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Comparative assessment of heavy metal contamination of abandoned and active dumpsite of Osun waste management, Ejigbo Road, Osogbo, Osun State, Nigeria

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ABSTRACT

This study conducts a comparative assessment of two dumpsites (abandoned and active dumpsite) around Osogbo metropolis Osun State Nigeria. Ten selected heavy metals (HMs) such as arsenic, copper, cobalt, cadmium, chromium, iron, nickel, manganese, lead and zinc were determined. The soil samples were collected, at strategic points to revealed variation in samples. The concentrations of HMs were quantitatively determined using atomic absorption spectroscopy. The results indicated that all the HMs determined were found between below detection limit (bdl) to 0.611 mg/kg and bdl –0.880 mg/kg for abandoned and active dumpsites, respectively. The concentration factor and geo-accumulation intensity revealed no contamination to strong contamination and from uncontaminated to strong contamination intensity, respectively. The concentrations for some of the HMs were below the tolerable recommendation level by National Environmental Standards and Regulation Enforcement Agency and Food and Agriculture Organization/World Health Organization in soil samples. This study recommends periodic monitoring and that possible decontamination of the dumpsite are crucial because these dumpsites were currently in use for crops cultivation such as maize, vegetable bananas, and some other arable plants. Also, HM concentrations in crops should be investigated and monitored at these dumpsites regularly in order to avert detrimental effects of HM pollution, which could manifest many years after exposure, as they are recalcitrant in the environment.

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Comparative assessment; heavy metals; abandoned and active dumpsite; Osun waste management; geo-accumulation; contamination factor

1. Introduction

Dumpsite refers to a certain part of the land set aside for disposal of untreated solid wastes in an uncontrolled manner, which in turn could have detrimental effects on the ecological imbalance of the ecosystem [1]. Solid wastes are heterogeneous which may consist of untreated waste materials of industrial, domestic, agricultural and hospital origins. These materials may include used clothes, leathers, nylon, papers, plastics, used batteries, electronic

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wastes, electroplating wastes, organic materials, syringes, and needles among others. These are the sources of the bulk of heavy metals (HMs) observed in dumpsites [2]. In Osogbo and most other Nigeria cities, wastes are not sorted into domestic, clinical, industrial and institutional but are co-deposited at the dumpsites. Therefore, they served as a repository for HMs and organic pollutants [3]. More often than not, the Government converted these dumpsites into developmental projects such as shopping malls, housing estates, recreation centres, schools and some general public utilities that lack a proper assessment of the pollution status of the land in terms of organic and HM pollutants [3]. In addition, some farmers believed that dumpsites composed of fertile soil and could serve as a good source of arable land for crops cultivations with no regard to the risk associated with HM pollution by the waste [4,5]. The leachate from the dumpsites containing HMs and organic contaminants are spread into the nearby underground water (wells) and surface water (rivers) contributing significantly to their HMs' concentrations thereby compromising the health of humans and is harmful to the environment [6]. Some of the HMs are naturally occurring in nature and they are required in micro quantity for the proper growth of plants. At elevated levels in the environment, they become dangerous to both fauna and flora. They are toxic when they are no longer being able to metabolise thereby get accumulated in the body tissues [6,7]. Depending on the concentration, heavy metals such as Fe, Mn and Cu could be naturally present in the environment and may enrich the soil nutrients. While few other metals such as Pb, Cd and Cr, are manufactured and are used for various industrial applications. They are hazardous, non-biodegradable and could persist in the environment for many years [5]. For instance, chronic ingestion of Cd may lead to gastrointestinal and pulmonary diseases [7]. A high dosage of Cr in humans resulted in haematological, respiratory and cardiovascular effects [7]. Ingestion of Pb affects the renal, reproductive and nervous systems [8]. Therefore, critical analysis of HMs in the dumpsite soils is very important for risk assessment of the waste in dumpsites. Since these contaminants adversely affect the quality of the ecosystem around the dumpsites, monitoring of the non-biodegradable pollutants such as HMs to recommend suitable remedial measures becomes imperatively important [9]. Hence, this study aims at determining and compare the levels of some selected potential HMs such as As, Cu, Co, Cd, Cr, Fe, Ni, Mn, Pb and Zn in abandoned and active waste dumpsite located within the Osogbo metropolis. The outcome of this study would provide much-needed information on the current pollution status associated with the selected HMs of abandon (Onibueja dumpsite) and active dumpsites (Eco Waste to Wealth Waste Recycling Centre Dumpsites) within the Osogbo metropolis. The results of levels of HMs determined in this study would be correlated with National Environmental Standards and Regulation Enforcement Agency (NESREA), World Health Organization (WHO), and offer recommendations on the associated risks, which may arise from the indiscriminate dumping of refuse, based on the toxicity of metals, suitability of the sites for developmental and agricultural purposes.

2. Materials and method

2.1. Study area and site description

This current study explored two major dumpsites within the Osogbo metropolis (abandoned and active dumpsite of Osun Waste Management Board Ejigbo Road, Osogbo), Osun State, Southwestern Nigeria on the geographical location of latitudes 7°46.110′ N, longitudes 4°32.379′ E and elevated within 285 m above sea level. According to the Köppen classification on climate, Osun state is classified as a tropical wet and dry climate with an annual temperature of 26.1°C, and precipitation of 1241 mm respectively mostly fall in summer [10]. The variation in precipitation with an average value of 193 mm between the driest and the wettest months had been noted [10]. The abandoned dumpsite was once active and there has been no dumping in recent times and is currently being used for farming activities. Among the food, crops currently been grown in the study sites and its environs include maize, vegetable, plantain, and cocoyam. The pictorial representation of the sampling locations across the dumpsites is shown in Figure 1. These dumpsites accommodate various wastes generated by the majority of residents of the state capital, Osogbo that consists of different kinds (heterogeneous) of wastes. The major inputs of waste into these dumpsites are; domestic waste, hospital waste, poultry wastes from poultry and saw-mill, chemical wastes, electronics wastes, and wastes from the mechanic workshop as well as wastes from various light-, medium- and large-scale industries within the environment. Major land use around these dumpsites include residential, commercial, industrial, agricultural practice and road construction where vehicular exhaust could contribute significantly to the existing waste on the soil. The proximity of houses to this dumpsite could result in HM pollution from dumpsites leachates to underground water such as boreholes and well which serve as the main

Figure 1. The cross-sections of site locations across the dumpsites within the Osogbo metropolis, (a) (Abandoned dumpsite) and (b) (active dumpsite). Site coordinates = (A1) 07°47′39.63″N 04°29′23.6″E, (A2) 07°47′40.73″N 04°29′24.14″E, (A3) 07°47′47.29″N 04°29′27.35″E, (A4) 07°47′51.28″N, 04°29′30.31″E, (A5) 07°47′46.62″N 04°29′30.92″E.(B1) 07°46′31.19″N 04°26′40.15″E, (B2) 07°46′28.96″N 04°26′38.03″E, (B3) 07°46′35.93″N 04°26′33.35″E, (B4) 07°46′29.81″N 04°26′30.05″E, (B5) 07°46′24.46″N 04°26′30.81″E

source of water for various households around this area. Farmlands for the cultivations of some arable crops by the local farmers and stream waters (river networks) where local people depend as a source of their water for washing and bathing purposes are also very close to these dumpsites.

