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Influence of Waste Type on Heavy Metal Enrichment in Dumpsite Soils in Ijebu-Ode, Southwestern Nigeria

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Abstract

Heavy metals occur naturally in soils, but their concentrations may be elevated by anthropogenic activities such as improper disposal of waste. Dumpsites are particularly significant sources as various waste streams can release different metal assemblages into soils. In this study, we investigate concentration and distribution of heavy metals in soils around different dumpsites in Ijebu-Ode, southwestern Nigeria. The idea is that dumpsites dominated by synthetic and mixed domestic wastes, especially plastic-related waste, would show higher heavy-metal enrichment than other dumpsites. Five soil samples collected from five dumpsites associated with different types of waste were analyzed for their elemental concentration using X-Ray Fluorescence (XRF). The results were evaluated using contamination indices such as Contamination Factor (CF), Geo-accumulation index (I_{geo}) and Pollution Load Index (PLI). Results reveal the following range of values of metal concentration: Copper (Cu) 54 - 3637 ppm, Zinc (Zn) 13 - 1342 ppm, Arsenic (As) 49 - 112 ppm, and Lead (Pb) 2 - 38 ppm. The highest concentrations of heavy metals, which were Cu and Zn, occurred at the plastic-waste dumpsite, suggesting that waste composition influences metal enrichment in dumpsite soils. High CF of 2.57 - 173.19, 24.50 - 56.00, 0.94 - 9.65 were recorded for Cu, As and Zn, respectively. Pollution Load Index (PLI) values revealed that the soil quality at all sampled dumpsites was deteriorated as their PLI values were higher than 1 in the soil (2.63 - 7.42). The findings indicate that dumpsite soils in the study area are environmentally degraded and may serve as secondary sources of metal exposure to surrounding soils, surface runoff, plants and human populations. And that the type of waste may influence heavy metal concentration of soil.

Keywords

Heavy Metals, Dumpsite Soils, Geo-Accumulation Index, Contamination Factor, Heavy Metal Concentration

1. Introduction

Soil is one of Earth's life-sustaining components and plays a vital role in agriculture, biodiversity, and maintaining environmental health [1]. Heavy metals such as As, Cd, Cr, Pb, and Hg occur naturally via geological processes like volcanic eruptions and the weathering of rocks [2]. Additionally, anthropogenic activities such as mining activities, manufacturing, and the use of synthetic products like pesticides, paints, industrial waste and batteries contribute significantly to soil contamination by releasing heavy metals into the environment [3]. This often results in their high concentrations relative to background values. Heavy metals can accumulate in soil through emissions from rapidly expanding industrial companies, dumping of waste, leaded gasoline, paint and application of fertilizers [4], and can be released both in compound (organic and inorganic) and elemental forms. Accumulation in soils results in reduction of soil fertility and disruption of microbial communities essential for nutrient cycling and plant growth [3].

The uptake of heavy metals by plants from soils at high concentration may result in a great health risk, taking into consideration food-chain implications [5]. Environmental risks such as pediatric heavy metal poisoning, permanent damage to the central nervous system due to chronic exposure to mercury, and lung cancer due to inhaling of chromium have been linked to heavy metal contamination in soil, water and plants [6].

Waste from factories and manufacturing processes, household waste, and electronic waste are often items that contain heavy metals. For example, household waste could include batteries, electronics and fluorescent bulbs, which degrade and release heavy metals such as Cd, Pb and Hg into the environment. Waste dumpsites, therefore, are usually sources of a significant amount of heavy metal occurrences. As such, this study aims to determine the concentration and distribution of heavy metals and evaluate the contamination status of soils in the study area.

The idea behind this study is that poorly managed dumpsites act as localized geochemical hotspots, with waste composition controlling concentration and type of heavy metal enrichment in surrounding soils.

