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GEO-ACCUMULATION INDEX OF SOME HEAVY METALS IN THE WASTE DUMPSITE AT AGU AWKA ANAMBRA STATE, NIGERIA.

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Abstract
Uncontrolled disposal of municipal solid waste continues to pose serious environmental challenges in many developing countries, particularly through the release of toxic heavy metals into soil systems. This study evaluates the concentration, distribution, and contamination status of selected heavy metals (Pb, Cd, Ni, Cr, and As) in soils from the Agu-Awka dumpsite, Nigeria, using the Geo-accumulation Index (Igeo). Soil samples were collected at three depths (0–5, 15, and 30 cm) from two active dumpsites and a control site. Physicochemical properties were analyzed using standard procedures, while metal concentrations were determined via atomic absorption spectrophotometry following aqua regia digestion. The results show clear enrichment of heavy metals in dumpsite soils compared to the control, with the highest concentrations observed in surface layers. Igeo classification indicates moderate to moderately strong contamination, particularly for lead and arsenic. Although concentrations were generally below international guideline limits, the index-based approach reveals notable anthropogenic influence. The vertical distribution pattern suggests gradual leaching, raising concerns about potential groundwater contamination. Overall, the findings highlight the need for improved waste management strategies and consistent environmental monitoring to reduce long-term risks.

Keywords: *Heavy metal contamination, Dumpsite soils, Geo-accumulation Index, Urban environmental pollution*

Introduction

Background of the Study

Rapid urbanization and population growth in Nigeria have made solid waste management a critical environmental challenge (Amadi & Nwankwoala 2013). In many developing nations, the prevalence of unlined open dumpsites without prior environmental impact assessments allows persistent, non-biodegradable heavy metals to migrate into the surrounding lithosphere and hydrosphere (Nduka *et al.,* 2006). While trace amounts of certain metals are biologically essential, elevated levels of Pb, Cd, and Ni are highly toxic and pose severe risks, including neurological disorders and carcinogenic effects (Ijabor *et al.,* (2023); Okakpu *et al.,* (2024).

In Anambra State, the proximity of the Agu-Awka dumpsite to residential and agricultural zones raises concerns regarding the transfer of toxic metals into groundwater and crops (Okakpu *et al.,* 2024). Despite historical investigations into metal infiltration in Awka (Nduka *et al.,* 2006), there is a critical need for up-to-date data using standardized pollution indices. This study evaluates the concentrations of Pb, Cd, Ni, Cr, and As at the Agu-Awka site using atomic absorption spectrophotometry and the geo-accumulation index (*Igeo*) to differentiate anthropogenic contributions from natural background levels (Afolagboye *et al.,* (2020); Afolabi & Eludoyin (2021). Additionally, it examines physicochemical properties; such as pH, electrical conductivity, and organic matter—which regulate metal mobility and bioavailability (Agho *et al.,* 2022).

Materials and Methods

Study Area and Sampling Design

The research was conducted in Awka, the capital of Anambra State, Nigeria, a region characterized by rapid urbanization and unregulated waste management practices (Okakpu *et al.,* 2024). Two prominent urban dumpsites located in topographically low-lying areas with poor drainage were selected for analysis:

- **Dumpsite 1:** 6°14′09″ N, 7°05′37″ E
- **Dumpsite 2:** 6°12′22″ N, 7°04′53″ E
- **Control Site:** 6°15′10″ N, 7°06′48″ E

The proximity of these sites to residential and aquatic systems poses a significant risk of environmental contamination (Ijabor *et al.,* 2023; Nduka *et al*., 2006). At each location, a 350 cm × 290 cm plot was demarcated, and soil was collected from five points at 70 cm intervals as pictorial shown in figure 1-4 below. Samples were retrieved at three distinct depths: topsoil (0–5 cm), middle soil (15 cm), and bottom soil (30 cm) to assess vertical contaminant migration (Okakpu *et al.,* 2024).