2.2. Sample collection and preservation

A total number of 10 samples, 5 samples in each dumpsite (abandoned and active dumpsites) represented by A and B respectively were collected on 28 March 2021. Grab sampling technique was used for the soil samples collection taken from different points where global positioning system (GPS) was used for the identification and points locations. Site coordinates are appended in footnote 1. Samples were collected between 0 and 30 cm depth using a stainless-steel soil Auger. A pre-acetone-washed foil was used for the collection of the soil samples, wrapped and transported safely to the laboratory (Department of Science Laboratory Technology, Osun State Polytechnic, Iree). Samples were carefully handled to avoid any possible contaminations or interferences following the standard procedure as reported by Ahlers et al. [11]. The air-dried samples were ground, sieved using a 2 mm mesh sieve size. The soil physicochemical properties such as pH, electrical conductivity, total dissolved solids, salt concentration, and resistance were determined using a multi-metre probes while organic matter and soil organic matter contents were determined using standard wet digestion Walkley Black Method [12].

2.3. Samples preparation and instrumental analysis

The HM contents in the sample extracts were determined using an AOAC method 1990 [13]. Briefly, about 3 g each of the test samples was weighed and digested with 20 mL of the acid mixture (Conc.HNO_3/$HClO_4$/Conc.H_2SO_4 acids) in the ratio 2:1:1. The solution was heated until a clear digest was obtained [13]. The digest was allowed to cool down, diluted with distilled water to the 50 mL mark, and filtered through watchman filter paper. A portion of the filtrate was used for atomic absorption spectrometer (AAS) analysis. The AAS of Buck scientific model 200A System was set up with optical alignment of the system. A mixed standard was prepared in parts per million ranges (ppm) for calibration. These solutions along with the samples were aspirated into the air/acetylene flame of the nebuliser channel of the spectrometer set up for each. The concentrations of each HM were then calculated by extrapolation using the standard curve. The detection limit of the AAS used for HMs determinations was noted to be 0.001 μg/mL (ppm). To maintain the integrity of the samples, all the sample preparations were performed promptly within two weeks of post samples collection and all the quality control measures were carefully observed. Analytical grade HNO_3, $HClO_4$ and Conc.H_2SO_4 acids were used for metal digestion. All sample containers were soaked with the acid solution, prewashed with detergents and tap water and finally with deionised water. Plastic containers were used throughout the sample preparations to avoid the metals been adhered into the wall of glass containers. To avoid any carry-over effect from one site to the others, the remnants of soil from the soil Auger were adequately removed just before taken the next samples. Blank determinations were carried out for each set of analyses using the same reagents to check for any cross contaminations from any of the materials used.

2.4. Data analysis

Statistical analyses were performed using SPSS version 25. A student's t-test of 2 tails was used to separate means of HM concentrations and soil properties across the sampling point's sites in this study. All statistical analyses were carried out at a 95% confidence level with significant differences ($p < 0.05$). All analyses were conducted in triplicate, and the results were determined as the mean values.

The pollution levels in the soil at the dumpsites, the HM contamination factor (CF) for each of the heavy metals analysed are evaluated using Equation (1) as proposed by Hakanson [14] and Ngole-Jeme [15].

$$CF = {}^{C_n}\!/_{B_n} \tag{1}$$

where CF, Cn and Bn represent contamination factor, measured concentration, and background values of metals, respectively. The following CF values represent different contaminations levels in the environment; CF < 1 (low contamination); 1 ≤ CF < 3 (moderate contamination); 3 ≤ CF < 6 (high contamination factor); CF ≥ 6 (considered very high contamination).

The degree of pollution in this study was evaluated using Geo-Accumulation Index (Igeo). Muller [16] presented the geo-accumulation index (Igeo) as shown in Equation 2

$$I_{geo} = log_2\left({}^{C_n}\!/_{1.5B_n}\right) \tag{2}$$

Therefore, Cn and Bn denote measured concentration HM in the sample and the geo-chemical background concentration respectively and the constant 1.5 represent a correction factor, which could account for the any possible variation in the system as proposed by Barbieri [17]. According to Huu et al. [18], the pollution level by HMs is monitored according to the progressive numerical value of the seven-contamination index as follows. Igeo < 0 = class 0 (practically uncontaminated), Igeo > 0 − 1 = class 1 (uncontaminated to moderate intensity), Igeo > 1–2 = class 2 (moderate contamination intensity), Igeo > 2–3 = class 3 (moderate to strong contamination intensity), Igeo > 3–4 = class 4 (strong intensity), Igeo > 4–5 = class 5 (strong to very strong contamination intensity) and Igeo > 5 = class 6 (very strong contamination intensity).

3. Results and discussion

3.1. Heavy metal contents in soil samples and soil physicochemical parameters

The pollution levels at the dumpsites, the HM concentrations determined in this study are presented in Figures 2(a,b) while the significant differences between the abandoned and active dumpsites are shown in Figure 3. The composition of the waste materials, microbial decomposition rate has been reported as the most significant factors controlling the distribution of the HMs in the soil [19]. The levels of HM concentrations at the dumpsites generally are in order as Cu > Zn > Fe > Mn > Ni > Pb > Cd > Cr ≤ As ≤ Co at both dumpsites A and B.

The results of the physicochemical parameters are presented in Table 3. The pH of abandoned and active dumpsites ranged from 5.62 (A1) to 6.95 (A5) and 6.32 (B1) to 7.22 (B4), respectively. This indicates that the soil at the abandoned and active

