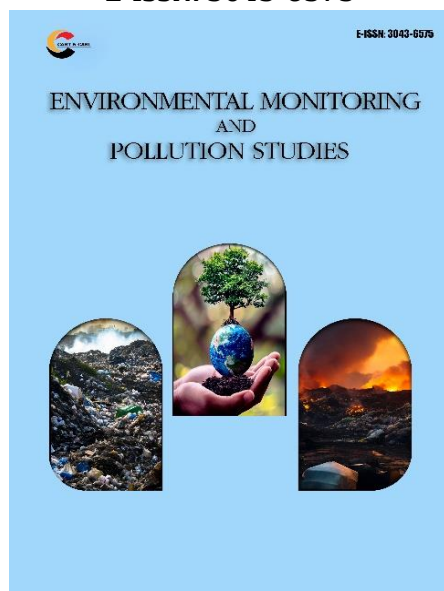




E-ISSN: 3043-6575



Ecological Risk Assessment of Heavy Metal Status in the Soil around the Idu Dumpsite, Abuja, Nigeria

Abstract

Environmental pollution studies through risk assessment indicators could enhanced the effectiveness of remediation and environmental sustainability practice of the environment. Through the adoption of indicators such as contamination factor (CF), geo-accumulation index (Igeo), pollution load index (PLI), enrichment factor (EF), the study carried out an ecological risk assessment of heavy metal (HM) status in the soil around the Idu dumpsite, Abuja, Nigeria. A laboratory technique based on American Public Health Association (APHA) 3030E and American Society for Testing Materials (ASTM 4691) standard and procedure, heavy metal such as Iron (Fe), Arsenic (As), Chromium (Cr), Copper (Cu), Zinc (Zn), Cadmium (Cd) and Lead (Pb) were analysed. The finding revealed that the CF of the HM descended as Cd (15.24) > Cu (0.13) > Fe (0.07) > Pb (0.05) > Cr (0.034) > Zn (0.02) > As (0.01), EF descended as Cd (218.38) > Cu (1.90) > Fe (1) > Pb (0.69) > Cr (0.51) > Zn (0.3) > As (0.1), Igeo descended as Cd (3.35) > Cu (-3.50) > Fe (-4.43) > Pb (-4.96) > Cr (-5.40) > Zn (-6.17) > As (-7.81) and risk index (RI) descended as Cd (457.2) > Cu (0.65) > Pb (0.25) > As (0.1) > Fe (0.07) > Cr (0.068) > Zn (0.02). The outcome indicated that among the HM, Cd had very high CF, exceptionally high EF, high pollution Igeo and significantly high environmental risk. The adoption of ecological risk indicators in the assessment of environmental pollution further enhance the approach to effective remediation action and management.

Keywords: Environmental Pollution, Contamination Factor, Heavy Metal, Ecological Indicators, Dumpsite

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Received: 25 October 2025

Accepted: 18 November 2025

Published: 22 November 2025

Citation

Otu, M.A., Woke, G.N. and Edwin-Wosu, N.L. (2025). Ecological Risk Assessment of Heavy Metal Status in the Soil around the Idu Dumpsite, Abuja, Nigeria. *Environmental Monitoring and Pollution Studies*, 2(1), 62-69
<https://doi.org/10.70726/emps.2025.216269>

Introduction

Environmentally harmful agents resulting from anthropogenic activities are numerous and remain among the major issues faced by various governments, communities, individuals, scientists, and regulators across the globe. As a result of developments in both technology and industrial activities, many of the world's resources are not utilised sustainably, while the processing of these resources often leads to the discharge of products and by-products into the environment, resulting in environmental degradation (Shahid et al. 2021). The resulting impact of this product and by-products as pollutants in the environment can range from local to regional, as well as transboundary, as pollutants capable of being transferred, dispersed, and stored in several environmental components (Khalid et al., 2020).