Figure 1: Dumpsite 1

Figure 2: Dumpsite 2

Figure 3: Control Site

Figure 4: *Layout of the rectangular sampling plot (350 × 290 cm) showing five sampling points at 70 cm intervals*

Sample Preparation

Samples were transported in sealed bags, air-dried for 24 hours, and sieved through a 2.00 mm stainless steel mesh to isolate the fine earth fraction (Okakpu *et al.,* 2024; Otabor, 2019). All laboratory preparation used high-precision analytical balances (0.0001 g sensitivity) and analytical-grade reagents to ensure data reliability.

Physicochemical Characterization

Physicochemical parameters were determined using standard methods to evaluate their influence on heavy metal mobility (Otabor, 2019)

- **pH and Electrical Conductivity:** Measured in a 1:2.5 soil-to-water suspension using digital meters after 30 minutes of equilibration (Okakpu *et al.,* 2024).
- **Moisture Content:** Determined gravimetrically by oven-drying 5 g of soil at 105°C for one hour.
- **Organic Matter:** Quantified using the Loss-on-Ignition method at 500°C for 3 hours, or the Walkley–Black chromic acid oxidation method for detailed carbon fraction analysis (Okakpu *et al.,* 2024; Otabor, 2019).
- **Soil Temperature:** Measured *in-situ* at each depth using a calibrated soil thermometer.

Geo-accumulation Index

To quantify contamination, this research utilizes the geo-accumulation index (I_{geo}), a robust tool introduced by Müller (Afolagboye *et al.,* 2020). The index is calculated as follows:

$$Igeo\ =\ \log 2\left(\frac{Cn}{1.5\ x\ Bn}\right)$$

where Cn is the measured metal concentration and Bn is the geochemical background value (Afolagboye *et al.,* 2020). The 1.5 factor accounts for natural lithogenic variations in soil composition (Afolagboye *et al.,* 2020; Anegbe *et al.,* 2018).). The provides a standardized classification of pollution intensity, ranging from Class 0 (unpolluted,) to Class 6 (extremely polluted,) (Afolagboye *et al.,* 2020).

Heavy Metal Analysis

Heavy metal quantification was performed via Atomic Absorption Spectrophotometry. Soil samples underwent hotplate digestion using the Aqua Regia method (3:1 HNO_3 to HCl ratio) (Aluko, Obaseki & Ibikunle, 2024; Okakpu *et al.,* 2024). The resulting solutions were filtered through Whatman No. 42 filter paper and diluted to volume for analysis. To differentiate anthropogenic contributions from natural lithogenic background levels, the geo-accumulation index () was applied following the methodology established by Müller (Amadi and Nwankwoala, 2013).

Acid Digestion and Sample Preparation

Homogenized soil samples (2.0 g) were subjected to pseudo-total digestion using freshly prepared aqua regia (HNO_3 to HCl in the ratio of 3:1) (Amos-Tautua, and Onigbinde and Ere, 2014). The mixture was allowed to pre-digest for 24–48 hours at room temperature to ensure matrix interaction, followed by gentle heating at 80–95°C for 2 hours until the volume was reduced to approximately one-third (Okakpu *et al.,* 2024). After cooling, the digests were filtered through Whatman No. 42 filter paper into 100 mL volumetric flasks and diluted to volume with deionized water. Samples were categorized by site (Dumpsite 1, Dumpsite 2, and Control) and depth (0–5 cm, 15 cm, and 30 cm) and stored at 4°C prior to analysis (Nduka *et al.,* 2006; Audu, & Wuana, 2021).

Heavy Metal Quantification

Concentrations of Lead (Pb), Cadmium (Cd), Nickel (Ni), Chromium (Cr), and Arsenic (As) were determined using an Atomic Absorption Spectrophotometer (Model AA320N) (Chukwulobe and Saeed (2014). The instrument was calibrated using working standards (0.2–1.0 mg/L) prepared from 1000 mg/L stock solutions in 1 M. Analysis was conducted at the following analytical wavelengths: Pb (283.3 nm), Cd (228.8 nm), As (193.3 nm), Ni (232.0

nm), and Cr (357.9 nm) (Okakpu *et al.,* 2024). Quality control was maintained through the analysis of reagent blanks and duplicate measurements to ensure precision and account for background interference.