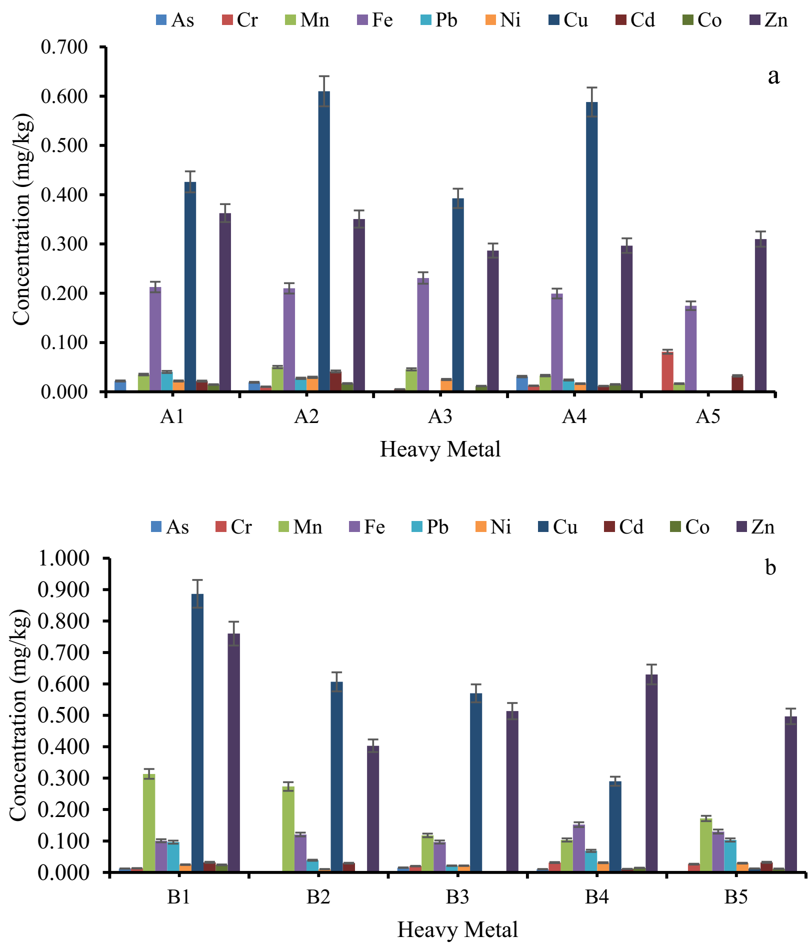

Figure 2. Distribution of heavy metal in soil samples collected from (a) abandoned dumpsite, (b) active dumpsite. A1 – location 1, A2 – location 2, A3 – location 3, A4 – location 4, A5 – location 5 (Abandoned dumpsite) and B1 – location 1, B2 – location 2, B3 – location 3, B4 – location 4, B5 – location 5 (Active dumpsite).

dumpsites is within the slightly acidic to neutral pH. The pH is used in determining the carbonate, bicarbonate and corrosion index of water [20,21]. Therefore, the pH at these dumpsites may partially cause dissolution of HMs during the wet season; thereby encourage the leaching into the underground water. The conductivity of solution soil sampled at the dumpsites ranges from 84 µs (A3) to 296 µs (A1) and 230 µs (B3) to 1998 µs (B2) respectively. Conductivity indicates the amount of ionisable inorganic compounds in water [22]. The result of the soil solution under investigation indicates that its ionisation ranges from low to high levels. The high values observed in the active dumpsite could be attributed to recent inputs from anthropogenic activities of various materials containing various ions. The total dissolved solids (TDS) give the overall effects of dissolved particulates in soil solution [23]. The result shows that the TDS for the studied sites ranges from 41 mg/l (A3) to 145 mg/l (A1) and 114 mg/l (B3) to 979 mg/l (B2) for abandoned and active dumpsites, respectively. The high TDS value in

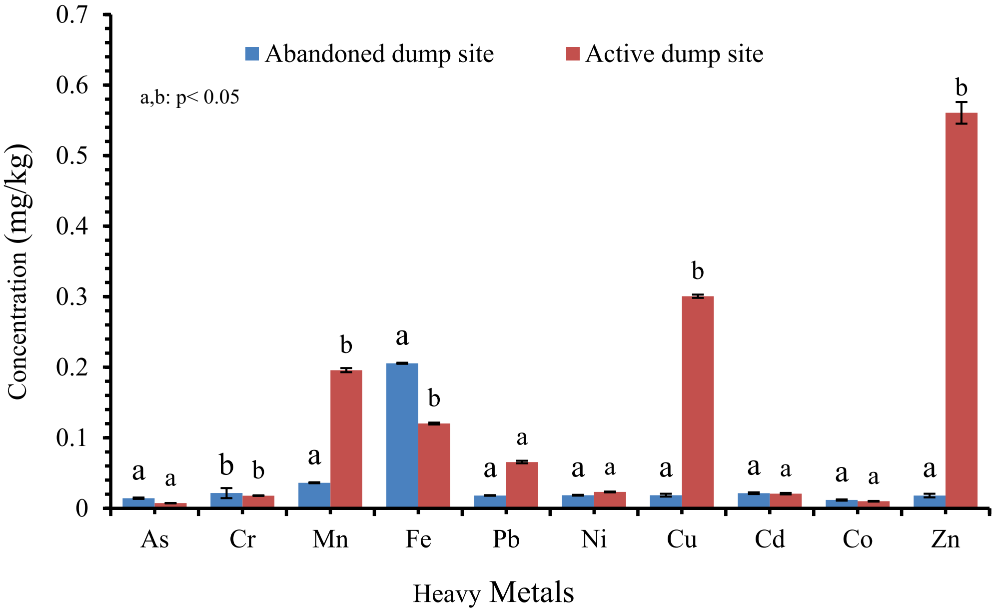

Figure 3. A t-test, 2 tails analysis of HMs determination on abandoned and active dumpsites. Different superscript letters indicate a significant difference ($p < 0.05$).

active dumpsite is proportional to conductance observed, indicating the active deposition of heterogeneous materials riched in minerals. The elevated values of TDS could cause either temporary or permanent hardness of underground water in the nearby location and could hurt aquatic flora and fauna [23]. The result of salt concentrations in this study is in tandem with both conductivity and TDS values. The organic carbon (OC) of the sampling sites ranges from 2.89% (A2) to 3.32% (A4) and 0.96% (B4) to 1.86% (B3), respectively. Similar trends were observed for soil organic matter (SOM) along with the sites. The SOM values ranged between 11.62% (A2) to 13.29% (A4) and 4.54% (B4) to 7.83% (B3) for abandoned and active dumpsites, respectively. The elevated values observed in the abandoned dumpsite compared to the active dumpsite in this study could be as a result of decaying processes over time which consists of decomposed plants and animal tissues, conversion of inorganic and organic materials into nutrients, thus enhances the soil productivity [24]. The high SOM content could improve soil texture, structure, water-holding capacity, soil productivity and microbial biomass properties thereby encourage the sorption of heavy metals and inhibit herbicides leaching and in turn reducing the soil toxicity and contamination of surface and groundwater.

3.2. Levels of HMs in soil

The concentrations of arsenic (As) ranged below the detection limit (bdl) to 0.031 and bdl to 0.015 in abandoned and active dumpsites, respectively. The highest As concentration was obtained at the location A4 (0.031 mg/kg), this was found below the permissible levels of 20.0 mg/kg for Nigerian soils as recommended by FAO/WHO [25,26]. Agbeshie et al. [27] reported 0.40 to 0.44 mg/kg in the municipal waste dumpsite, Sunyani, Ghana. The level of As was found to show no significant differences ($p < 0.05$) between the abandoned and active dumpsites. In some cases, as compounds have been reported to adsorb strongly to soils and have a short range of transportation through leachate into the groundwater and surface water [28]. The associated effects such as skin damage increased risk of cancer, and problems with the circulatory system related as have been reported [28].

The level of copper (Cu) in soil from both abandoned and active dumpsites were between BDL to 0.610 mg/kg, 0.012 to 0.887 mg/kg, respectively. The level obtained in this study was found below what was reported by Alam et al. [29] from the soil within the landfill site Mogla Bazar in Sylhet, Bangladesh. Agyarko et al. [30] also reported an elevated value for Cu between 5.70 and 27.0 mg/kg across selected refuse dump soils in Ghana. The levels recorded in this study were below the 100 mg/kg permissible limit of Cu in Nigerian soil as given by FAO/WHO [25] and lower than the concentration range in soil 2 – 250 mg/kg [31]. There is a clear significant difference ($p < 0.05$) in Cu concentrations between the abandoned and active dumpsites. Copper is an essential element, plays a significant role in plants, microorganisms, animals, and humans development. Cu, despite being an essential element, its high doses in humans can be detrimental such as causes of anaemia, liver and kidney damage, and stomach as well as intestinal irritation.

