Fine Chemical Engineering
http://ojs.wiserpub.com/index.php/FCE/

Research Article

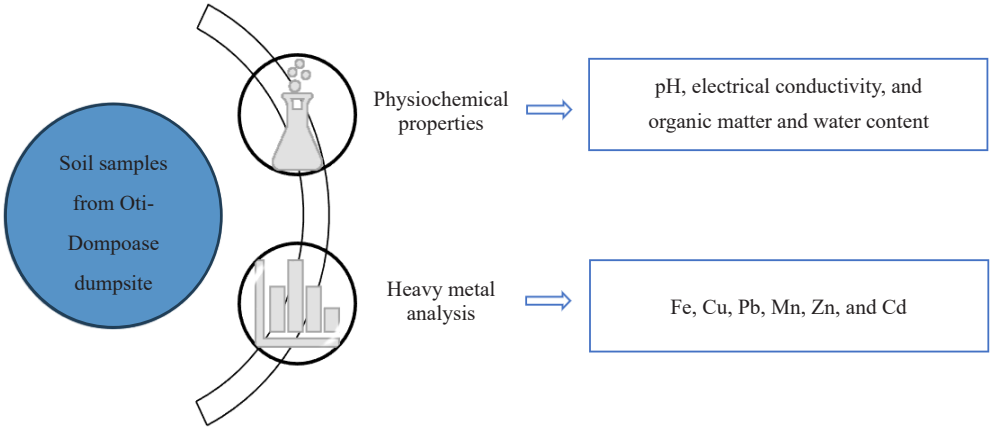
Heavy Metal Pollution Studies of Soil from the Oti-Dompoase Dump-site in Kumasi

Marian Asantewah Nkansah*, Anthony Seyram Kofi Adzibolosu, Moses Ernest Kumah, Ernest Bennin, Dominic Adrewie

Department of Chemistry, Kwame Nkrumah University of Science and Technology, Kumasi, Ghana
Email: mankansah.sci@knust.edu.gh

Received: 22 April 2024; **Revised:** 2 August 2024; **Accepted:** 16 August 2024

Graphical Abstract



Abstract: Waste disposal sites contribute a great deal to environmental pollution. The degree of pollution brought on by heavy metal contamination of soil collected from the Oti-Dompoase dump site in Kumasi of Ashanti region, Ghana was investigated in this study. Twelve (12) composite samples of the surface soil were taken in total at 10 cm depth from the dumpsite to conduct metal analysis. The measurement of heavy metal concentration was done utilizing Atomic Absorption Spectrometer, which uses the absorbance at various wavelength of the electromagnetic spectrum to determine the chemical identity of constituents of the sample and their concentrations with the help of standard solutions and Beer-Lambert law. The mean metal concentrations of soil samples were reported and arranged in terms of magnitude as follows: Iron (2,582.21 mg/kg) > Copper (348.50 mg/kg) > Lead (324.85 mg/kg) > Manganese (192.27 mg/kg) > Zinc (146.24 mg/kg) > Cadmium (7.06 mg/kg). Physiochemical properties such as electrical conductivity (EC), pH and organic matter and water content (%) were also investigated using a PHYWE electrical conductivity meter, pH meter and an oven, respectively. Most of the parameters analysed indicated pollution when compared to baseline values, while human exposure levels were within World Health Organization (WHO) standards. Assessments using geo-statistics of

DOI: https://doi.org/10.37256/fce.5220244793

different hazard indicators, including pollution load index, contamination factor (CF), and geo-accumulation, all point to heavy metal pollution of the soil samples. Cadmium contamination was very high based on the pollution indices (CF, geo-accumulation, and pollution load) and manganese has the lowest level of pollution. There is limited data on the extent of pollution caused by the Oti-Dompoase dumpsite and this study will serve to fill this knowledge gap and contribute to the Millenium Development Goal seven (7) by providing data on the extent of pollution of soil around the Oti-Dompoase dumpsite and highlight the need for regular monitoring and on-site remediation strategies to safeguard the site to ensure environmental sustainability.

***Keywords*:** heavy metals, waste disposal, pollution indices, soil

1. Introduction

The highest layer of crust of the earth, known as the soil, is composed of both organic and inorganic substances. Approximately 45% of soil is made up of minerals, 20-30% water, 5% organic matter, and 20-30% air.[1] Soil contains minerals, gases, fluids, and living organisms that provide support for various life forms on earth. The pedosphere, or body of soil on earth, has three (3) important purposes: (i) as a medium for plant growth; (ii) to store, supply, and purify water; and (iii) to alter the atmosphere and natural surroundings to support life on Earth. The lithosphere, hydrosphere, atmosphere, and biosphere all interact with the soil.[2] Soil is a key element of the biosphere on Earth but rapidly growing industrial districts, high metal waste disposal, the use of lead paint gasoline, petrochemical spills, pesticides, pollutants from coal combustion, and sewage sludge can all cause soil to become poisoned.[3]

Frequently occurring heavy metals in polluted soils include lead (Pb), zinc (Zn), iron (Fe), chromium (Cr), copper (Cu), nickel (Ni) and cadmium (Cd). Heavy metals, although naturally present in soil, can have their concentrations raised by anthropogenic and geological activity to levels that may be harmful to plants, animals, and humans. Information about the chemical characteristics and changes in the environment, particularly those in the food chain, is the foundation of current legislation relating to public health and environmental protection at both the national and international levels.[4] An attempt used in the prevention of heavy metal contamination in soil would involve understanding the contamination source, basic metal chemistry, as well as the health effects associated with these heavy metals.

Members in urban areas produce a lot of solid trash due to population increase and economic development. While in rural areas, solid waste is mostly generated from human settlements, commercial activities and small industries.[5] Soil pollution through waste release has become a global concern. Millions of tons of hazardous industrial waste from various sources annually find their way to dumpsites.[6] The negative effects of hazardous metals on people, animals, and plants make the atmospheric presence of heavy metals a major concern when it exceeds tolerable limits.[7] Studies in various parts of the world indicate the occurrence of heavy metal pollution of soil due to industrial and anthropogenic activities and has been shown to likely be transferred through the ecosystem. Studies have been reported in countries like India,[8-10] China,[11-16] Nigeria[17-22] and Ghana [23-26] among others.

