

Assessment of heavy metal pollution resulting from informal E-wastes recycling in the Greater Accra Region of Ghana

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Research

Keywords: E-waste recycling, heavy metals, Igeo, PLI, CF, Spatial distribution, Ashaiman scrapyard

Posted Date: May 3rd, 2021

DOI: <https://doi.org/10.21203/rs.3.rs-390412/v1>

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Abstract

This study investigated the levels and spatial distributions of four selected heavy metals in the soil and drainage components emanating from informal E-waste recycling activities at Ashaiman scrapyards, in the Greater Accra Region, Ghana. The metals are Cadmium (Cd), Chromium (Cr), Copper (Cu) and Lead (Pb). Five sampling sites were randomly selected, with top and sub-soil sampled from the two open burning areas (hereafter H and F). Three sites in the drainage that runs through the scrapyards were similarly selected for sample collection; a control upstream (soil-sediment-water; WSC) and two experimental units downstream (soil-sediment-water; WS1 and surface water only; WS2). Four control topsoil samples were taken at distances of 25, 50, 75 and 100 m away from the scrapyards. Composite samples of three sampling units per site, including pH analysis, with two replications per treatment, were investigated using standard methods. Spatial distribution of the metals in the scrapyards were analyzed using Inverse Distance Weighted (IDW) interpolation method. Coefficient of variation (CV) was used to investigate the source of pollution. The pollution levels were investigated using three criteria, namely Geoaccumulation Index (Igeo), Contamination Factor (CF) and Pollution Load Index (PLI). Correlation analysis was used to evaluate the relationships between the metals. Mean CV of 88.5% suggests that the scrapyards pollution is anthropogenically-driven. Igeo of soil samples from the scrapyards revealed the following: (i) Cd and Pb (unpolluted to strongly polluted), (ii) Cu (unpolluted to moderately polluted), and (iii) Cr (unpolluted). CF revealed the following: (i) Cd (moderate to strong pollution), (ii) Cu (moderate pollution), (iii) Cr (low pollution), and (iv) Pb (high pollution), but the metals exhibited moderate PLIs. Spatial distribution maps revealed heavy metal pollution decline with distance away from the scrapyards, which was inversely related to pH levels. WSC showed lower heavy metal concentrations than WS 1, while the lowest levels were detected in WS 2. Generally, moderate to very strong correlations existed among the metals in the scrapyards. In conclusion, the scrapyards were the epicenter of E-waste pollution primarily driven by human activities.

1. Introduction

E-wastes cover Electrical and Electronic Equipment (EEE) and their parts that have been discarded by their owners as wastes without the intent of re-use or recycling. Due to their different lifespan profiles, different E-wastes have different environmental and health impacts as well as different economic value [1]. Owing to rapid changes in technological updates and upgrades of EEE, industrialization and modernization, increase in disposal income and the popularized increase in the use of EEE, there is an upsurge in the acquisition and utilization of electrical and electronic products. Consequently, the generation of E-wastes is one with the largest and fastest growth rates among wastes in the world. Asia contributed most to the generation of E-waste in 2019, generating close to 24.9 million metric tons (Mt), followed by Europe (12.0 Mt), Americas (13.1 Mt), Africa (2.9 Mt) and Oceania (0.7 Mt) [1, 2].

As a result of free and illegal trading activities and the lack of implementation of environmental policies, African countries receive high quantities of potential E-waste materials from developed countries. Nigeria and Ghana are notably mentioned [3]. Around 600,000 of used EEE were imported into Nigeria in 2010.

Also, close to 30% of second-hand imports into the country were considered non-functioning and thus regarded as E-waste. Ghana's E-waste quantities rose from 63,000 tons per year in 2003 to 169,000 tons per year in 2008 with a further increment to 215,000 tons in 2009. Only 30% of the total electrical appliances that arrived in Ghana in 2009 were determined to be new, with the rest regarded as used products, 15% of which were either faulty or outmoded and thus could not be sold, eventually ending up in the informal recycling sector [4].

However, E-waste materials in Africa are poorly managed, due to unawareness of the public on the dangers of poor disposal systems, lack of safe systems of disposal, absence of government policy and legislation or the enforcement of same and the domination of E-waste management by the unhindered and badly equipped informal sector [1]. Manual dismantling, open burning and land filling, of E-wastes result in the release of toxic substances, including polycyclic aromatic hydrocarbons (PAHs), organochlorine compounds, phthalates and heavy metals [2, 5]. The release of these compounds results in atmospheric pollution, soil acidification and leaching, polluting both ground and surface waters. Soil composition and viability to support plant life is compromised severely following E-waste contamination while deteriorating the quality of water resources causing a reduction in their physicochemical characteristics including pH, phosphate, oxygen and chloride levels [6, 7]. Essentially, poor E-waste management has a negative outlook on the realization of the Sustainable Development Goals (SDGs), particularly Goals 3 (Good Health and Well-being), 6 (Clean Water and Sanitation), 8 (Decent Work and Economic Growth), 11 (Sustainable Cities and Communities), 12 (Responsible Consumption and Production) and 14 (Life Below Water) [1].

Heavy metals are significant components of E-wastes. The application of these metals in electrical gadgets is influenced by factors such as good electrical conductivity to minimize power losses, providing an inert environment in operations to ensure reliability of functioning as well the use of metals compatible with manufacturing processes [8]. Approximately 60% of E-wastes constitute metal such as gold (Au), copper (Cu), iron (Fe) and tin (Sn) [2, 6]. The parent circuit board of many electrical gadgets houses many heavy metals, including arsenic (As), cadmium (Cd), lead (Pb) and mercury (Hg) [2]. Also, Pb constitutes close to 0.4-1.0 kg of the total mass of cathode ray tube found in computer monitors and television sets respectively.

Heavy metals released during informal E-wastes recycling are absorbed into living tissues usually through the inhalation of toxic fumes and particulate matter, and ingestion of contaminated food and water [5]. Cd is a known carcinogen of the lungs, kidney and prostate, and also induces abdominal pains and infertility. Exposure to chromium (Cr) causes cardiovascular diseases, haematological and neurological effect and sometimes even death. Pollution resulting from Pb induces memory loss, dullness, sperm damage and miscarriages, while gastrointestinal effect including nausea and diarrhea, as well as neurological effect and male infertility stemming from sperm damage, result from exposure to Cu [9, 10].

E-waste recycling activities in Ghana is dominated by the informal sector, largely due to poor implementation of environmental related laws, and also for socio-economic reasons. It is estimated that between 121,800 to 201,600 individuals are involved in the informal E-waste sector in Ghana. The formal recycling sector in Ghana receives only about 0.2% of E-waste for treatment [11]. Unsurprisingly, Ghana is noted for having one of the biggest informal E-waste recycling in Africa, at the Agbogbloshie scrapyard.

This research was to assess the levels and spatial distributions of selected four heavy metals (Cd, Cr, Pb, Cu) at an informal E-waste recycling site and evaluate their levels based on permissible ranges specified by the World Health Organization (WHO), Food and Agricultural Organization (FAO) of the United States and the Environmental Protection Agency (EPA) of Ghana. The second objective was to investigate the degree of pollution using geoaccumulation index (I_{geo}), contamination factor (CF) and pollution load index (PLI). The rest of the paper are organized into the following sections: (i) Sect. 2 describes data and methods, (ii) Sect. 3 is devoted to results and discussion, and (iii) Sect. 3 describes the conclusion, recommendation and future work.

2. Materials And Methods

2.1. Study area

The Ashaiman scrapyard is located at the entry into the township from the Tema

metropolis, about 0.12 km from the Accra-Tema Motorway. Covering a land size of about 0.07 km², it is located on latitude 05° 41' 4.99" N and longitude 00° 01' 37.28" W. The region is generally flat with savannah grasses and shrubs being the dominant vegetation. The topsoil is mostly sandy-clay, with the subsoil being predominantly clay [12].

