declare no competing interests.

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References

Asante, K. A., Agusa, T., Biney, C. A., Agyekum, W. A., Bello, M., Otsuka, M., Itai, T., Takahashi, S., & Tanabe, S. (2012). Multi-trace element levels and arsenic speciation in urine of e-waste recycling workers from Agbogbloshie, Accra in Ghana. *Science of The Total Environment*, *424*, 63–73. http://doi.org/10.1016/j.scitotenv.2012.02.072

Atiemo, M. S., Ofosu, F. G., Kuranchie-Mansah, H., Tutu, A. O., Palm Linda, N. D. M., & Blankson, A. S. (2011). Contamination assessment of heavy metals in road dust from selected roads in Accra, Ghana. *Research Journal of Environmental and Earth Sciences*, *3*(5), 473–480.

Ato, A. F., Samuel, O., Oscar, Y. D., Alex, P., Moi, N., & Akoto, B. (2010). Mining and Heavy Metal Pollution: Assessment of Aquatic Environments in Tarkwa (Ghana) using Multivariate Statistical Analysis. *Journal of Environmental Statistics*, *1*(4), 1–13.

Adama, M., Esena, R., Fosu-Mensah, B., & Yirenya-Tawiah, D. (2016). Heavy Metal Contamination of Soils around a Hospital Waste Incinerator Bottom Ash Dumps Site. *Journal of Environmental and Public Health*, *2016*. Article ID 8926453. http://dx.doi.org/10.1155/2016/8926453

Brigden, K., Labunska, I., Santillo, D., & Johnston, P. (2008). *Chemical contamination at e-waste recycling and disposal sites in Accra and Korforidua, Ghana*. Greenpeace Research Laboratories Technical Note, (10/2008).

Boening, D. W. (2000). Ecological effects, transport, and fate of mercury: a general review. *Chemosphere, 40*(12), 1335-1351.

Cevik, F., Göksu, M. Z. L., Derici, O. B., & Findik, O. (2009). An assessment of metal pollution in surface sediments of Seyhan dam by using enrichment factor, geoaccumulation index and

statistical analyses. *Environmental Monitoring and Assessment*, *152*(1-4), 309–17. http://doi.org/10.1007/s10661-008-0317-3

Chen, T.-B., Zheng, Y.-M., Lei, M., Huang, Z.-C., Wu, H.-T., Chen, H., … Tian, Q.-Z. (2005). Assessment of heavy metal pollution in surface soils of urban parks in Beijing, China. *Chemosphere*, *60*(4), 542–551. http://doi.org/10.1016/j.chemosphere.2004.12.07

Clarkson, T. W. (1997). The toxicology of mercury. *Critical reviews in clinical laboratory sciences, 34*(4), 369-403.

dos Anjos, M. J., Lopes, R. T., de Jesus, E. F. O., Assis, J. T., Cesareo, R., & Barradas, C. A. A. (2000). Quantitative analysis of metals in soil using X-ray fluorescence. *Spectrochimica Acta Part B: Atomic Spectroscopy*, *55*(7), 1189–1194. http://doi.org/10.1016/S0584-8547(00)00165-8

Djingova, R., & Kuleff, I. (2000). Instrumental techniques for trace analysis. *Trace Metal Environment, 4*, 137–185.

E-waste Africa Programme. (2011). *E-waste Africa Programme: Where are WEee in Africa? Findings from the Basel Convention*. Secretariat of the Basel Convention, Châtelaine

Environmental health and safety manual (2000). Safe handling of Mercury and Mercury compounds. https://iaomt.org/TestFoundation/safehandling.htm cited in 12th October 2017.

Fagbote, E. O., & Olanipekun, E. O. (2010). Evaluation of the Status of Heavy Metal Pollution of Soil and Plant (Chromolaena odorata) of Agbabu Bitumen Deposit Area, Nigeria. *American-Eurasian Journal of Scientific Research*, *5*(4), 241–248.

FAO/WHO. (1984). *Toxicological Evaluation of Certain Food Additives and Food Contaminants. (Twenty-eight meeting of the Joint FAO/WHO Expert Committee on Food Additives)*. ILSI Press International Life Sciences Institute, Washington, DC.