Blood and bone abnormalities, kidney damage, reduced mental ability and neurological damage have been reported to be caused by being exposed to harmful heavy metals like cadmium and lead.[27] Some of these wastes are transferred into organisms in the soil and plants in several ways.[28] Due to a rise in geological and human activity, heavy metal-polluted soil is now widespread throughout the globe.[29]

Plants grown in soils contaminated with heavy metals exhibit decreased growth, performance, and yield.[30] Even though heavy metals are naturally prevalent in soil, their concentrations are not high and are harmless to plants and animals.[31] Metal smelting, fossil fuel combustion, sewage sludge, production of batteries and municipal waste disposal all are some of the activities which elevate heavy metal concentrations to harmful levels in soils.[32]

Problems associated with improper waste management and disposal have assumed alarming dimensions with its related effects on the environment. Due to their potential impact on food chains, high concentration of heavy metals in soil is a serious concern. The soil system is contaminated by hazardous metal discharges from a variety of human activities, including industry, agriculture, fossil fuel combustion, vehicle emissions, mining and metallurgical processes, and the disposal of solid waste. Because heavy metals are non-biodegradable, they continue to exist over many years in sediments where they may have environmental and health effects.[33] In this study, Atomic Absorption Spectroscopy (AAS)

is utilized in the determination of the heavy metals content because it has been shown to be simple, accurate, sensitive and cost effective with adequate sample preparation and is comparable with relatively modern and more expensive techniques like Inductively Coupled Plasma Mass Spectrometry (ICP-MS). This has made AAS very popular over the years in elemental analysis, evidenced by the large number of publications which employ AAS.[34]

2. Materials and methods

2.1 *Description of sampling site*

The study was conducted in the municipality of Asokwa, a town which was established under Section 3 of the Local Governance Act of 2016 and a Legislative Instrument (L.I.) 2294, 2018 Act of Parliament, which split it from the Kumasi Metropolitan Assembly (KMA) on December 21, 2017 (Act 936). The distance between Kumasi Central and Asokwa is 2 km, however, and the road distance is 2.9 km. The municipality has one of Ghana's largest wood markets. The Municipal landfill is located at one of its communities called Oti-Dompoase.

2.2 *Experimental procedures*

2.2.1 *Sampling*

At the dumpsite, 12 composite soil samples were collected at 12 different representative points as shown in Figure 1. The soil samples were taken at 10 cm depth from each sampling point and a 30 m interval was set between sampling locations. The 10 cm depth was considered to represent the top layer of soil to which humans or animals may be exposed.

Figure 1. Map of Oti landfill site showing sampling points. *S = sample points
Source of map: https://earthexplorer.usgs.gov/

2.2.2 *Physiochemical parameters*

2.2.2.1 *pH determination*

20 g of soil samples were combined in a 1:5 ratio with distilled water. Glass rod pulses were applied to the suspension intermittently for 30 minutes, and then left for an hour. The pH was then measured after inserting the combination electrode into the supernatant. The pH value is a measure of the soil water system's hydrogen ion activity and expresses soil acidity and alkalinity. It is a very important soil property, as it determines the nutrient availability, microbial activity, and soil physical condition.[35]

2.2.2.2 *Electrical conductivity determination*

Electrical conductivity (EC) expresses solution ion content that defines the current carrying capacity while providing a clear understanding of the soluble salts in the soil. The electrical conductivity meter from Phywe Systeme GmbH & Co. (PHYWE) was used to determine the conductivity of the soil samples. In the determination, the equipment was first calibrated by washing with potassium chloride (KCl) solution. Soil to water suspension in a ratio of 1:2 was prepared for all samples. The suspension was agitated for about half an hour and left undisturbed for around thirty minutes to allow the soluble salts to completely dissolve. The soil was allowed to settle, and the conductivity meter was again rinsed with distilled water and then inserted into the solution. EC values were recorded.

2.2.2.3 *Organic matter and moisture content determination*

After being cleaned, a crucible was put in a 105 °C pre-heated oven to dry to a constant weight, which was then recorded as W0. A 5 g (W1) air-dried soil sample was also added to the crucible, dried at 105 °C to a consistent weight, and recorded as W2. The moisture composition of the soil was assessed using the change in soil weight. At a temperature of 360 °C, the soil sample was put in an oven and allowed to ash for 5 hours. With the aid of a pair of tongs, the crucible was removed, put in a desiccator, and allowed to cool. The weight of the crucible and its contents was weighed and reported as W3. Organic matter content was measured using the relation, W2-W3.

2.2.3 *Digestion of samples*

To stop microbial deterioration, 48 hours were spent air-drying soil samples at room temperature. The samples were repeatedly homogenized and softly crushed with the aid of a mortar and pestle, and afterwards passed through a 2 mm plastic sieve before analysis. Heavy metal content of soil was extracted using hydrochloric acid (HCl) and nitric acid (HNO_3) in a 3:1 ratio via acid digestion. The digests were poured into a clean labeled 50 mL volumetric flask. A blank was prepared in a similar manner. The samples were prepared for examination and stored in storage bowls with a lid.

2.2.4 *Analysis of the metals*

Using the Analytic Gena Atomic Absorption Spectrophotometer (model novAA-400P), the concentrations of six metals, namely Fe, Mn, Cu, Pb, Zn, and Cd in mg/L were determined in all the samples. Prior to determining the amounts of each element, the AAS was calibrated using standard solutions in the 0.1-10 mg/L range. The instrument detection limit was determined, and background adjustment was made. Plotted graphs of the calibration points for the different metals were done using the readings from the standards. There was a blank analysis run. A combination of air and acetylene was employed to create the analytical flame. Each hollow cathode lamp was used to measure the metal concentrations. Acetylene and air served as the fuel and support for the atomic absorption spectrophotometer's operation.

Slit width of 1.0 nm was used for Mn and Pb, 0.5 nm for Zn, Cu and Cd and 0.2 nm for Fe. The wavelengths for Mn, Zn, Pb, Cu, Fe and Cd were 257.610, 213.857, 220.353, 327.395, 510 and 228.8 nm respectively.

2.3 *Statistical analysis*

Descriptive statistics were performed, and standard deviations were calculated to depict the level of dispersion

in the distribution of various heavy metals and to imply the indirect effects of chosen elements in the investigated environment. Pearson's correlation was used to determine the correlation between the metals detected with the aid of Microsoft Office Excel and GraphPad Prism 8.

2.3.1 *Pollution assessment indices*

Using different quantitative contamination rates, the state of possible heavy metal contamination in the soils investigated in this study was assessed.

2.3.1.1 *Geo-accumulation index (Igeo)*

To estimate the extent of elemental pollution in soil, the geo-accumulation index (Igeo) was utilised, and it was calculated from equation 1 below.[36]

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

Where Cn is the determined concentration of the metal of interest in the sample, and the metal's geochemical background concentration/value or reference value (n) is represented by Bn. The constant 1.5 enables for the investigation of fluctuations in baseline values and very little anthropogenic influences for a particular metal in the environment.[37] The Bn values of the metals were Cd (0.1), Cu (2.8), Zn (5.7), Pb (4.4), Mn (13.4), and Fe (15.4).[38] The extent of contamination is then assessed from the Igeo using Table A1 found in the supplementary data as a guide.

