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Distribution of heavy metals in soils from abandoned dump sites in Kumasi, Ghana

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ABSTRACT

This study investigated the heavy metal content and the extent of pollution in soils from abandoned dump sites in Kumasi, Ghana. Concentrations of heavy metals in the 70 soil samples were determined using a Niton XL3t GOLD field portable X-ray fluorescence spectrometer and confirmed on an Agilent 7800 inductively coupled plasma-mass spectrometer. Mercury was determined with a Lumex mercury analyzer. Mean concentrations of metals in soils were in the order: Zn (166 mg/kg). Cr (67 mg/kg) > Cu (32 mg/kg), Ni (22 mg/kg) > Pb (11 mg/kg) Cd (8.9 mg/kg) > As (4.2 mg/kg) > Hg (0.04 mg/kg) for Kronum; and Zn (558 mg/kg), Cu (347 mg/kg), Pb (288 mg/kg) > Cr (77 mg/kg) > Ni (35 mg/kg) > As (11 mg/kg) > Cd (3.0 mg/kg) > Hg (0.19 mg/kg) for Amakom. Pollution indices (geo-accumulation, contamination factor, pollution load and potential ecological risk) indicated very high contamination for arsenic, cadmium and lead at Kronum and arsenic, cadmium, copper, lead and zinc at Amakom. Mercury recorded the least level of pollution for both dump sites. Regular monitoring of these abandoned dump sites is required. Remediation programs in these sites should also be instituted.

Introduction

Heavy metals are described as those metals with a specific gravity higher than 5 g/cm^3 [1]. Heavy metals are stable elements that cannot be metabolized by biological organisms and are also not biodegradable. As such they are passed up the food chain to humans resulting in biomagnification. Some heavy metals, such as iron and nickel are essential to the survival of all forms of life in low concentrations. However, others such as lead, cadmium and mercury are toxic to living

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organisms even in low concentrations and can cause anomalies in metabolic functions of organisms especially at higher concentrations [2]. Heavy metals occur naturally in the ecosystem with large variations in concentrations. In modern times, anthropogenic activities have also introduced some of these heavy metals into the ecosystem [3]. Human exposure to heavy metal contaminated soils occurs through inhalation of contaminated dust, ingestion, and dermal contact [4].

Proper disposal of waste has been a serious problem in Ghana. In some cases, waste is dumped recklessly with no regard to environmental implications, while at some dump sites, waste is burnt in the open and ashes abandoned at the sites. The burning of waste gets rid of the combustible materials and oxidize the metals, leaving the ash richer in heavy metals. After the process of oxidation and corrosion, these metals dissolve in rainwater and leach into the soil from where they are picked up by growing plants, thereby entering the food chain [5]. Improper waste management methods either results in the contamination of groundwater, or most of the metal contaminants are washed away by runoff into streams and rivers, thus, contaminating the aquatic environment. Consequently, these metals can accumulate in fish and other aquatic organisms posing a health threat to the consumers [6,7].

Dump sites also emit obnoxious odors and smoke that cause illness to people living near them. In a number of health surveys in communities close to dump sites, a wide range of human health problems, including respiratory symptoms, irritation of the skin, nose and eyes, gastrointestinal problems, psychological disorders and allergies, were reported [8]. Co-disposal of agricultural and industrial hazardous wastes with municipal wastes can expose people to chemical and radioactive hazards. Unconsolidated solid waste can also obstruct streamflow resulting in the formation of stagnant water bodies that become breeding grounds for disease-causing organisms such as mosquitoes.

Only a small fraction of waste generated in the country is recycled [9]. Dump sites and landfills are the main receptacles for domestic and industrial waste in Ghana. Dumping of refuse/waste is practiced in every community in the country. Abandoned dump sites are usually turned into other land uses such as crop cultivation, recreational parks or building of human residences. Sometimes, the soil is also excavated for soil amendments elsewhere because of the rich mineral and organic content but without assessing the health risks they pose to organisms and the environment. However, despite their widespread presence and the importance of dump sites in the country, they have been sparsely studied especially with regard to their mineral and toxic content. The few studies so far conducted have focused on large landfills [10,11], dump sites at light industrial hubs [12], and e-waste recycling sites [13,14]. Agyarko and his team [15] compared the concentrations of an array of metals (including As, Cd, Co, Cr, Cu, Fe, Hg, Mo, Ni, Pb and Zn) in a dump site in an urban center to those in a rural community in Ghana and adduced that metals loading in the urban dump site exceeded the threshold and therefore posed health risks. On the other hand, a study on the impact of heavy metals and soil physicochemical properties of another dump site [16] concluded that heavy metal contamination was within the FAO/WHO permissible limits. To make informed decisions and policies on heavy metal contamination, stakeholders need to know how much metals the waste receptacles (including waste dump sites) discharge into the general environment.

This study was undertaken to determine the concentrations of heavy metals (As, Cd, Cr, Cu, Hg, Ni, Pb and Zn) in soils from dump sites at Amakom and Kronum, in the Kumasi metropolis, Ghana. Residents around these dump sites are perceived to be at a considerable risk of exposure to the toxic metals. There is therefore the need to assess the pollution risks (contamination factor, geo-accumulation index, pollution load, and potential ecological risk) the metals in the abandoned dump sites pose to the environment.

Experimental

Study area

The study was conducted at 2 dump sites at Amakom and Kronum, suburbs of Kumasi in the Ashanti region of Ghana. The Kumasi metropolis lies between latitudes 6.35–6.40° and longitude 1.30–1.37°, with an area coverage of about 299 km^2. Kumasi features a tropical wet and dry climate, a relatively constant temperature throughout the year and two different rainy seasons: a longer rainy season from March through July and a shorter rainy season from September to November. The annual average rainfall in the area is around 1,400 mm [17]. The dump site at Kronum which was once active has been abandoned for about 15 years. It is situated near residential facilities. Although abandoned, both liquid and solid wastes are still discarded at the site. It is currently used for farming activities due to the waterlogged nature of the site. Some of the crops found on the site included cassava, plantain and cocoyam. The Amakom dump site falls between Akwatia line and Dagomba Line (an emerging e-waste recycling hub in Kumasi).

Soil sampling and preparation

Samples were collected in October 2018 from several locations at 5 to 15 m apart using a stratified random sampling approach. The soil samples were collected with the aid of clean plastic hand shovels at 0–10 cm below the topsoil and placed into well labelled ziploc bags. The positions of the sampling points were recorded with the help of a geographic positioning system. Duplicate samples were taken from every fifth sample point. In all, 70 soil samples were collected from both sites. Figs. 1 and 2 show the sampling points at the Kronum and Amakom dump sites respectively. Control samples were taken from the KNUST botanical gardens. The soil samples collected from each dump site were transported to the