The scrapyard (Fig. 1), adapted from Okine [13], houses large metal containers which store E-waste materials until they are ready to be worked on. Dismantling and sorting activities are performed in sheds and wooden structures at sections of the scrapyard while majority of the burning is done on the open field, though few burning activities are done at the dismantling and sorting areas. At the time of research, two main sites were identified where open burning was taking place. E-waste materials found in the scrapyard included refrigerators, television sets, computers, cables, radios and incandescent light bulbs.

Located very close and separating the scrapyard from a dumpsite is a drain that flows from the northern end of the scrapyard and serves as irrigation for farm crops and drinking water for herds of cattle. The aerial view of the sampling points for the study is displayed in Plate 1.

2.2. Sample collection

2.2.1 Soil samples

Two burning sites (hereafter Site F and Site H) were chosen for soil sampling. Site F is located at the central portion of the scrapyard. Major parts of this site were used for open burning of E-wastes, though

few sections served as dumping grounds material after dismantling, sorting and burning. Site H lies closer to the drain running through the scrapyard. This site is used both for open burning and dumping of E-waste materials.

Samples were taken in the early morning of 16th July 2019. At each burning site, five top soil samples were randomly taken at five different sites (marked as 1A, 2A, 3A, 4A and 5A) within a soil depth of 0-10 cm and five subsoil samples from the sites but different level (marked as 1B, 2B, 3B, 4B, and 5B) within a depth profile of 10-20 cm. Thus, from each burning site 10 soil samples were taken, and a total of 20 samples were obtained from the two burning areas. Four other top soil samples were randomly taken at distances of 25, 50, 75 and 100 m from the scrapyard (marked as HV 20, HV 50, HV 75 and HV 100, respectively) to determine the horizontal distance from the scrapyard at which levels of heavy metals will be detected and also serve as control as well as background conditions for assessing the pollution levels. At all the sampling sites, a composite sample made up of three sampling units was collected. Soil samples were collected using newly purchased stainless-steel garden shovel and a standard measuring rule to determine the vertical depth of the soil profile. Samples were collected into plastic bowls with tightly fitting lids pre-cleaned with nitric acid. They were then sent to the Ghana Standards Authority for further treatment and analysis.

The coordinates at sampling points were recorded using GPS software.

2.2.1 Water samples

A composite of three sampling units of soil-sediment-water was collected upstream about 140 m from the scrapyard and as control (WS C). A similar procedure was replicated for two experimental units, namely soil-sediment-water samples (WS 1) at 50 m and purely surface wastewater (WS 2) at about 70 m both downstream of the scrapyard. These sampling stations were randomly selected from a range of stations that were accessible. Samples from WSC, WS 1 and WS 2 were used to test the hypothesis that high levels of heavy metals are expected to be sediment than the surface wastewater. Coordinates were measured using GPS software. pH of these samples was measured on site using a handheld HANNA pH meter calibrated with buffer solutions of pH 4, 7 and 10. The samples were collected and sent to the same place just as the soil samples.

2.3 Sample preparation and pH determination

2.3.1 Soil sample preparation and pH determination

Soil samples were air dried at around 105^o C to eliminate wetness and obtain constant weights representative of the soil only. They were then passed through a 2 mm non-metallic mesh to separate and remove rocks exceeding 6.35 mm. The soil particles passing the mesh were thoroughly homogenized by manual milling with a mortar and pestle. These preparations were necessary for good dissolution during chemical treatments and increasing the accuracy of the sample analysis [14]. To three grams of each of the dried and sieved soil samples in a 25 mL beaker (which had been pre-cleaned and thoroughly washed

with distilled water), 15 mL of aqua regia were added and the resulting sample solution digested in a fume chamber for about 30 minutes to remove any foreign material that might interfere with the analytical results. Following cooling, there was addition of distilled water to the digested soil sample. This was then filtered into a 100 mL volumetric flask using the Johnson test paper filter paper with a diameter of 125 mm. Distilled water was then added to the solution to the 100 mL mark. Spatial distributions of topsoil and subsoils were determined using Inverse Distance Weighted (IDW) interpolation method [15].

The soil pH analysis was conducted following the procedure described by Al-Busaidi et al. [16] by dissolving two grams of each sample in distilled water in a 1:1 ratio and stirred to a uniform suspended mixture using a clean glass rod. The samples were then allowed to settle for about 10 minutes and then continually stirred for about 15 minutes using a magnetic stirrer on a magnetic sifter plate. The samples were allowed to settle and their pH determined using the same calibrated instrument just as in the wastewater sample case.

2.3.2 Water sample preparation and pH determination

Two replicates each from WS 1 and WS 2 samples were digested by drawing 100 mL of each replicate into a beaker, to which 25 mL mixture of 3:2 conc. HNO_3 and conc. HCl were added and the solution digested in a fume chamber for about 20 minutes. For efficient digestion of the water samples, additional 10 mL of conc. HCl were added and heated again in the fume chamber for about 15 minutes. Upon cooling, further filtration was carried out. Distilled water was added to the filtrate and made up to the 100 mL mark.

For each soil/water sample, calibration curves were prepared using heavy metal standards: 0.50, 1.00, 2.00 and 4.00 mg L^{-1} standards were each prepared in the spectrophotometric quantification of Cr, Cu and Pb while calibration curves of concentrations 0.10, 0.20, 0.40 and 0.80 mg L^{-1} were prepared in the case of Cd. For each soil/water sample, duplicate analyses were performed using Perkin Elmer 400 Atomic Absorption Spectrophotometer (AAS) with air-acetylene gas serving as fuel for the flame. Where concentrations were very high, serial dilutions were performed on the samples and thereafter their dilution factors factored in the determination of their concentrations. All the results from soil and wastewater analyses were compared to Ghana Environmental Protection (EPA), World Health Organization (WHO), Food and Agricultural Organization (FAO) permissible limits.

2.4. Indices for determination of soil pollution

Three pollution indices were employed to evaluate the pollution levels of the four heavy metals in the scrapyards and its environs.

2.4.1. Geoaccumulation Index (Igeo)

Igeo determines the contamination of heavy metals by assessing their concentrations in sampled soils relative to background concentrations during pre-industrial periods [17, 18]. Igeo is computed using the mathematical formula given as follows:

$$I_{geo} = \log_2 (C_n / 1.5B_n) \quad (1)$$

where C_n is a measure of the heavy metal levels in the sediment under investigation while B_n represents the geochemical background level [18]. The constant 1.5 is used to lessen possible variations in the background data. In this study the four soil control sites were used as the geochemical background information by computing their expected values. Soils can be categorized into seven quality grades of pollution, as follows: Practically unpolluted, where $I_{geo} < 0$; unpolluted to moderately polluted where $I_{geo} = 0-1$; moderately polluted where $I_{geo} = 1-2$; moderately to strongly polluted where $I_{geo} = 2-3$; strongly polluted where $I_{geo} = 3-4$; strongly to extremely polluted where $I_{geo} = 4-5$ and extremely polluted where $I_{geo} > 5$ [18, 19].

2.4.2. Contamination Factor (CF)

CF evaluates quantities of an element in a sample normalized over that of pre-industrial baseline value for the element. Mathematically, CF [20] is expressed as

$$CF = C_e / C_i \quad (2)$$

where C_e and C_i are respectively the concentration levels of the heavy metal in the sample of interest and the background value of the heavy metal of interest. Based on values obtained, soil or sediments can be classified as follows: no or low contamination where $CF < 1$; moderate contamination where $1 < CF < 3$; considerable contamination where $3 < CF < 6$; very high contamination where $CF > 6$ [21].

2.4.3. Pollution Load Index (PLI)

PLI [20] examines the mutual contribution of a group of metals to the pollution of a site. Mathematically, $PLI = (CF_1 \times CF_2 \times CF_3 \times CF_4 \times CF_5 \times \dots \times CF_n)^{1/n}$ (3)

where CF represents the contamination factor of each heavy metal element in a sampled soil and n is the number of heavy metals under consideration. The PLI gives an indication of whether the site under consideration is: lightly polluted, where $PLI \leq 1$; moderately polluted, where $1 < PLI \leq 3$; highly polluted, where $PLI > 3$ [21, 22].