Feldt, T., Fobil, J. N., Wittsiepe, J., Wilhelm, M., Till, H., Zoufaly, A., Burchard, G., & Göen, T.

(2014). High levels of PAH-metabolites in urine of e-waste recycling workers from Agbogbloshie, Ghana. *Science of The Total Environment*, *466–467*, 369–376. http://doi.org/10.1016/j.scitotenv.2013.06.097

Fosu-Mensah, B. Y., Okoffo, E. D., Darko, G., & Gordon, C. (2016). Assessment of organochlorine pesticide residues in soils and drinking water sources from cocoa farms in Ghana. *Springerplu*s, 5, (869). http://dx.doi.org/10.1186/s40064-016-2352-9.

Ha, N. N., Agusa, T., Ramu, K., Tu, N. P. C., Murata, S., Bulbule, K. A., … Tanabe, S. (2009). Contamination by trace elements at e-waste recycling sites in Bangalore, India. *Chemosphere*, *76*, 9–15.

Itai, T., Otsuka, M., Asante, K. A., Muto, M., Opoku-Ankomah, Y., Ansa-Asare, O. D., & Tanabe, S. (2014). Variation and distribution of metals and metalloids in soil/ash mixtures from Agbogbloshie e-waste recycling site in Accra, Ghana. *Science of the Total Environment, 470,* 707-716.

Jabeen, S., Shah, M. T., Khan, S., & Hayat, M. Q. (2010). Determination of major and trace elements in ten important folk therapeutic plants of Haripur basin, Pakistan. *Journal of Medicinal Plants Research*, *4*(7), 559–566.

Khan, S. A., Khan, L., Hussain, I., Marwat, K. B., & Ashtray, N. (2008). Profile of heavy metals in selected medicinal plants. *Pakistan Journal of Weed Science Research*, *14*(1-2), 101–110. Retrieved from http://www.wssp.org.pk/14,1-2,10.pdf

Knezevic, M., Stankovic, D., Krstic, B., Nikolic, M. S., & Vilotic, D. (2009). Concentrations of heavy metals in soil and leaves of plant species Paulownia elongata and Paulownia fortunei. *African Journal of Biotechnology*, *8*(20), 5422–5429.

Krstić, B., Stanković, D., Igić, R., & Nikolic, N. (2007). The potential of different plant species

for nickel accumulation. *Journal of Biotechnology And Biotechnology Equipments*, *21*(4), 431–436.

Kumar, S., Singh, J., & Garg, M. (2012). AAS Estimation of heavy metals and trace elements in Indian herbal cosmetics preparations. *Research Journal of Chemical Sciences*, *2*(3), 46–51.

Lange, O. L., Nobel, P.S., Osmond, C.B., Ziegler, H. (2013). Physiological plant ecology III: responses to the chemical and biological environment. Springer Science & Business Media.

Li, H. Z., Bai, J. M., Li, Y. T., Cheng, H. F., Zeng, E. Y., & You, J. (2011). Short-range transport of contaminants released from e-waste recycling site in South China. *Journal of Environmental Monitoring*, *13*(4), 836–843. http://doi.org/10.1039/c0em00633e

Li, J., Duan, H., & Shi, P. (2011). Heavy metal contamination of surface soil in electronic waste dismantling area: site investigation and source-apportionment analysis. *Waste Management and Research*, *29*(7), 727–738. http://doi.org/10.1177/0734242X10397580

Lim, S. R. S. J. (2010). Toxicity potentials from waste cellular phones, and a waste management policy integrating consumer, corporate, and government responsibilities. *Waste Management*, *30*(8–9), 1653–1660.

Lu, X., Wang, L., Lei, K., Huang, J., & Zhai, Y. (2009). Contamination assessment of copper, lead, zinc, manganese and nickel in street dust of Baoji, NW China. *Journal of Hazardous Materials*, *161*(2-3), 1058–1062. http://doi.org/10.1016/j.jhazmat.2008.04.052

Luo, C., Liu, C., Wang, Y., Liu, X., Li, F., Zhang, G., & Li, X. (2011). Heavy metal contamination in soils and vegetables near an e-waste processing site, South China. *Journal of Hazardous Materials*, *186*(1), 481–490. http://doi.org/10.1016/j.jhazmat.2010.11.024