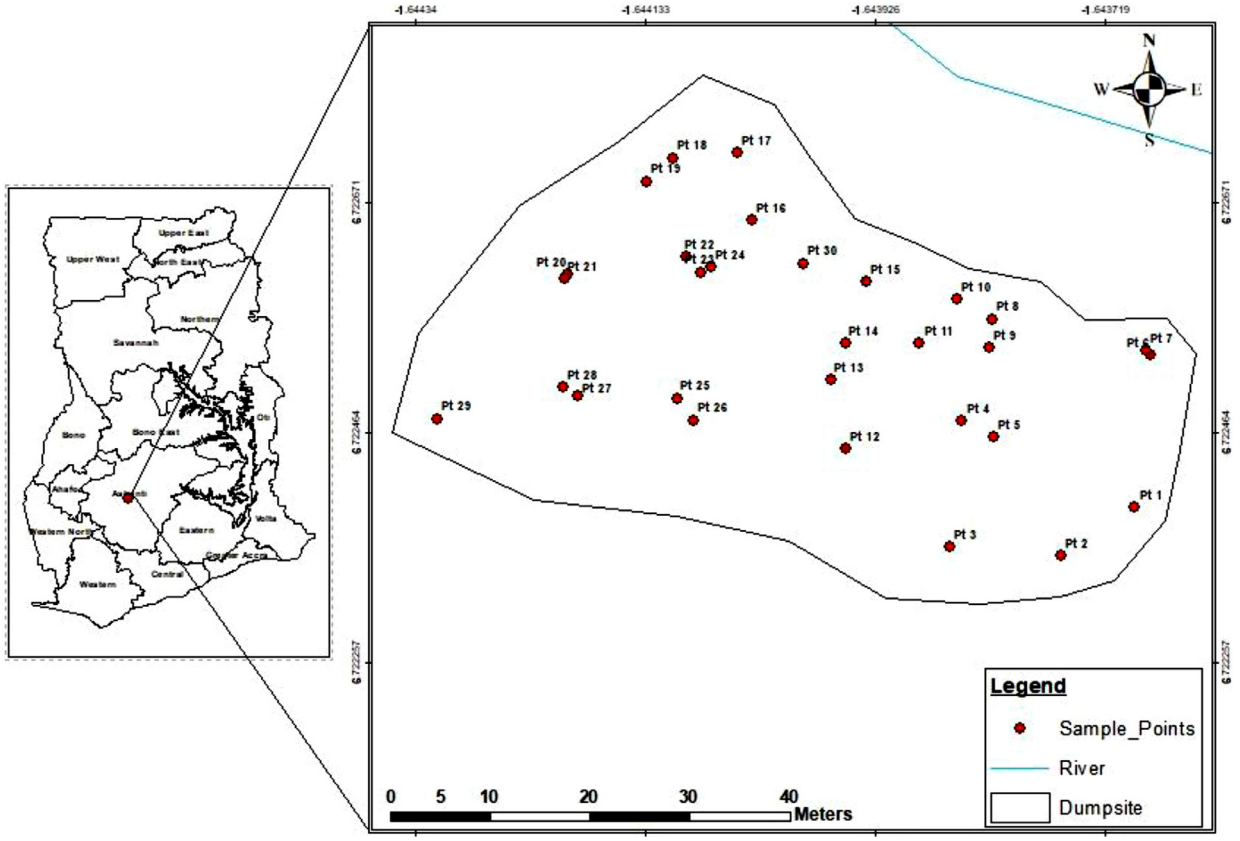

Fig. 1. Map of Kronum showing sampling points.

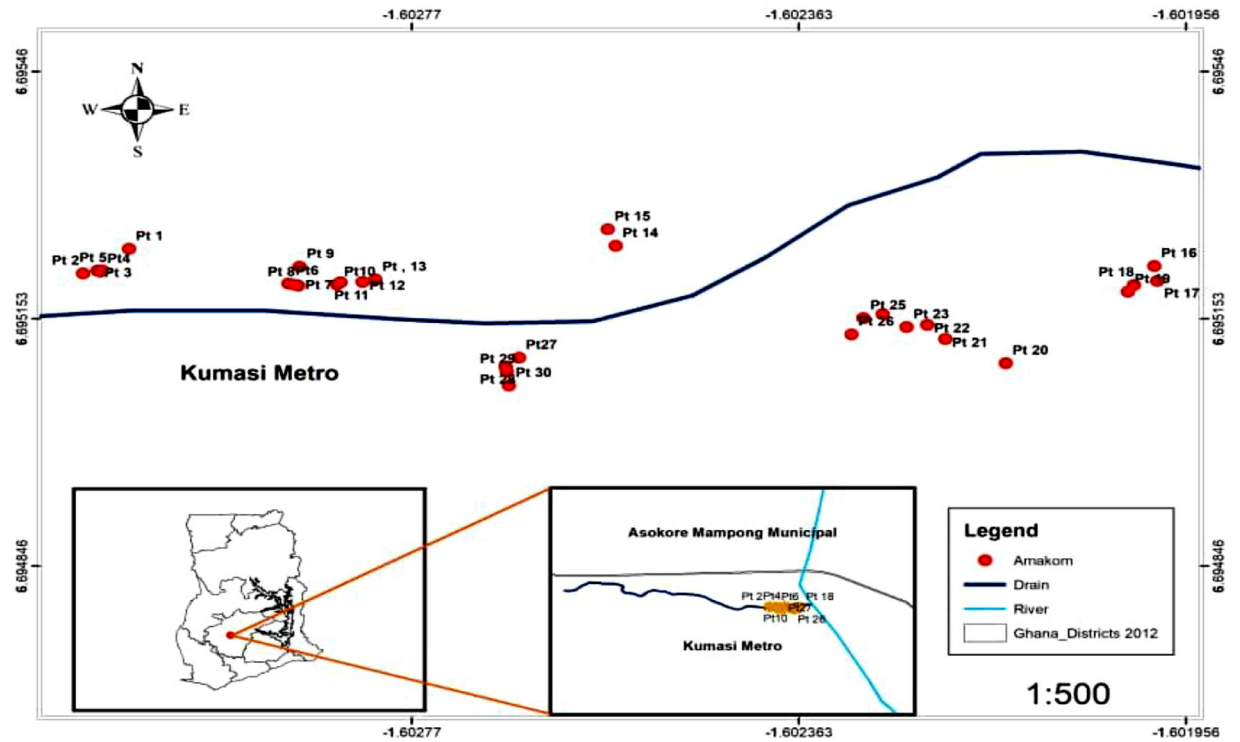

Fig. 2. Map of Amakom showing sampling points.

Table 1
Descriptive statistics of metal concentration (mg/kg) and physicochemical parameters of soil from dump sites at Kronum and Amakom

Metals/Physicochemical Property	Method detection limit	Kronum Dump site				Amakom Dump site				Reference Standards	
		Max	Average	SD	Median	Max	Average	SD	Median	*[34]	**[33]
As	<2.3	9.8	4.8	1.5	4.5	50	12	9.6	9.4	12	29
Cd	<2.9	209	13	37	3.0	6.5	5.9	0.3	6.0	10	0.8
Cu	<8.0	130	32	20	30	2395	347	404	182	63	36
Cr	4.6	147	66	31	69	232	77	39	70	64	100
Hg	<0.005***	0.10	0.04	0.02	0.03	1.01	0.2	0.2	0.14	6.6	0.3
Ni	<7.1	69	26	12	20	60	34	14	33	45	35
Pb	<2.7	86	13	17	2.0	333	309	410	182	140	85
Zn	<9.0	1121	166	201	98	1433	558	273	537	200	140
TOC		13	9.3	1.9	6.0	15	7.9	3.2	6.8		
TDS (mg/l)		809	787	16	792	380	307	46	306		
pH		9.1	7.8	0.6	7.9	8.3	7.5	0.5	**7.5**		
EC (µS/cm)		1091	335	216	268	1486	637	385	568		

Min – minimum value recorded; Max – maximum value recorded; SD: standard deviation of dataset
* CCME: Canadian Council of Ministers of Environment
** VROM: Dutch Ministry of Housing, Spatial Planning and the Environment
*** Value determined with Lumex Hg analyzer, all other detection limits were found using XRF

laboratory, air-dried and homogenized. The dried samples were crushed with a clean mortar and pestle and then sieved using a 2 mm sieve. The sieved soils were placed in ziploc bags and stored for laboratory analysis.