2.6. Statistical analysis

Means of the heavy metal concentrations were computed and compared to reference values. The associated standard deviations were computed to determine the distributions of the metals. Differences in means were analyzed using t-test at 95% confidence level. These parameters were computed using Microsoft Excel software 2016 version. The relationships among the metals in the topsoil and subsoil at

sites H and F were quantified using Pearson correlations. Coefficient of variations (CVs) of the heavy metal concentrations were computed to determine the source of pollution, using by SPSS version 21.0.

3. Results And Discussion

3.1. Soil pH and heavy metal accumulation

3.1.1 Soil pH

Table 1 displays the permissible levels of metals in soil and water by Ghana EPA, WHO/FAO, whereas Tables 2-3 present pH and the four heavy metal concentrations at Sites F and H. pH values ranged from mild acidic to high alkaline conditions (5.88- 8.03) with an average of 7.13 at for Site F (Table 2). At site H (Table 3), pH ranged from 6.07 to 7.78, with a mean of 6.94. Heavy metal adsorption and retention by soil increases generally occur within a pH range of 4-7 [23, 24], thus the pH range could partly account for the elevated levels of heavy metals in the samples. pH values recorded were within the WHO benchmark of 6.5-8.5, except for three samples (5.88 at Site F and 6.07, 6.38 at site H), where pH values were below the 6.5 minimum threshold. Relatively high pH value recorded in sample 5B (8.03) could be due to the presence of alkaline batteries, steel mill, and ashes from the incineration processes at the E-waste site.

3.1.2. Heavy metal concentration

Several factors, such as electron activity, soil texture, soil pH, ionic strength and level of organic matter, affect the metallic forms in soil matrix. Cd was found to be the least in concentration among the heavy metals in the two soil profiles at site F, from non-detection levels to a maximum of 1.57 ppm and an average concentration of 0.48 ppm (Table 2). With the exception of one sub-soil sample with a concentration of 1.57 ppm, all Cd concentrations at Site F were below the Ghana EPA permissible limit of 1 ppm and the WHO/FAO standard of 3 ppm (Tables 1-2). Cd mobility is dependent on several factors such pH and presence of organic matter that has strong affinity for the metal. The mean pH at this site was alkaline (7.13), which limits its availability, thus accounting for its low concentrations at this site [25, 26-28]. At site H, Cd concentrations were relatively higher, with a minimum of 0.29 ppm and a maximum of 13.56 ppm and an average concentration of 4.14 ppm, which exceeds both Ghana EPA and the WHO/FAO standards (Tables 1 and 3). At this site, the mean pH was 6.94. The slightly acidic conditions may have contributed to the high levels of the metal. E-waste materials with Cd at the scrapyard include printed circuit boards, batteries, accumulators, cathode ray tubes and ultraviolet lights. Site H had higher concentrations of Cd than Site F because Cd-containing E-waste materials were located more at the former site than the latter.

The minimum and maximum concentrations recorded at site F for Cr ranged from 13.97 to 162.50 ppm with an average concentration of 77.33 ppm. Most Cr concentrations exceeded the Ghana EPA threshold value of 30 ppm (Tables 1-2). Three samples also had Cr concentrations (123.07, 162.50 and 117.27 ppm) above the WHO/FAO standard of 100 ppm. However, Cr levels obtained in samples from site H were below the permissible limit of WHO/FAO and Ghana EPA with minimum and maximum concentrations of

15.95 and 30.11 ppm, respectively and an average of 21.00 ppm (Tables 1 and 3). Comparatively, Cr concentrations at site F were higher than those at site H, which could be due to the fact that the metal containers that house E-waste materials were closer to site F. They are typically composed of steel and chromium, so any wear and tear on the metal adds on Cr concentrations to the soil, pH also being a factor.

At site F (Table 2), the minimum and maximum concentrations recorded for Cu were 29.97 and 253.42 ppm, respectively, with an average concentration of 114.85 ppm. The concentrations exceeded permissible levels of Ghana EPA (20 ppm) and the WHO/FAO standards of 100 ppm (Table 1). Also, the minimum and maximum concentrations of Cu at site H ranged from 5.24 to 108.76 ppm with an average concentration of 48.37 ppm, which were above the national and international limits (Tables 1 and 3). Cu finds application in most electrical and electronic appliances, such as printed circuit boards, cathode ray tubes, bare/insulated wires and in refrigeration units. Majority of the samples had high levels of Cu in the topsoil than the subsoil. These may be attributable to the strong binding between Cu and organic matter and minerals in the soil. Consequently, its mobility is suppressed, and hence cannot be leached into the subsoil [29, 30]. Also, the prevailing alkaline conditions in the topsoil played a critical role (Table 3).

Ranging from 13.58 to 276.78 ppm, with an average concentration of 77.07 ppm, at site F, Pb level was found to have exceeded the WHO/FAO and Ghana EPA standard of 50 and 20 ppm, respectively (Tables 1-2). Elevated levels were detected for Pb, ranging from 17.81 to 1000.85 ppm, with an average concentration of 341.43 ppm at site H, with so obvious exceedance (Tables 1 and 3). The lowest and the highest levels were all detected on the topsoil. E-waste materials with Pb include cathode ray tubes, fluorescent bulbs, batteries and fuses. The elevated Pb levels from site F to H is reflective of low organic matter in the presence of slightly alkaline to near-neutral mean soil pH. It is contemplated that the elevated levels of Pb is a consequence of metal accumulation arising for all the operational years of the scrapyard. The extent of pollution at site F and H can be respectively expressed as follows: Cu > Cr > Pb > Cd and Pb > Cu > Cr > Cd.

Heavy metals concentrations in this study were similar to other E-waste research [4, 31, 32]. Generally, Cu and Pb were in high concentrations in most of the research studies, suggesting an extensive use of the two metals in electrical appliances, whereas Cd concentrations seem to be on the lower side in most E-waste soils in other research works (e.g., Table 4).

3.3. Statistical Studies

Tables 5a-g present the relationships between the metal levels at the following sampling sites: (i) Topsoil at site F, (ii) Subsoil at F, (iii) Topsoil at site H, (iv) Subsoil at site H, (v) Topsoil at F and H, (vi) Subsoil at F and H, and (vii) Topsoil and subsoil over the scrapyard. These were quantified using Pearson correlation coefficient metric r .

The following were the key findings at the following sampling sites: (i) In the topsoil at site F, only Cd and Cu were significant, but exhibited out-of-phase relation ($r = 0.667$; $p < 0.01$; Table 5a); (ii) In the subsoil at

site F (Table 5b), Cu, Cd, and Pb all exhibited in-phase relationships (Cu vs. Cd $r=0.926$; $p<0.01$; Pb vs Cd $r=0.956$; $p<0.05$; Pb vs. Cu $r=0.889$; $p<0.05$);

In the topsoil at site H (Table 5c), it is only Pb and Cu that were significant and exhibited an in-phase relationship ($r=0.675$; $p < 0.01$). In the subsoil at site H (Table 5d), Cr, Cd, and Cu showed significant in-phase relationships (Cr vs. Cd $r=0.786$; $p<0.01$; Cu vs. Cd $r= 0.978$; $p<0.05$; and Cu vs. Cr, $r= 0.653$; $p<0.01$).

In the topsoil at F and H (Table 5e), Cd, Cr and Cu at site F, and Cr and Pb at site H, showed good correlations. The in-phase relationship ranged from $r=0.693$ to 0.779 ; $p<0.05$ and $p<0.01$). These were captured for Pb vs. Cr, Cr vs. Cd, and Cd vs Cu. In contrast, Cd vs. Cr ($r=-0.770$; $p<0.01$) showed an out-of-phase relationship. Across the scrapyards, in the study area (Table 5g), the topsoil and subsoil revealed in-phase relationships for Cr vs. Cr ($r=0.821$; $p<0.05$), Pb vs Cd ($r=0.734$; $p<0.01$) and Pb vs. Pb ($r=0.79$; $p<0.05$).