In Nigeria, the most used method of waste disposal is through the landfill system due to its simplicity and the least cost of maintenance (Gonzalez-Valencia et al., 2015); however, this method easily causes the release of toxic substances into the environment. Landfills or dumpsites remain one of the most common human-induced contaminated sites in many

developing countries, including Nigeria; hence, toxic substances (such as carcinogenic heavy metals) are closer to the human environment than ever. This is generally due to poor landfill management and leachate contamination prevention, and some are cited close to the living environment, which is of significant concern to public health (Ogbuehi et al., 2022).

Waste disposal through landfilling remains the most common method of solid waste management in many developing cities and poses a potential threat to various environmental components (Afolabi and Eludoyin, 2021; Aja et al., 2021). One of the landfilling system's consequences is leachate emission (Hussein et al., 2019). Leachate is aqueous waste discharged from solid waste due to various physical, chemical, and biological interference in landfill systems (Youcai, 2018; Parvin et al., 2021) and contains soluble organic compounds, inorganic contaminants, suspended solids, heavy metals, and dangerous substances (Wdowczyk and Szymanska-Pulikowska, 2021). The improper management of landfill/dumpsites and generated leachate can cause a significant impact on the surrounding surface and groundwater (Ololade et al., 2019; Jablonska-Trypuc et al., 2021) and farmland (Vaverkovet al., 2020).

Heavy metals pose the most significant threat among various leachate compositions due to their non-biodegradable, toxic, environmental persistence, bioaccumulative, endocrine-disrupting, and carcinogenic nature (Hazrat et al., 2019). Due to its persistent nature, heavy metals can be amassed in the environment over a period, leading to possible food chain contamination. Accumulation of potentially toxic heavy metals in biota causes a potential health threat to their consumers, including humans (Hazrat et al., 2019). Conversion techniques of leachate analysis are primarily based on chemical testing to ascertain the concentration of heavy metals and organic compounds with carcinogenic, estrogenic, and toxic properties (Jablonska-Trypuc et al., 2021). These methods allow for a preliminary estimation of the danger and risk leachate poses to the environment and humans (Clarke et al., 2015).

Beyond the establishment of environmental pollution through the physical, chemical and biological assessment, studies such as Sulaiman et al. (2018), Aja et al. (2020), Yahaya et al. (2021), Afolabi and Adesope (2022), and Afolabi et al. (2023) have adopted various environmental risk indicators, such as Contamination Factor (CF), Geo-accumulation Index (Igeo), and Pollution Load Index (PLI), to establish the pollution status of an environment, such as a dumpsite. It is on this ground that the present study carried out an ecological

risk assessment of heavy metal status in the soil around the Idu dumpsite, Abuja, Nigeria.

Material and Methods

Study Area

The study area was the Idu Dumpsite, located within the Idu Industrial Area of the Abuja Municipal Area Council (AMAC) in Nigeria's Federal Capital Territory (FCT). Geographically, the Idu area lies between latitudes 9°03'44" N and longitude 7°20'32" E (Figure 1) in the northeastern part of Abuja. The site is accessible through the Idu Industrial Road, adjoining major transport and industrial corridors that support manufacturing, metal works, and automobile activities (Enitan et al., 2018).

The Idu dumpsite serves as one of the main solid waste disposal points for Abuja, receiving a mixture of municipal, industrial, and construction wastes. Its proximity to residential settlements, small-scale industries, and surface drainage channels increases the potential for environmental contamination and human exposure (Enitan et al., 2018). The surrounding environment falls within the Guinea Savannah ecological zone, characterised by moderate relief, tropical climate, and an annual rainfall of about 1,500 mm between April and November. Soils in the area are typically ferruginous tropical soils prone to leaching and metal accumulation, while drainage patterns flow toward low-lying wetlands and streams (Enitan et al., 2018).

Sample Collection Procedure

The samples for the study were collected on the 2nd of May, 2025, using standard procedure and required apparatus such as bottles, icebox, gloves, marker, handheld global positioning system (GPS) and zip-lock bags.