2.3.1.2 *Contamination factor (CF)*

The extent of metal contamination was determined utilizing the CF, which measures the proportion of a soil's metal concentration to background levels. Equation 2 was used to calculate the CF.

$$\text{CF} = \frac{\text{Csample}}{\text{Cbackground}} \tag{2}$$

Where CF is the heavy metal contamination factor, Csample is the concentration of heavy metal in the sample, and the heavy metal concentration in the continental crustal average/baseline concentration is represented by Cbackground.[39]

2.3.1.3 *Pollution load index (PLI)*

The pollution load index of the metal pollutants was determined to evaluate the overall pollutant load of the samples using the relation below.

$$\text{PLI} = \left(\text{CF1} \times \text{CF2} \times \text{CF3} \times \ldots \text{CFn}\right)^{1/n} \tag{3}$$

Where CF indicates the metal contamination factor and n represents a specific metal contamination factor. Unpolluted (PLI < 1), moderately polluted (PLI = 1-3), highly polluted (PLI = 3-5), or very highly polluted (PLI > 5) samples are classified using PLI values.[40-41]

2.3.2 *Health risk assessment model*

2.3.2.1 *Exposure dose*

Based on the average of samples from each location, the amount of heavy metals exposure was computed. The model used to calculate human exposure to heavy metals in this study is based on those established by the United States

Environmental Protection Agency. The average daily dosage (ADD) (mg/kg/day) of exposure modes for a pollutant comprising dermal contact, ingestion, and inhalation were determined using Equations (4), (5), and (6), according to the Exposure Factors Handbook:

$$ADDing = c \times CF \times R_{ing} \times EF \times ED \times BW \times AT \quad (4)$$

$$ADDinh = c \times CF \times R_{inh} \times EF \times ED/PEF \times BW \times AT \quad (5)$$

$$ADDderm = C \times (SL \times SA \times CF \times ABS \times EF \times ED)/(BW \times AT) \quad (6)$$

Where ADDderm is the daily metal exposure amount through dermal contact (mg/kg/day), ADDing is the daily metal exposure amount through ingestion (mg/kg/day), ADDinh is the daily metal exposure amount through inhalation (mg/kg/day). Table 1 shows the exposure variables for various models, based on US EPA and environmental site assessment guidelines (2009).

Table 1. Exposure factors for dose models.

Factor	Definition	Unit	Value	
			Children	Adult
C	Concentration of The Contaminant in the soil	mg/kg		
R_{ing}	Ingestion Rate of Soil	mg/day	200	100
EF	Exposure Frequency	days/year	350	350
ED	Exposure Duration	years	6	24
BW	Average Body Weight	kg	15	55.9
AT	average time	days	365 × ED	365 × ED
CF	conversion factor	kg/mg	1×10^{-6}	1×10^{-6}
R_{inh}	inhalation rate	m^3/day	5	20
PEF	particle emission factor	m^3/kg	1.32×10^9	1.32×10^9
SA	surface area of the skin that contacts the dust	cm^2	1,800	5,000
SL	skin adherence factor for dust	mg/cm^2	1	1
ABS	dermal absorption factor (chemical specific)		0.001	0.001

Carcinogenic risk is the possibility that someone will likely get cancer of any kind because of lifelong exposure to cancer-causing agents at a risk level considered acceptable for regulatory purposes ranging from 1×10^{-6}-1×10^{-4}. Risks greater than 1×10^{-4} are regarded intolerable, whereas risks less than 1×10^{-6} are thought to have no effect on health.

2.3.2.2 *Hazard quotient*

After calculating the ADD for each of the three exposure pathways, a Hazard Quotient (HQ) based on non-cancer harmful risk can be determined by dividing daily dose by a specific reference dose (RfD).

$$HQ = ADD/RfD \quad (7)$$

The reference dose, with exact values specified in Table A2 of the supplementary data, is an estimate of the maximum allowed risk to the human population from daily exposure while taking sensitive groups into account over the course of a lifetime. The RfD value threshold can be used to determine whether there is a detrimental health effect over time. If the average daily dose (ADD) value is less than the reference dose, no adverse health effects are expected; conversely, if the ADD value is greater than the RfD, the exposure pathway is anticipated to induce adverse human health effects. When HQ < 1 indicates that there will be no adverse health consequences and HQ > 1 suggests that there will be potential unfavourable health impacts. To calculate the cancer risk, the dosages of carcinogens are multiplied by the corresponding slope factor (Sf). In addition, the hazard index (HI = ΣHQ) was calculated, which represents the overall possible non-carcinogenic impacts caused by several chemicals.

3. Results and discussion

3.1 *Heavy metals content of samples*

Table 2. Heavy metal concentrations of all the sampling points

Sample	Pb mg/kg	Zn mg/kg	Cd mg/kg	Mn mg/kg	Cu mg/kg	Fe mg/kg
S1	1.43 ± 12.11	64.70 ± 1.29	BDL	500.30 ± 92.87	103.40 ± 73.90	74.97 ± 755.98
S2	19.37 ± 7.39	95.90 ± 2.32	BDL	252.43 ± 18.14	50.80 ± 89.76	8,169.60 ± 1,684.65
S3	88.80 ± 13.92	151.45 ± 1.290	BDL	199.02 ± 2.03	688.05 ± 102.38	78.04 ± 755.051
S4	47.08 ± 2.59	84.70 ± 1.20	BDL	165.70 ± 8.01	224.60 ± 37.36	7,003.30 ± 1,332.99
S5	7.84 ± 10.54	137.55 ± 12.65	BDL	83.90 ± 32.68	51.10 ± 89.67	6,213.90 ± 1,094.98
S6	1,295.00 ± 8.93	188.55 ± 0.99	60.25 ± 26.50	343.70 ± 45.66	985.30 ± 192.00	3,550.50 ± 291.94
S7	168.50 ± 6.27	175.60 ± 1.41	12.90 ± 0.16	107.70 ± 25.50	652.30 ± 91.60	1,600.50 ± 296.01
S8	257.80 ± 4.06	157.90 ± 0.55	BDL	76.60 ± 34.88	1,008.20 ± 198.91	841.90 ± 524.74
S9	1,087.50 ± 15.21	161.00 ± 6.40	0.37 ± 0.65	387.50 ± 58.86	101.30 ± 74.53	619.01 ± 591.94
S10	234.95 ± 9.17	194.45 ± 0.20	7.415 ± 0.72	165.02 ± 8.22	73.30 ± 82.98	2,200.50 ± 115.11
S11	299.05 ± 6.65	174.30 ± 8.46	3.79	10.00 ± 54.96	8.60 ± 102.48	592.30 ± 600.00
S12	390.88 ± 21.04	168.74 ± 6.79	BDL	15.40 ± 53.33	235.00 ± 34.22	42.60 ± 765.84
AVG	324.85 ± 407.86	146.24 ± 40.51	7.06 ± 16.50	192.27 ± 146.58	348.50 ± 361.25	2,582.21 ± 2,826.12