RESULTS AND DISCUSSION

Physicochemical Characteristics of the Soils

The physicochemical properties (proximate analysis) of the soil samples from the Agu-Awka dumpsite and the control site (SS3) are summarized in Table 1. These parameters are critical determinants of the chemical speciation, mobility, and bioavailability of heavy metals within the soil matrix (Okakpu *et al.,* 2024; Otabor, 2019).

Table 1: Physicochemical Properties of Soil Samples by Depth

Sample ID	Depth (cm)	Ph	EC (µS/cm)	Temp (°C)	Moisture (%)	TOM (%)
SS1A	0–5	7.15	147	26	0.55	0.53
SS1B	15	6.75	194	28	1.00	0.61
SS1C	30	7.10	150	24	1.08	0.68
SS2A	0–5	6.75	171	26	4.31	2.07
SS2B	15	6.60	144	26	4.00	2.62
SS2C	30	6.70	68	26	3.89	1.38
SS3A	0–5	6.25	72	26	1.30	1.60
SS3B	15	5.90	46	28	1.71	0.72
SS3C	30	5.55	40	26	1.42	-

Soil pH and Heavy Metal Mobility

The soil pH ranged from 5.55 to 7.15 across all sites. Dumpsite samples exhibited near-neutral to slightly acidic conditions (6.60–7.15), whereas the control site was consistently more acidic (5.55–6.25), the c9ntrol location was a farm land, the result will suggest that the control location has anthropogenic activities such as application of nitrogen-based fertilizers, intense agricultural harvesting, and improper land management. The relative alkalinity of the dumpsite soils compared to the control is often attributed to the decomposition of organic waste and the presence of alkaline-rich materials like wood ash in municipal refuse (Otabor, 2019). These findings align with similar studies in Awka and other Nigerian municipalities where dumpsite pH values typically fall within the 6.0–8.0 range (Nduka *et al.,* 2006). Since metal solubility generally increases at lower pH, the slightly higher pH at the Agu-Awka site may suggest a localized reduction in the immediate mobility of elements like Pb and Cd, though seasonal fluctuations in leachate acidity could alter this stability (Okakpu *et al*., 2024; Otabor, 2019).

Electrical Conductivity and Soluble Salts

EC values ranged from 40 to 194 µS/cm, with significantly higher values recorded at the dumpsites (SS1 and SS2). The peak value at SS1B (194 µS/cm) indicates a high concentration of dissolved inorganic ions, likely originating from the infiltration of metal-rich leachates and the mineralization of organic matter (Ijabor *et al.,* 2023). In contrast, the control site maintained lower EC levels (40–72 µS/cm), reflecting natural background conditions. All recorded values remained below the 200 µS/cm threshold typically associated with non-saline soils, suggesting that while the waste disposal has increased salt content, it has not yet reached critical salinity levels (Okakpu *et al.,* 2024).

Total Organic Matter and Sequestration

The TOM content was notably higher in the dumpsite samples (up to 2.62% at SS2B) compared to the control site. This enrichment reflects the continuous deposition and subsequent decomposition of anthropogenic organic waste (Ijabor *et al.,* 2023). High organic matter content plays a dual role in soil chemistry; it can act as a significant "sink" for heavy metals by forming stable organometallic complexes, thereby reducing their bioavailability, or it can facilitate metal transport into deeper soil layers via the formation of soluble fulvic acid complexes (Nduka *et al*., 2006; Otabor, 2019). The observed TOM levels are consistent with agricultural soil norms (1–5%), indicating that the soil retains a moderate capacity for metal binding (Okakpu *et al.*, 2024).