1.1. Site Description and Climate

The study area is located between 6˚81'94"N to 6˚85'00"N and 3˚90'22"E to 3˚93'33"E. It is mainly accessible by major roads, minor roads and footpaths which link to both the major and minor roads. The climate of the study area is tropical. It has two distinct seasons: wet season and dry season.

1.2. Geological Features

The geology of Ijebu-Ode and environs has been described by Osinowo and Olayinka (2013) to belong to the transition geological environment between the Precambrian Basement Complex rocks of southwestern Nigeria and the Cretaceous sedimentary units of the Abeokuta Group in the eastern part of the Dahomey Basin [7]. The northern (northeast, northwest and north central) is underlain by basement rocks of migmatite gneiss complex, which comprises of biotite granite gneiss, biotite-hornblende gneiss that intrude schistose host rocks such as biotite schist, quartzite schist, talc-tremolite schist, and muscovite schists (**Figure 1**). The southern portion is overlain by Ise Formation of the Abeokuta Group that unconformably overlies the basement rocks. The sedimentary unit comprises mainly of grits, arkosic sandstones, siltstones and clay with occasional conglomerate of predominantly arenaceous materials.

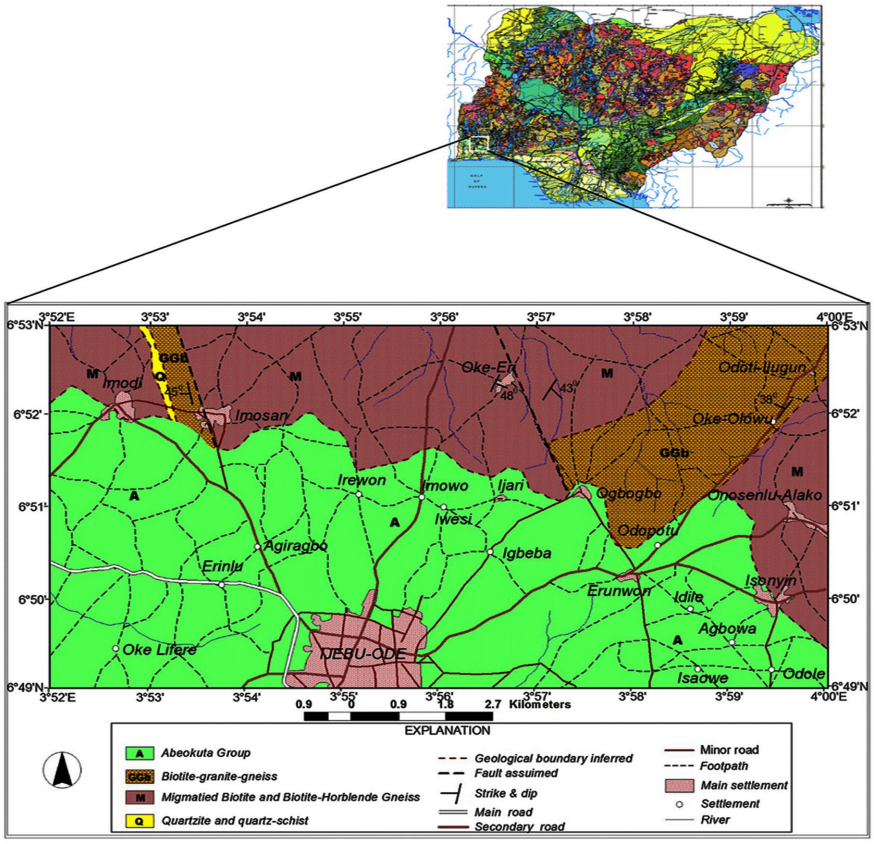

Figure 1. Geological map of the study location. Adapted from Osinowo & Olayinka (2013) [7].

