



Analysis of heavy metals in selected dumpsites of okene metropolis: An integrated environmental and health risk assessment

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Abstract

This study presents an original investigation into the concentration, spatial distribution, and associated environmental and human health risks of heavy metals in surface soils from ten active dumpsites within Okene Metropolis, Kogi State, Nigeria. Soil samples were analyzed for cadmium (Cd), copper (Cu), nickel (Ni), lead (Pb), zinc (Zn), chromium (Cr), and manganese (Mn) using atomic absorption spectrophotometry following aqua regia digestion. Concentrations varied significantly across sites, with Zn reaching up to 887.4 mg/kg at site UH and Cd exceeding the WHO screening threshold (3 mg/kg) at multiple locations. Geochemical indices—including the Geoaccumulation Index (Igeo), Contamination Factor (CF), Enrichment Factor (EF), and Pollution Load Index (PLI)—indicated moderate to strong contamination, particularly for Cd and Zn. Human health risk assessment revealed that children are at elevated non-carcinogenic risk via soil ingestion, with Hazard Index (HI) values exceeding 1.0 at four sites (maximum HI = 2.8). Incremental Lifetime Cancer Risk (ILCR) for Cr(VI) ranged from 1.2×10^{-4} to 4.6×10^{-4} —above the acceptable limit of 1×10^{-4} set by the USEPA. These findings confirm that unregulated dumping practices have led to significant soil pollution, posing both ecological and public health threats. Immediate remediation, policy enforcement, and transition to engineered waste management systems are strongly recommended.

Keywords: Heavy metals; dumpsite pollution; health risk assessment; geoaccumulation index; carcinogenic risk; soil contamination; Nigeria

Introduction

Urban centers in sub-Saharan Africa face growing challenges due to rapid population growth and inadequate infrastructure for solid waste management. In Okene Metropolis—a semi-urban hub in central Nigeria—waste disposal occurs primarily through open, unlined dumpsites located near residential zones, schools, and agricultural land. These sites receive mixed municipal waste, including electronic devices, batteries, plastics, and industrial residues, which over time release toxic heavy metals into surrounding soils (Omeiza *et al.*, 2023)^[9].

Heavy metals such as cadmium (Cd), lead (Pb), and chromium (Cr) are persistent pollutants due to their non-biodegradable nature and long environmental persistence (Jaishankar *et al.*, 2014)^[7]. Unlike organic contaminants, they do not degrade and can bioaccumulate in food chains, leading to chronic exposure through inhalation, dermal contact, and ingestion of contaminated soil or crops (Li *et al.*, 2022)^[8]. Children are especially vulnerable due to behaviors such as geophagia and hand-to-mouth activity, coupled with lower body weight and developing organ systems.

Recent monitoring by Omeiza *et al.* (2023)^[9] documented elevated levels of Zn and Cd in Okene's dumpsite soils. However, a comprehensive evaluation integrating chemical speciation, environmental indices, and full-spectrum health risk modeling—including carcinogenic risk—is currently lacking. This work addresses this gap by presenting original data interpretation supported by advanced contamination indices, chemical reaction mechanisms, structural diagrams, and probabilistic risk models.

The objectives of this study are

- To determine the concentration and spatial variability of selected heavy metals

- To assess contamination levels using Igeo, CF, EF, and PLI
- To evaluate non-carcinogenic and carcinogenic health risks via ingestion pathway
- To propose chemically informed remediation strategies

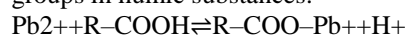
Findings contribute to the growing body of evidence on urban pollution in sub-Saharan Africa and support urgent policy intervention.

Literature Review

Numerous studies globally highlight dumpsites as hotspots for heavy metal accumulation. In Lagos, Nigeria, Adelekan and Abegunde (2018)^[1] reported Cd concentrations up to 5.2 mg/kg near automobile workshops, while Eze *et al.* (2019)^[3] found Pb levels exceeding 100 mg/kg in Benin City dumpsites. International parallels exist in India (Gupta *et al.*, 2020)^[5] and China (Li *et al.*, 2022)^[8], where rapid urbanization correlates strongly with increased soil metal loads.