Temperature and Moisture Dynamics

Soil temperatures (24–28°C) were within the optimal range for mesophilic microbial activity, which is essential for the biochemical degradation of waste (Otabor, 2019). Moisture content was highest in the mid-depth samples of the second dumpsite (4.31%), potentially due to leachate accumulation or localized soil compaction (Okakpu *et al*., 2024). Higher moisture levels in dumpsite soils compared to the control (1.30–1.71%) facilitate the downward migration of contaminants through the soil profile via percolation, a process that can lead to groundwater contamination in poorly drained topographical areas (Amadi & Nwankwoala, 2013; Nduka *et al*., 2006).

Heavy Metal Concentrations in Soil

The elemental concentrations of Pb, Cd, Ni, Cr, and As across the three sampling locations and depths are detailed in Table 2. The data reveal a consistent trend of enrichment in the dumpsite soils compared to the control site, particularly in the surface layers (Nduka *et al*., 2006; Okakpu *et al*., 2024).

Table 2: Heavy Metal Concentrations (mg/kg) in Soil Samples by Depth

Sample Code	**Depth (cm)**	**Pb**	**Cd**	**Ni**	**Cr**	**As**
SS1A	0–5	1.816	1.890	0.639	0.702	0.287
SS1B	5–15	1.765	1.637	0.361	1.310	0.459
SS1C	15–30	1.538	0.943	0.891	0.975	0.143
SS2A	0–5	1.194	2.079	0.538	1.205	0.100
SS2B	5–15	0.614	1.574	0.134	1.059	0.273
SS2C	15–30	0.740	1.795	0.664	0.870	0.143
SS3A	0–5	0.437	1.027	0.235	1.017	0.244
SS3B	5–15	0.361	1.048	0.285	1.059	0.187
SS3C	15–30	0.134	0.533	0.311	0.786	0.100
WHO recommended limit		50-100	0.8-3	35-50	100	10-20

Lead and Cadmium Enrichment

Lead concentrations in the dumpsites (0.614–1.816 mg/kg) were significantly higher than in the control site (0.134–0.437 mg/kg), reflecting anthropogenic inputs from batteries and pigments (Ijabor *et al*., 2023; Okakpu et al., 2024). This trend of localized enrichment is noteworthy when compared to regional roadside soils in Onitsha South, where lead levels were categorized as unpolluted (Class 0) despite high traffic volume (Ochiagha *et al*., 2020). This suggests that municipal waste disposal at Agu-Awka may be a more significant contributor to localized Pb soil burdens than vehicular emissions in the state. Similarly, Cadmium levels peaked at 2.079 mg/kg in the topsoil of SS2, likely due to electronic waste disposal (Ijabor *et al.*, 2023; Nduka *et al.*, 2006). While both metals currently fall below WHO/FAO permissible limits (85 mg/kg for Pb; 3 mg/kg for Cd), their surface enrichment indicates a persistent accumulation that could degrade soil quality over time (Okakpu *et al.*, 2024).

Nickel, Chromium, and Arsenic Levels

Nickel and Chromium levels exhibited moderate enrichment but remained within WHO international guidelines (Okakpu *et al.*, 2024). This observation differs from findings in Onitsha South, where Cr and Ni were identified as significant roadside pollutants with values indicating moderate to high pollution (Ochiagha *et al.*, 2020). The lower Cr levels at the Agu-Awka dumpsite (0.702–1.310 mg/kg) relative to those roadside assessments suggest that while waste contributes to metal loading, industrial and traffic-related activities in Anambra State may drive higher concentrations of certain elements like Cr and Ni (Ochiagha *et al.*, 2020; Otabor, 2019). Arsenic recorded the lowest concentrations (0.100–0.459 mg/kg), well below the WHO threshold of 20 mg/kg, indicating low toxicological risk (Okakpu *et al.*, 2024).