2. Materials and Methods

Methods employed in this study are summarized as follows:

1) Soil sampling: Five soil samples were collected from five dumpsites in the study area with the aid of hand trowel. The samples were stored in airtight bags and properly labelled as B1 to B5. At each dumpsite, one grab soil sample was collected from a randomly selected point within the visibly affected waste-disposal

area. Samples were taken at an approximate depth of 0.5ft, using a clean hand trowel. The same sampling technique was applied across the five locations to support comparability among dumpsites. Because this was a preliminary screening study, one grab sample was used to represent each site. This design, however, does not capture spatial variability within each site. As such, future studies should include replicate and composite sampling, and broader coverage at each dumpsite. The sites were categorized based on direct field observation and photographic documentation of the dominant waste materials at each sampling location. Site B1 was classified as a plastic-rich waste dumpsite because it was visually dominated by plastic bottles, plastic containers and plastic packaging materials. Site B2 was classified as a mixed domestic waste dumpsite as it contained mixed domestic waste, including plastics, paper/cardboard, textile materials, sacks, rubber materials, and discarded tyre. B3 was dominated by mixed plastic packaging, nylon bags, paper/cardboard, wrappers and sacks. Sites B4 and B5 were classified as roadside mixed municipal/domestic dumpsites because they contained plastics, sacks, paper/cardboard, packaging materials, textile-like materials and other mixed refuse deposited along road margins or near roadside waste containers. These categories are qualitative field-based descriptors, as no formal waste sorting, weighing or compositional analysis was carried out.

2) Sample preparation: The samples were air-dried and thereafter disaggregated using a clean porcelain mortar and pestle. After each disaggregation, the mortar and pestle were cleaned with cotton wool and methylated spirit to avoid sample contamination. They were then sieved through a 75 μm sieve to allow only fine fractions to be used for analysis and tests. Each sample was then stored in labelled sample bags for analysis.

3) Laboratory analysis: For geochemical analysis, the samples were milled with an iron mill, a pressed pellet was made using Hoechst wax and analyzed using a Wavelength Dispersive X-Ray Fluorescence (WD-XRF), which is a Rigaku-Primus IV, with a Rh tube, and ZXS software. Results are quantitative. The XRF analysis was performed at Department of Geology, University of the Free State, South Africa.

4) Statistical analysis: To infer the distribution of the different metal concentrations in the study area, descriptive statistics such as mean and Standard Deviation (SD).

5) Soil quality/contamination index: Contamination index was undertaken to determine the soil quality and potential effect of metals on both human health and the ecosystem. The evaluation was carried out using Contamination Factor (CF), Geo-accumulation Index (I_{geo}) and Pollution Load Index (PLI).

Contamination Factor (*CF*): This represents the ratio of an individual metal value to the background values in soil. The CF value monitors the heavy metal enrichment in soil over a long period of time. CF value is calculated as:

$$\mathrm{CF} = C_{\mathrm{metal}} / C_{\mathrm{background}}$$

where C_{metal} is concentration of metal in the soil, while $C_{\mathrm{background}}$ is background value or concentration of metal in control sample. A CF value ≥ 6 represents very high contamination, 3 ≤ CF < 6 is considerable contamination, 1 ≤ CF < 3 is mod-

erate contamination, and CF < 1 shows low contamination of a given metal [8] [9].

Geo-accumulation Index (I_{geo}): The geo-accumulation index (I_{geo}) is a common approach employed to evaluate metal enrichment above background or baseline concentration in soil. I_{geo} is used to evaluate heavy metal pollution by comparing current concentrations of the elements with control or background values. The Geo-accumulation index can be calculated using the equation proposed by Muller (1969) [10]:

$$\mathrm{I}_{\mathrm{geo}} = \log_2\left(C_n/(1.5B_n)\right)$$

where C_n is concentration of the element in the sample, while B_n is background value, and the constant 1.5 is allowed for analyzing fluctuations in the content of a given substance. The interpretation of the result was based on the geo-accumulation index scale. This scale, which was distinguished into seven classes by [10], shows the various interpretations for the I_{geo} (**Table 1**).