Soil samples (3-composite samples) were collected at three designated points within the dumpsite area at a distance of 100-150m away from each point. At each point, a radius of about 5-10 m was made around the point, and 5 random soil samples were collected around the radius into a collection pan at a depth of about 0-15 cm and mixed to form a composite sample for the designated point. The process was repeated for each point. All samples were collected while wearing gloves to prevent contamination, and the collected samples were instantly placed in an icebox and appropriately labelled and taken to the laboratory (Myrtle Analytical Laboratory and Innovation Limited) for analysis. Geographical coordinates of each sampling point were recorded with a handheld global positioning system

(GPS), and the detailed geographical information of the sampling points was recorded and presented in Table 1 and Figure 1.

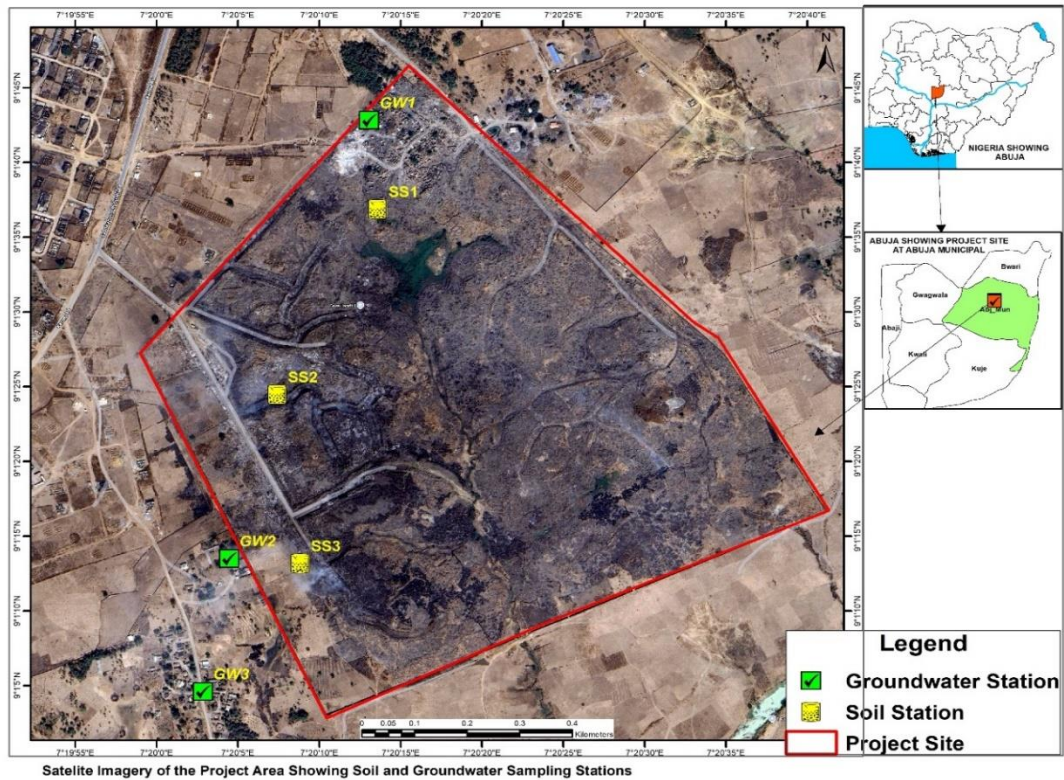


Figure 1: Overview of the Idu dumpsite and sampling points for groundwater and soil samples

Table 1: Sampling Points Details and Geographical Information

Description	Code	Latitude	Longitude
Soil Point 1	SS1	9.026913	7.337109
Spoil Point 2	SS2	9.023466	7.335393
Soil Point 3	SS3	9.020329	7.335788