From these results, it has been revealed that the in-phase relationships dominate the relationships and suggest synchronization of activities and chemical processes emanating from human E-waste recycling activities, whereas the out-of-phase relationships suggest otherwise. For instance, the in-phase relationships observed between pairs of heavy metals may be due to the dual complementary usage they have in certain EEE products. Cd and Pb find close applications in cathode ray tubes where Cd is used as the fluorescent powder coatings to produce color while Pb is employed to absorb the UV lights and X-rays produced. Cd is added to Cu to form alloys in Cd-Cu wire which are more resistant to softening at higher temperatures. Pb is also alloyed to Cu to act as a lubricant and also assist in chip break up, thereby increasing the machinability of the Cu metal. Since site H is used as a burning site and dumping grounds for burnt E-waste products, heavy metals may be carried from site F to site H. This could explain the positive correlation between heavy metals at different sites.

A coefficient of variation (CV) analysis carried out to determine if the presence of the heavy metals was due to natural or anthropogenic source showed CV for Cd, Cr, Cu and Pb to be 137, 58, 61 and 104%, respectively at site F, and 108, 22, 125 and 93% for Cd, Cr, Cu and Pb, respectively at site H. According to Guo et al. [33], a CV less than 20% indicates natural sources while values greater than 50% imply anthropogenic sources. By inference the heavy metal pollutions were due to anthropogenic sources, specifically E-waste activities.

An independent t-test analysis showed statistically significant differences in mean concentrations of the heavy metals, which are as follows:

1. significant difference between Cd concentrations at site F (Mean (M)=0.39, Standard deviation (SD)=0.53) and Cd concentrations at site H (M=4.14, SD=4.46), with a t-value of -2.50 and p-value of 0.02 (data are not normally distributed; skewed).
2. significant difference between Cr concentrations at site F (M=77.33, SD=44.57) and Cr concentrations at site H (M=21.00, SD=4.65), with a t-value of -3.98 and p-value of 0.001 (data are normally distributed).

3. significant difference between Cu concentrations at site F (M=114.85, SD=70.33) and Cu concentrations at site H (M=48.37, SD=6.58), with a t-value of 2.27 and p-value of 0.04 (data are normally distributed).
4. significant difference between Pb concentrations at site F (M=77.07, SD=80.10) and Pb concentrations at site H (M=341.43, SD=317.96), with a t-value of -2.55 and p-value of 0.02 (data are not normally distributed; skewed for Pb at site F and normally distributed for same metal at site H).

3.4. Indices of pollution

3.4.1. Geoaccumulation Index

Table 6 below shows I_{geo} of sampled soil of the two sites. The I_{geo} showed site F was practically uncontaminated with Cd (average $I_{geo} = -1.58$) and Cr (average $I_{geo} = -1.07$) but unpolluted to moderately polluted with Cu (average $I_{geo} = 0.53$) and Pb (average $I_{geo} = 0.76$). At site H, index of geoaccumulation showed a moderate to strong pollution with Cd (average $I_{geo} = 2.16$) and Pb (average $I_{geo} = 2.64$), a practically unpolluted soil with Cr (average $I_{geo} = -2.72$), and Cu (average $I_{geo} = -1.63$). Site H appears more contaminated than site F, probably due to its dual role as a burning and dumping site for E-waste materials. Pb levels at site H for instance was in category 3 of the I_{geo} classification.

3.4.2. Contamination Factor and Pollution Load Index

Table 7 shows CF and PLI of the two sites. The CF showed site F had moderate contamination of Cd (average CF= 1.30) and Cu (average CF=2.55), low contamination of Cr (average CF= 0.86), and considerable contamination of Pb (average CF= 3.85). At site H, CF showed very high contamination of the soil with Cd (average CF= 13.80) and Pb (average CF= 17.07), no or low contamination of the soil with Cr (average CF= 0.24), moderately contaminated soil with Cu (average CF= 1.08). Again, results show more contamination of Site H than Site F, possibly because of the dumping activities in addition to the open burning. PLI of both sites were found to be moderately polluted, with averages of 1.47 and 2.16 at sites F and H, respectively.

3.5. Spatial distribution of heavy metals

Figures 2-4 show spatial distribution patterns of the heavy metals at the two sites, which were analyzed using the Inverse Distance Weighted (IDW) interpolation method. The analysis revealed elevated levels of heavy metals in subsoil (Cd, Pb at site H and Cr, Cu at site F), which indicates a possible leaching from the surface soil. The distribution pattern showed Cu retained more at the topsoil of site F and the northern section of site H, indicating high presence of organic matter. Spatial maps also revealed site H was polluted more with Pb and Cd while site F was polluted with mostly Cr and Cu.

3.6. Concentration differences at increasing distance from scrapyards

Figure 8 depicts the metal concentrations as a function of distance away from the scrapyard. Soil samples taken at 25, 50, 75 and 100 m away from the scrapyard were mostly sandy. pH values were mildly acidic, decreasing with distance away from the scrapyard, but within the WHO 6.5-8.5 thresholds. This is expected, as increasing distance from the scrapyard means decreasing heavy metals concentrations, which are mostly alkaline. This finding is comparable to a study by [34] where the pH at a dumpsite decreased from 5.9 to 4.7 at a distance of 18 m from the dumpsite.

The results practically revealed no Cd in these soil samples. Samples taken within the 25 m distance were found to contain respective concentrations of 20.73, 24.94 ppm for Cr and Cu and were within safe levels set by WHO/FAO but slightly above permissible levels of Ghana EPA with respect to Cu. However, Pb recorded a concentration of 155.17 ppm which exceeds the safe levels of Pb in soil as determined by both WHO/FAO and Ghana EPA. pH of the soil sample at 25 m was almost neutral at 6.97.

The levels of Cr and Cu in soil samples within the 50 m boundary were again within the safe limits set by WHO/FAO, but above permissible levels of Ghana EPA, with respective concentrations of 25.18 and 96.73 ppm. Pb levels again exceeded the 50 ppm threshold of WHO/FAO and the 20 ppm threshold of Ghana EPA, reaching levels of 74.72 ppm. pH of the soil sample at 50 m was mildly acidic at 6.58. Soil samples taken 75 m from the scrapyard had concentrations of 4.122 ppm (Cr), 4.600 ppm (Cu) and 5.965 ppm (Pb) while at a 100 m distance variation, soil samples analyzed revealed no levels of Cr, 1.260 ppm of Cu and 8.970 ppm of Pb. It can be thus inferred that the activities at the scrapyard still have effect 25 to 50 m away from it. However, since soil samples taken at 25 and 50 m were close to the Accra – Tema motorway, contamination from road dust is still possible since heavy metals can be found in tires and brake abrasion, combustion exhaust and pavements wear [35], which can be transported by rain, runoff, dry deposition, and atmospheric drifts. and Further research will be needed to investigate this proposition.

With a general decline in the concentrations of heavy metals from the 75 and 100 m distance, the high levels of heavy metals within the scrap yard can be attributed mainly to that of the E-waste activities. Comparably, concentrations of Cr, Cu and Pb were several times higher within the scrapyard than outside of it.

The decreasing concentrations of heavy metals with increasing distances from the scrapyard agrees with other research studies which explored the effect of increasing distance from source on concentration levels of heavy metals [36, 37].