Total metal concentration analysis

Samples were examined using a Niton XL3t GOLD field portable X-ray fluorescence (FP-XRF) spectrometer following the United States Environmental Protection Agency Method 6200 protocols [18,19]. A portion of the sieved sample was placed in a small (~ 30 mm) polyethylene container with a propylene film so that it was three-quarters full. It was then placed in the instrument shroud and scanned for 180 s [20]. Average recoveries obtained by running 3 reference material (NIST 2709a) were always $\geq$75$\pm$5%. Reproducibility tests conducted by analyzing 9 replicate samples generated average relative percent difference of 21% for As, 11% for Cr, 7.5% for Cu, 9.2% for Ni, 13% for Pb, and 7.7% for Zn indicating satisfactory reproducibility. Typically, the FP-XRF gives results of 24 elements but 8 toxicologically important ones were used in this study. The method detection limits varied widely between the metals (Table 1)

Comparison of XRF data on ICP-MS

Nine samples, representing different settings and the locations, were acid-digested and analyzed using an Agilent 7800 inductively coupled plasma-mass spectrometer (ICP-MS) to validate the data obtained from the XRF. Prior to ICP-MS analysis 1 g each of the sieved soil samples were acid digested in 10 mL portions of 1:1:1 nitric acid-hydrochloric acid-water mixture at 95 °C for 1 h on a heating block. The digested samples were then filtered and made to volume using dilute hydrochloric acid before analysis based on the US-EPA standard method 6020B [21]. There was a strong linear correlation between the XRF and ICP-MS data with the following r^2 values, As (0.868), Cr (0.978), Cu (0.999), Pb (0.996), Ni (0.903), and Zn (0.834); $p<0.01$ for all the elements. Cadmium concentrations in most of the samples were below detection and as such were excluded from the statistical comparison.

Mercury analysis

Mercury concentrations in the samples were determined with an automatic mercury analyzer (Lumex RA 915M, St Petersburg, Russia) equipped with a pyrolysis unit (Lumex 92) for heating solid samples. The operational principle of the instrument is based on the absorption of the 254 nm resonance radiation by mercury atoms using Zeeman correction for background absorption [22]. A known mass (~ 0.3 g) of the dry sample was placed in the sample cell of the Pyro-915+ operating at a heating temperature of 450 °C and airflow of 1 L/min [20]. The run time for signal peaking was about < 1 min. The developed peaks were then integrated against a reference calibration (Cat: 500292: Lumex, St Petersburg, Russia) to obtain the concentrations. The detection limit based on the signal/noise ratio of 3 was 0.0005 mg/kg.

Soil pH, TDS and electric conductivity

The pH, electrical conductivity (EC), and total dissolved solids (TDS) of the samples were determined using Milwaukee Mi 805 combined meter for pH, EC, and TDS/Temperature. Approximately 20 g of soil sample was added to 40 mL of distilled water and thoroughly mixed. The mixture was allowed to settle for 1 h after which the pH, EC and TDS were read from the probe.

Total organic carbon

Soil samples were analyzed for total organic carbon using the loss on ignition method [23]. Two grams of the sample was weighed directly into a crucible and placed in a pre-heated oven at 105 °C for 2 h. The samples were removed and cooled to room temperature in a desiccator before weighing. The samples were then placed in a furnace and heated to 550 °C for 4 h. The samples were removed from the furnace and allowed to cool to room temperature in a desiccator and re-weighed. Replicate measurements were carried out to ensure the reproducibility of results. Organic matter content was calculated as the difference between the initial and final sample weight divided by the initial sample weight multiplied by 100%.

Data processing and evaluation

Data obtained from this work were analyzed using Microsoft Excel. Statistical analyses such as correlation analysis were performed using Minitab® 16. Metal distribution map and box plots were drawn using Arc-GIS and Minitab®16.

Estimation of level of contamination

The extent of metal contamination can be evaluated by either comparing site-specific data to background reference data or through the use of pollution indices and enrichment factors. In this work, contamination was assessed using the geo-accumulation index, contamination factors, pollution load and potential ecological risk indices.

Geo-accumulation index (Igeo)

The geo-accumulation index (Igeo) was used as a reference in estimating the extent of elemental pollution in the soil [24]. It was computed according to Eq. 1.

$$\text{Igeo} = \log_2 \frac{\text{Cn}}{1.5\text{Bn}} \tag{1}$$

Where Cn is the measured concentration of the examined metal in the sample, Bn is the geochemical background concentration/value or reference value of the metal (n). The factor or constant 1.5 allows for the analysis of possible variations in background values for a given metal in the environment as well as very small anthropogenic influences [25]. The value for Bn of the metals were: As 6.5; Cd 0.52; Co 4.3; Hg 0.06; Ni 14.2; Pb 31; Cr 58.4 [17]

Contamination factor (Cf)

Contamination factor (Cf), which is the ratio of the concentration of a metal in the soil to background levels, was used to assess the extent of metal contamination. The CF was calculated using Eq. 2.

$$\text{Cf} = \frac{\text{Chm}}{\text{Ccrustal}} \tag{2}$$

Where **Cf** is the contamination factor of the heavy metal, **Chm** is the concentration of the heavy metal in the sample and **Ccrustal** is the concentration of the heavy metal in the continental crustal average/baseline concentration [17].

Pollution load index

To estimate the overall pollution status of the samples, the pollution load index (PLI) of the metal contaminants was calculated using Eq. 3.

$$\boldsymbol{PLI} = (CF_1 \times CF_2 \times CF_3 \times \ldots CF_n)^{1/n} \tag{3}$$

Where CF represents the contamination factor of metal, n represents a specific metal contamination factor. The PLI values are used to classify samples as; unpolluted (PLI $\leq$ 1), moderately polluted (PLI = 1–3), highly polluted (PLI = 3–5) or very highly polluted (PLI $>$ 5) [26,27].

Potential ecological risk

The potential ecological risk index (PERI) was used to assess the degree of heavy metal pollution in soils based on the contamination factor of heavy metals (CF) and the response of the environment to the contaminant (TrF). The PERI was calculated as the sum of individual risk indices (RI) from Eq. 4 as follows:

$$\text{PERI} = \sum_{i=1}^{n} (\text{TrF} \times \text{CF}) \tag{4}$$

Where TrF represent the toxic response factor of the metal, CF is contamination factor and n represent the number of metals under study. Toxic response factor for metals are in the order of Zn = 1, Cr = 2, Co = Cu = Pb = 5, Ni = 6, As = 10, Cd = 30 and Hg = 40. The degree of ecological risk was classified as PERI $\leq$ 40 (low risk), 40 $\leq$ PERI $\leq$ 80 (moderate risk), 80 $\leq$ PERI $\leq$ 160 (considerable risk), 160 $\leq$ PERI $\leq$ 320 (high risk), and PERI $\geq$ 320 (very high risk) [28].