Data Analysis

Laboratory Analysis

Based on the American Public Health Association (APHA) 3030E, the sample was digested ~1 g with HNO₃, covered and heated to near-boiling (about 95°C) for ~15 minutes and cooled. 5 mL of HNO₃ was added and heated again to near-boiling for 15 min and then cooled. Slowly, 3–5 mL 30% H₂O₂ was added in small portions, allowing the reaction to subside before heating to ~95°C, then cooled. The acidified water samples were filtered using Whatman ashless filter paper and thereafter analysed with Atomic Absorption Spectrophotometer (Shimadzu AA-6650) using standard method (ASTM 4691) to

determine the level of heavy metals (Iron (Fe), Arsenic (As), Chromium (Cr), Copper (Cu), Zinc (Zn), Cadmium (Cd) and Lead (Pb)) in the sample (Sokpuwu, 2017; Afolabi & Adesope, 2022).

Ecological Risk Estimation (Indicators)

Contamination Factor (CF): CF was adopted in order to ascertain the extent of soil contamination with heavy metals. CF is express.

$$CF = C_n / B_n \dots\dots\dots \text{Eq. 1}$$

Where, C_n= Concentration of heavy metals in soil samples and B_n= Background value of heavy metals in natural

state. The heavy metals are classified based on the CF as CF<1: Low, $1 \leq CF < 3$: Moderate, $3 \leq CF < 6$: Considerable High and $CF \geq 6$: Very High (Hakanson, 1980; Afolabi and Eludoyin, 2021).

Enrichment Factor (EF): EF can be used to differentiate between the metals originating from anthropogenic activities and those from natural sources (Muzerengi, 2017). Enrichment factor of the metals was calculated as the ratio of elemental concentration of sediment normalized to a reference Fe. EF is expressed as;

$$EF = \frac{C_x/C_{ref}}{B_x/B_{ref}} \dots \dots \dots \text{Eq. 2}$$

Where: C_x = Concentration of HM content in the anthropogenically impacted soil, C_{ref} = Concentration of referenced metal in the anthropogenically impacted soil, B_x = Concentration of HM content in the undisturbed soil and B_{ref} = Concentration of referenced metal in the undisturbed soil. The heavy metals are classified as EF <1: Zero Enrichment, $1 \leq EF < 3$: Less Enrichment, $3 \leq EF < 5$: Moderate Enrichment, $5 \leq EF < 10$: Moderately Enrichment, $10 \leq EF < 25$: High Enrichment, $25 \leq EF < 50$: Very High Enrichment and $EF > 50$: Exceptionally High Enrichment (Aja et al, 2021).

Geo-Accumulation Index (I_{geo}): I_{geo} estimated the contamination magnitude of the heavy metals in the anthropogenically impacted soil/sediment. I_{geo} is express thus;

$$I_{geo} = \log_2 \frac{HM_s}{1.5 \times HM_c} \dots \dots \dots \text{Eq.3}$$

Where; HM_s = Samples heavy metal concentration, HM_c = Reference heavy metal concentration and 1.5 = Constant. The heavy metals are classified as $I_{geo} \leq 0$: No Pollution, I_{geo} (0-1): Moderate Pollution, I_{geo} (1-2): Strong Pollution, I_{geo} (2-3): High Pollution, I_{geo} (3-4): Very High Pollution, I_{geo} (4-5): Severe Pollution and $I_{geo} \leq 5$: Extreme Pollution (Loska et al., 2004; Aja et al, 2021).

Pollution Load Index (PLI): PLI was adopted to estimate the comparison in the extent of pollution among the sampled soil/sediment from different locations based on the time factor. PLI is express as:

$$PI = \sqrt[n]{CF_1 * CF_2 * CF_3 * \dots \dots \dots CF_n} \dots \dots \dots \text{Eq. 4}$$

Where PLI= Pollution Load Index, CF = Contamination factor, and n= number of elements. The PLI >1 indicates polluted, while PLI<1 indicates no pollution (Afolabi and Eludoyin, 2021).