3.7. Heavy metal concentrations in sediment and water

The metal concentrations in the drain both upstream and downstream are shown in Table 9. Soil-sediment-water samples (WSC) taken outside the scrapyard showed lower concentration of heavy metals than those obtained within the scrapyard particularly at WS 1, while the four heavy metals were absent within the water at WS 2. Water sediment outside the scrapyard (WSC) was found to contain Cd and Cr, with respective concentrations of 0.03 and 11.95 ppm, whereas the levels of Cu and Pb were 5.84 and 5.89 ppm, respectively. Water sediments within the scrapyard (WS1) were found to contain 0.49 ppm Cd,

and a concentration of 217.98 ppm, for Cu. Cr had a concentration of 12.28 ppm while Pb had a concentration of 44.77 ppm. The levels of the toxic metals in the water sediments of WS1 increased significantly within the scrapyards as one moves downstream from WSC. With the wastewater drain lying in a lower plain to the two burning sites, and with movement of air current across the drain from the two burning sites, it can be fairly postulated that the E-waste activities are a possible origin for the heavy metals in the soil-sediment water samples, through the actions of wind drift and dry deposition. One other possibility is the presence of E-waste materials found near or inside the drain, causing heavy metals to dissolve into the wastewater as has been reported elsewhere [38].

The relatively concentrated amounts of heavy metals of soil-sediment-samples (WS1), compared to no detection in the surface wastewater samples at WS2 supports the research hypothesis, that heavy metals tend to be high in sediments and settleable particles than surface water [39]. WSC and WS1 samples had mild alkaline pH, indicative of the presence of the heavy metals. Levels of heavy metals in the drain represented by WS1 were all above the standard permissible levels of Ghana EPA and WHO/FAO. This is of a major concern since the drain serves as irrigation source for farm crops as well as drinking water for herds of cattle near the scrapyards.

4. Conclusions

The research revealed soil and drainage system of the Ashaiman scrapyards were polluted with Cu, Pb, Cr and Cd, mainly due to open burning and dumping of E-waste materials. The CV results indicate that the metal pollution is primarily anthropogenically driven. The research further showed levels of the heavy metals exceeded permissible limits of WHO/FAO (2011) and Ghana EPA. Igeo of soil samples from scrapyards ranged from practically unpolluted levels (Cr, Cd and Cu) to strongly polluted levels (Pb). CF at scrapyards ranged from low contamination (Cr) to a very high contamination (Cd and Pb) with a moderate PLI. Spatial distribution maps revealed pollution of the heavy metals, especially at the western north of site H and the central portion of site F.

Consequently, environmental laws and regulations on management and recycling of E-wastes should be enforced by local authorities to prevent further contamination and pollution of the scrapyards and its environs. Public awareness and education on the adverse effect of informal recycling practices should be intensified.

The study has further shown that Cd levels (at sites F and H) and Pb levels (at site F) in the scrapyards suggest skewed distributions relative to Cr and Cu (at both sites) and Pb (at site H), which are normally distributed. This outcome provides insight into modeling the behavior of these metals in future. Finally, future studies can also focus on investigation of heavy metals contamination in workers at the scrapyards and herds of cattle around the environment.

Declarations

Availability of data and materials

All data generated or analyzed during this study are included in this published article.

Competing interests

The authors declare there is no conflicting interest regarding this study.

Funding

The present study had no funding sources of any kind.

Authors' contributions

The corresponding author (Isaac Kow Tetteh) supervised the entire research—conceptualization, synthesis of ideas, scope, experimental design, analysis framework, data interpretation, review and editing the manuscript. The first author (Albert Kwame Teye) performed the field and lab work as well as contributed to writing the manuscript. All authors read and approved the final manuscript.

Acknowledgements

The authors express appreciation to the workers of the Ashaiman scrapyards for their cooperation in carrying out this study. Our appreciation also goes to the laboratory staff of Ghana Standard Authority where the soil and water samples were analyzed.

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Tables

Table 1 Ghana EPA and WHO/FAO permissible levels of heavy metals in soil and water

Heavy Metal	EPA Ghana Limit in soil (ppm)	EPA Ghana Limit water (ppm)	WHO/FAO Limit in soil (ppm)	WHO/FAO Limit in water (ppm)
Cd	1	-	3	0.01
Cr	30	0.1	100	0.1
Cu	20	-	100	0.2
Pb	20	0.1	50	5

Table 2 Concentration and pH of soil samples at site F

Site /Sample	Latitude	Longitude	Concentration of selected heavy metals (ppm)				pH
			Cd	Cr	Cu	Pb	
F							
1A	5.682713N	0.029065W	0.92	73.02	82.60	99.63	7.36
1B	5.682713N	0.029065W	n.d	123.07	70.74	13.58	7.14
2A	5.682441N	0.029085W	0.05	49.08	129.37	276.78	6.86
2B	5.682441N	0.029085W	0.03	13.97	29.97	38.73	5.88
3A	5.682558N	0.028997W	0.17	162.50	122.30	83.48	6.80
3B	5.682558N	0.028997W	0.12	117.27	92.22	14.10	7.35
4A	5.682700N	0.028879W	0.11	60.81	219.82	32.97	7.38
4B	5.682700N	0.028879W	0.02	36.37	73.64	40.25	7.46
5A	5.682575N	0.029130W	0.52	67.49	74.42	38.75	7.04
5B	5.682575N	0.029130W	1.57	69.74	253.42	132.45	8.03
MEAN			0.39	77.33	114.85	77.07	7.13
MIN			0.02	13.97	29.97	13.58	5.88
MAX			1.57	162.50	253.42	276.78	8.03
STD.V			0.53	44.57	70.34	80.10	0.56

n. d..... not detected

Table 3 Concentration and pH of soil samples at site H

Site /Sample	Latitude	Longitude	Concentration of Heavy Metals (ppm)				pH
			Cd	Cr	Cu	Pb	
1A	5.683217N	0.029051W	0.29	17.11	108.76	84.29	7.78
1B	5.683217N	0.029051W	0.34	15.40	7.07	59.43	6.58
2A	5.683190N	0.028980W	1.67	30.11	5.24	300.25	6.91
2B	5.683190N	0.028980W	1.05	15.95	10.76	514.80	7.09
3A	5.683153N	0.028938W	13.56	25.25	12.40	17.81	7.38
3B	5.683153N	0.028938W	2.34	22.32	14.05	46.61	7.44
4A	5.683145N	0.029027W	6.87	21.11	48.00	572.79	6.50
4B	5.683145N	0.029027W	0.53	17.31	6.85	261.26	6.07
5A	5.683328N	0.028788W	7.96	23.10	185.77	1000.85	7.24
5B	5.683328N	0.028788W	6.79	22.32	84.76	556.20	6.38
MEAN			4.14	21.00	48.37	341.41	6.94
MIN			0.29	15.40	5.24	17.81	6.07
MAX			13.56	30.11	185.77	1000.85	7.78
STD.V			4.46	4.65	60.58	317.96	0.54

Table 4 Review of research studies on heavy metals concentrations (ppm) in E-waste

Locations	Cd	Cr	Cu	Pb	Reference
Abuja, Nigeria	2.50±0.08	42.4±2.6	3483±980	5650±750	[40]
Accra, Ghana	3	47	14300	3530	[6]
Bangalore, India	0.478	54	429	126	[41]
Beijing, China	3	101.29	180.66	187.30	[42]
Accra, Ghana	7.96	23.10	185.77	1000.85	Current research

Table 5a Correlation of soil heavy metal concentrations in topsoil at site F

	<i>Cd</i>	<i>Cr</i>	<i>Cu</i>	<i>Pb</i>
<i>Cd</i>	1			
<i>Cr</i>	-.105	1		
<i>Cu</i>	-.667 ^b	-.119	1	
<i>Pb</i>	-.314	-.268	-.106	1

^bSignificant correlation at the 0.01 level (2-tailed).

Table 5b Correlation of heavy metal concentrations in subsoil at site F

	<i>Cd</i>	<i>Cr</i>	<i>Cu</i>	<i>Pb</i>
<i>Cd</i>	1			
<i>Cr</i>	-.155	1		
<i>Cu</i>	.926 ^b	.168	1	
<i>Pb</i>	.956 ^a	-.282	.889 ^a	1

^aSignificant correlation at the 0.05 level (2-tailed).