Pollution Load Index (*PLI*): PLI assesses soil quality. It is an index for the total assessment of the degree of contamination in soils. It is calculated as the *n*th root of the number of multiplied CF values by the following formula based on the contamination factor values of individual elements [11]:

$$\mathrm{PLI} = \left\{(\mathrm{CF1})(\mathrm{CF2})(\mathrm{CF3})\cdots(\mathrm{CF4})\right\}^{1/n}$$

where *n* is the number of metals.

This empirical index provides a simple, comparative means for assessing the level of heavy metal pollution in a location [9]. PLI results can be excellent, pollution, or deterioration (**Table 2**). When PLI > 1, metal concentrations are higher than the allowable limit, while a PLI < 1 shows that the average metal concentrations are lower than the allowable limit, however does not always mean lack of anthropogenic source or other enrichment over background concentrations [9], [12].

In this study, background values or concentrations of metals used in determining CF, I_{geo}, and PLI are from Akinade and Olisa (2014) [9], who investigated heavy metal concentration and distribution in soils, road dust and stream sediments of Ijebu-Ode and environ, Southwestern Nigeria (see their **Table 1**).

Table 1. Classes of I_{geo} [10].

Classes	I_{geo} class	Degree of contamination
1	0	unpolluted
2	0 - 1	unpolluted to moderately polluted
3	1 - 2	moderately polluted
4	2 - 3	moderately to highly polluted
5	3 - 4	highly polluted
6	4 - 5	highly to very highly polluted
7	>5	very highly polluted

Table 2. Classes of PLI.

PLI value	Soil quality level
<1	excellent
1	baseline pollutant level
>1	progressive deterioration of soil quality

3. Results and Discussions

3.1. Heavy Metal Distribution and Statistical Analysis

The results of the geochemical analysis of the soil samples revealed varying concentrations of heavy metals (**Table 3**). The concentration of Vanadium (V) ranged 134 - 237 ppm with a mean value of 181.4 ppm, Chromium (Cr) ranged 151 - 236 ppm with a mean value of 197 ppm, Cobalt (Co) ranged 33 - 79 ppm with a mean value of 48 ppm, Nickel (Ni) ranged 18 - 37 ppm with a mean value of 29.6 ppm, Copper (Cu) ranged 54 - 3637 ppm with a mean value of 970.4 ppm, Zinc (Zn) ranged 131 - 1342 ppm with a mean value of 734 ppm, Arsenic (As) ranged 49 - 112 ppm with a mean value of 79 ppm, Strontium (Sr) ranged 123 - 266 ppm with a mean value of 183.6 ppm, Barium (Ba) ranged 215 - 362 ppm with a mean value of 290.2 ppm, Lead (Pb) ranged 2 - 38 ppm with a mean value of 38 ppm, and Thorium (Th) ranged 15 - 23 ppm with a mean value of 18.4 ppm (**Table 3**, **Figure 2**). The mean value of the concentration of all the metals exceeds their background concentration values of [9] except for Pb (see **Table 3**). This indicates that these metals, except for Pb, could be anthropogenic in origin [13]. Since the mean value of Pb concentration is lower than its crust value, this may be an indication that Pb is of natural origin [13] [14]. However, at one of the dumpsites (location B1), the concentration of Pb (35 ppm) is higher than its crust value (17 ppm). Hence, the origin of Pb in the soils of the study area could be both anthropogenic and natural. The most striking enrichment pattern was observed for Cu and Zn, especially at location B1, where Cu reached 3637 ppm and Zn reached 1342 ppm. This location corresponds to the dumpsite associated with plastic waste, suggesting that plastic-rich waste may be an important contributor to metal enrichment in the study area. Plastics and plastic-associated waste materials may contain metal-bearing pigments, stabilizers, fillers, additives, coatings, wires, printed labels and other synthetic components.