Degree of Contamination Index (DCI): DCI was utilized to estimate the sum of the CF of the studied metals. DC is expressed as:

$$DCI = \sum_{i=1}^n CF \dots \dots \dots \text{Eq. 5}$$

The DC of the heavy metals are classified as DCI<1: Low: $1 \leq DCI < 3$: Moderate: $3 \leq DCI < 6$: Considerable, and $DCI \geq 6$: Very High (Hakanson, 1980; Afolabi and Eludoyin, 2021).

Modified Degree of Contamination (MDC): As the name implies, it is the modification of the DCI equation, which is expressed as;

$$MDC = \frac{\sum_{i=1}^n CF}{n} \dots \dots \dots \text{Eq. 6}$$

Where n= Number of heavy metals. MDC is classified as MDC<1: Nil to Very Low Degree of Contamination, $1.5 \leq MDC < 2A$: Low Degree of Contamination, $2 \leq MDC < 4$: Moderate Degree of Contamination, $4 \leq MDC < 8$: High Degree of Contamination, $8 \leq MDC < 16$: Very High Degree of Contamination, $16 \leq MDC < 32$: Extremely High Degree of Contamination and $MDC \geq 32$: Ultra-High Degree of Contamination (Abraham and Parker, 2008; Afolabi & Eludoyin, 2021).

Risk Index (RI): RI is express as the given product of the contamination factor (CF) of the heavy metals and toxicological response factor (Tr) of each heavy metal (Kumar et al., 2018; Aja et al, 2021), and it is expressed as thus;

$$RI = CF_n \times T_r \dots \dots \dots \text{Eq. 7}$$

The RI of the heavy metals were classified as RI < 30: Low Risk, RI: 30-60: Moderate Risk, RI: 60 -120: Considerable Risk, RI: 120-240: High Risk and RI >240: Significantly High Risk (Aja et al, 2021).

Modified Ecological Risk Index (MRI): MRI is express as the given product of the enrichment factor (EF) of the heavy metals and toxicological response factor (Tr) of each heavy metal (Aja et al., 2021), and it is expressed as thus;

$$MRI = EF_n \times T_r \dots \dots \dots \text{Eq. 8}$$

The MRI of the heavy metals were classified as MRI < 40: Low Risk, MRI 40-80: Moderate Risk, MRI 80-160: Considerable Risk, MRI 160-320: High Risk and MRI >320: Very High Risk (Aja et al, 2021).

Results and Discussion

The environmental risk status of the heavy metals in the soil sample was assessed and presented in Table 2.

Contamination Factor (CF): At SS1, the CF of the heavy metals descended as Cd (15.24) > Cu (0.13) > Fe (0.07) > Pb (0.05) > Cr (0.034) > Zn (0.02) > As (0.01) and their classification ranged from low CF in Cu, Fe, Pb, Cr, Zn and As to very high in Cd. A similar pattern was noticed in the CF trend of SS2 and SS3 with similar classification of low CF (Cu, Fe, Pb, Cr, Zn and As) and very high (Cd). The environmental risk assessment of the soil based on CF indicated that all the HMs (Fe, As, Cr, Cu, Zn, Cd and Pb) had CF estimated below 1 (that is, <1) except Cd with CF of >1; hence, HMs are classed as low contamination for all HMs and very high contamination for Cd. The CF reported therein was similar to those reported by Bubu et al. (2017) for Cr, Cu, Zn, and Pb and Afolabi et al. (2024) for Cu and Zn for sediment from Bonny Creek. The CF < 1 implies that the soil of the dumpsite is not contaminated with Fe, As, Cr, Cu, Zn, and Pb, and the outcome is similar to the finding of Afolabi and Adesope (2022) for similar rivers around the vicinity of the study area.

Enrichment Factor (EF): For EF at the SS1, the heavy metals descended as Cd (218.38) > Cu (1.90) > Fe (1) > Pb (0.69) > Cr (0.51) > Zn (0.3) > As (0.1) and their classification ranged from exceptional high enrichment in Cd, less enrichment in Cu and Fe to zero enrichment in Pb, Cr, Zn and As. A similar pattern was noticed in the CF trend of SS2 and SS3 with a similar classification. The EF of the sample showed that all HMs showed EF<1, indicating zero enrichment except Cd, with EF >50 indicating exceptionally high enrichment. According to Mohammed and Abdu (2014), the enrichment of the environmental component can be linked to various human actions. Similarly, Ohiagu et al. (2020) suggested that EF > 1 can be linked to human-related activities, while EF ≤ 1 could be due to natural phenomena such as weathering.