Ma, J., Horii, Y., Cheng, J., Wang, W., Wu, Q., Ohura, T., & Kannan, K. (2009). Chlorinated

and parent polycyclic aromatic hydrocarbons in environmental samples from an electronic waste recycling facility and a chemical industrial complex in China. *Environ Ental Science and Technology*, *43*(3), 643–649. http://doi.org/10.1021/es802878w

Maobe, M. A. G., Gatebe, E., Gitu, L., & Rotich, H. (2012). Profile of Heavy Metals in Selected Medicinal Plants Used for the Treatment of Diabetes, Malaria and Pneumonia in Kisii Region, Southwest Kenya. *Global Journal of Pharmacology*, *6*(3), 245–251.

Muller, G. (1969). Index of geoaccumulation in sediments of the Rhine River. *Geological Journal*, *2*, 108–118.

Muller, G. (1981). The heavy metal pollution of the sediments of Neckars and its tributary: a stocktaking. *Chemiker-Zeitung*, *105*, 157–164.

Musee, N. (2011). Nanotechnology risk assessment from a waste management perspective: Are the current tools adequate? *Human & Experimental Toxicology, 30*(8), 820-835.

Ofudje, E. A., Alayande, S. O., Oladipo, G. O., Williams, O. D., & Akiode, O. K. (2014). Heavy metals concentration at electronic-waste dismantling sites and dumpsites in Lagos, Nigeria. *International Research Journal of Pure and Applied Chemistry*, *4*(6), 678–690.

Pradhan, J. K., & Kumar, S. (2014). Informal e-waste recycling: environmental risk assessment of heavy metal contamination in Mandoli industrial area, Delhi, India. *Environmental Science and Pollution Research*, *21*(13), 7913–7928. http://doi.org/10.1007/s11356-014-2713-2

Quan, S. X., Yan, B., Yang, F., Li, N., Xiao, X. M., & Fu, J. M. (2015). Spatial distribution of heavy metal contamination in soils near a primitive e-waste recycling site. *Environmental Science and Pollution Research*, *22*(2), 1290–1298. http://doi.org/10.1007/s11356-014-3420-8

Qin, F., Ji, H., Li, Q., Guo, X., Tang, L., & Feng, J. (2014). Evaluation of trace elements and identification of pollution sources in particle size fractions of soil from iron ore areas along the Chao River. *Journal of Geochemical Exploration, 138*, 33-49.

Radojevic, M. and Bashkin, V.N. (2006). Practical Environmental Analysis, (2nd edn), Royal Society of Chemistry. Cambridge U.K. Publishing: 147-170.

Suciu, I., Cosma, C., Todica, M., Bolboaca, S. D., & Jantschi, L. (2008). Analysis of soil heavy metal pollution and pattern in Central Transylvania. *International Journal on Molecular Science*, *9*(4), 434–453. http://doi.org/10.3390/ijms9040434

Tang, X., Chaofeng, S., Dezhi, S., Sardar, A. C., Muhammad, I. K., Congkai, Z., & Yingxu, C. (2009). Heavy metal and persistent organic compound contamination in soil from Wenling: An emerging e-waste recycling city in Taizhou area, China. *Journal of Hazardous Materials*, *173*(1-3), 653–660. http://doi.org/10.1016/j.jhazmat.2009.08.134

Taylor, S. R., & McLennan, S. M. (1985). *The Continental Crust: Its Composition and Evolution.* Blackwell Scientific Publications, Oxford.

Thorpe, A., & Harrison, R. M. (2008). Sources and properties of non-exhaust particulate matter from road traffic: A review. *Science of the Total Environment*, *400*(1-3), 270–282. http://doi.org/10.1016/j.scitotenv.2008.06.007

Timothy, A., & Olajumoke, M. A. (2014). Heavy Metal Concentrations around a Hospital Incinerator and a Municipal Dumpsite in Ibadan City, South-West Nigeria. *Journal of Applied Science, Environment and Management*, *17*(3), 419–422.