During prolonged exposure to sunlight, rainfall, heat, abrasion, and microbial activity, these materials may gradually break down, releasing associated metals into the surrounding soil [15] [16]. Furthermore, dumpsites often contain, in addition to plastics, other waste, including packaging materials, electrical fragments, cans, batteries, paints, rubber, textiles, and household residues, many of which may also contribute Cu and Zn to the soil system. The high Cu concentration at B1 may therefore reflect both direct input from plastic-associated materials and indirect input from mixed consumer waste disposed together with plastics. Zn enrichment may be linked to the occurrence of Zn-bearing additives, pigments, rubber residues, galvanized materials, and other domestic waste components. The simultaneous

elevation of Cu and Zn at the same location supports the interpretation that waste composition, rather than natural geological background alone, influenced the observed geochemical pattern. Although this investigation is preliminary and based on five samples, the contrast between B1 and the other locations suggests that plastic-rich dumpsites may function as localized hotspots for metal accumulation in urban soils. The B1 hotspot should, however, be interpreted with caution because waste type may not be the only controlling factor. Other site-specific conditions, such as dumpsite age, burning history, drainage and leachate pathways, nearby traffic inputs, and local lithological variations, may also contribute to spatial differences in metal concentrations. Thus, B1 is best interpreted as a potential heavy-metal hotspot associated with plastic-rich waste, while further replicated sampling and source-characterization studies are required to distinguish waste-type effects from other site-specific conditions.

Table 3. Concentrations of each metal and their respective mean, and Background Concentration (BC) [9].

Elements	B1	B2	B3	B4	B5	Range	Mean ± SD	BC
V	134	237	155	161	220	134 - 237	181.4 ± 44.55	68
Cr	236	201	151	172	225	151 - 236	197 ± 35.57	89
Co	79	43	33	42	43	33 - 79	48 ± 17.83	5
Ni	37	18	37	34	22	18 - 37	29.6 ± 8.96	8
Cu	3637	54	243	829	89	54 - 3637	970.4 ± 1522.87	21
Zn	1342	131	668	1120	409	131 - 1342	734 ± 498.06	139
As	112	55	110	69	49	49 - 112	79 ± 30.11	2
Sr	156	151	266	222	123	123 - 266	183.6 ± 58.65	17
Ba	295	215	362	311	268	215 - 362	290.2 ± 54.22	56
Pb	38	2	2	2	2	2 - 38	9.2 ± 16.10	35
Th	14	15	23	23	17	15 - 23	18.4 ± 4.34	7

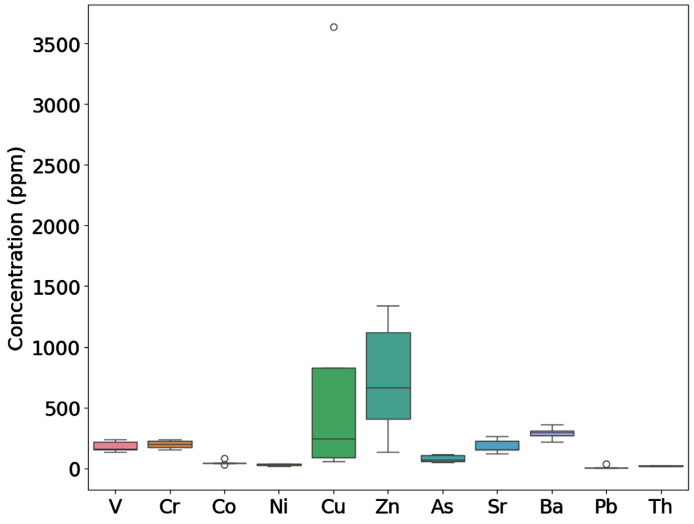

Figure 2. Boxplots of heavy metal concentrations in the dumpsite soil.