^bSignificant correlation at the 0.01 level (2-tailed).

Table 5c Correlation of heavy metal concentrations in topsoil at site H

	<i>Cd</i>	<i>Cr</i>	<i>Cu</i>	<i>Pb</i>
<i>Cd</i>	1			
<i>Cr</i>	.177	1		
<i>Cu</i>	-.105	-.526	1	
<i>Pb</i>	.079	.004	.675 ^b	1

^bSignificant correlation at the 0.01 level (2-tailed).

Table 5d Correlations of heavy metal concentrations in subsoil at site H

	<i>Cd</i>	<i>Cr</i>	<i>Cu</i>	<i>Pb</i>
<i>Cd</i>	1			
<i>Cr</i>	.786 ^b	1		
<i>Cu</i>	.978 ^a	.653 ^b	1	
<i>Pb</i>	.542	.080	.613	1

^aSignificant correlation at the 0.05 level (2-tailed).

^bSignificant correlation at the 0.01 level (2-tailed).

Table 5e Correlations of heavy metal concentrations at topsoil at sites F and H

<i>H/F</i>	<i>Cd</i>	<i>Cr</i>	<i>Cu</i>	<i>Pb</i>
<i>Cd</i>	-.405	-.770 ^a	.700 ^b	-.029
<i>Cr</i>	.779 ^a	.043	-.295	-.505
<i>Cu</i>	.151	.080	-.556	.000
<i>Pb</i>	-.505	.693 ^a	-.538	-.372

^aSignificant correlation at the 0.05 level (2-tailed).

Table 5f Correlations of heavy metal concentrations in subsoil at sites F and H

<i>H/F</i>	<i>Cd</i>	<i>Cr</i>	<i>Cu</i>	<i>Pb</i>
<i>Cd</i>	.973 ^a	.723 ^b	.970 ^a	.673 ^b
<i>Cr</i>	.530	.298	-.011	-.758 ^b
<i>Cu</i>	.951 ^a	.723 ^b	.965 ^a	.412
<i>Pb</i>	.896 ^a	.497	.954 ^a	.775 ^b

^aSignificant correlation at the 0.05 level (2-tailed).

^bSignificant correlation at the 0.01 level (2-tailed).

Table 5g Correlations of heavy metal concentrations in the topsoil and subsoil over the scrapyards

<i>Topsoil/subsoil</i>	<i>Cd</i>	<i>Cr</i>	<i>Cu</i>	<i>Pb</i>
<i>Cd</i>	.585	-.364	-.291	.279
<i>Cr</i>	-.351	.821	.410	-.444
<i>Cu</i>	.181	.062	.203	-.105
<i>Pb</i>	.734 ^b	-.372	-.157	.791 ^a

^aSignificant correlation at the 0.05 level (2-tailed).

^bSignificant correlation at the 0.01 level (2-tailed).

Table 6 Igeo of four heavy metals at sampled sites

il sample	Igeo of heavy metals							
	Site F				Site H			
	Pb	Cu	Cr	Cd	Pb	Cd	Cu	Cr
	1.73	0.29	-0.89	1.03	1.49	-0.64	0.69	-2.98
	-1.14	0.07	-0.13	n.d	0.99	-0.39	-3.26	-3.13
	3.21	0.94	-1.46	-3.24	3.32	1.89	-3.69	-2.17
	0.37	-1.17	-3.27	-3.99	4.10	1.22	-2.65	-3.08
	1.48	0.86	0.27	-1.39	-0.75	4.91	-2.45	-2.42
	-1.09	0.45	-0.20	-1.86	0.64	2.38	-2.26	-2.60
	0.14	1.70	-1.15	-2.01	4.26	3.93	-0.49	-2.68
	0.42	0.13	-1.89	-4.76	3.12	0.23	-3.30	-2.96
	0.37	0.14	-1.00	0.22	5.06	4.15	1.46	-2.55
	2.14	1.91	-0.95	1.81	4.21	3.92	-0.33	-2.60
MEAN	0.76	0.53	-1.07	-1.58	2.64	2.16	-1.63	-2.72

Table 7 CF and PLI of the four heavy metals at sampled sites

Sample	Site F				Site H					
	CF		PLI		CF		PLI			
	Pb	Cu	Cd	Cr	Pb	Cd	Cu	Cr	PLI	
	4.98	1.84	3.06	0.81	2.18	4.22	0.96	2.42	0.19	1.17
	0.68	1.57	-	1.37	1.36	2.97	1.14	0.16	0.17	0.55
	13.8	2.88	0.16	0.55	1.36	15.01	5.55	0.12	0.34	1.34
	1.94	0.67	0.09	0.16	0.37	25.74	3.50	0.24	0.18	1.40
	4.17	2.72	0.57	1.81	1.85	0.89	45.22	0.28	0.28	1.33
	0.71	2.05	0.42	1.30	0.94	2.33	7.80	0.31	0.25	1.09
	1.65	4.89	0.37	0.68	1.19	28.64	22.91	1.07	0.24	3.58
	2.01	1.64	0.06	0.40	0.52	13.06	1.75	0.15	0.19	0.91
	1.94	1.65	1.75	0.75	1.43	50.04	26.54	4.13	0.26	6.13
	6.62	5.63	5.25	0.78	3.51	27.81	22.64	1.88	0.25	4.14
MAN	3.85	2.55	1.30	0.86	1.47	17.07	13.80	1.08	0.24	2.16

Table 8 Concentrations of heavy metals and pH at varying distance from scrapyard

Sample	Latitude	Longitude	Concentration of selected heavy metals (ppm)				pH
			Cd	Cr	Cu	Pb	
HV 25	5.682392N	0.027973W	n.d	20.73	24.94	155.17	6.97
HV 50	5.682438N	0.027473W	n.d	25.18	96.73	74.72	6.58
HV 75	5.682677N	0.026773W	n.d	4.12	4.60	5.97	6.71
HV 100	5.6826190N	0.026582W	n.d	n.d	1.26	8.97	6.72
MEAN				16.68	31.88	61.21	6.75
MIN				4.12	1.26	5.97	6.58
MAX				25.18	96.73	155.17	6.97
STD.V				11.10	44.48	70.22	0.16

Table 9 Heavy metals concentrations in water samples

Sample	Latitude	Longitude	Heavy metal concentration (ppm)				pH
			Cd	Cr	Cu	Pb	
WS C	5.684598N	0.026144W	0.03	11.95	5.84	5.89	7.55
WS 1	5.683145N	0.029027W	0.49	12.28	217.98	44.77	7.49
WS 2	5.683328N	0.028788W	n.d	n.d	n.d	n.d	7.61
MEAN			0.26	12.12	111.91	25.33	7.55
MIN			0.03	11.95	5.84	5.89	7.49
MAX			0.49	12.28	217.98	44.77	7.61
STD.V			0.33	0.23	150.00	27.49	0.06