*BDL = Below Detection Limit; *AVG = Average

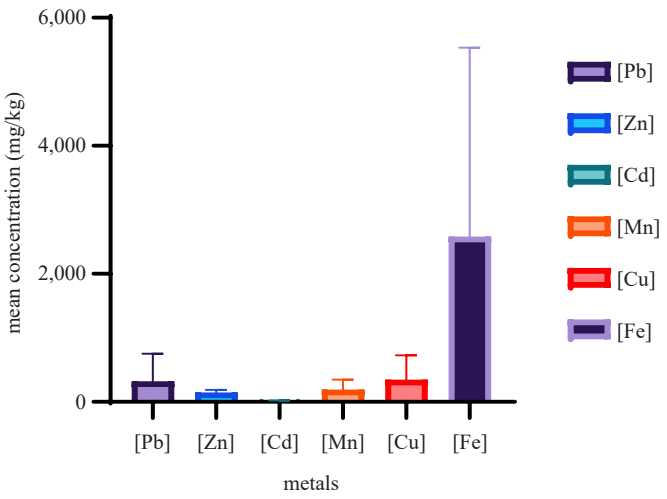


Figure 2. Mean concentrations of metals in all samples

The concentration of metals in the samples is presented in Table 2. The results showed that Fe with the mean concentration of 2,582.21 mg/kg has the highest concentration whereas Cd and Zn are present in trace amounts, and their order is Fe > Cu > Pb > Mn > Zn > Cd as shown in Figure 2. The existence of metallic materials in the earth's crust and waste that contains iron is thought to be the cause of the high Fe content in the soil.[42-44] The concentration of the metals studied was found to be generally higher than levels measured in Gosa dumpsite in Nigeria.[18] The levels were however lower than the averages determined by Onwukeme and Eze for selected dumpsites in southeastern Nigeria.[45]

3.1.1 *Iron*

Fe is an element (micronutrient) required by plants for general growth and development that can be found in soil. The mean concentration of iron was found to be higher than the concentration (1,662.61 mg/kg) measured at a similar soil depth in the vicinity of the Gosa dumpsite in Nigeria.[18] The various Fe concentrations at each sample collection point deviated from their mean concentration by 2,826.12 mg/kg. However, Fe was found to be mobile away from the dumpsite, which could lead to toxicity if left unattended. Obasi et al. found a similar movement of Fe in their studies and linked it to the high mobility of Fe metals.[46] The concentration of Fe was found to be within the acceptable limits of metal concentrations as specified by FAO/WHO.

3.1.2 *Lead*

Lead is a hazardous metal with a high bioavailability and poor mobility. Lead is known to persist for a long time in surface soils,[47] hence dust is a major concern when it comes to Pb exposure.[48] Pb concentrations ranged from 1.43 mg/kg to 1,295 mg/kg (Table 2), with a variation of 407.86 mg/kg from the mean value of 324.85 mg/ kg. This mean value of Pb is higher than the level of Pb found in Gosa dumpsite in Nigeria, which was measured as 21.47 mg/kg.[18] The high amounts of Pb found in the Oti dumpsite soil are equivalent to those found in other Kumasi waste sites. According to Akoto et al., roughly 25% of Pb in soil from the Aboabo waste site in Kumasi was accessible to plants and other organisms.[49] Most metals were found to be trapped in leftover fractions in that study, indicating that they are locked up in crystalline formations and so unable to be absorbed by plants or used by some living things.[49]

3.1.3 *Copper*

Copper levels varied from 8.6 mg/kg to 1,008.2 mg/kg, with a mean of 348.50 mg/kg. Copper values are over the safe limit of 100 mg/kg.[50] The average concentration found can be linked to the burning of electronics and other copper-based wastes like vehicle spare parts. Copper is required for the proper functioning of the body, as a cofactor in redox

enzymes and to keep blood chemistry balanced. At large concentrations, however, copper can be hazardous.[51]

3.1.4 *Zinc*

Zinc concentrations in the study ranged from 64.7 mg/kg to 194.45 mg/kg, with a mean of 146.24 mg/kg, which is well within the 300 mg/kg acceptable level for soils.[4] The presence of zinc in soil at various locations could be due to the burning of electronic devices and the presence of dry cells in municipal waste.[52] Zinc is required for growth, healing, and overall health in all species and is a cofactor in various enzymes.[51]

3.1.5 *Manganese*

Manganese is present naturally in most soils. It is one of the most important minerals for human survival, according to Dara and Mishra.[53] This study's findings are close to those of Adaikpoh,[54] who investigated the heavy metal distribution and enrichment in soils from waste dump locations in Imoru and environs in southwest Nigeria. All the manganese concentration levels were determined to be within the World Health Organization's manganese in soil samples.

3.1.6 *Cadmium*

Cadmium levels in soil samples were found to be higher than the WHO/FAO limit of 3 mg/kg. This study found greater levels of cadmium than Nazir et al.[55] The high cadmium concentration may be due to domestic effluents or atmospheric deposition from nearby industrial activity. High cadmium levels result in chronic and acute poisoning, damage to the liver, kidney, vascular system, immunological system, and effects on the gastrointestinal and reproductive systems.[56]

3.2 *Pearson's correlation analysis*

The pairwise relationships within the data were determined using Pearson's correlation analysis and the results are shown. Positive correlation was found for the levels of Pb/Cd (0.69) as shown in Table 3.

Table 3. Metal to metal coefficient matrix for soil samples

	[Pb]	[Zn]	[Cd]	[Mn]	[Cu]	[Fe]
[Pb]	1.00					
[Zn]	0.52	1.00				
[Cd]	0.69[a]	0.42	1.00			
[Mn]	0.33	-0.43	0.25	1.00		
[Cu]	0.33	0.35	0.54[b]	-0.03	1.00	
[Fe]	-0.22	-0.41	0.06	-0.02	-0.23	1.00

[a]Correlation is significant at the 0.05 level (two tailed), $P < 0.05$.
[b]Correlation is not significant at the 0.05 level (two tailed), $P > 0.05$.

3.3 *Pollution indices*

The calculated Igeo values are summarized in Table 4. The levels of metal pollution are in the order: Cd > Cu > Pb

> Zn > Fe > Mn. The degree of pollution for Cd is classified as extremely contaminated, for Cu as moderate to heavily contaminated, for Pb as moderately contaminated, and for Zn and Fe as uncontaminated to moderately contaminated. All the metals were found to have significantly contaminated the dumpsite.

The contamination factors (CF) and pollution load indices (PLI) are also presented in Table 4. The PLI determines the total amount of heavy metal toxicity in each sample by combining the effects of all heavy metals analysed. The contamination factor revealed that most of the elements in the dumpsite had moderate contamination levels. Fe had a very high contamination factor and Mn had a very low contamination factor but in all, the pollutant load index (PLI) was high for the Oti-Dompoase dumpsite.