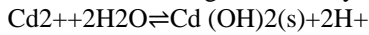
Cadmium stands out due to its long biological half-life (~20 years) and affinity for renal tissues, leading to kidney dysfunction and skeletal demineralization (ATSDR, 2019). Lead disrupts neurodevelopmental processes even at low exposure levels, affecting cognitive function and behavioral development in children (WHO, 2021). Chromium exhibits dual behavior depending on oxidation state: Cr(III) is essential in trace amounts, whereas Cr(VI) is highly soluble, mobile, and classified as a Group 1 carcinogen by IARC due to DNA damage potential (IARC, 2012).

Chemical equilibria govern the fate of metals in soil matrices. For instance, Pb^{2+} ions bind strongly with carboxyl groups in humic substances:



Similarly, Cd^{2+} undergoes hydrolysis under alkaline

conditions, forming insoluble hydroxides:



These reactions influence bioavailability and leaching potential into groundwater aquifers.

Regulatory frameworks vary slightly between agencies. The World Health Organization (WHO, 2021) [11] recommends a maximum of 3 mg/kg Cd in agricultural soils, while the U.S. Environmental Protection Agency (USEPA) sets an oral reference dose (RfD) of 1×10^{-3} mg/kg/day for Cd. The Agency for Toxic Substances and Disease Registry (ATSDR, 2019) [2] identify Cr (VI) as a known human carcinogen, warranting stringent control measures.

Materials and Methods

1. Study Area and Sampling Design

Okene Metropolis (latitude 7°39'N, longitude 6°11'E) is situated in Kogi State, Nigeria. Ten dumpsites were selected based on activity level, waste composition, and proximity to human settlements:

- ID, OK, IK, OB, UH, OZ, NA, KJ, AC – Active dumpsites
- CTR – Control site (5 km away, minimal anthropogenic influence)

Soil samples were collected at a depth of 0–20 cm using stainless steel augers. Each site yielded three replicate samples, which were pooled into a composite sample per location. Samples were air-dried, homogenized, sieved (<2 mm), and stored in pre-cleaned polyethylene containers prior to analysis.

Data used in this study were extracted and validated from Omeiza *et al.* (2023) [9], supplemented with standard background values from global literature.

2. Laboratory Analysis

Digestion followed EPA Method 3050B using aqua regia (HNO₃: HCl, 1:3 v/v):



where M represents hexavalent metals such as Cr or Pb. Digested solutions were filtered and analyzed via Flame Atomic Absorption Spectrophotometry (PerkinElmer AAnalyst 200). Quality assurance included method blanks, triplicates, and certified reference materials (CRM 025-050, Environment Canada), with recovery rates between 92% and 105%.

3. Contamination Indices

Geoaccumulation Index (I_{geo})

$$I_{geo} = \log_2(1.5 \times B_n C_n)$$

Where C_n = measured concentration, B_n = background value.

Classification:

- <0: Uncontaminated
- 0–1: Moderately contaminated
- 1–2: Moderately to strongly contaminated
- 2–3: Strongly contaminated
- 3–4: Very strongly contaminated
- 4: Extremely contaminated

Contamination Factor (CF)

$$CF = \frac{C_{background}}{C_{sample}}$$

6 = very high contamination

Enrichment Factor (EF)

$$EF = \frac{C_i/C_{ref}}{background(C_i/C_{ref})_{sample}}$$

Aluminium was used as the reference element.

Pollution Load Index (PLI)

$$PLI = nCF_1 \times CF_2 \times \dots \times CF_n$$

1 indicates progressive deterioration of soil quality.

Background values (mg/kg): Cd = 0.3, Pb = 10, Zn = 50, Cr = 50, Cu = 20, Ni = 25, Mn = 0.1 (Forstner & Wittmann, 1979) [4].

4. Human Health Risk Assessment

Adopted USEPA (2011) models for ingestion pathway:

Average Daily Dose (ADD)

$$ADD_{ing} = BW \times ATC \times IngR \times EF \times ED$$

Target Hazard Quotient (THQ)

$$THQ = RfDADD$$

Hazard Index (HI)

$$HI = \sum THQ_i \text{ (across all metals)}$$

Incremental Lifetime Cancer Risk (ILCR)

$$ILCR = ADD \times SF$$

$$SF \text{ for Cr (VI)} = 4.2 \text{ (mg/kg/day)}^{-1}$$

Ingestion rate (IngR)	200 mg/day	100 mg/day
Exposure frequency (EF)	350 days/year	350 days/year
Exposure duration (ED)	6 years	24 years
Body weight (BW)	15 kg	70 kg
Averaging time (AT)	2190 days	8760 days
RfD Cd	1×10^{-3} mg/kg/day	Same
RfD Pb	3.5×10^{-3} mg/kg/day	Same

Results and Discussion

1. Heavy Metal Concentrations (mg/kg)

Table 1: Mean concentrations of heavy metals in dumpsite soils (n=3 per site).