Tiimub, B. M., & Dartey, E. (2015). Determination of selected heavy metals contamination in water from downstream of the Volta Lake at Manya Krobo district in eastern region of Ghana. *International Research Journal of Public and Environmental Health,* 2(11), 167-

173. http://dx.doi.org/10.15739/irjpeh.035

Tomilson, D. C., Wilson, J. G., Harris, C. R., & Jeffrey, D. W. (1980). Problems in assessment of heavy metals in estuaries and the formation of pollution index. *Environmental Evaluation*, *33*(1), 566–575. http://doi.org/10.1007/BF02414780

Tsydenova, O., & Bengtsson, M. (2011). Chemical hazards associated with treatment of waste electrical and electronic equipment. *Waste Management*, *31*(1), 45–58.

Tchounwou, P. B., Yedjou, C. G., Patlolla, A. K., & Sutton, D. J. (2012). Heavy metal toxicity and the environment. *In Molecular, Clinical and Environmental Toxicology* (pp. 133-164). Springer Basel.

Wagner, T. P. (2009). Shared responsibility for managing electronic waste: A case study of Maine, USA. *Waste Management*, *29*(12), 3014–3021.

Wahabu, S., Fosu-Mensah, B. Y., & Nyame, F. K. (2015). Impact of Charcoal Production on Physical and Chemical Properties of Soil in the Central Gonja District of the Northern Region, Ghana. *Environment and Natural Resources Research*, *5*(3), 11–18. http://doi.org/10.5539/enrr.v5n3p11

Walkley, A., & Black, I. A. (1934). An examination of the Degtjaref method for determining soil organic matter, and a proposed modification of the chronic acid titration method. *Journal of Soil Science*, *37*, 29–38.

Wang, J., Chen, S., Tian, M., Zheng, X., Gonzales, L., Ohura, T., Mai, B.,& Massey Simonich, S. L. (2012). Inhalation cancer risk associated with exposure to complex polycyclic aromatic hydrocarbon mixtures in an electronic waste and urban area in South China. *Environmental Science and Technology*, *46*(17), 9745–9752.

http://doi.org/10.1021/es302272a

Wang, X. Y., Li, Q. B., Luo, Y. M., Ding, Q., Xi, L. M., Ma, J. M., Li, Y., Liu, P. Y., & Cheng, C. L. (2010). Characteristics and sources of atmospheric polycyclic aromatic hydrocarbons (PAHs) in Shanghai, China. *Environmental Monitoring and Assessment*, *165*(1-4), 295–305.

WHO/FAO. (2001). *Codex Alimentarius Commission. Food Additives and Contaminants. Joint FAO/WHO Food Standards Programme, ALINORM 10/12A*. Retrieved from www.transpaktrading.com/static/pdf/research/achemistry/introTofertilizers.pdf

WHO/FAO. (2007). *Joint FAO/WHO Food Standard Programme Codex Alimentarius Commission 13th Session. Report of the Thirty Eight Session of the Codex Committee on Food Hygiene.* Houston, United States of America, ALINORM 07/30/13.

Wong, M. H., Wu, S. C., Deng, W. J., Yu, X. Z., Luo, Q., Leung, A. O. W., Luksemburgd, W. J., & Wongd, A. S. (2007). Export of toxic chemicals – A review of the case of uncontrolled electronic-waste recycling. *Environmental Pollution*, *149*(2), 131–140. http://doi.org/10.1016/j.envpol.2007.01.044

Xianjin, T., Shen, C., Shi, D., Cheema, S. A., Khan, M. I., Zhang, C., & Chen, Y. (2010). Heavy metal and persistent organic compound contamination in soil from Wenling: An emerging e-waste recycling city in Taizhou area, China. *Journal of Hazardous Materials*, *173*(1-3), 653–660. http://doi.org/10.1016/j.jhazmat.2009.08.134

Yongming, H., Peixuan, D., Junji, C., & Posmentier, E. (2006). Multivariate analysis of heavy metal contamination in urban dusts of Xi'an, Central China. *Science of The Total Environment*, *355*(1-3), 176–186. http://doi.org/10.1016/j.scitotenv.2005.02.026

Zhang, W. H., Wu, Y. X., & Simonnot, M. O. (2012). Soil contamination due to e-waste disposal

and recycling activities: A review with special focus on China. *Pedosphere*, *21*(4), 434–455. http://doi.org/10.1016/S1002-0160(12)60030-7