Results and discussion

Physicochemical properties

The descriptive statistics (mean, standard deviation, maximum, and median) values of the physicochemical properties of soils from Kronum and Amakom dump sites are presented in Table 1. The pH is one of the main factors which determine the availability, retention, and mobility of nutrients and heavy metals in soils. At low pH, metals are more bioavailable to plants and hence could pose severe toxicity problems compared to alkaline soils. The pH of the soil samples ranged from slightly acidic to slightly basic with most of the soil samples falling into the neutral range. The pH values obtained in this study are similar to those reported for other dump sites [15,24,29]. The average TOC of the soils from the Kronum and Amakom dump sites are similar to TOC observed from Meduma and Mampong dump sites in Ghana [15] but much higher than those recorded in soils from Abrepo, Ayigya, and Buokrom dump sites in Kumasi, Ghana [29]. Organic matter may interact with heavy metals, resulting in the formation of stable metal-organic matter complexes in soils. While immediately unavailable, such complexes can be degraded under oxidizing conditions and make the metals bioavailable [30,31].

Heavy metal concentrations

The spatial distribution of the metals based on interpolations of the concentrations relative to the geospatial positions of the sampled point [32] is presented in Fig. 3 (Kronum) and 4 (Amakom). As seen in Fig. 3, Pb was concentrated in the central areas of the Kronum dump site whereas Ni was heavily concentrated in the upper west quadrant. Chromium is mainly found in the far-east and far-west areas of the dump site. The central areas of the Kronum dump site is most concentrated with Cd. For the Amakom dump site (Fig. 4), the eastern areas of the dump site were heavily concentrated with As, Cd and Ni. Chromium and Pb were mostly found in the central areas. Metals that form part of the same concentration hotspot may either be present in similar minerals in the soil or may have emanated from similar anthropogenic activity.

Descriptive statistics for the concentrations of heavy metals (As, Cd, Cr, Cu, Hg, Ni, Pb, and Zn) in the soil samples along with the Dutch target values [33] and Canadian environmental soil quality guideline for residential land use [34] are summarized in Table 1. On average, the total concentration of metals obtained from this study was high when compared to international soil quality guidelines. For soils from Kronum dump site, the average concentrations of As, Hg, Ni, and Pb were lower than the Dutch and Canadian limits. The average concentrations of Cr (66 mg/kg) in Kronum dump site soils was higher than the Canadian guideline but lower than Dutch standards. For soils collected from the Amakom dump site (Table 1), the average levels of Ni and Hg were lower than the guidelines. Average As concentration was about 2-folds higher in Amakom than in Kronum but below the Dutch limit. The average concentration of Cd found in Amakom was half that found in Kronum dump site soils but 7-folds higher than the Dutch standard. Cr levels were around the same value as the Canadian limit but lower than the Dutch limit. The average concentrations of Cu, Pb and Zn in the Amakom dump site samples however exceeded both guidelines. In general, the levels of all metals, other than Cd, were higher in Amakom dump site soils than those found at Kronum. Whereas mean Hg concentration at Kronum was 0.04 mg/kg, the mean concentration at Amakom was 0.2 mg/kg. For Cu, the mean concentration at Amakom was about 10 times greater than the Kronum mean concentration. Levels of Pb at Kronum were also over 20 times less than that obtained from Amakom. The data suggested the Amakom dump site was more contaminated than the Kronum dump site.

Pb is a toxic metal with exceptionally low mobility and high bioavailability. Pb is known to persist in surface soils for a long time [20] and thus, dust is of particular concern in Pb exposure [35]. Although both Cu and Zn are essential elements, human ingestion of high concentrations can lead to gastrointestinal diseases [35,36]. The high concentration of Cu, Pb, and Zn in the soil samples from Amakom, therefore, presents a major concern. These high levels of Cu, Pb, and Zn in Amakom dump site soils may be the result of improper disposal of metals scraps or other metal-containing products such as paints and cosmetics. Pharmaceutical wastes are regularly deposited at some of these dump sites and landfills [37] and may thus serve as a potential source of heavy metals. Herbal medicines are also known to contain heavy metals [38] and their indiscriminate disposal may also contribute to the heavy metal load in the dump site. The concentrations of Cd at two locations in Kronum were high and this may be from municipal waste, sewage sludge, nickel-cadmium batteries, and fertilizers. Another metal found in high concentrations is Cr which may have been introduced into the soil from the disposal of scrap metals and products made from cement. The sequence of occurrence of metals is Zn > Cu > Pb > Cr > Ni > As > Cd > Hg in soil samples from Amakom and Zn > Cr > Cu > Ni > Pb > Cd > As > Hg in soil sample from Kronum.

The high levels of Pb in the dump site soil from Amakom is comparable to results obtained from the analysis of soils from other dump sites in Kumasi. Akoto et al., (2019) showed that about 25% (~3000 mg/kg) of Pb in soil from the Aboabo dump site in Kumasi was available in fractions available to plants and other organisms. Interestingly, in that study, it was shown that most metals were locked up in the residual fractions, indicating that they are locked up in crystalline structures and thus unavailable for plant uptake or use by some living organisms [39]. However, the high concentrations of metals observed at Amakom warrants immediate action to prevent exposure to humans and other organisms in the vicinity of the dump site. Odai and coworkers [29] also reported low levels of Cd (1.86 – 2.87 mg/kg) in soils from dump sites at Ayigya, Buokrom and Abrepo, all suburbs of Kumasi. It was also observed that the levels of Pb in the soils from Ayigya, Buokrom and Abrepo dump sites were much higher than other metals, with concentrations between 51 and 55 mg/kg. A scan through the literature on heavy metals concentrations in soils from landfills and dump sites regularly show high levels of Cr and Pb