Geo-Accumulation Index (I_{geo}): For I_{geo} at the SS1, the heavy metals descended as Cd (3.35) > Cu (-3.50) > Fe (-4.43) > Pb (-4.96) > Cr (-5.40) > Zn (-6.17) > As (and their classification ranged from very high pollution in Cd to no pollution in Cu, Fe, Pb, Cr, Cu Fe and Zn. A similar pattern was noticed in the CF trend of SS2 and SS3 with a similar classification. The estimated I_{geo} for soil samples have values lower than zero ($I_{geo} > 0$), indicating no pollution for Fe, As, Cr, Cu, Zn, and Pb except Cd, with I_{geo} 3-4 indicating high pollution. The result indicates the dumpsite is highly polluted with Cd. Bubu et al. (2017), Ustaoglu (2020), and Afolabi et al. (2024) reported a

similar outcome for I_{geo} status for HMs for sediment along the Bonny River, indicating that any of the HMs do not pollute the sediment of their studied location.

Pollution Load Index (PLI): The PLI of the soil indicated 0.07, 0.15, 0.05, 0.02, 0.01, 15.15 and 0.008 for Fe, Cu, Pb, Zn, As, Cd and Cr, respectively. The PLI is classified as no pollution with Fe, Cu, Pb, Zn, As and Cr and polluted soil with Cd. The PLI values of the soil HMs are < 1, indicating no pollution except for Cd, with a PLI value of 15.15 indicating pollution of the soil with Cd. The outcome indicated that the concentration values of the PTEs cannot be taken to have polluted the sediment. Afolabi and Adesope (2022) reported a similar outcome for PLI status for similar rivers around the vicinity of the study area.

Degree of Contamination Index (DCI): The DCI of the soil indicated 0.21, 0.44, 0.15, 0.06, 0.03, 45.44 and 0.114 for Fe, Cu, Pb, Zn, As, Cd and Cr, respectively. The DCI is classified as low contamination with Fe, Cu, Pb, Zn, As and Cr and very high contamination with Cd. The DCI values of the soil HMs are < 1, indicating a low degree of contamination except for Cd, with a DCI value of 45.44 indicating a very high degree of contamination of the soil with Cd.

Modified Degree of Contamination (MDC): The MDC of the soil indicated 0.07, 0.15, 0.05, 0.02, 0.01, 15.15 and 0.04 for Fe, Cu, Pb, Zn, As, Cd and Cr, respectively. The MDC is classified as very low degree of contamination with Fe, Cu, Pb, Zn, As and Cr and a very high degree of contamination with Cd. MDC values of the soil HMs are < 1, indicating a very low degree of contamination except for Cd, with an MDC value of 15.15 indicating an ultra-high degree of contamination of the soil with Cd.

Risk index (RI): For RI at the SS1, the heavy metals descended as Cd (457.2) > Cu (0.65) > Pb (0.25) > As (0.1) > Fe (0.07) > Cr (0.068) > Zn (0.02) and their classification ranged from low risk index with Fe, Cu, Pb, Zn, As and Cr and significantly high risk with Cd. A similar pattern was noticed in the RI trend of SS2 and SS3 with a similar classification. The environmental risk estimation of the studied area based on the RI estimation indicated that HMs of the soil have a value of <30, indicating low risk except for Cd, with a RI of >240 indicating a significantly high risk.