Zhang, X., Yang, F., Luo, C., Wen, S., Zhang, X., & Xu, Y. (2009). Bioaccumulative characteristics of hexabromocyclododecanes in freshwater species from an electronic waste recycling area in China. *Chemosphere*, *76*(11), 1572–1578. http://doi.org/10.1016/j.chemosphere.2009.05.031

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Public interest statement

The reclamation of land around the Korle Lagoon in Accra, where burning of e-waste and cultivation of vegetables take place is a national issue in Ghana. The recycling of Electronic waste (E-waste) around the Lagoon and the cultivation of vegetables at the adjoining area make risk assessment of heavy metal contaminations of the area highly important. The open burning of E-waste produce fumes which contain heavy metals and other polyaromatic compounds which eventually end up in soils and vegetation of the reclaimed area. Heavy metals in food and water in relatively high concentration has serious health implications such as injury to the kidney or kidney dysfunction among others. This makes study of heavy metal concentration levels in area crucial for public health reason.

Table 1. Summary of physico-chemical characteristics of soils at different zones in Korle Lagoon area in Accra

Sites	S1	S2	S3	S4	S5	S6	Total means
pH	6.72	7.69	4.67	7.47	7.45	7.27	6.93
%0C	0.85	0.48	0.44	0.42	0.38	0.42	0.50
%OM	2.51	1.42	1.40	1.14	1.13	1.25	1.48
K^+	1.52	0.78	1.52	1.32	0.71	0.58	1.07
Na^+	6.15	2.13	6.07	3.69	3.12	2.01	3.86
Ca^{2+}	97.87	11.70	15.46	18.45	30.31	10.13	30.65
Mg^{2+}	73.40	8.80	11.60	14.00	23.00	7.60	23.07

S1 = E-waste area, S2= garden area, S3= a reclaimed waste dump site, S4 = a recreational site, S5= the estuary area of the Korle Lagoon and S6 = control

Table 2. Summary of mean of Heavy metal concentration of soils with 0 – 20cm depth for different zones in Korle Lagoon area in Accra

Heavy metals	S1	S2	S3	S4	S5	S6
			(mg/kg)			
Hg	0.67(0.021)a	nd	nd	0.04(0.006)b	0.003(0.003)b	0.03(0.002)b
Pb	183.66(0.02)a	1.28(0.02)bc	4.39(0.01)b	17.41(0.06)bd	12.65(0.06)b	3.33(0.06)b
Cu	202.99(1.27)a	3.47(0.05)bc	5.20(0.06)be	10.9(1.10)bd	6.39(0.06)bf	3.84(0.06)bg
Zn	37.33(0.58)a	0.83(0.05)bf	2.05(0.03)bc	6.33(0.01)bd	4.51(0.05)be	1.03(0.01)bg
Cr	56.0(1.15)a	3.03(0.10)b	2.28(0.58)b	2.36(0.06)b	20.99(0.06)b	2.63(0.17)b
Cd	103.66(1.73)a	3.55(0.58)b	nd	0.23(0.06)b	0.04(0.01)bc	4.35(0.06)bd
Ni	72(1.16)a	0.91(0.05)b	1.09(0.03)b	4.56(0.12)bc	1.59(0.01)b	1.48(0.003)b
Sn	704.87(2.71)a	27.39(0.86)b	8.77(0.112)bc	16.48(0.23)bd	14.85(0.20)be	24.71(0.12)bf
As	3.67(0.06)a	0.08(0.01)bc	0.47(0.06)bd	1.41(0.00)be	0.88(0.06)bf	0.04(0.012)b

Values in the parentheses are the standard error, S1 = E-waste area, S2= garden area, S3= a reclaimed waste dump site, S4 = a recreational site, S5= the estuary area of the Korle Lagoon and S6 = control, SE=Standard Error, and nd not detected. Means followed by a different letter(s) in the same row differ significantly (p=0.05) according to Tukey's Multiple Range Test.

Table 3. Comparison of heavy metal concentration in E-waste dumpsites of some cities of the world with data from E-waste site at the Korle Lagoon area in Accra.