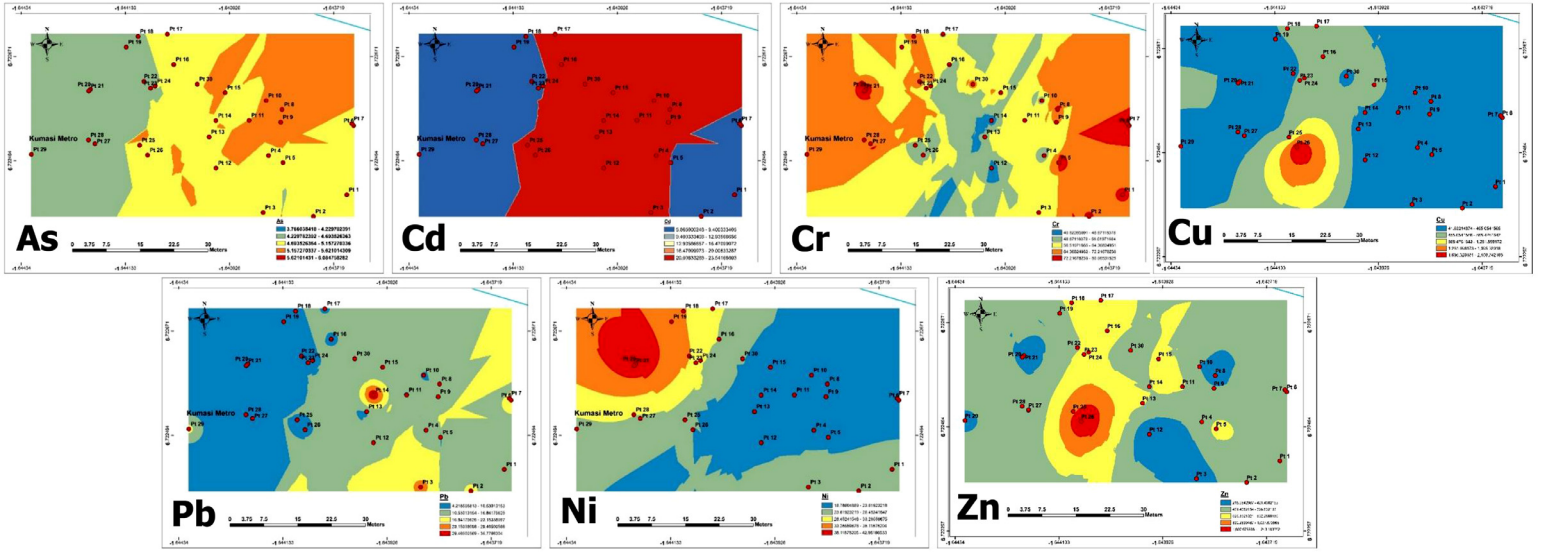

Fig. 3. Distribution pattern of heavy metals in soils from dump site at Kronum: There were high levels of Cd in most samples taken. The eastern part of the dumpsite recorded relatively high levels of As and Cr. Ni was found mainly in the north-eastern part of the dumpsite.

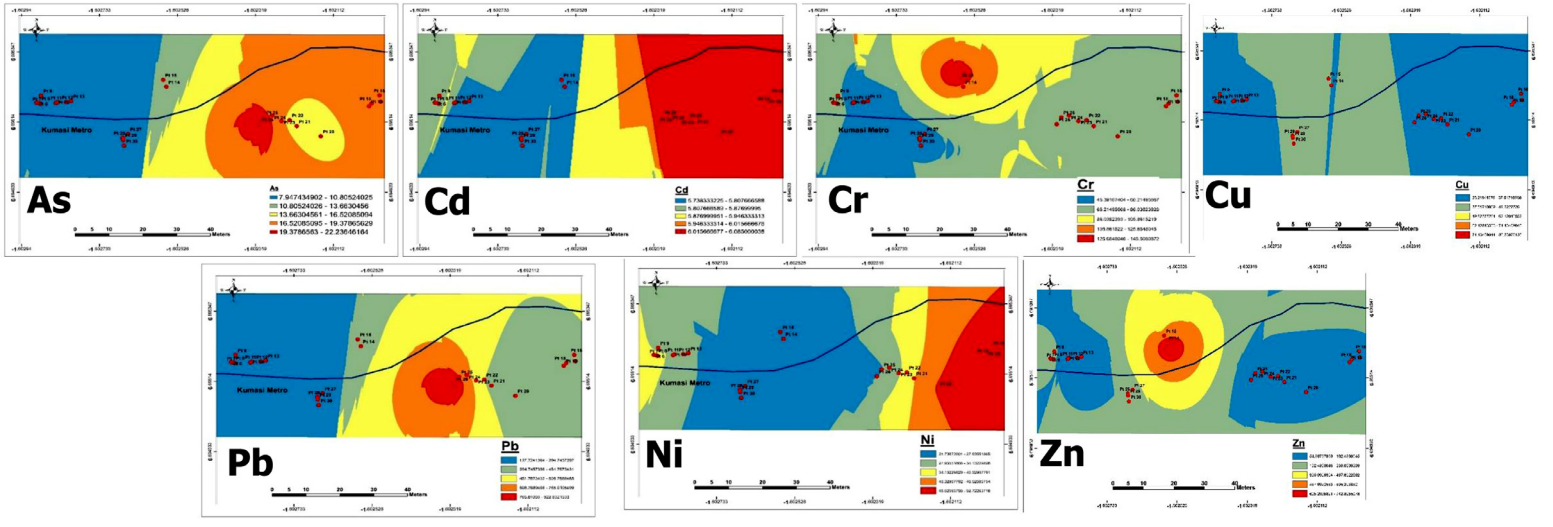

Fig. 4. Distribution pattern of heavy metals in soils from dump site at Amakom – As, Cd and Ni were concentrated in the eastern part of the dumpsite whereas Pb and Zn were found mainly in the central areas.

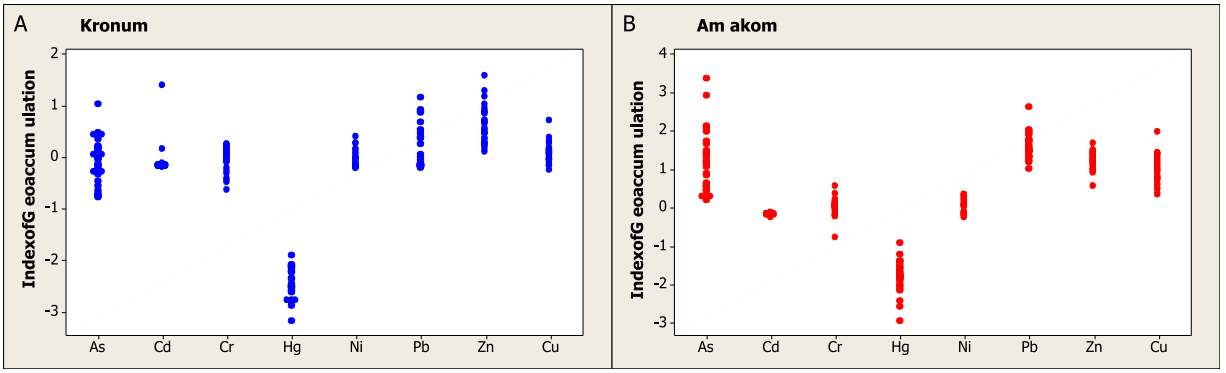

Fig. 5. Individual plots of geo-accumulation index for metals in dumpsite soils from A. Kronum and B. Amakom dump sites. As, Cd, Pb and Zn were classified to have polluted the Kronum dumpsite soils whereas Amakom was highly polluted with Zn, Cu, Pb and As.