3.2. Contamination Factor (CF)

The calculated CF for heavy metals in the dumpsites in the study area is displayed in Table 4, with Figure 3 showing the boxplots of the contamination factor. CF for V ranged 1.97 - 3.49, CF for Cr ranged 1.70 - 2.65, CF for Ni ranged 2.25 - 4.63 and CF for Th ranged 2.00 - 3.29. These values all indicate moderate to considerable contamination. CF for Zn ranged 0.94 - 9.65, indicating low to very high contamination; CF for Co ranged 6.60 - 15.80, CF for As ranged 24.50 - 56.00 and CF for Sr ranged 7.24 - 15.65, which all indicate very high contamination. CF for Cu ranged 2.57 - 173.19 and Ba ranged 3.84 - 6.46, which both indicate considerable to high contamination, while CF for Pb ranged 0.06 - 1.09, which indicates no to low contamination (Figure 3 and Table 5). Metals with significant contamination factors in the dumpsites include As, Co, Cu, and Sr, indicating that the dumpsites are not merely passive waste storage areas but may act as active zones of soil quality deterioration. The very high CF values for Cu and As are particularly important because they indicate enrichment far above expected background levels. The extremely high CF value for Cu at the plastic-waste dumpsite (B1) further supports the interpretation that waste type may control the magnitude of contamination. Therefore, management strategies should prioritize waste segregation, plastic-waste reduction and restriction of uncontrolled dumping in areas close to residential land, agricultural soils or drainage channels.

Table 4. Contamination factor calculated using background concentration for selected heavy metals in dumpsites in Ijebu-Ode.

Elements	B1	B2	B3	B4	B5	Range	Remark
V	1.97	3.49	2.28	2.37	3.24	1.97 - 3.49	moderate to considerable contamination
Cr	2.65	2.26	1.70	1.93	2.53	1.70 - 2.65	moderate to considerable contamination
Co	15.80	8.60	6.60	8.40	8.60	6.60 - 15.80	very high contamination
Ni	4.63	2.25	4.63	4.25	2.75	2.25 - 4.63	moderate to considerable contamination
Cu	173.19	2.57	11.57	39.48	4.24	2.57 - 173.19	considerable to very high contamination
Zn	9.65	0.94	4.81	8.06	2.94	0.94 - 9.65	low to very high contamination
As	56.00	27.50	55.00	34.50	24.50	24.50 - 56.00	very high contamination
Sr	9.18	8.88	15.65	13.06	7.24	7.24 - 15.65	very high contamination
Ba	5.27	3.84	6.46	5.55	4.79	3.84 - 6.46	considerable to high contamination
Pb	1.09	0.06	0.06	0.06	0.06	0.06 - 1.09	no to low contamination
Th	2.00	2.14	3.29	3.29	2.43	2.00 - 3.29	moderate to considerable contamination

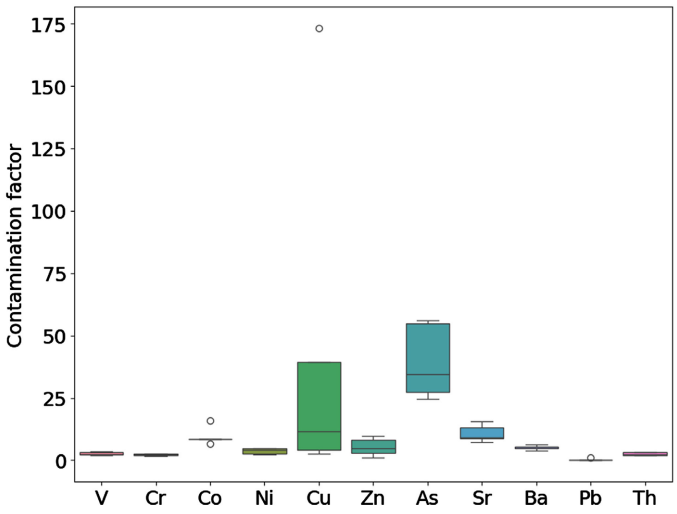

Figure 3. Boxplots of contamination factors of heavy metals in soils around dumpsites in Ijebu-Ode.

3.3. Geo-Accumulation Index (I_{geo})

I_{geo} values for both V and Cr range 0 to 1, indicating unpolluted to moderately polluted, while I_{geo} value for Co ranged 2 to 3, indicating moderately polluted to highly polluted (**Table 5**, **Figure 4**).