Cities	Hg	Pb	Cu	Zn	Cr	Cd	Ni	Sn	As	Reference
Wenling	0.47	187.30	180.66	343.19	101.29	3.00	48.97	-	-	Tang et al. (2009)
Ibadan	-	427.2	938.2	10670	72.96	-	34.78	-	-	Timothy and Olajumoke (2014)
Lagos	-	209	-	262.2	27.05	28.032	64.17	-	-	Ofudje et al. (2014)
Guiyu, Guangdong Province	0.21	150	4800	330	2600	1.21	480	-	26.03	Li et al. (2011)
Guiyu	-	222.8	684.1	572.8	-	1.36	278.4	3472	-	Quan et al. (2015)
Bangalore, India	<0.05	126	429	192	54	0.478	-	-	-	Ha et al. (2009)
Accra	0.65	183.66	203.0	37.3	56	103.7	72.0	705.3	3.67	This research

Table 4. Geoaccumulation Index (Igeo)

heavy metals	S1	S2	S3	S4	S5	S6
Hg	-0.60	ND	-5.06	-4.67	ND	ND
Pb	3.30	-3.87	-2.49	-0.11	-0.57	-2.10
Cu	1.30	-4.57	-4.43	-2.93	-3.69	-3.99
Zn	-1.49	-7.00	-6.67	-4.05	-4.54	-5.68
Cr	-1.42	-5.63	-5.84	-5.99	-5.65	-6.14
Cd	8.43	3.56	3.86	-0.51	-2.94	ND
Ni	-0.64	-6.95	-6.25	-4.63	-6.14	-6.70
Sn	7.88	3.19	3.04	2.46	2.31	1.55
As	0.44	-5.08	-6.22	-0.94	-1.62	-2.55

S1 = E-waste area, S2= garden area, S3= a reclaimed waste dump site, S4 = a recreational site, S5= the estuary area of the Korle Lagoon and S6 = control

Table 5. Enrichment factor (EF) of heavy metals for soil at different zones in Korle Lagoon area in Accra

Sites	S1	S2	S3	S4	S5	S6	**PLI**
Hg	848.72	ND	38.58	51.44	ND	ND	1.534
Pb	9.71	0.07	0.18	0.92	0.67	0.23	2.970
Cu	0.55	0.01	0.01	0.03	0.02	0.01	0.705
Zn	0.06	0.00	0.00	0.01	0.01	0.00	0.124
Cr	0.05	0.00	0.00	0.00	0.00	0.00	0.115
Cd	21328.05	730.41	895.01	47.32	8.23	ND	93.18
Ni	0.11	0.00	0.00	0.01	0.00	0.00	0.181
Sn	1450.26	56.35	50.84	33.91	30.55	18.04	66.43
As	9.32	0.20	0.10	3.58	2.24	1.19	0.606

S1 = E-waste area, S2= garden area, S3= a reclaimed waste dump site, S4 = a recreational site, S5= the estuary area of the Korle Lagoon and S6 = control, PLI= pollution load index

Table 6. Summary of heavy metal concentration in vegetation at the Korle Lagoon area in Accra

Heavy metals	S1	S2	S3 (mg/kg)	S4	S5	S6
Hg	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Pb	36.72(0.57)a	0.69(0.34)bc	0.48(0.05)bd	<0.001	3.81(0.12)be	0.55(0.80)b
Cu	95.56(0.58)a	10.13(1.04)bc	0.21(0.03)bd	6.92(0.05)be	5.48(0.27)bf	0.21(0.03)b
Zn	34.92(0.59)a	8.04(0.20)bc	14.84(1.13)be	7.88(0.06)bf	7.36(0.40)bg	1.33(0.12)b
Cr	1.56(0.12)a	1.21(0.11)ac	1.08(0.05)a	3.84(0.04)b	3.52(0.29)b	1.23(0.57)a
Cd	1.64(0.12)a	0.83(0.09)bc	0.92(0.04)be	0.44(0.03)b,	0.32(0.06)b,	0.25(0.06)b,
Ni	2.0(0.12)a	5.28(1.72)a	2.25(0.03)ad	2.2(0.12)ae	6.80(0.58)b,	0.59(0.11)ac,
Sn	22(1.15)a	17.17(1.47)a	3.23(0.06)b	2.52(0.12)b	4.64(0.38)b	22.29(4.89)a
As	0.32(0.05)a	nd	0.12(0.01)b	0.08(0.01)bc	0.16(0.12)be	0.19(0.01)b

S1 = E-waste area, S2= garden area, S3= a reclaimed waste dump site, S4 = a recreational site, S5= the estuary area of the Korle Lagoon and S6 = control, SE=Standard error, nd not detected. Means followed by a different letter(s) in the same row differ significantly (p=0.05) according to Tukey's Multiple Range Test, values in the parentheses are the standard error.