Table 4. Geo-accumulation Indices, Contamination Factor and Pollution Load Index (PLI) of the soil samples studied

Heavy Metals	Geo accumulation Indices	Contamination Factor
Pb	1.26	73.83
Zn	0.84	25.66
Cd	18.80	70.60
Mn	0.38	14.35
Cu	2.01	124.46
Fe	0.49	167.68
PLI		40.34

3.3.1 *Indexes of pollution compared to other studies.*

Uncontaminated to moderately contaminated soil was identified in Medina (Accra), Medoma (Kumasi), and Tunsuom (Mampong) disposal sites for Cd and Pb based on geo-accumulation indices.[57] In a landfill site in Aba, Nigeria,[21] the determined Igeo value for Cd was moderate pollution which is not comparable to the Igeo obtained from Oti-Dompoase. The Igeo and contamination factor value of Cd found in Amakom and Kronum in Ghana was lower than that of Oti-Dompoase.[48] However, manganese was lower in Oti-Dompoase than Aba in Nigeria. A side-by-side comparison with other studies is presented in Table 5.

Table 5. Igeo comparison with other studies

Heavy Metals	Oti-Dompoase	Medina[57]	Medoma[57]	Tunsuom[57]	Aba[21]	Kronum[48]	Amakom[48]
Pb	1.26	0.54	0.97	0.82	3.007	< 1.50	1.00 to 2.62
Zn	0.84	3.03	3.36	2.95	2.513	0.11 to 1.58	0.58 to 1.69
Cd	18.80	2.40	2.06	2.06	1.828	< 1.50	< 0.00
Mn	0.38				3.442		
Cu	2.01	1.58	1.38	0.44	1.098	< 1.00	0.34-2.07
Fe	0.49	0.12	0.63	-0.02			

3.4 *Physiochemical parameters*

Table 6 shows the descriptive statistics (range, standard deviation, and median) for the physicochemical parameters of soils from the dump site. The availability, retention, and movement of nutrients and heavy metals in soils are all influenced by pH. Plants have more access to metals at low pH, and therefore pose a greater risk of toxicity than in alkaline soils.[58]

The pH of the soil samples ranged from (8.47-7.63) which is slightly basic, with the majority being in the neutral range. The increased pH values could be due to mineral build-up from garbage on the dumpsite.[59] A comparable pH was found at the Oke-Ese dumpsite in Ilesha. Most soils in the pH range of 6.0-9.0 are said to contain metals that aren't always in the free form, and so aren't likely to be bioavailable.[35]

Because the pH of all the soil samples studied falls within this range, the metals studied in this study may not be accessible to plants until favourable conditions, such as acidic precipitation prevail on the soil. In soil, pH affects solute concentration as well as pollutant sorption and desorption.[60]

The pH levels found in this study were comparable to those found at other dump sites.[36,61-62] The average organic matter content of the dump site soils is comparable to that of the Meduma and Mampong dump sites in Ghana,[57] but significantly higher than that of the Abrepo, Ayigya, and Buokrom dump sites in Kumasi, Ghana.[62]

Table 6. Physiochemical property of the soil samples

	pH	Conductivity	Organic Matter Content (%)	Moisture Content Content (%)
Mean ± SD	8.07 ± 0.25	1,021.33 ± 448.32	2.70 ± 1.30	22.70 ± 2.12
Range	7.63-8.47	389-1,967	1.98-3.89	19.34-25.54
WHO Standard	6.50-8.50	1,400	-	

3.5 *Human health assessment*

3.5.1 *Exposure assessment*

People who live nearby are at significant risk to their environment and health when the soil becomes contaminated with heavy metals. The effects of heavy metal contamination on children and adults were investigated through three channels (dermal contact, ingestion, and inhalation).

The Average Daily Dose (ADD) non-carcinogenic risk (Hazard quotient, HQ) and the cancer risk were calculated, and the results are presented in Table 7.

From the results, the ADDing, ADDinh and ADDderm for all the metals were found to be less than 1 (ADD < 1). On average, the highest risk route of exposure for adults and children was ingestion, followed by inhalation, and then dermal being the least. Daily heavy metal consumption was observed to follow the same pattern as Qing et al.[16]

The HQ values for ingestion and dermal contact were < 1 for all metals detected, signifying no adverse effect for the children and adults. The sum of calculated HQs is the hazard index (HI).[63] The HI value for the metals through dermal contact, ingestion, and inhalation as a means of exposure for adults and children were all less than 1 signifying no likelihood of non-carcinogenic effect as shown in Table 8.

Due to the lack of carcinogenic slope factors for Cu, Zn, Mn, and Cu in the literature, only the slope factors for Pb and Cd were provided. At the dumpsite, the cancer risk values for Pb and Cd were found to be 1.77×10^{-7} (Pb) for children and 9.47×10^{-8} for adults. Also, for children, 6.77×10^{-4} (Cd) and for adults, 3.63×10^{-4} (Cd) (Table 9). The risk index for Pb was 10^{-6} for both adults and children, indicating no possible carcinogenic risk, whereas the risk index for Cd was 10^{-4} for both adults and children, pointing to a likely risk of cancer.

Table 7. Daily Dose in three models

Metals	ADDing (mg/kg/day)		ADDinh (mg/kg/day)		ADDderm (mg/kg/day)	
	Children	Adult	Children	Adult	Children	Adult
Pb	2.08×10^{-3}	1.11×10^{-3}	7.87×10^{-14}	8.44×10^{-14}	3.74×10^{-5}	2.79×10^{-5}
Zn	9.35×10^{-4}	5.02×10^{-4}	3.54×10^{-14}	3.80×10^{-14}	1.68×10^{-5}	1.25×10^{-5}
Cd	4.51×10^{-5}	2.42×10^{-5}	1.71×10^{-15}	1.84×10^{-15}	8.12×10^{-7}	6.06×10^{-7}
Mn	1.23×10^{-3}	6.60×10^{-4}	4.66×10^{-14}	5.00×10^{-14}	2.21×10^{-5}	1.65×10^{-5}
Cu	2.23×10^{-3}	1.20×10^{-3}	8.44×10^{-14}	9.06×10^{-14}	4.01×10^{-5}	2.99×10^{-5}
Fe	1.65×10^{-2}	8.86×10^{-3}	6.25×10^{-13}	6.71×10^{-13}	2.97×10^{-4}	2.21×10^{-4}

Table 8. Health Risk Assessment

METALS	HQing		HQinh		HQderm		HI	
	Children	Adult	Children	Adult	Children	Adult	Children	Adult
Pb	5.93×10^{-1}	3.18×10^{-1}	2.23×10^{-11}	2.40×10^{-11}	7.12×10^{-2}	5.31×10^{-2}	6.65×10^{-1}	3.71×10^{-1}
Zn	3.12×10^{-3}	1.67×10^{-3}	1.18×10^{-13}	1.27×10^{-13}	2.80×10^{-5}	2.09×10^{-5}	3.14×10^{-3}	1.69×10^{-3}
Cd	4.51×10^{-2}	2.42×10^{-2}	1.71×10^{-12}	1.84E-12	8.12×10^{-2}	6.06×10^{-2}	1.26×10^{-1}	8.48×10^{-2}
Mn	8.78×10^{-3}	4.71×10^{-3}	9.31×10^{-13}	9.99×10^{-13}	1.58×10^{-4}	1.18×10^{-4}	8.94×10^{-3}	4.83×10^{-3}
Cu	5.57×10^{-2}	2.99×10^{-2}	2.10×10^{-12}	2.25×10^{-12}	3.34×10^{-3}	2.49×10^{-3}	5.90×10^{-2}	3.24×10^{-2}
Fe	2.36×10^{-2}	1.27×10^{-2}	8.93×10^{-13}	9.59×10^{-13}	3.71×10^{-4}	2.77×10^{-4}	2.40×10^{-2}	1.29×10^{-2}