Cadmium (Cd) is one of the least prominent HM found in the soils from the dumpsites in this study. The concentrations ranged between 0.00 to 0.041 mg/kg and 0.00 to 0.031 mg/kg in abandoned and active dumpsites, respectively. Results from this study indicated that there are no significant differences ($p < 0.05$) in the levels of Cd recorded between the abandoned and active dumpsites. The level found in this study was relatively lower as compared to what was reported by Agyarko et al. [30]. Agbeshie et al. [27] also reported between 0.19 and 0.32 mg/kg in the municipal dumpsite in Chana. The level of Cd concentrations recorded in this study was below permissible levels as recommended by FAO/WHO, 2001 (3 mg/kg) and AEP, 2016 (3.8 mg/kg). The lower level of Cd recorded in this study could be attributed to insignificant inputs of materials such as batteries, PVC materials, coatings, and motor oils containing Cd metal. Despite being rare HM, reports have shown that Cd is highly injurious HMs with serious potential health risks to humans [32,33].

The chromium (Cr) load in the soil from abandoned and active dumpsites investigated in this study were between 0.00 to 0.081 mg/kg and 0.00 to 0.031 mg/kg. These values were found below the concentration range in soil (5–1500 mg/kg) as reported by Radojevic and Bashkin; Stewart et al. [31,34] and lower than 100 mg/kg stipulated for Nigerian soil by NESREA [25]. The target and intervention values for Cr metal for a reference soil were given as 20 mg/kg [35]. Cr has been reported to have a direct relationship with allergic dermatitis in humans [27]. Cr might find its way into the landfill through various sources, such as waste from personal care products, plastics, and diesel engines utilising anti-corrosive agents and leach into the groundwater.

Cobalt (Co) concentrations are 0.00 to 0.017 mg/kg and 0.00 to 0.024 mg/kg for abandoned and active dumpsites, respectively. The reported values here were below the concentration soil range of 0.5–65 mg/kg and lower than the reported concentration range (387.5 mg/kg to 1337.5) from selected active dumpsites in Southeastern, by Eze et al. [36]. Co showed no significant differences ($p < 0.05$) at the different sites. The geo-accumulation intensity and concentration factors recorded for Co in this study indicated that the soil at the dumpsites may be practically uncontaminated and no pollution by Co thereby routine monitoring is important to mitigate future pollution and safety of lives of inhabitants around these areas.

The concentrations of nickel (Ni) in this study varied from 0.00 to 0.029 mg/kg and 0.010 to 0.031 mg/kg in abandoned and active dumpsites, respectively. It was noticed that the levels of Ni found do not follow a specific pattern in its distribution within different locations investigated and there are no significant differences ($p < 0.05$) in the level of Ni between abandoned and active dumpsites. Ni concentration levels across the sites could be due to the discharge of industrial effluent containing Ni as the dumpsite contains heterogeneous materials. The level of Ni was found below 70 mg/kg stipulated for Nigerian soil by NESREA [25] and (2 – 750 mg/kg) in soil [31]. The level of Ni found in this study is lower compared to what was reported by Akanchise et al. [37] (35 mg/kg) in the soils from abandoned dumpsites in Kumasi, Ghana. Ni is known to be toxic to man and might reach the food chain through plant uptake from contaminated soil [38,39]. Seilkop & Oller [40] had reported that Ni has detrimental effects on human health such as dermatitis, allergy, organ diseases, and cancer of the respiratory system.

The lead (Pb) level found in this study was higher at the active dumpsite (0.021 to 0.103 mg/kg) compared to what was recorded at the abandoned dumpsite (0.00 to 0.040 mg/kg). The presence of Pb could be attributed to the possible deposition of materials containing Pb metal such as batteries, food packaging material, PVC materials, and insecticide-related products [19]. There are no significant differences ($p < 0.05$) between the level of Pb found in abandoned and active dumpsites in this study. Although, the levels of Pb in this study across different locations were found to be below the reasonable levels of 2–300 mg/kg in soil samples as reported by Radojevic & Bashkin [31]. The concentration of Pb as reported by Kinuthia et al. [41] in soil samples from Davis and Shirtliff site (471.17 mg/kg), Chief's Camp (B), and Railways Lower (C) sites were 255.50 and 211.00 mg/kg respectively which were higher than what was found in this study. Pb concentration was noticed to be lower than the tolerable levels as given by Bowen (2–200 mg/kg), FAO/WHO (50 mg/kg), and 164 mg/kg limit for Pb in Nigerian soils as given by NESREA [25]. Pb is non-essential metal, but toxic, even in trace amounts, considered a lethal HM and affects humans when adsorbed into the body system through ingestion [42–44]. Pb could significantly interrupt the water balance, mineral nutrition and enzyme activities if present at high concentration levels. Jarup [45] reported that Pb is considered a potential carcinogen, which has a close association with many diseases, such as cardiovascular, kidney, blood, nerves, and bone diseases.

Zinc (Zn) is one of the predominant HMs in this study ranked second after Cu. Higher concentrations of Zn were recorded at active dumpsite compared to the abandoned one as presented in Figure 1(a,b). There is a clear significant difference ($p < 0.05$) between the studied locations. The presence of Zn in dumpsite soils investigated could be a result of improper disposal of Zn-containing materials like paints and cosmetics, dyes, dry-cell batteries, fungicides, and soaps [46]. Another possible source is herbal medicines, which are known to contain HMs (Nkansah et al. [47] thereby their improper discharge could lead to a significant increase in the source of Zn in the dumpsite. The levels of Zn found in this study were compared to other studies conducted in other areas across the world, it was noticed that the level of Zn in this study was lower than the Zn content from Akouedo

(1164 mg/kg) in Abidjan [48]. The Yamoussoukro dumpsite (487 mg/kg) in Ivory Coast (Yobouet et al. [49]) from AlAIN (117 mg/kg) of the United Arab Emirates (Yin et al. [50]), and (344 mg/kg dry soil) of municipal open-air dumpsite within its vicinity of Bonoua, Ivory Coast (Bongoua-Devisme et al.) [2]. The value of Zn obtained in this study is lower than the stipulated 421 mg/kg limit of Zn in Nigerian soil by NESREA [25]. At a specific concentration level, Zn metal is known to be environmentally non-biodegradable with potential toxic effects on living organisms. Various health-related effects such as blood and bone disorders, kidney damage decreased mental capacity and neurological damage could result from Zn if expose by man [51–54].