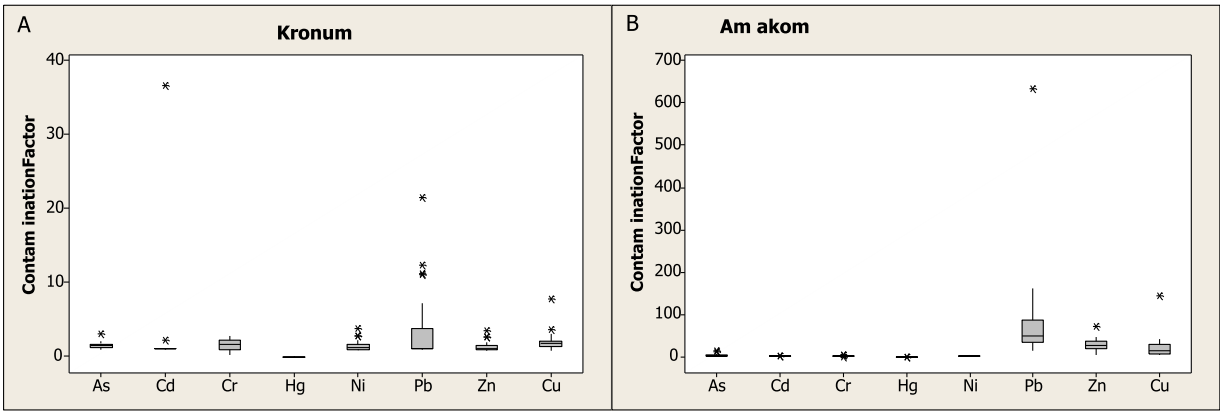

Fig. 6. Boxplots of Contamination factor for metals in soil at A. Kronum and B. Amakom dump sites. Most metals in Kronum recorded low contamination factors whereas As, Cd, Cu, Pb and Zn recorded high contamination at Amakom.

in particular [8,15,26,39]. Even though most of these metals may be in forms that are not bioavailable, as shown by the Akoto study [39], the regular presence of these metals in dump site and landfill soils is probably a reflection of the absence and/or enforcement of regulations on the disposal of heavy metal-containing materials in Ghana. Many dump sites and landfill sites in developing countries are usually operated without regard to acceptable standards, resulting in the release of leachates and toxic gases into the environment [40]. The fact that some are situated near residential facilities, schools and community playgrounds expose children especially to considerable risk.

Assessment of metal contamination

Geo-accumulation index (Igeo)

The calculated Igeo values are summarized as individual value plots in Fig. 5. The Igeo values for As, Cd, Cr, Cu, Ni, Pb and Hg showed generally no pollution at Kronum (Fig. 5a). However, the Igeo values of Zn ranged from 0.11 to 1.58 at Kronum indicating no pollution to moderate pollution. The degree of pollution or contamination of these metals follow the order of Zn > As > Cr > Pb > Cd > Hg > Ni. At Amakom (Fig. 5b), the Igeo values for As, Pb, Cu and Zn ranged from 0.20 to 3.37, 1.00 to 2.62, 0.34 to 2.07 and 0.58 to 1.69 respectively. Thus, the degree of pollution in reference to As is classified as no pollution to high pollution, that of Pb as moderate pollution to strong pollution, Zn as no pollution to moderate pollution and no pollution to high pollution for Cu. The Igeo values of Cr, Ni, Hg and Cd showed no pollution. The degree of pollution or contamination of metals at Amakom follows the order of Pb > As > Cu > Zn > Ni > Cd > Cr > Hg. It was generally observed that Amakom was highly polluted with Zn, Cu, Pb and As whereas Kronum is highly polluted with Cd, As and Pb.

Contamination factor (Cf) and pollution load (PL)

The contamination factors (Cf) and pollution load indices (PLI) were calculated using Eqs. (2) and (3) respectively and are represented in a boxplot. Fig. 6a shows the boxplot for the contamination factor of the various metals in soils collected from the Kronum dump site while Fig. 6b represents the contamination factor of metals in soils from the Amakom dump site. The pollution load was calculated using background data from the KNUST botanical gardens and the results are shown in Fig. 7. The PLI indicates the overall level of heavy metal toxicity in a particular sample and gives the combined effect

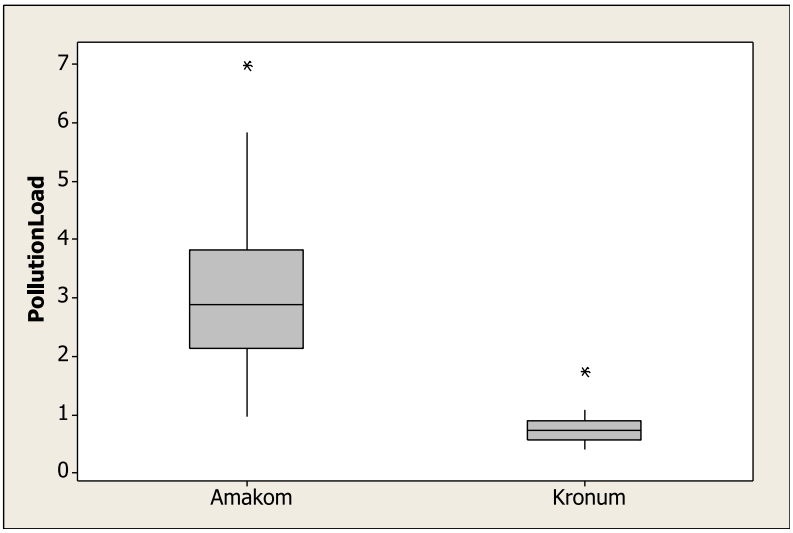

Fig. 7. Boxplots of Pollution Load of metals at both Kronum and Amakom dump sites. The PLI for Amakom is described as high whereas that of Kronum is moderate.

Table 2
Potential Ecological Risk Index (PERI) Estimated for Soil Samples from Dump sites in Amakom and Kronum

METAL	Amakom		Kronum	
	PERI	Remarks	PERI	Remarks
As	271.37	High Risk	104.59	Considerable Risk
Cd	218.51	High Risk	476.84	Very High Risk
Cu	773.11	Very high Risk	69.32	Moderate Risk
Cr	24.68	Low Risk	22.22	Low Risk
Hg	9.66	Low Risk	1.80	Low Risk
Ni	79.75	Moderate Risk	60.98	Moderate Risk
Pb	2949.37	Very High Risk	121.97	Considerable Risk
Zn	200.93	High Risk	9.34	Low Risk

Classification: PERI $\leq$ 40 (low risk), 40 $\leq$ PERI $\leq$ 80 (moderate risk), 80 $\leq$ PERI $\leq$ 160 (considerable risk), 160 $\leq$ PERI $\leq$ 320 (high risk), and PERI $\geq$ 320 (very high risk) [41].

of all elements analyzed. The results of the contamination factor showed that most of the elements in Kronum recorded low contamination levels. Hg recorded extremely low contamination level while Pb recorded considerate contamination. At Amakom, As, Cd, Cu, Pb and Zn recorded high contamination with Hg having low contamination while Cr and Ni fell within moderate contamination range. The pollution load index (PLI) predicted high PLI for Amakom and moderate PLI value for Kronum as depicted in Fig. 7.

Potential ecological risk

To get a more accurate assessment of heavy metal pollution in terms of ecological risk; potential ecological risk indices were determined, and the results presented in Table 2. Potential ecological risk indices indicate overall pollution. The metals exhibited increase in their risk indices at the various sampling points; ranging low risk to very high risk in the order: Hg$<$ Cr $<$ Ni $<$ Zn $<$ Cd $<$ As $<$ Cu $<$ Pb for Amakom and Hg $<$ Zn $<$ Cr $<$ Ni $<$ Cu $<$ As $<$ Pb $<$ Cd. The overall ecological risk for the metals was high.