Figures

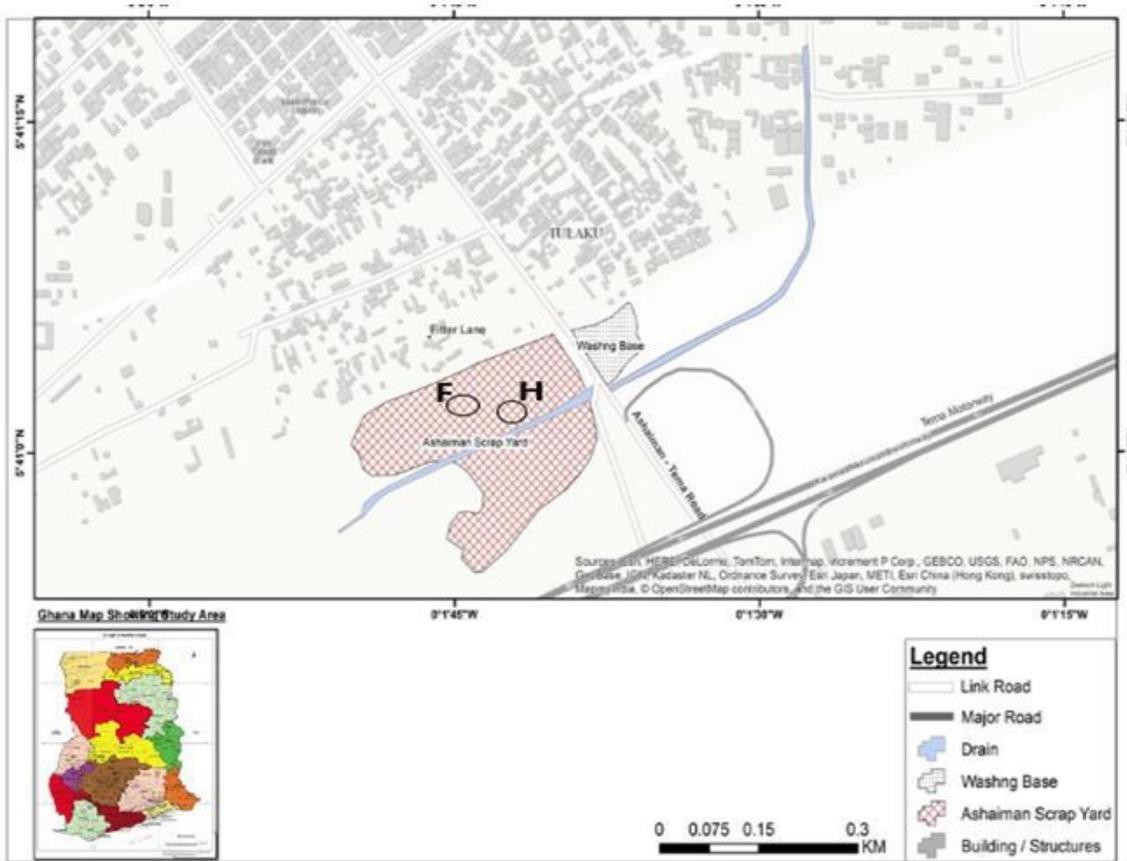


Figure 1

Map showing scrapyard at Ashaiman (Adapted from Okine [13])

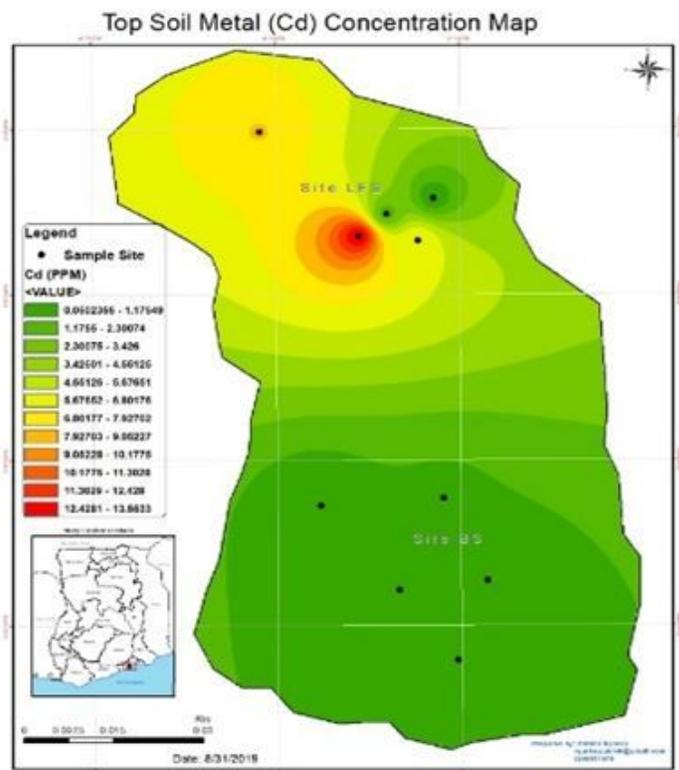
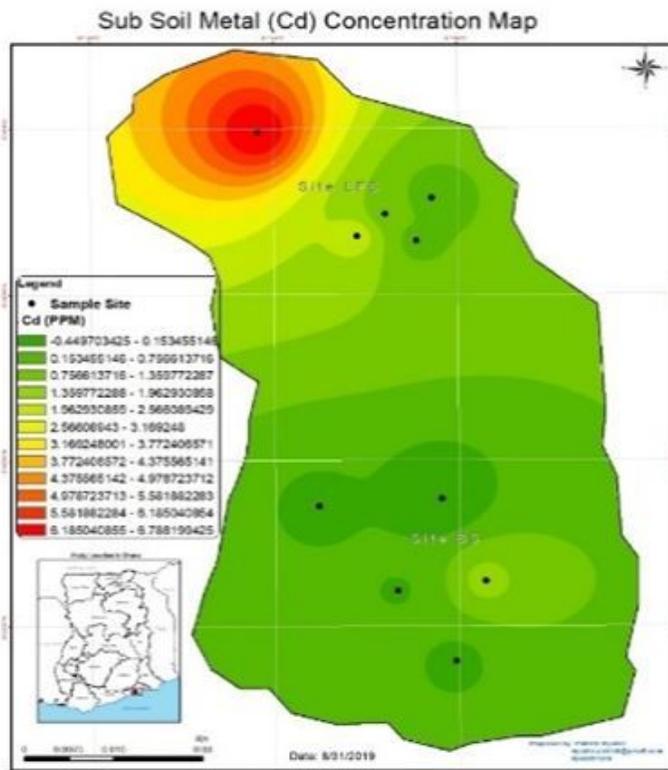


Figure 2

Spatial distributions of Cd in subsoil (L) and topsoil (R) of sites F and H

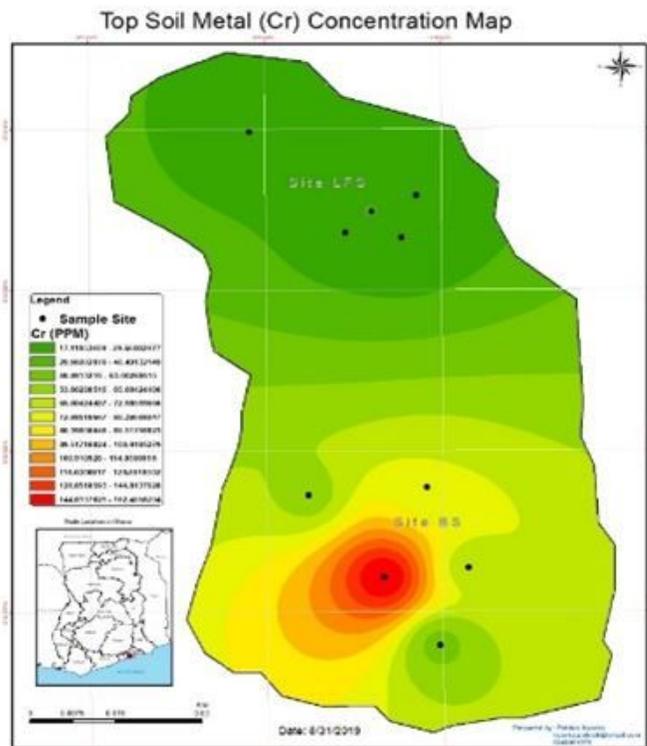
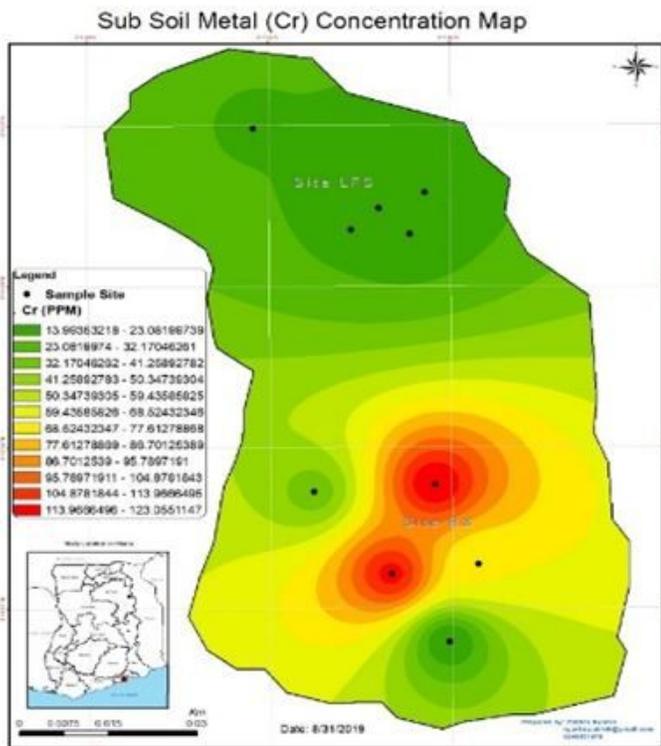