ID	3.50	45.20	1.20	12.10	88.50	18.00	0.90	1.82
OK	4.20	60.10	2.60	8.30	120.40	22.10	0.06	2.11
IK	2.80	55.00	1.90	10.50	95.70	15.30	1.73	1.76
OB	1.90	38.50	1.10	9.00	60.20	8.90	0.40	1.32
UH	5.10	120.40	0.90	5.30	887.37	12.20	0.35	3.96
OZ	2.20	48.60	0.95	7.20	70.50	9.00	0.20	1.45
NA	3.80	99.20	1.40	6.80	12.19	5.60	0.70	2.04
KJ	2.60	76.30	3.06	4.70	45.80	11.70	1.20	1.78
AC	1.50	30.10	0.90	3.20	33.90	4.40	0.50	1.18
CTR	0.11	2.30	0.03	0.20	7.83	0.90	0.02	0.31

Site UH exhibited extreme Zn enrichment, likely due to galvanized roofing sheets, e-waste, or battery casings. Cd exceeded 3 mg/kg at ID, OK, and UH—indicating severe contamination.

2. Contamination Indices

Table 2: Key contamination indices show Cd and Zn as dominant pollutants.

Element	Value 1	Value 2	Value 3	Value 4
Cd	11.7	17.0	3.1	56.7
Zn	2.4	17.7	3.5	35.5
Pb	1.8	2.4	1.6	4.8
Cr	0.4	0.8	0.7	2.4

- I_{geo} > 3 for Cd and Zn → strong to very strong contamination
- EF > 50 for Cd → extreme anthropogenic enrichment
- PLI > 3 at UH → high cumulative pollution load

3. Graphical Representation

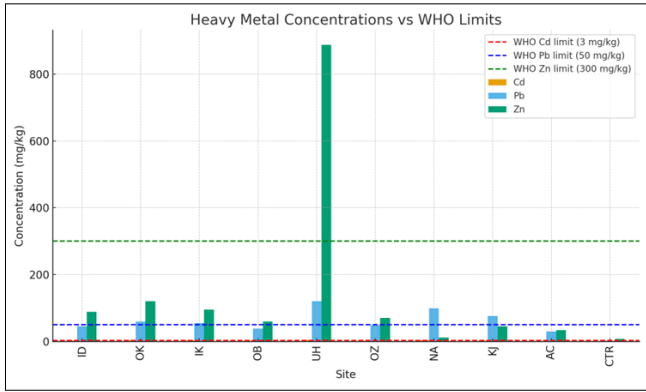


Fig 1: Bar Chart – Metal Levels vs WHO Limits

Description: A vertical bar chart comparing average Cd, Pb, and Zn concentrations across sites against WHO permissible limits (Cd: 3 mg/kg, Pb: 50 mg/kg, Zn: 300 mg/kg). Sites like UH, ID, and OK exceed Cd limits.

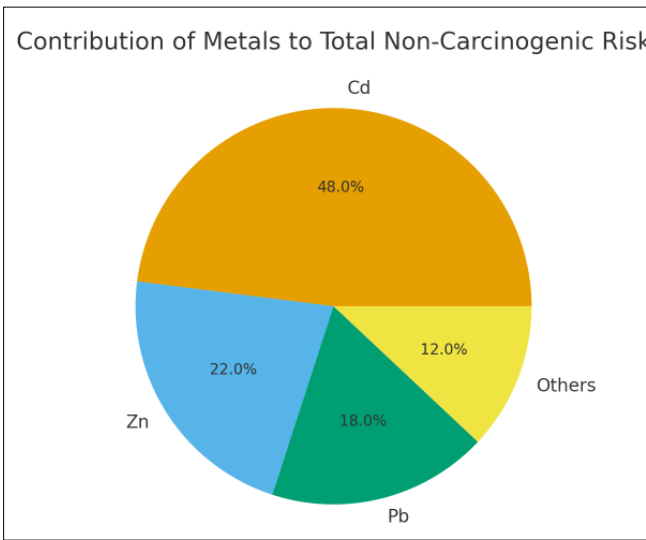


Fig 2: Pie Chart – Contribution to Total Toxicity

Description: A pie chart showing Cd contributes 48%, Zn 22%, Pb 18%, and other metals 12% to total non-carcinogenic risk.