The levels of iron (Fe) in the soil samples collected at the abandoned and active landfill in this study were also high, Figures 2(a,b). The level could be considered very high contamination based on the CF values (Table 1) and Igeo information that is at moderate to strong contamination intensity in some of the locations across the dumpsites in this study. There is a significant difference ($p < 0.05$) in Fe concentrations between the two landfill sites investigated. The level of Fe could be due to the fact that natural soils containing a significant amount of Fe [55–59]. Amusan et al. [60] also reported that Nigerian soil contains a significant amount of Fe. The concentration of Fe recorded in this study was found to be lower than the reported concentration in selected refuse dump soils in Ghana (1180.00 to 4230.00 mg/kg), Agyarko et al. [29]. Osibote and Rabiu [61] also reported an elevated value for Fe (18.74–40.83 mg/kg) in the soil samples collected around landfill sites, Cape Town, South Africa. The level was compared and found to be lower than 400 mg/kg recommended by FAO/WHO [25,26] for Nigerian soils and 5000–100,000 mg/kg as recommended by Radojevic and Bashkin (2006) [31]. Fe is contained in several household and industrial materials. Dumping of various Fe-containing materials could contribute a significant amount of Fe to these dumpsites. Due to the long biological half-lives of Fe, studies had shown that Fe has the potential to alter normal human body tissues performance thereby result in various diseases [62–66].

The concentrations of manganese (Mn) ranged between 0.017 to 0.050 mg/kg and 0.103 to 0.313 mg/kg in abandoned and active dumpsites Figures 2(a,b) respectively. Higher concentrations of Mn were found in the active dumpsite than what was obtained at the abandoned dumpsite. Mn showed significant differences ($p < 0.05$) between the two dumpsites investigated in this study. The Source of Mn is mostly considered to be of natural origin (lithogenic). However, fuel additive diesel is another potential source of Mn [67,68]. The value reported by Alam et al. [29] in the soil close to the open landfill site

Table 1. Pollution status of the heavy metals associated with CF.

S/N	As	Cr	Mn	Fe	Pb	Ni	Cu	Cd	Co	Zn
A1	0.220	0.000	0.875	10.633	0.576	0.367	0.213	1.083	0.489	0.604
A2	0.088	0.258	1.258	10.500	0.390	0.489	0.305	2.067	0.567	0.584
A3	0.000	0.133	1.142	11.550	0.000	0.417	0.196	0.000	0.389	0.478
A4	0.310	0.308	0.825	9.967	0.343	0.278	0.294	0.583	0.500	0.494
A5	0.000	2.033	0.417	8.733	0.000	0.000	0.000	1.617	0.000	0.517
B1	0.120	0.325	7.833	5.033	1.376	0.411	0.443	1.600	0.800	1.267
B2	0.000	0.000	6.833	6.033	0.552	0.167	0.303	1.467	0.000	0.672
B3	0.150	0.500	2.942	4.833	0.305	0.356	0.285	0.000	0.000	0.856
B4	0.100	0.783	2.583	7.600	0.981	0.517	0.145	0.550	0.478	1.050
B5	0.000	0.658	4.292	6.500	1.476	0.489	0.006	1.600	0.389	0.828

Mogla Bazar in Sylhet, Bangladesh (5.08 to 133.60 mg/kg) was higher than what was obtained in this study. Mn is of major concern due to its potential to harm living organisms.

3.3. The extent of heavy metals pollution

3.3.1. Concentration factor

The degree of HM pollution in soil collected across the two dumpsites (abandoned and active dumpsites) investigated in this study was evaluated using CF as presented in Table 1. The result of CF indicated that Fe was found to be the most polluted heavy metal at both abandoned and active dumpsites as the CF ≥ 6 which is considered very high contamination) according to Hakanson's [14] classification approach. Although the abandoned dumpsite was found to be more enriched with Fe compared to the active dumpsite. Mn was found between 3 ≤ CF < 6 (high contamination factor) to CF ≥ 6 (considered very high contamination) at active dumpsite (B) but the degree of contamination with Mn at the abandoned dumpsite (A) was less significant which was between CF < 1 (low contamination) to 1 ≤ CF < 3 (moderate contamination). Other HMs, which were found between CF < 1 (low contamination) to 1 ≤ CF < 3 (moderate contamination) are Cr < Pb < Zn < Cd suggesting a potential threat to the community health. A low CF value for As, Ni, and Cu (0.00 to 0.576) indicating a non-possible pollution condition across the sites.

3.3.2. Geo-accumulation index (Igeo)

Results on the geo-accumulation index of the dumpsite samples by HMs are presented in Table 2, and the calculated Igeo values are summarised as individual value plots in Figures 4 (a,b) respectively. The Igeo values for As, Cr, Pb, and Ni showed generally no pollution at dumpsites A and B as the numerical value of the index (Igeo < 0 = class 0) indicating practically uncontaminated. The Igeo values of Cd and Zn were also found to be negatives at the abandoned dumpsite (A) but their values were 0.093 and 0.105 at points B1 and B3 respectively, indicating that the Igeo > 0 – 1 value is under class 1 (uncontaminated to moderate intensity). However, the Igeo for Cu in this study has positive values of 2.103, 2.685 (points A2 and A4) and 1.037 and 0.063 (points B1 and B4) respectively. Based on the Huu [18] prediction, it could be noted that abandoned dumpsite has high level of Cu metal pollution with Igeo > 2–3 = class 3 (moderate to strong contamination intensity) but position B1 and B2 are in the range of Igeo > 0 – 1 = class 1 (uncontaminated to moderate intensity) to Igeo > 1–2 = class 2 (moderate contamination intensity). Positions B1, B3 and B5 (2.385, 1.169 and 1.901) are mostly polluted by Mn with numerical values of between Igeo > 1–2 = class 2 (moderate contamination intensity) to Igeo > 2–3 = class 3 (moderate to strong contamination intensity). Thus, the degree of pollution about Fe is classified as uncontaminated to strong contamination at the abandoned dumpsite and uncontaminated to moderate contamination intensity at the active dumpsite. It was generally observed that active dumpsite was more polluted with Mn, Cd, Cu, Fe and Zn, whereas abandoned dumpsite is highly polluted with Fe and Cu. Therefore, Figures 4(a,b) reflected the Igeo concentration value where the maximum and minimum Igeo for all the HMs evaluated in this study were extrapolated but Mn, Fe and Cu correlated positively.

Table 2. Geo-accumulation index (Igeo) of heavy metals.

S/N	As	Cr	Mn	Fe	Pb	Ni	Cu	Cd	Co	Zn
A1	−2.769	*	−0.778	2.826	−1.380	−2.032	−2.816	−0.469	−1.617	−1.311
A2	−2.923	−2.538	−3.535	−5.077	−3.813	−3.059	2.103	−4.127	−4.261	−0.201
A3	*	−3.492	−0.918	2.963	*	−2.263	−3.452	*	−2.161	−1.602
A4	−2.275	−3.804	−4.003	−5.290	−2.129	−3.644	2.685	−1.363	−3.898	−0.151
A5	*	−0.128	−1.903	2.772	*	*	*	−3.588	*	−1.539
B1	−3.644	−2.206	2.385	1.747	−0.124	−1.867	−1.758	0.093	−0.907	−0.244
B2	*	*	−4.256	−4.797	−4.568	−4.776	1.037	−5.184	*	−1.067
B3	−3.322	−1.585	1.169	1.427	−0.982	−0.774	−1.848	*	*	0.105
B4	−3.322	−3.411	−4.443	−4.144	−2.882	−4.237	0.063	−1.447	−1.651	−0.772
B5	*	−1.836	1.901	1.201	−0.393	−0.854	−6.404	−3.518	−4.771	−0.238