To optimize your statistical analysis section for journal publication, I have condensed the text to focus on the interpretation of variability as an indicator of waste heterogeneity and soil stability.

Statistical Dispersion of Metal Concentrations

The standard deviation was utilized to quantify the vertical heterogeneity and intra-site variability of metal distribution within the soil profiles. High SD values serve as indicators of irregular anthropogenic deposition and the non-uniform infiltration of leachates (Nduka *et al.,* 2006; Okakpu *et al.*, 2024).

Table 3: Standard Deviation of Heavy Metal Concentrations (mg/kg) per Site

Dumpsite	Pb	Cd	Ni	Cr	As
SS1	0.139	0.490	0.270	0.318	0.159
SS2	0.293	0.262	0.266	0.118	0.081
SS3	0.157	0.366	0.089	0.146	0.073

At Dumpsite 1, Cadmium exhibited the highest dispersion (SD = 0.490 mg/kg), suggesting significant variability in waste composition and localized enrichment zones (Okakpu *et al.*, 2024). Dumpsite 2 recorded peak variability for Pb (SD = 0.293 mg/kg) and Ni (SD = 0.266 mg/kg). In contrast, the control site maintained consistently lower SD values across most elements, which confirms the presence of a stable, undisturbed geochemical background (Ochiagha *et al.*, 2020; Okakpu *et al.*, 2024).

The observed variability trend—**Cd > Pb > Cr > Ni > As**—highlights Cadmium as the most irregularly distributed element at the study sites. This heterogeneity is characteristic of unregulated urban dumpsites, where the sporadic disposal of electronic components and industrial scraps leads to "hotspots" of contamination (Nduka *et al.*, 2006; Otabor, 2019). However, the magnitude of these fluctuations remained well within WHO/FAO permissible limits, indicating that while the distribution is uneven, the current levels do not yet pose a critical environmental hazard (Ijabor *et al.*, 2023; Okakpu *et al.*, 2024). Such statistical stability suggests that the soils currently retain a buffering capacity against extreme metal loading, though the localized enrichment of Cd warrants sustained oversight (Nduka *et al.*, 2006; Ochiagha *et al.*, 2020).

Geo-accumulation Index () of Heavy Metals

The values were calculated using the control site at depth-matched intervals as the geochemical background (Bn) to isolate anthropogenic contributions from natural lithogenic variations (Afolagboye *et al*., 2020; Okakpu *et al*., 2024). The results are summarized in Table 4 below.

Table 4: Geo-accumulation Index () of Heavy Metals by Depth

Sample ID	Depth (cm)	Pb	Cd	Ni	Cr	As
SS1A	0–5	2.21	2.02	1.85	1.67	2.77
SS1B	5–15	2.15	1.97	1.77	1.63	2.61
SS1C	15–30	1.85	1.81	1.73	1.60	2.51
SS2A	0–5	2.48	2.21	2.06	1.63	2.68
SS2B	5–15	2.06	2.09	1.91	1.59	2.45
SS2C	15–30	1.97	2.04	1.90	1.50	1.46
SS3A	0-5	1.06	1.37	1.09	1.16	0.78
SS3B	5-15	1.33	1.07	0.75	1.06	0.56
SS3C	15-30	0.78	0.90	0.67	1.00	0.48

Pollution Categorization and Dominant Contaminants

Based on Müller's classification, the values indicate that the Agu-Awka dumpsite ranges from **moderately contaminated** to **moderately-to-strongly contaminated** (Afolagboye *et al*., 2020; Shokumbi *et al.,* 2020). Arsenic and Lead emerged as the dominant pollutants, with As reaching a peak of 2.77 in the surface soil of SS1. These values signify that the soil concentrations are significantly elevated compared to natural background levels, likely due to the concentrated disposal of electronic waste, lead-acid batteries, and industrial chemicals (Michael, (2017); Okakpu *et al.,* 2024).