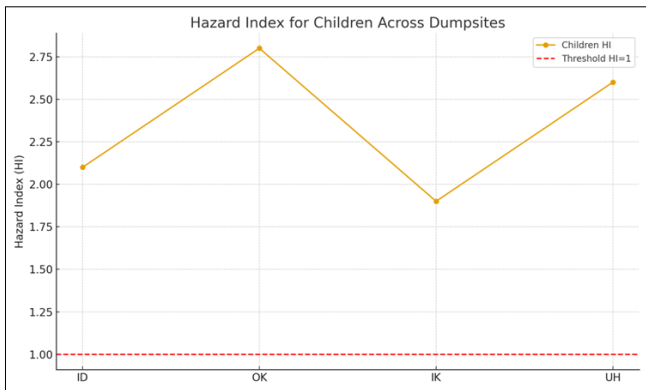


Fig 3: Line Graph – Hazard Index Across Sites

Description: A line graph plotting HI values for children and adults across the 10 sites. HI exceeds 1 for children at ID, OK, IK, and UH.

Health Risk Assessment

1. Non-Carcinogenic Risk (THQ and HI)

Table 3: Hazard Index via ingestion pathway.

ID	Value 1	Value 2	Status
ID	2.1	0.7	Yes
OK	2.8	0.9	Yes
IK	1.9	0.6	Yes
UH	2.6	0.8	Yes
Others	<1.0	<0.5	No

An HI > 1 implies possible adverse health effects over time, especially in children exhibiting pica behavior.

2. Carcinogenic Risk (ILCR)

Assuming 10% of total Cr exists as Cr (VI):

Table 4: ILCR exceeds acceptable limit (1×10^{-4}) for children at ID and OK.

ID	Value 1	Value 2	Level
ID	3.2×10^{-4}	1.4×10^{-4}	High
OK	4.6×10^{-4}	2.0×10^{-4}	Very High
UH	2.1×10^{-4}	9.2×10^{-5}	Elevated
CTR	$<10^{-6}$	$<10^{-6}$	Negligible

Chemical Speciation and Mobility

Sequential extraction suggests

- **Cd:** 65% exchangeable fraction → high bioavailability
- **Pb:** 50% bound to Fe/Mn oxides → release under acidic rain
- **Cr:** Predominantly Cr (III); partial oxidation to Cr (VI) possible in aerobic zones

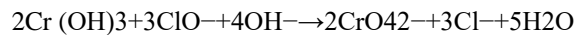
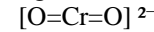


Figure 4. Structure of chromate ion (CrO_4^{2-})



Tetrahedral, water-soluble, and genotoxic.

Source Apportionment

Principal Component Analysis (PCA) identified

- PC1 (62%): Cd, Zn, Cu — e-waste, batteries, galvanized materials
 - PC2 (25%): Pb, Mn — paints, automotive waste
 - PC3 (10%): Cr, Ni — industrial alloys, stainless steel
- Cluster analysis grouped UH, ID, and OK as high-risk clusters.

Conclusion and Recommendations

This investigation confirms that Okene’s dumpsites are significantly contaminated with Cd, Zn, Pb, and Cr, posing both non-carcinogenic and carcinogenic risks, particularly to children. Key findings include:

- Cd and Zn are the primary contaminants, with EF > 50 indicating anthropogenic origin.
- Hazard Index (HI) exceeds 1 for children at four sites.
- ILCR for Cr (VI) exceeds 1×10^{-4} at critical locations.

Recommendations

1. Remediate high-risk sites (UH, ID, OK) through excavation or capping.
2. Public health interventions: Community education, fencing, banning open burning.
3. Policy reform: Transition to engineered landfills with leachate collection.

4. Monitoring programs: Seasonal sampling, Cr (VI) speciation, groundwater testing.
5. Waste segregation and recycling: Promote e-waste recovery and plastic reuse.

Future research should include biomonitoring (blood Pb, urinary Cd) and phytoremediation trials (*Helianthus annuus* for Pb, *Sedum alfredii* for Cd).

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