Values were negligible = *

3.4. Comparison of extent of pollution with other regions

The soils from dumpsites (abandoned and active) in the Osogbo metropolis were classified as being uncontaminated with As, Pb and Ni to moderately uncontaminated for Cr, Cd, Cu and Zn. Moderate to strong contamination intensity based on geo-accumulation indices Huu [18] was observed for Mn and Fe at both abandoned and active dumpsites in this study. However, a study from an abandoned landfill in Kumasi-Ghana based on the Igeo values reported for As, Cu, Pb and Zn (0.20 to 3.37, 0.34 to 2.07, 1.00 to 2.62 and 0.58 to 1.69), respectively. The results showed that, no pollution to high pollution for As, no pollution to high pollution for Cu, moderate pollution to strong pollution for Pb and Zn as no pollution to moderate pollution [37]. Amadi et al. [69] reported moderate pollution for Cd and As in the samples collected from a landfill site in Aba, Nigeria. Also, Alam et al. [28] reported that Igeo for Fe, Zn, Cu, and Mn were less than zero (0) in the soil samples collected within the vicinity of the open landfill site, Mogla Bazar, in Sylhet, Bangladesh showed insignificant soil pollution associated with that HMs investigated. Although the soils were reported to be moderately polluted with Pb and Cd in some sites with the Igeo values ranged from −7.93 to 1.14, and −5.91 to 1.16 with a mean concentration of -2.14 ± 3.06 and -1.69 ± 1.80 for Pb and Cd, respectively. Correlation between soil properties, heavy metal concentration and the sampling sites

To identify the relationship between soil physicochemical properties and distributions of heavy metals across the dumpsites, statistical analysis was performed using a t-test to detect the interrelation among the HM contents. Results are shown in Table 3. There were significant differences between the soil physicochemical properties (electrical conductivity, total dissolved solids, salt content in terms of salinity, resistance, organic carbon and soil organic matter content concerning abandoned and active dumpsite (A and B) except for pH), which was found to be insignificant at $p < 0.05$. Among the HMs, As, Co, Cd, Ni, Cr and Pb showed no significant difference between dumpsites A and B but HMs like Cu, Mn,, Zn and Fe showed a moderate number of significant relationships between dumpsites A and B. This indicates the vulnerable condition for the study areas associated with the heavy metals.

4. Conclusion

Soil samples around the two selected dumpsites within the Osogbo metropolis (abandoned and active dumpsite of Osun Waste Management Board Ejigbo Road, Osogbo), Osun State Nigeria were investigated to determine the levels of HMs in this study. The soil samples were

Table 3. A t-test relationship coefficient between soil properties and heavy metals at different dumpsites.

Sites	pH	TDS*	EC*	Salt*	Resistance*	OC*	SOM*	As	Cu*	Co	Cd	Ni	Cr	Mn*	Pb	Zn*	Fe*
A1	5.62	145	296	0.206	3.39	3.24	12.96	0.022	0.426	0.015	0.022	0.022	0.000	0.035	0.040	0.363	0.213
A2	6.46	74	152	0.132	6.66	2.89	11.62	0.019	0.610	0.017	0.041	0.029	0.010	0.050	0.027	0.351	0.210
A3	6.45	41	84	0.099	11.76	3.26	12.97	BDL	0.393	0.012	0.000	0.025	0.005	0.046	0.000	0.287	0.231
A4	6.58	84	162	0.138	6.16	3.32	13.29	0.031	0.588	0.015	0.012	0.017	0.012	0.033	0.024	0.297	0.199
A5	6.95	65	130	0.123	7.59	3.04	12.13	BDL	BDL	0.000	0.032	0.000	0.081	0.017	0.000	0.310	0.175
B1	6.32	694	1413	0.835	0.72	1.81	7.65	0.012	0.887	0.024	0.032	0.025	0.013	0.313	0.096	0.760	0.101
B2	6.65	979	1998	1.181	0.50	1.63	7.09	BDL	0.607	0.000	0.029	0.010	0.000	0.273	0.039	0.403	0.121
B3	7.10	114	230	0.174	4.34	1.86	7.83	0.015	0.570	0.000	0.000	0.021	0.020	0.118	0.021	0.513	0.097
B4	7.22	129	262	0.190	3.82	0.96	4.54	0.010	0.290	0.014	0.011	0.031	0.031	0.103	0.069	0.630	0.152
B5	6.81	952	1943	1.148	0.51	1.68	7.17	BDL	0.012	0.012	0.032	0.029	0.026	0.172	0.103	0.497	0.130
t-test	0.169	0.033	0.034	0.035	0.013	0.000	0.000	0.307	0.009	0.769	0.958	0.481	0.821	0.005	0.312	0.005	0.000

*sig difference between A & B ($p < 0.05$).

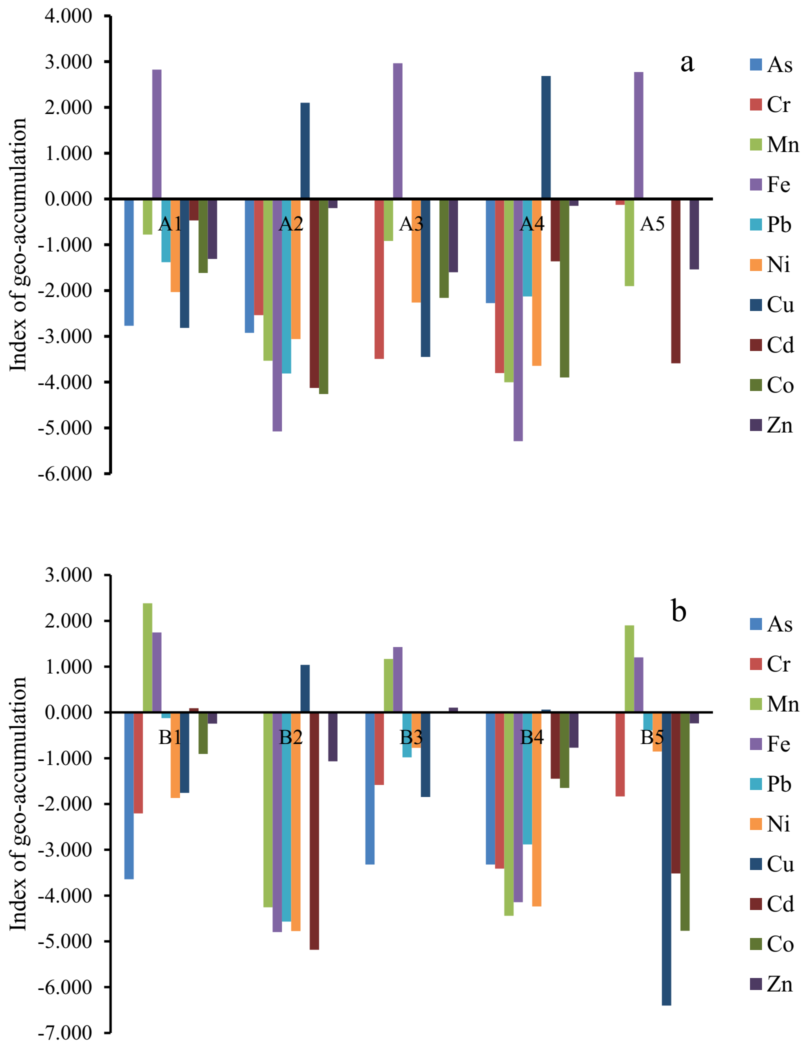

Figure 4. Geo-accumulation index of selected heavy metal at (a) abandoned dumpsite, (b) active dumpsite.