Comparison of pollution indices with other studies

Soils from dump sites in Madina, Kumasi and Mampong were classified as being uncontaminated to moderately uncontaminated for Cd, Hg, Pb, Cr, Co, Ni and As based on geo-accumulation indices [15]. In another study from Aboabo abandoned landfill in Kumasi-Ghana, the Igeo values for Pb and Cr showed strong pollution which was similar to that estimated for Amakom [39]. In a landfill site in Aba, Nigeria [8], the recorded Igeo value for Cd and As showed moderate pollution similar to the Igeo obtained for Amakom. The Igeo for Cr and Ni also showed no pollution similar to the value calculated for Kronum. Generally, the Igeo and contamination factor values of Cd, Cr, Ni, Hg found in Amakom and Kronum, Ghana were lower. However, those of As and Pb were higher in Amakom and Kronum than in Aba.

Conclusion

This study has established that there were moderate concentrations of heavy metals (arsenic, cadmium, chromium, copper, lead, mercury, nickel, and zinc) in dump site soils at Amakom and Kronum with few of the metal concentrations exceeding International soil quality guidelines. The metals detected were found to be evenly distributed in the study area with a slightly higher concentration of lead found at the Western and North-Eastern part of Kronum and Amakom dump sites respectively. Index of geo-accumulation and contamination was found to be greatest for arsenic and lead at Amakom and Kronum respectively. However, the overall pollution of metals for dump site at Amakom was extremely higher than that of Kronum. This could be associated with the disposal of metal scraps, electronic waste, cosmetics, and drugs or from the bedrock. Plants grown on the dump site at Kronum can accumulate heavy metals which can be transferred through the food chain to man, posing a potential health risk. The toxic metals could also potentially impact the ecosystem negatively.

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Author contributions

LSB, GD and MD conceived the study and designed all experiments. Samples were collected by TA and SB. All experiments were carried out by TA, SB and MD. Data analysis was by TA, SB, LSB, GD and MD. All authors read and approved the final manuscript.

Data availability

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

Declaration of Competing Interest

All authors declare no competing financial, professional, or personal interests that might have influenced the performance or presentation of the work described in this manuscript.

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References

[1] A.S. Erses, M.A. Fazal, T.T. Onay, W.H. Craig, Determination of solid waste sorption capacity for selected heavy metals in landfills, J. Hazard. Mater. 121 (2005) 223–232 https://doi.org/10.1016/j.jhazmat.2005.02.011.
[2] Z. Arifin, R. Puspitasari, N. Miyazaki, Heavy metal contamination in Indonesian coastal marine ecosystems: a historical perspective, Coast. Mar. Sci. 35 (2012) 227–233 http://www.academia.edu/download/52235482/Heavy_metal_contamination_in_Indonesian_20170321-5653-xts625.pdf .
[3] J.P. Vareda, A.J.M. Valente, L. Durães, Assessment of heavy metal pollution from anthropogenic activities and remediation strategies: a review, J. Environ. Manage. 246 (2019) 101–118 https://doi.org/10.1016/j.jenvman.2019.05.126.
[4] S. Charlesworth, M. Everett, R. McCarthy, A. Ordóñez, E. de Miguel, A comparative study of heavy metal concentration and distribution in deposited street dusts in a large and a small urban area: Birmingham and Coventry, West Midlands, UK, Environ. Int. 29 (2003) 563–573 https://doi.org/10.1016/S0160-4120(03)00015-1.
[5] S. Kanmani, R. Gandhimathi, Assessment of heavy metal contamination in soil due to leachate migration from an open dumping site, Appl. Water Sci. 3 (2013) 193–205 https://doi.org/10.1007/s13201-012-0072-z.
[6] L.I. Ezemonye, P.O. Adebayo, A.A. Enuneku, I. Tongo, E. Ogbomida, Potential health risk consequences of heavy metal concentrations in surface water, shrimp (Macrobrachium macrobrachion) and fish (Brycinus longipinnis) from Benin River, Nigeria, Toxicol. Reports. 6 (2019) 1–9 https://doi.org/10.1016/j.toxrep.2018.11.010.
[7] H. Liu, G. Liu, Z. Yuan, M. Ge, S. Wang, Y. Liu, C. Da, Occurrence, potential health risk of heavy metals in aquatic organisms from Laizhou Bay, China, Mar. Pollut. Bull. 140 (2019) 388–394 https://doi.org/10.1016/j.marpolbul.2019.01.067.
[8] A.N. Amadi, H.O. Nwankwoala, Evaluation of heavy metal in soils from Enyimba Dumpsite in Aba, Southeastern Nigeria using contamination factor and geo-accumulation index, Energy Environ. Res. 3 (2013) https://doi.org/10.5539/eer.v3n1p125.
[9] K.N. Burns, S.K. Sayler, R.L. Neitzel, Stress, health, noise exposures, and injuries among electronic waste recycling workers in Ghana, J. Occup. Med. Toxicol. 14 (2019) 1–11 https://doi.org/10.1186/s12995-018-0222-9.
[10] H.M. Jafaru, G.N.N. Dowuona, T.A. Adjadeh, E.K. Nartey, P.M. Nude, D. Neina, Geochemical assessment of heavy metal pollution as impacted by municipal solid waste at Abloradjei waste dump site, Accra-Ghana, Res. J. Environ. Earth Sci. 7 (2015) 50–59 https://doi.org/10.19026/rjees.7.1695.
[11] J. Osei, S.K. Osae, J.R. Fianko, D. Adomako, C. Laar, A.K. Anim, S.Y. Ganyaglo, M. Nyarku, E.S. Nyarko, The impact of oblogo landfill site in Accra – Ghana on the surrounding environment, Res. J. Environ. Earth Sci. 3 (2011) 633–636.
[12] K. Kodom, K. Preko, D. Boamah, X-ray Fluorescence, XRF) analysis of soil heavy metal pollution from an industrial area in Kumasi, Ghana, Soil Sediment Contam, An Int. J. 21 (2012) 1006–1021 https://doi.org/10.1080/15320383.2012.712073.
[13] P. Cao, T. Fujimori, A. Juhasz, M. Takaoka, K. Oshita, Bioaccessibility and human health risk assessment of metal(loid)s in soil from an e-waste open burning site in Agbogbloshie, Accra, Ghana, Chemosphere 240 (2020) 124909 https://doi.org/10.1016/j.chemosphere.2019.124909.