I_{geo} value for Ni ranged 1 to 2, indicating moderately polluted, Cu ranged 1 to 7, indicating moderately polluted to very highly polluted, and Zn ranged −1 to 3, indicating unpolluted to very highly polluted.

Table 5. Geo-accumulation index calculated using background concentration for selected heavy metals in soils from different dumpsites in Ijebu-Ode.

Elements	B1	B2	B3	B4	B5	Range	Implication
V	0	1	1	1	1	0 - 1	unpolluted to moderately polluted
Cr	1	0	0	0	1	0 - 1	unpolluted to moderately polluted
Co	3	3	2	2	3	2 - 3	moderately polluted to highly polluted
Ni	2	1	2	2	1	1 - 2	moderately polluted
Cu	7	1	3	5	1	1 - 7	moderately polluted to very highly polluted
Zn	3	−1	2	2	1	−1 - 3	unpolluted to highly polluted
As	5	4	5	5	4	4 - 5	highly polluted to very highly polluted
Sr	3	3	3	3	2	2 - 3	moderately polluted to highly polluted
Ba	2	1	2	2	2	1 - 2	moderately polluted
Pb	0	−5	−5	−5	−5	−5 - 0	unpolluted
Th	0	1	1	1	1	0 - 1	unpolluted to moderately polluted

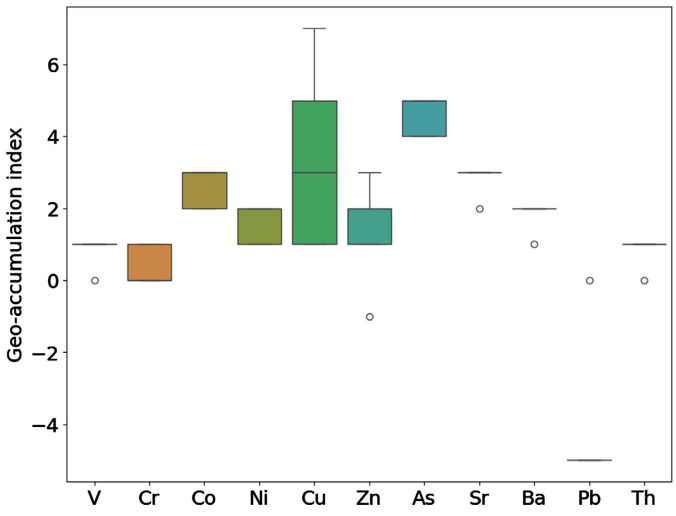

Figure 4. Boxplots of the geo-accumulation index.

I_{geo} value for As ranged 4 to 5, indicating highly polluted to very highly polluted, Sr ranged 2 to 3, indicating moderately polluted to highly polluted, while I_{geo} value for Ba ranged 1 to 2, indicating moderately polluted. I_{geo} value for Pb ranged from −5 to 0, indicating unpolluted, while Th ranged 3 to 2, indicating moderately polluted to highly polluted.

Thus, the I_{geo} results reveal unpolluted for Pb, unpolluted to moderately polluted for V and Cr, moderately polluted for Ba and Ni, moderately polluted to highly polluted for Co, Sr and Th, moderately polluted to very highly polluted for Cu, unpolluted to highly polluted for Zn, and highly polluted to very highly polluted for As. The I_{geo} results reinforce the contamination factor pattern by showing that Pb is generally unpolluted, while Cu, As, Co, Sr, and Zn show varying degrees of pollution. The classification of Cu as moderately polluted to very highly polluted is environmentally significant because Cu is an essential micronutrient at low concentration but may become toxic to soil organisms and plants at elevated levels [17] [18]. In a similar way, the highly polluted to very polluted status of As is of concern since As is toxic even at relatively low exposure levels [3] [19]. These results imply that the dumpsite soils may pose ecological risks if metals are mobilized into nearby soils, crops, shallow groundwater or surface runoff pathways.