Table 9. Carcinogenic Risk Assessment

METAL	ADD × SF	
	Children	Adult
Pb	1.77×10^{-7}	9.47×10^{-8}
Cd	6.77×10^{-4}	3.63×10^{-4}

4. Conclusion and recommendations

The study has determined the levels of heavy metals in a dumpsite and the associated pollution and risk. The results show that all the samples contained some amounts of the examined elements: Lead, Zinc Manganese, Copper,

and Iron, whereas Cadmium was also found to be present in some samples. It was also discovered that some sample points had larger concentrations of these metals than others; this could be due to the presence of garbage containing higher concentrations of these heavy metals, as well as the geological formation of the places. The concentrations of the other metals were within the acceptable range.

Biodegradable solid waste mineralization and breakdown in solid waste dumps could also be responsible for the higher metal concentrations. However, the Lower concentrations of specific elements (Cd, Zn, and Mn) in dumpsites identified could also be attributed to a higher percentage of non-biodegradable wastes which could have impeded microorganisms from biodegrading solid waste.[6]

The higher status of lead followed by copper and zinc might be attributed to garbage from dumps, primarily alloys, plastic cables, used batteries, demolished buildings, power lines, etc. Cadmium and lead had the highest contamination factor and index of geo-accumulation at the dumpsite. The contamination factor revealed that majority of the elements in the dumpsite were higher than 36, suggesting that the landfill site has a remarkably high contamination factor. The pollutant load index was high for the dumpsite.

Geo-statistical analyses of various metals show pollution of the soil. However, overall metal pollution at the Oti-Dompoase dumpsite was significantly higher than that of Amakom and Kronum. This could be attributed to the discarding of cosmetics, electronics, medicines, and metal scraps.[48] Heavy metals can accumulate in plants growing on the dumpsite, which can be passed down the food chain to humans, causing a health risk. Toxic metals may have a harmful impact on the ecology.

The findings are critical components of decision-making factors in the management of contaminated sites. The findings demonstrated that heavy metal pollution in soil may pose an unacceptable risk to human health, particularly if the contaminated land surrounding metallurgical plants is used for agriculture. The limitation of this study is that the sampling was done in one day and did not consider long term dynamics of the soil contents that may be due to natural and other anthropogenic activities, therefore a long-term routine study is suggested to capture the average concentration and changes/stability in constituents at the dumpsite.

Data availability

The data that supports the findings of this research study are available within the article.

Funding statement

The study did not receive any funding.

Conflict of interest

The authors certify that they have NO affiliations with or involvement in any organization or entity with any financial or non-financial interests in the subject matter or materials discussed in this manuscript.

References

[1] Gatiboni, L. Soils and Plant Nutrients, Chapter 1. In *North Carolina Extension Gardener Handbook*, 2nd ed.; Moore, K. A., Bradley, L. K., Eds.; NC State Extension, Raleigh, NC, 2022.

[2] Berhe, A. A.; Kleber, M. Erosion, deposition, and the persistence of soil organic matter: Mechanistic considerations and problems with terminology. *Earth Surf. Proc. Land*. **2013,** *38*(8), 908-912.

[3] Zhang, M. K.; Liu, Z. Y.; Wang, H. Use of single extraction methods to predict bioavailability of heavy metals in polluted soils to rice. *Commun. Soil Sci. Plant Anal*. **2010,** *41*(7), 820-831.

[4] Kabata-Pendias, A. *Trace Elements in Soils and Plants*; CRC Press: Boca Raton, 2011.