[14] J. Yang, J. Bertram, T. Schettgen, P. Heitland, D. Fischer, F. Seidu, M. Felten, T. Kraus, J.N. Fobil, A. Kaifie, Arsenic burden in e-waste recycling workers – a cross-sectional study at the Agbogbloshie e-waste recycling site, Ghana, Chemosphere 261 (2020) 127712 https://doi.org/10.1016/j.chemosphere.2020.127712.
[15] K. Agyarko, E. Darteh, B. Berlinger, Metal levels in some refuse dump soils and plants in Ghana, Plant, Soil Environ 56 (2010) 244–251 https://doi.org/10.17221/13/2010-PSE.
[16] A.A. Agbeshie, R. Adjei, J. Anokye, A. Banunle, Municipal waste dumpsite: Impact on soil properties and heavy metal concentrations, Sunyani, Ghana, Sci. African. 8 (2020) e00390 https://doi.org/10.1016/j.sciaf.2020.e00390.
[17] G. Darko, M. Dodd, M.A. Nkansah, Y. Aduse-Poku, E. Ansah, D.D. Wemegah, L.S. Borquaye, Distribution and ecological risks of toxic metals in the topsoils in the Kumasi metropolis, Ghana, Cogent Environ. Sci. (2017) 3 https://doi.org/10.1080/23311843.2017.1354965.
[18] U.S. EPA, Method 6200: Field Portable X-Ray Fluorescence Spectrometry for the Determination of Elemental Concentrations in Soil and Sediment, 1998. http://yosemite.epa.gov/r9/sfund/r9sfdocw.nsf/3dc283e6c5d6056f88257426007417a2/e599199dc919b049882576a300616943/$file/attachment1.pdf#_ga=1.260838029.1899728909.1418825614.
[19] G. Darko, S. Adjei, M.A. Nkansah, L.S. Borquaye, K.O. Boakye, M. Dodd, Accumulation and bioaccessibility of toxic metals in root tubers and soils from gold mining and farming communities in the Ashanti region of Ghana, Int. J. Environ. Health Res. 00 (2020) 1–11 https://doi.org/10.1080/09603123.2020.1772203.
[20] A.R. Rweyemamu, M.A. Nkansah, G. Darko, M. Dodd, Contamination and human health risk due to toxic metals in dust from transport stations in the Kumasi Metropolis, Ghana, Chem. Africa. (2020) https://doi.org/10.1007/s42250-020-00174-z.
[21] US-EPA, EPA Method 6020b - Inductively Coupled Plasma - Mass Spectrometry, 2014. https://doi.org/10.4324/9781315853178.
[22] S. Sholupov, S. Pogarev, V. Ryzhov, N. Mashyanov, A. Stroganov, Zeeman atomic absorption spectrometer RA-915+ for direct determination of mercury in air and complex matrix samples, Fuel Process. Technol. (2004) 473–485 https://doi.org/10.1016/j.fuproc.2003.11.003.
[23] O. Heiri, A.F. Lotter, G. Lemcke, Loss on ignition as a method for estimating organic and carbonate content in sediments: Reproducibility and comparability of results, J. Paleolimnol. 25 (2001) 101–110 https://doi.org/10.1023/A:1008119611481.
[24] T. Prechthai, P. Parkpian, C. Visvanathan, Assessment of heavy metal contamination and its mobilization from municipal solid waste open dumping site, J. Hazard. Mater. 156 (2008) 86–94 https://doi.org/10.1016/j.jhazmat.2007.11.119.
[25] M. Barbieri, The importance of enrichment factor (EF) and geoaccumulation index (Igeo) to evaluate the soil contamination, J. Geol. Geophys. 5 (2016) https://doi.org/10.4172/2381-8719.1000237.
[26] S. Atiemo, F. Ofosu, I.J.K. Aboh, H. Kuranchie-Mensah, Assessing the heavy metals contamination of surface dust from waste electrical and electronic equipment (e-waste) recycling site in Accra, Ghana, Res. J. Environ. Earth Sci. 4 (2012) 605–611 http://www.academia.edu/download/42693289/Assessing_the_Heavy_Metals_Contamination20160215-980-1ikm02l.pdf .
[27] A.S. Likuku, K.B. Mmolawa, G.K. Gaboutloeloe, Assessment of heavy metal enrichment and degree of contamination around the copper-nickel mine in the Selebi Phikwe Region, Eastern Botswana, Environ. Ecol. Res. 1 (2013) 32–40 https://doi.org/10.13189/eer.2013.010202.
[28] T. Pavesi, J.C. Moreira, Mechanisms and individuality in chromium toxicity in humans, J. Appl. Toxicol. 40 (2020) 1183–1197 https://doi.org/10.1002/jat.3965.
[29] S.N. Odai, E. Mensah, D. Sipitey, S. Ryo, E. Awuah, Heavy metals uptake by vegetables cultivated on urban waste dumpsites: case Study of Kumasi, Ghana, Res. J. Environ. Toxicol. 2 (2008) 92–99 https://doi.org/10.3923/rjet.2008.92.99.
[30] Y. Zhu, W. Fan, T. Zhou, X. Li, Removal of chelated heavy metals from aqueous solution: a review of current methods and mechanisms, Sci. Total Environ. 678 (2019) 253–266 https://doi.org/10.1016/j.scitotenv.2019.04.416.
[31] E.J.M. Temminghoff, S.E.A.T.M. Van Der Zee, F.A.M. De Haan, Copper mobility in a copper-contaminated sandy soil as affected by pH and solid and dissolved organic matter, Environ. Sci. Technol. 31 (1997) 1109–1115 https://doi.org/10.1021/es9606236.
[32] Y. Xie, T. Bin Chen, M. Lei, J. Yang, Q.J. Guo, B. Song, X.Y. Zhou, Spatial distribution of soil heavy metal pollution estimated by different interpolation methods: accuracy and uncertainty analysis, Chemosphere 82 (2011) 468–476 https://doi.org/10.1016/j.chemosphere.2010.09.053.
[33] VROM, Circular on target and intervention values for soil remediation, Reference DBO/1999226863., 2000. http://goo.gl/xXY1nS.
[34] CCMECanadian Soil Quality Guidelines for the Protection of Environmental and Human Health, Canadian Council of Ministers of the Environment, 2007.
[35] ATSDR, Toxicological profile for leadATSDR's Toxicol. Profiles, CRC Press, 2002 https://doi.org/10.1201/9781420061888_ch106.
[36] ATSDR, Toxicological profile for zincATSDR's Toxicol. Profiles, CRC Press, 2002 https://doi.org/10.1201/9781420061888_ch163.
[37] L.S. Borquaye, E. Ekuadzi, G. Darko, H.S. Ahor, S.T. Nsiah, J.A. Lartey, A.H. Mutala, V.E. Boamah, E. Woode, Occurrence of antibiotics and antibiotic-resistant bacteria in landfill sites in Kumasi, Ghana, J. Chem. 2019 (2019) 1–10 https://doi.org/10.1155/2019/6934507.
[38] M.A. Nkansah, S.T. Hayford, L.S. Borquaye, J.H. Ephraim, Heavy metal contents of some medicinal herbs from Kumasi, Ghana, Cogent Environ. Sci. 2 (2016) 1234660 https://doi.org/10.1080/23311843.2016.1234660.
[39] O. Akoto, C. Nimako, J. Asante, D. Bailey, N. Bortey-Sam, Spatial distribution, exposure, and health risk assessment of bioavailable forms of heavy metals in surface soils from abandoned landfill sites in Kumasi, Ghana, Hum. Ecol. Risk Assess. An Int. J. 25 (2019) 1870–1885 https://doi.org/10.1080/10807039.2018.1476125.
[40] T.K. Boateng, F. Opoku, O. Akoto, Heavy metal contamination assessment of groundwater quality: a case study of Oti landfill site, Kumasi, Appl. Water Sci. 9 (2019) 33 https://doi.org/10.1007/s13201-019-0915-y.
[41] O. Gyamfi, P.B. Sorenson, G. Darko, E. Ansah, J.L. Bak, Human health risk assessment of exposure to indoor mercury vapour in a Ghanaian artisanal small-scale gold mining community, Chemosphere 241 (2020) 125014 https://doi.org/10.1016/j.chemosphere.2019.125014.