Figure 3

Spatial distributions of Cr in subsoil (L) and topsoil (R) of sites F and H

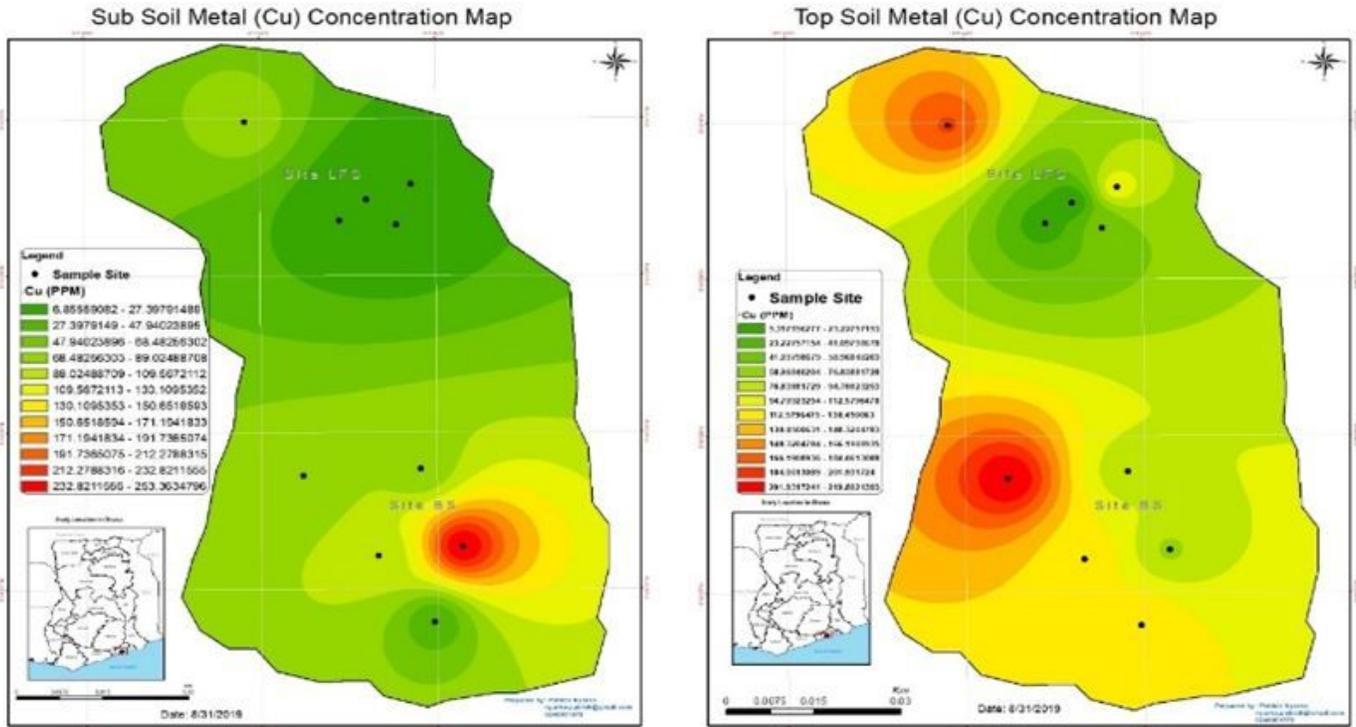


Figure 4

Spatial distributions of Cu in subsoil (L) and topsoil (R) of sites F and H

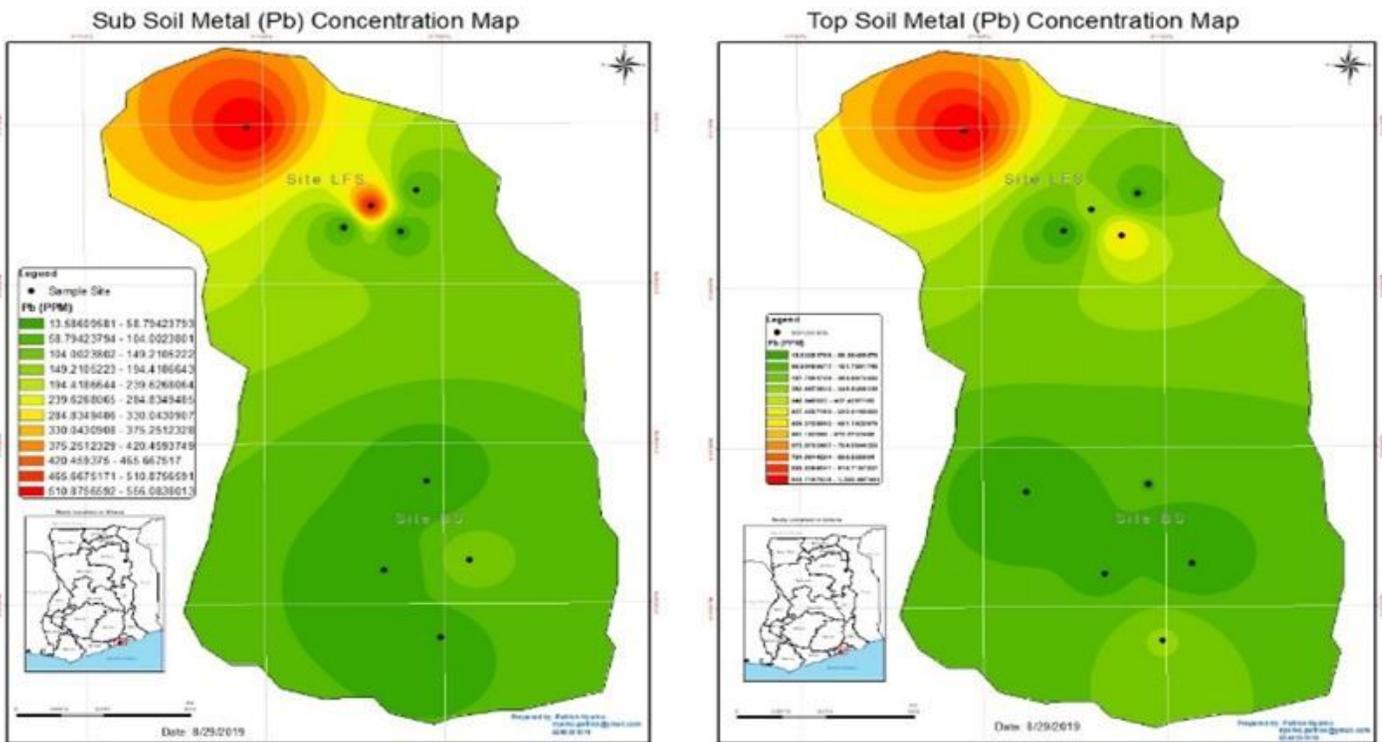


Figure 5

Spatial distributions of Pb in subsoil (L) and topsoil (R) of sites F and H