[5] Verge, A.; Rowe, R. K. A framework for a decision support system for municipal solid waste landfill design. *Waste Manag. Res*. **2013,** *31*(12), 1217-1227.
[6] Ukpong, E. C.; Agunwamba, J. C. Effect of open dumps on some engineering and chemical properties of soil. *Cont. J. Eng. Sci*. **2011,** *6*(2), 45-55.
[7] Caylak, E. Health risk assessment for trace metals, polycyclic aromatic hydrocarbons and trihalomethanes in drinking water of Cankiri, Turkey. *J. Chem*. **2012,** *9*(4), 1976-1991.
[8] George, A.; Venugopal, A.; Vashisht, A. K. Heavy metal contamination in soil and groundwater around industrial areas of Kollam District, Kerala, India. *Environ. Monit. Assess*. **2023,** *195*(2), 1-14.
[9] Vig, N.; Ravindra, K.; Mor, S.; Shabani, M. Heavy metal pollution assessment of groundwater and associated health risks around coal thermal power plant, Punjab, India. *Int. J. Environ. Sci. Technol*. **2023,** *20*(3), 6259-6274.
[10] Neeraj, A.; Hiranmai, R. Y.; Iqbal, K. Comprehensive assessment of pollution indices, sources apportionment and ecological risk mapping of heavy metals in agricultural soils of Raebareli District, Uttar Pradesh, India, employing a GIS approach. *Land Degrad. Dev*. **2023,** *34*(1), 173-195.
[11] Wang, S. L.; Xu, X. R.; Sun, Y. X.; Liu, J. L.; Li, H. B. Heavy metal pollution in coastal areas of South China: A review. *Mar. Pollut. Bull*. **2013,** *76*(1-2), 7-15.
[12] Shi, J.; Zhao, D.; Ren, F.; Huang, L. Spatiotemporal variation of soil heavy metals in China: The pollution status and risk assessment. *Sci. Total Environ*. **2023,** *871*, 161768.
[13] Mao, X.; Sun, J.; Shaghaleh, H.; Jiang, X.; Yu, H.; Zhai, S.; Hamoud, Y. A. Environmental assessment of soils and crops based on heavy metal risk analysis in Southeastern China. *Agronomy* **2023,** *13*(4), 1107.
[14] Hu, N. W.; Yu, H. W.; Deng, B. L.; Hu, B.; Zhu, G. P.; Yang, X. T.; Wang, T. W.; Zeng, Y.; Wang, Q. Y. Levels of heavy metal in soil and vegetable and associated health risk in peri-urban areas across China. *Ecotoxicol. Environ. Saf*. **2023,** *259*, 115037.
[15] Zhang, Y.; Song, B.; Zhou, Z. Pollution assessment and source apportionment of heavy metals in soil from lead-Zinc mining areas of south China. *J. Environ. Chem. Eng*. **2023,** *11*(2), 109320.
[16] Xiao, Q.; Zong, Y.; Lu, S. Assessment of heavy metal pollution and human health risk in urban soils of steel industrial city (Anshan), Liaoning, Northeast China. *Ecotoxicol. Environ. Saf*. **2015,** *120*, 377-385.
[17] Amadi, N. Assessment of dominant heavy metals in selected solid waste dumpsites in Port Harcourt metropolis, Nigeria. *Int. J. Adv. Res. in Biol. Sci*. **2023,** *10*(5), 177-187.
[18] Omada, J. I.; Ogoko, E. C.; Kelle, H. I.; Gideon, Y. B. Heavy metal pollution indices in soil and plants within the vicinity of the Gosa Dumpsite in Abuja, Nigeria. *Environ. Geochem. Health*. **2024,** *46*(7), 1-19.
[19] Awokunmi, E. E.; Asaolu, S. S.; Adefemi, S. O.; Gbolagade, A. Y. Contributions of municipal solid waste to heavy metal concentration in soil near oke ese dumpsite, Ilesha, Osun State, Nigeria. *Int. J. Environ. Prot*. **2015,** *5*(1), 44-51.
[20] Olayiwola, H. A.; Abudulawal, L.; Adewuyi, G. K.; Azeez, M. O. Heavy metal contents in soil and plants at dumpsites: A case study of Awotan and Ajakanga dumpsite Ibadan, Oyo State, Nigeria. *J. Environ. Earth Sci.* **2017,** *7*(4), 11-24.
[21] Amadi, A. N.; Nwankwoala, H. O. Evaluation of heavy metal in soils from enyimba dumpsite in Aba, Southeastern Nigeria using contamination factor and geo-accumulation index. *Energy Environ. Res.* **2013,** *3*(1), 125-134.
[22] Obasi, N. A.; Akubugwo, E.; Ugbogu, O. C.; Otuchristian, G. Assessment of physicho-chemical properties and heavy metals bioavailability in dumpsites along enugu-port harcourt expressways, South-east, Nigeria. *Asian J. Appl. Sci*. **2012,** *5*(6), 342-356.
[23] Obiri-Nyarko, F.; Quansah, J. O.; Asare, S. V.; Fynn, O. F.; Okrah, C.; Debrah, S. K.; Karikari, A. K. Determination of threshold values and heavy metal pollution assessment of soils in an industrial area in Ghana. *Environ. Monit. Assess*. **2024,** *196*(6), 1-19.
[24] Gyabaah, D.; Awuah, E.; Kuffour, R. A.; Antwi-Agyei, P.; Wiafe, S.; Asiedu, S. B. Assessment of dumpsites leachate, geotechnical properties of the soil, and their impacts on surface and groundwater quality of Sunyani, Ghana. *Environ. Adv*. **2024,** *16*, 100548.
[25] Hadzi, G. Y.; Essumang, D. K.; Ayoko, G. A. Assessment of contamination and potential ecological risks of heavy metals in riverine sediments from gold mining and pristine areas in Ghana. *J. Trace Elem. Miner.* **2024,** *7*, 100109.
[26] Klutse, C. K.; Quayson, M. A.; Forson, A.; Nuveadenu, C.; Asare, E. A. Ecotoxicity of heavy metals in soil around long-term e-waste recycling sites in Tema and Ashaiman areas of Ghana. *Environ. Monit. Assess*. **2024,** *196*(1), 1-17.
[27] Esakku, S.; Palanivelu, K.; Joseph, K. Assessment of Heavy Metals in a Municipal Solid Waste Dumpsite. In *Workshop on Sustainable Landfill Management*; Chennai, India, 2003; pp 139-145.
[28] Akinbile, C. O.; Yusoff, M. S. Solid waste generation and decomposition using compost bin technique in Pulau Pinang, Malaysia. *Waste Manag. Res*. **2012,** *30*(5), 498-505.

[29] Alloway, B. J. Sources of Heavy Metals and Metalloids in Soils. In *Heavy Metals in Soil: Trace Metals and Metalloids in Soil and Their Bioavailability*; Wiley, 2013; pp 11-50.
[30] Chibuike, G. U.; Obiora, S. C. Heavy metal polluted soils: Effect on plants and bioremediation methods. *Appl. Environ. Soil Sci*. **2014,** *2014*, 52708.
[31] Raskin, I.; Kumar, P. N.; Dushenkov, S.; Salt, D. E. Bioconcentration of heavy metals by plants. *Curr. Opin. Biotechnol*. **1994,** *5*(3), 285-290.
[32] Jie, C.; Jing-zhang, C.; Man-zhi, T.; Zi-tong, G. Soil degradation: A global problem endangering sustainable development. *J. Geogr. Sci*. **2002,** *12*(2), 243-252.
[33] Mackevičiene, G.; Štriupkuviene, N.; Berlinskas, G. Accumulation of heavy metals and radionuclides in bottom sediments of monitoring streams in Lithuania. *Ecology* (Engl. Transl.) **2002,** *2*.
[34] Inobeme, A.; Mathew, J. T.; Jatto, E.; Inobeme, J.; Adetunji, C. O.; Muniratu, M.; Onyeachu, B. I.; Adekoya, M. A.; Ajai, A. I.; Mann, A.; Olori, E.; Akhor, S. O.; Eziukwu, C. A.; Kelani, T.; Omali, P. I. Recent advances in instrumental techniques for heavy metal quantification. *Environ. Monit. Assess*. **2023,** *195*(4), 452.
[35] Porteous A. *Hazardous Waste Management Handbook*; Butterworths: London, 1985.
[36] Prechthai, T.; Parkpian, P.; Visvanathan, C. Assessment of heavy metal contamination and its mobilization from municipal solid waste open dumping site. *J. Hazard. Mater*. **2008,** *156*(1-3), 86-94.
[37] Barbieri, M. The importance of enrichment factor (EF) and geoaccumulation index (Igeo) to evaluate the soil contamination. *J. Geol. Geophys*. **2016,** *5*(1), 1-4.
[38] de Almeida Júnior, A. B.; do Nascimento, C. W. A.; Biondi, C. M.; de Souza, A. P.; do Rêgo Barros, F. M. Background and reference values of metals in soils from Paraíba state, Brazil. *Rev. Bras. Cienc. Solo*. **2016,** *40*, 1-13.
[39] Darko, G.; Dodd, M.; Nkansah, M. A.; Aduse-Poku, Y.; Ansah, E.; Wemegah, D. D.; Borquaye, L. S. Distribution and ecological risks of toxic metals in the topsoils in the Kumasi metropolis, Ghana. *Cogent. Environ. Sci*. **2017,** *3*(1), 1-15.
[40] Mmolawa, K. B.; Likuku, S.; Gaboutloeloe, G. K. Assessment of heavy metal pollution in soils along major roadside areas in Botswana. *Afr. J. Environ. Sci. Technol*. **2011,** *5*, 186-196.
[41] Ofosu, F. G.; Hopke, P. K.; Aboh, I. J. K.; Bamford, S. A. Characterization of fine particulate sources at Ashaiman in Greater Accra, Ghana. *Atmos. Pollut. Res*. **2012,** *3*(3), 301-310.
[42] Vose, P. B. Iron nutrition in plants: A world overview. *J. Plant. Nutr*. **1982,** *5*(4-7), 233-249.
[43] Colombo, C.; Palumbo, G.; He, J. Z.; Pinton, R.; Cesco, S. Review on iron availability in soil: Interaction of Fe minerals, plants, and microbes. *J. Soils Sediments*. **2014,** *14*(3), 538-548.
[44] Wang, J. P.; Guo, X. K. Impact of electronic wastes recycling on environmental quality. *Biomed. and Environ. Sci*. **2006,** *19*(2), 137-142.
[45] Onwukeme, V. I.; Eze, C. V. Identification of heavy metals source within selected active dumpsites in southeastern Nigeria. *Environ. Anal. Health. Toxicol.* **2021,** *36*(2), e2021008.
[46] Obasi, N. A.; Akubugwo, E. I.; Ugbogu, O. C.; Otuchristian, G. Assessment of physicho-chemical properties and heavy metals bioavailability in dumpsites along enugu-port harcourt expressways, South-east, Nigeria. *Asian J. of Appl. Sci*. **2012,** *5*(6), 342-356.
[47] Darko, G.; Adjei, S.; Nkansah, M. A.; Borquaye, L. S.; Boakye, K. O.; Dodd, M. 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*. **2020,** *32*(2), 426-436.
[48] Akanchise, T.; Boakye, S.; Borquaye, L. S.; Dodd, M.; Darko, G. Distribution of heavy metals in soils from abandoned dump sites in Kumasi, Ghana. *Sci. Afr*. **2020,** *10*, e00614.
[49] Akoto, O.; Nimako, C.; Asante, J.; Bailey, D.; Bortey-Sam, N. 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*. **2019,** *25*(7), 1870-1885.
[50] Kloke, A. *Content of Arsenic, Cadmium, Chromium, Fluorite, Lead, Mercury and Nickel in Plants Grown on Contaminated Soil*; United Nations ECE Symposium on Effects of Airborne Pollution on Vegetation, Warsaw, 1979.
[51] McBride, M. B. *Environmental Chemistry of Soils*; Oxford University Press, Inc.: New York, 1994.
[52] Benedicta, A.; Davar, P. Waste to wealth potentials of municipal solid waste: A case study of Ga-East Municipal Assembly, Ghana. *Afr. J. Environ. Waste Manag*. **2014,** *2*(1), 113-121.
[53] Dara, S. S.; Mishra, D. D. *A Textbook of Environmental Chemistry and Polution Control (With Energy, Ecology, Ethics and Society)*; S. Chand & Company Ltd: New Delhi, 2006.
[54] Adaikpoh, E. O. Distribution and enrichment of heavy metals in soils from waste dump sites within imoru and environs, Southwest Nigeria. *J. Environ. Earth Sci.* **2013,** *3*(14), 45-55.