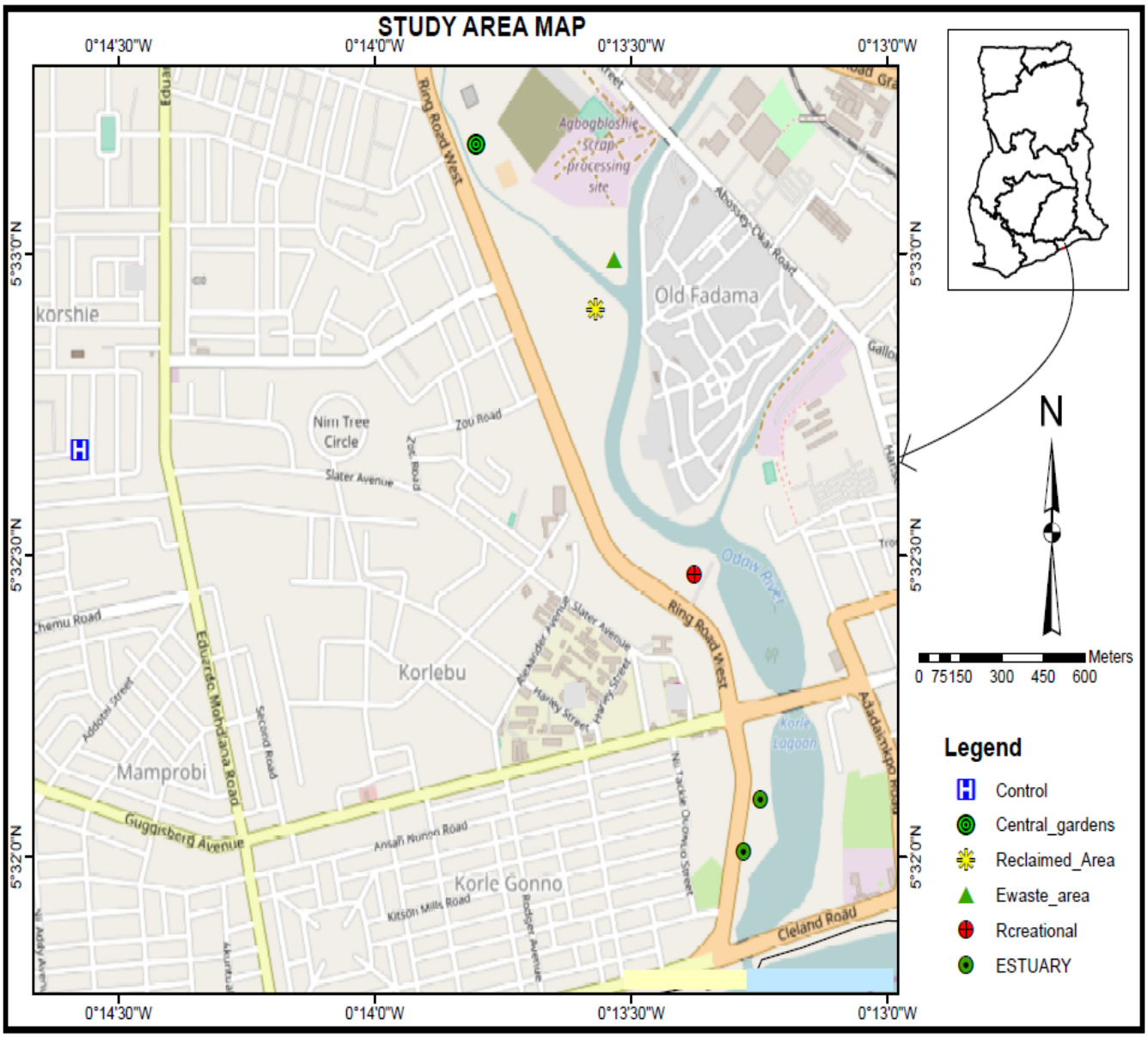

Figure 1. Map of the study area showing sampling sites