3.4. Pollution Load Index (PLI)

The assessed Pollution Load Index (PLI) values for the dumpsite soils ranged 2.63 - 7.42, revealing that all sampled locations exceeded the baseline value of 1. Location B1, which corresponds to the plastic dumpsite, has the highest PLI value of 7.42 (**Figure 5** and **Table 6**), indicating the greatest deterioration in the quality of the soils. Additionally, the elevated PLI at B1 aligns with the high Cu and Zn concentrations recorded at the same location and further supports the interpretation that plastic-rich waste may contribute substantially to metal loading in the soil.

The other locations (B2, B3, B4 and B5) have PLI values above the PLI baseline

level, suggesting deterioration in the quality of soils in these locations, and that contamination is not only restricted to the plastic-waste dumpsite. However, the magnitude of deterioration varies among the locations, suggesting that waste composition, degree of waste accumulation, duration of dumping, leachate generation and local soil properties may impact the level of metal enrichment [20], [21]. What this implies is that each dumpsite represents a potential source of metal release into the surrounding environment. As such, the PLI results provide evidence that the dumpsites require environmental monitoring and improved waste-management intervention.

Table 6. PLI values for dumpsites soils in Ijebu-Ode.

Location	PLI
B1	7.42
B2	2.63
B3	4.18
B4	4.69
B5	3.13

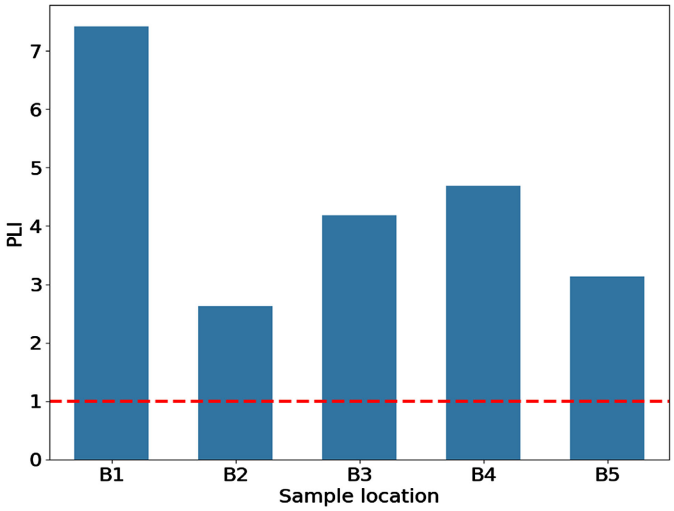

Figure 5. Bar chart showing PLI across all locations. The broken red line is the PLI baseline level.

4. Conclusions

This study evaluated heavy metal concentrations and contamination status in five dumpsite soils from Ijebu-Ode, southwestern Nigeria. Results show that the dumpsite soils are enriched in several metals, especially Cu, Zn, and As. The highest Cu and Zn concentrations, as well as the highest Pollution Load Index (PLI), were recorded from the plastic-rich waste dumpsite, suggesting an association between waste composition and metal enrichment; however, additional replicated sampling and source characterization studies are required to establish causation.

The results of contamination indices (Contamination Factor (CF), Geo-accumulation index (I_{geo}), and Pollution Load Index (PLI)) indicate that the sampled dumpsite soils are environmentally degraded. The environmental significance of these findings is that dumpsite soils may act as secondary sources of heavy metals release into surrounding soils, drainage systems, shallow groundwater, and possibly plants cultivated near contaminated sites. Overall, this study demonstrates that unmanaged dumpsites in the study area are emerging geochemical hotspots that require routine monitoring and targeted waste-management intervention.

Future studies should include a larger number of samples, seasonal sampling, background/control soils, soil pH and organic matter analysis, and ecological or human-health risk assessment to better evaluate the heavy metals' mobility, bioavailability, and exposure implications.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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