[55] Nazir, R.; Khan, M.; Masab, M.; Rehman, H. U.; Rauf, N. U.; Shahab, S.; Ameer, N.; Sajed, M.; Ullah, M.; Rafeeq, M.; Shaheen, Z. Accumulation of heavy metals (Ni, Cu, Cd, Cr, Pb, Zn, Fe) in the soil, water and plants and analysis of physico-chemical parameters of soil and water collected from Tanda Dam Kohat. *J. Pharm. Sci. Res*. **2015,** *7*(3), 89-97.
[56] Orisakwe, O. E. Lead and cadmium in public health in Nigeria: Physicians neglect and pitfall in patient management. *N. Am. J. Med. Sci*. **2014,** *6*(2), 61-70.
[57] Agyarko, K.; Darteh, E.; Berlinger, B. Metal levels in some refuse dump soils and plants in Ghana. *Plant Soil Environ*. **2010,** *56*(5), 244-251.
[58] Ahmadpour, P.; Ahmadpour, F.; Sadeghi, S. M.; Tayefeh, F. H.; Soleimani, M.; Abdu, A. B. *Evaluation of Four Plant Species for Phytoremediation of Copper-Contaminated Soil*; Elsevier Inc., 2015.
[59] Awokunmi, E. E.; Asaolu, S. S.; Adefemi, S. O.; Gbolagade, A. Y. Contributions of municipal solid waste to heavy metal concentration in soil near Oke Ese dumpsite, Ilesha, Osun State, Nigeria. *Int. J. Environ. Prot*. **2015,** *5*(1), 44-51.
[60] Elliott, H. A.; Liberati, M. R.; Huang, C. P. Competitive adsorption of heavy metals by soils. *J. Environ. Qual*. **1986,** *15*(3), 214-219.
[61] Agyarko, K.; Darteh, E.; Berlinger, B. Metal levels in some refuse dump soils and plants in Ghana. *Plant Soil Environ*. **2010,** *56*(5), 244-251.
[62] Odai, S. N.; Mensah, E.; Sipitey, D.; Ryo, S.; Awuah, E. Heavy metals uptake by vegetables cultivated on urban waste dumpsites: Case study of Kumasi, Ghana. *Res. J. Environ. Toxicol*. **2008,** *2*(2), 92-99.
[63] Kurt-Karakus, P. B. Determination of heavy metals in indoor dust from Istanbul, Turkey: Estimation of the health risk. *Environ. Int*. **2012,** *50*, 47-55.

Appendix

Table A1. Geoaccumulation index (Igeo) and contamination factor (CF) classifications

Category	Description
Igeo < 0	Practically uncontaminated
0 < Igeo < 1	Uncontaminated to moderately contaminated
1 < Igeo < 2	Moderately contaminated
2 < Igeo < 3	Moderately to heavily contaminated
3 < Igeo < 4	Heavily contaminated
4 < Igeo < 5	Heavily to extremely contaminated
Igeo > 5	Extremely contaminated
CF < 1	Low contamination factor indicating low contamination
1 ≤ CF < 3	Moderate contamination factor
3 ≤ CF < 6	Considerably high contamination factor
CF ≥ 6	Very high contamination factor

Table A2. Reference Dose and Slope Factor for the heavy metals

METALS	RfDing (mg/kg/day)	RfDinh (mg/kg/day)	RfDder (mg/kg/day)	Sf (mg/kg/day)
Pb	3.50×10^{-3}	3.52×10^{-3}	5.25×10^{-4}	8.5×10^{-5}
Zn	3.00×10^{-1}	3.00×10^{-1}	6.00×10^{-1}	ND
Cd	1.00×10^{-3}	1.00×10^{-3}	1.00×10^{-5}	15
Mn	1.40×10^{-1}	5.00×10^{-2}	1.40×10^{-1}	ND
Cu	4.00×10^{-2}	4.02×10^{-2}	1.20×10^{-2}	ND
Fe	7.0×10^{-1}	7.0×10^{-1}	8.0×10^{-1}	ND

*ND = Not Determined