collected at depths of 0–30 cm, at strategic points using a global positioning system around the two dumpsites. The soils physicochemical properties were determined. The concentrations of HMs were determined using atomic absorption spectroscopy (AAS). The pollution status of the dumpsites was investigated using concentration factor and geo-accumulation index (Igeo values). The results revealed that all the HMs determined were found between below detection limit (bdl) to 0.611 mg/kg and bdl – 0.880 mg/kg for dumpsites A and B, respectively. Cu and Zn were found to be highest HMs determined with the concentration levels of 0.398–0.611 µg/kg, 0.290–0.880 mg/kg for Cu and 0.288–0.361 mg/kg, 0.399–0.760 mg/kg for Zn at dumpsites A and B, respectively. While Cr was found to be the least prevalent HMs in both dumpsites. The concentration factor and geo-accumulation intensity revealed no contamination to strong contamination and from uncontaminated to strong contamination intensity respectively across the sites. The levels of HMs in this study at the various sampling points of the dumpsites determined were below the recommended permissible limits as provided by the National Environmental Standards and Regulation Enforcement Agency and Food and Agriculture Organization/World Health Organization in soil samples. Therefore, there is a need for proper, continuous evaluation and possibly decontamination of the dumpsite because these dumpsites were currently in use for crops cultivation such as maize, vegetable bananas and some other arable plants.

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Compliance with ethical standards

Ethical compliance is not applicable for this study.

Disclosure statement

No potential conflict of interest was reported by the authors.

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References

[1] A. Adesewa and O. Morenikeji, J. Prev. Med. Hyg. **58** (4), E328–E333 (2017).
[2] A. Bongoua-Devisme, E. Bolou Bi, K. Kassin, C. Balland-Bolou-Bi, Y. Gueable, B. Adiaffi, A. Yao-Kouame, E. Djagoua, B. Affi Jeanne, B.B. Bolou Emile, K.K. Emmanuel, B.B. B. Clarisse, G.A. Yao Kohou, Y.A. Donatien Bernard, D. Eric and M. Valère, moi, Int. J. Eng. Res. **6** (5), 28 (2018).
[3] C.M.A. Iwegbue, G.E. Nwajei, J.E. Ogala and C.L. Overah, Environ. Geochem. Health **32**, 415 (2010). doi:10.1007/s10653-010-9285-y.
[4] G.A. Ebong, M.M. Akpan and V.N. Mkpenie, E-J. Chem. **5**, 281 (2018). doi:10.1155/2008/854103.
[5] A.O. Opaluwa, M. Nweze, O.D. Opaluma, M.O. Aremu, L.O. Ogbo, K.A. Abiola, I.E. Odiba, M. M. Abubakar and N.O. Nweze, Adv. Appl. Sci. Res. **3** (2), 780 (2012).
[6] H. Nsengimana, B. Bigirimana, M. Suwa, A. Mukubwa, W. Debruyn and N. Kalisa, Rwanda J. **25** (1), 21 (2012).
[7] P.B. Tchounwou, C.G. Yedjou, A.K. Patlolla and D.J. Sutton. In Molec. Clinic. Environ. Toxicol. **101** (2012). DOI:10.1007/978-3-7643-8340-4.
[8] A.L. Wani, A. Ara and J.A. Usmani, Interdis. Toxicol. **8** (2), 55 (2015). doi:10.1515/intox-2015-0009.
[9] F.B.G. Tanee and T.N. Eshalomi-Mario, Res. J. Environ. Toxicol. **9** (6), 342 (2015). doi:10.3923/rjet.2015.342.349.

[10] E.O. Eresanya, M.T. Daramola, O.S. Durowoju and P. Awoyele, R. Soc. Open Sci. **6**, 191021 (2019). doi:10.1098/rsos.191021.
[11] W.W. Ahlers, M.R. Reid, J.P. Kim and K.A. Hunter, Aust. J. Mar. Freshw. Res. **41**, 713 (1990). doi:10.1071/MF9900713.
[12] A. Walkley and I.A. Black, Soil Sci **63**, 251 (1934). doi:10.1097/00010694-194704000-00001.
[13] Association of Official Analytical (AOAC), *AOAC Official Methods of Analysis*, 15th ed. (Chemists, Arlington, VA, 1990), p. 84.
[14] L. Hakanson, Water Res. **14**, 1001 (1980). doi:10.1016/0043-1354(80)90143-8.
[15] V.M. Ngole-Jeme, Ambio **45**, 374 (2016). doi:10.1007/s13280-015-0726-9.
[16] G. Muller, Geojournal **2**, 108 (1969).
[17] M. Barbieri, J. Geo. Geophy. **5**, 10 (2016). doi:10.4172/2381-8719.1000237.
[18] H.H. Huu, Geol. Belgica **13**, 37 (2010).
[19] P. Twumasi, M.A. Tandoh, M.A. Borbi, A.R. Ajoke, E. Owusu-Tenkorang, R. Okoro and R. M. Dumevi, Afr. J. Agric. Res. **11**, 1608 (2016). doi:10.5897/AJAR2016.10907.
[20] R. Awual, Chem. Eng. J. **266**, 368 (2015). doi:10.1016/j.cej.2014.12.094.
[21] I. Skoczko, J. Piekutin and K. Ignatowicz, Desalin. Water Treat. **57**, 1611 (2016). doi:10.1080/19443994.2015.1043487.
[22] Z.Y. Li, Z.W. Ma, T.J. van der Kuijp, Z.W. Yuan and L. Huang, Total. Environ. **468**, 846 (2014).
[23] V. Somerset, C. Van Der Horst, B. Silwana, C. Walters and E. Iwuoha, Water Air Soil Pollut. **226** (43) (2015). doi:10.1007/s11270-015-2329-2.
[24] C.E. Enyoh and B.O. Isiuku, Int. J. Environ. Anal. Chem. 2020. doi:10.1080/03067319.2020.1773455
[25] NESREA, 1st Eleven Gazetted Regulations Federal Republic of Nigeria Official Gazette (2011).
[26] FAO/WHO, Codex Alimentarius Commission. *Food Additives and Contaminants. Joint FAO/WHO Food Standards Programme, ALINORM10/12A* (2001). www.transpaktrading.cm/static/pdf/research/achemistry/introTofertilizers.pdf
[27] A.A. Agbeshiea, R. Adjei, J. Anokye and A. Banunle, Scientif. Afr. **8**, e00390 (2020). doi:10.1016/j.sciaf.2020.e00390.
[28] A. Scragg, 2nd ed. (Oxford University Press, Oxford, UK, 2006), p. 145.
[29] R. Alam, Z. Ahmed and M.F. Howladar, 2019. Groundw Sustain Devdoi:10.1016/j.gsd.2019.100311.
[30] K. Agyarko, E. Darteh and B. Berlinger, Plant Soil Environ. **56**, 244 (2010). doi:10.17221/13/2010-PSE.
[31] M. Radojevic and V.N. Bashkin Practical environmental analysis. (Cambridge City, 2006), p. 72.
[32] C.F. Cranor, *Legally Poisoned* (Harvard University Press, Boston, 2011), p. 12.
[33] K.S. Kumar, H.U. Dahms, E.J. Won, J.S. Lee and K.H. Shin, Environ. Saf. **113**, 329 (2015). doi:10.1016/j.ecoenv.2014.12.019.
[34] E.A. Stewart, H. Max Grimshaw, J.A. Parkinson and C. Quarmby, *Blackwell Scientific Publications* (Osney Mead, Oxford, 1974) p. 165.
[35] Environmental Guidelines and Standards for the Petroleum Industry in Nigeria (EGASPIN), (Department of Petroleum Resources, Lagos, Nigeria, 2002), p. 276.
[36] V.C. Eze, V.I. Onwukeme and C. Ebere. Int. J. Environ. Anal. Chem. **1–22** (2020). DOI:10.1080/03067319.2020.1772778.
[37] T. Akanchise, S. Boakye, L.S. Borquaye, M. Dodd and G. Darko, Scientif. Afr. **10**, e00614 (2020). doi:10.1016/j.sciaf.2020.e00614.
[38] J. Bharat and S.K. Singh, Intern. J. Civ. Environ. Eng. **3** (3), 181 (2009).
[39] A.G. Onibokun and A.J. Kumuyi, *International Development Research Center Report* (Ibadan, Nigeria, 2004) p. 35. Ottawa: IDRC
[40] S.K. Seilkop and A.R. Oller, Regul. Toxicol. Pharmacol. **37**, 173 (2003). doi:10.1016/S0273-2300(02)00029-6.
[41] G.K. Kinuthia, D.B. Veronica Ngure, L. Reuben, W. Agnes and K. Luna, Scientif. Rep. **10**, 8434 (2020). doi:10.1038/s41598-020-65359-5.
[42] C. Fernandes, A. Fontaínhas-Fernandes, D. Cabral and M.A. Salgado, Environ. Monit. Assess. **136**, 267 (2008). doi:10.1007/s10661-007-9682-6.
[43] H.A. Olayiwola, L. Abudulawal, G.K. Adewuyi and M.O. Azeez, J. Environ. Earth Sci. **7**, 11 (2017).