Table 2: Environmental Pollution Status of the Heavy Metal Soil around the Idu Dumpsite

Soil Samples					Contamination Factors (CF)			Enrichment Factor (EF)			Geo-Accumulated Index (I _{geo})			Environmental Risk Assessment (RI and MRI)								
S/N	HMs	SS1	SS2	SS3	CF ₁	CF ₂	CF ₃	EF ₁	EF ₂	EF ₃	I _{geo1}	I _{geo2}	I _{geo3}	PLI	DCI	MDC	RI ₁	RI ₂	RI ₃	MRI ₁	MRI ₂	MRI ₃
1	Fe	3.280	3.281	3.282	0.07	0.07	0.07	1	1	1	4.43	4.43	4.43	0.07	0.21	0.07	0.07	0.07	0.07	1	1	1
2	Cu	2.000	2.341	2.256	0.13	0.16	0.15	1.90	2.22	2.14	3.50	3.27	3.33	0.15	0.44	0.15	0.65	0.8	0.75	9.5	11.1	10.7
3	Pb	0.966	0.968	0.963	0.05	0.05	0.05	0.69	0.70	0.69	4.96	4.95	4.96	0.05	0.15	0.05	0.25	0.25	0.25	3.45	3.5	3.45
4	Zn	1.982	1.980	1.975	0.02	0.02	0.02	0.3	0.3	0.3	6.17	6.17	6.17	0.02	0.06	0.02	0.02	0.02	0.02	0.3	0.3	0.3
5	As	0.012	0.010	0.010	0.01	0.01	0.01	0.1	0.08	0.08	7.81	8.08	8.08	0.01	0.03	0.01	0.1	0.1	0.1	1	0.8	0.8
6	Cd	2.286	2.245	2.280	15.24	15.0	15.2	218.38	214.40	217.67	3.35	3.32	3.34	15.15	45.44	15.15	457.2	450	456	6551.4	6432	6530.1
7	Cr	1.244	1.243	1.229	0.034	0.04	0.04	0.51	0.51	0.50	5.40	5.40	5.42	0.008	0.114	0.04	0.068	0.08	0.08	1.02	1.02	1

PLI: Pollution Load Index, DCI: Degree of Contamination Index, MDC: Modified Degree of Contamination

Background Value (B_n): Pb- 20, Cd- 0.15, Cr- 35, Fe-47, Cu-15.1, Zn-95, As-1.8

Toxicological Response Factor (Tr): Pb (5), Cd (30), Cr (2), As (10), Fe (1), Zn (1) and Cu (5)

Modified Ecological Risk Index (MRI): For MRI at the SS1, the heavy metals descended as Cd (6551.4) > Cu (9.5) > Pb (3.45) > Cr (1.02) > As (1) > Fe (1) > Zn (0.3) and their classification ranged low risk with Fe, Cu, Pb, Zn, As and Cr and very high risk with Cd. A similar pattern was noticed in the MRI trend of SS2 and SS3 with similar classification. The environmental risk estimation based on the MRI estimation indicated that HMs of the soil have a value of <40, indicating low risk, except for Cd, with MRI > 320, indicating very high risk. Afolabi and Adesope (2022) and Afolabi et al. (2024) reported a similar outcome for RI and MRI status for their study area.

Conclusion and Recommendations

Studies have shown that dumpsite operations have the capacity to lead to degradation of soil in the environment. The adoption of ecological risk indicators in the assessment of environmental pollution further enhances the approach to effective remediation action and management. The indicators adopted for this study have been able to establish that Cd among the heavy metals has a very high contamination factor, exceptionally high enrichment level and very high risk of environmental pollution. There is a need for the management of the facilities to initiate soil remediation measures such as phytoremediation or chemical stabilization, targeting cadmium hotspots and ensuring continuous environmental sustainability practices.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Credit Authorship Contribution Statement

Otu, M. A.: Conceptualization, Methodology, Formal analysis, Investigation, Resources, Data curation, Visualization, Project administration, Writing - original draft. **Woke, G. N. and Edwin-Wosu, N. L.:** Supervision, Methodology, Validation, Formal analysis, Data curation, Visualization, Review & Editing.

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