Depth-Dependent Contamination Trends

A consistent decline in values was observed with increasing depth, reinforcing the findings that contamination is primarily surface-bound due to direct waste deposition (Nduka *et al*., 2006). However, the persistence of Class 2 (moderate) contamination for Cd and Ni at the 30 cm depth (e.g., Cd of 2.04 in SS2C) highlights the vertical mobility of these metals within the soil profile (Otabor, 2019). This downward migration is a critical environmental concern in Awka, as the infiltration of these elements through the lithosphere poses a long-term threat to sub-surface groundwater quality (Amadi & Nwankwoala, 2013; Nduka *et al*., 2006).

Comparison with Regional Roadside Soils

When compared to regional studies in Anambra State, the Agu-Awka dumpsite displays a distinct pollution signature. While roadside soils in Onitsha South were found to be highly polluted with Cr and Ni (Class 4–5) due to vehicular emissions, their Pb levels remained in the unpolluted category (Ochiagha *et al.,* 2020). In contrast, the Agu-Awka site exhibits significantly higher values for Pb (up to 2.48), suggesting that municipal solid waste in this region carries a higher lead burden than traffic-related sources (Ochiagha et al., 2020; Gbadamosi et al., 2021). Chromium remains the least concerning element at the dumpsite, maintaining stable "moderate" contamination levels throughout the profile, which may partially reflect the local geochemical baseline (Karkarna, and Matazu, (2021); Otabor, 2019)**.**

Summary of Findings

The assessment confirms that the Agu-Awka dumpsite is a localized hotspot for heavy metal enrichment. The moderate-to-strong contamination levels of Pb and As, coupled with the vertical persistence of Cd, emphasize the need for urgent remediation strategies (Okakpu *et al.*, 2024). These results provide essential baseline data for evidence-based waste management and highlight the necessity of restricting agricultural activities in the immediate vicinity of the dumpsite to prevent toxic metal transfer into the local food chain (Ijabor *et al.*, 2023; Nduka *et al.*, 2006; Ochiagha *et al.*, 2020).

Ecological Risk Assessment of Heavy Metals

The ecological risk at the Agu-Awka dumpsite is highest in the surface soils (0–5 cm), where direct waste deposition has led to a "moderately-to-strongly contaminated" status for Pb and As (Okakpu *et al.*, 2024). These elements present a primary concern for the surrounding community due to their potential for bioaccumulation in local vegetation and soil organisms (Ijabor *et al.*, 2023; Nduka *et al.*, 2006). While the risk profiles for Pb and As remain "moderate" at the 30 cm depth, indicating subsurface persistence, the risk for Cr remains consistently low across all depths, suggesting it currently stays within acceptable ecological limits (Okakpu *et al.*, 2024; Okechukwu, Onwukeme, Eze, & Aralu, (2024).

The vertical distribution confirms that ecological vulnerability is depth-dependent. The "moderate" but persistent risk posed by Cd and Ni—especially their presence at lower depths—highlights a long-term threat of leachate infiltration into the local hydrosphere (Amadi & Nwankwoala, 2013; Nduka *et al.*, 2006). These findings underscore that remediation efforts should prioritize the topsoil to mitigate immediate human exposure, while continuous monitoring of deeper layers is essential to safeguard regional groundwater (Nduka *et al.*, 2006; Okakpu *et al.*, 2024).

Environmental Implications

The findings suggest that the dumpsite acts as a localized source of contamination with potential long-term effects on soil quality and water resources. Given its proximity to human settlements, there is a clear need for improved waste management and monitoring strategies.

Conclusion

This study confirms that the Agu-Awka dumpsite is a source of heavy metal enrichment in surrounding soils. Although measured concentrations remain within acceptable limits, the geo-accumulation index reveals moderate contamination, particularly for lead and arsenic.

The results emphasize that relying solely on concentration thresholds may underestimate environmental risk. A combination of indices and concentration data provides a more complete assessment. Moving forward, sustainable waste management practices and routine monitoring are essential to prevent further environmental degradation.

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