[44] A.B. Yilmax, Turk. J. Vet. Anim. Sci. **29**, 257 (2005).

[45] L. Järup, Br. Med. Bull. **68**, 167 (2003). doi:10.1093/bmb/ldg032.

[46] S. Peganova and K. Eder, Zinc In: Elements and their Compounds in the Environment in E. Merian, M. Anke, M. Ihnat and M. Stoeppler edited by (Wiley-VCH, Weinheim, Germany, 2004) Vol. 2, p. 1203.

[47] M.A. Nkansa, S.T. Hayford, L.S. Borquaye and J.H. Ephraim, Cog. Environ. Sci. **2**, 1234660 (2016). doi:10.1080/23311843.2016.1234660.

[48] I.K. Kouamé, D.L. Gone, I. Savane, E.A. Kouassi, K. Koffi, B.T.A. Goula and M. Diallo, Afrique Sci. **2** (1), 39 (2006).

[49] Y.A. Yobouet, K. Adouby, A. Trokourey and B. Yao, Int. J. Eng. Sci. Technol. **2** (5), 802 (2010).

[50] Y. Yin, C.A. Impellitteri, S.J. You and H.E. Allen, Sci. Total Environ. **287**, 107 (2002). doi:10.1016/S0048-9697(01)01000-2.

[51] D. McCluggage (Published by The Bird Hospital, CO, City, 1991), p. 64.

[52] *National Institute of Environmental Health Services Waste Landfill* (City, 2004), pp. 205. http://www.niehs.nih.gov/external/Fag/landfill.htm

[53] K. Nolan, J. Orthomol. Psychiatry **12** (4), 270 (2003).

[54] M.O.C. Ogwuegbu and W. Muhanga, J. Environ. **1**, 66 (2005).

[55] N. Abdu, A. Abdulkadir, J.O. Agbenin and A. Buerkert, Nutr. Cycling Agroecosyst. **89**, 387 (2011). doi:10.1007/s10705-010-9403-3.

[56] N. Abdu, J. Agbenin and A. Buerkert, J. Plant. Nutr. Soil Sci. **174**, 447 (2011). doi:10.1002/jpln.201000333.

[57] C. Ademoroti (Foludex Press Ltd, Ibadan, 1996), p. 22.

[58] O. Aluko, M. Sridhar and P. Oluwande, Int. J. Environ. Health Res. **2** (1), 32 (2003).

[59] N. Eddy, S. Odoemelem and A. Mbaba, J. Agric. Food Chem. **5** (3), 1349 (2006).

[60] A. Amusan, D. Ige and R. Olawale, J. Hum. Ecol. **17**, 167 (2005). doi:10.1080/09709274.2005.11905775.

[61] A.O. Osibote and A.M. Rabiu, Int. J. Environ. Sci. Dev. **7**, 11 (2016). doi:10.18178/ijesd.2016.7.11.890.

[62] R. Barzegar, A.A. Moghaddam, S. Soltani, N. Baomid, S.E. Tziriti, J. Adamowski and A. Inam, Environ. Earth Sci. **78**, 254 (2019). doi:10.1007/s12665-019-8250-z.

[63] A. Kumar, G. Subrahmanyam, R. Mondal, M.M.S. Cabral-Pinto and A.A. Shabnam, Chemosphere 2020c. doi:10.1016/j.chemosphere.2020.128855

[64] A. Kumar, M. Cabral-Pinto, A. Kumar, M. Kumar and P.A. Dinis, Appl. Sci. **10**, 7078 (2020b). doi:10.3390/app10207078.

[65] A. Kumar, A. Kumar and M.M.S. Cabral-Pinto, Int. J. Environ. Res. Pub. Health **17**, 2179 (2020a). doi:10.3390/ijerph17072179.

[66] L.N. Suvarapu and S.D. Baek, Toxicol. Ind. Health **33**, 79 (2017). doi:10.1177/0748233716654827.

[67] T. El-Hassan, M. Batarseh, H. Al-Omari, H. Ziadat, A. El-Alali, F. Al-Naser, B.W. Berdainer and A. Jiries, Soil Sediment. Contam. **15**, 357 (2006). doi:10.1080/15320380600751728.

[68] D.S. Sheppard, G.G.C. Claridge and I.B. Campbell, Appl. Geochem. **15**, 513 (2000). doi:10.1016/S0883-2927(99)00055-4.

[69] A.N. Amadi and H.O. Nwankwoala. Energy Environ. Res. **3** (2013). DOI:10.5539/eer.v3n1p125.