Analysis of Potentially Toxic Metals Contamination in Akinyele Local Government, Oyo State, Nigeria using Ecological Risk Indices

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DOI: https://doi.org/10.5281/zenodo.17437871

Abstract
Soil samples from tropical ecosystems in Akinyele Local Government, Oyo State, Nigeria, were analyzed for potentially toxic metal concentration (Cr, Cu, Pb, Mn, Zn) using sequential extraction techniques to assess contamination levels and ecological risks. The concentration ranges were as follows: Cr (0.23–0.26 mg/kg), Cu (0.44–2.42 mg/kg), Pb (0.56–1.15 mg/kg), Mn (5.01–6.16 mg/kg), and Zn (3.73–10.02 mg/kg) respectively. No significant seasonal variations in average metal levels were observed across the study sites, indicating persistent contamination throughout the year. Contamination Factor (CF) and Pollution Load Index (PLI) assessments identified considerable anthropogenic contamination ($3 < CF < 6$) and deteriorated soil quality ($PLI > 1$) at sites B, C, and D, likely linked to local industrial and agricultural activities. Ecological risk indices, including Hazard Quotient and Risk Quotient, corroborated pollution indices, revealing a moderate hazard sequence: Zn > Mn > Pb > Cu > Cr. The findings highlight the potential health risks to humans and adverse effects on soil ecosystems, underscoring the need for continuous monitoring and remediation efforts in the region.

Keywords: Pollution load index, Contamination factor, Soil, Metal, Ecological risk

Introduction

Landfill sites, commonly referred to as dumps or dumping grounds, serve as major repositories for waste disposal and can significantly impact surrounding soil environments. Soil itself is a dynamic system composed of organic matter, minerals, gases, liquids, and living organisms, collectively forming the pedosphere and interacting with the lithosphere, hydrosphere, atmosphere, and biosphere (Felipe & Marta, 2020; Schad, 2018). The soil matrix consists of solid-phase minerals and organic matter, interspersed with pores that contain air and water (Zhang et al., 2014; Schad & Dondeyne, 2014). Waste generation in Sub-Saharan Africa (SSA) is projected to reach 62 million tonnes annually. African urban centers generate waste at rates ranging from 0.3 to 1.4 kg per capita per day, compared to an average of 1.22 kg per capita per day in developed countries. Municipal solid waste (MSW) management remains a significant challenge across SSA, despite widespread awareness of its ecological and environmental impacts. The rapid increase in solid waste volumes is driven by factors such as rural-to-urban migration, industrial growth, and rising living standards (Rouhani & Hejaman, 2024). Notably, SSA is the fastest urbanizing region globally, concurrently experiencing escalating poverty levels. Poor waste management practices contribute to serious health and environmental risks. Environmental experts emphasize that understanding the quantity and composition of MSW is essential for effective waste management planning (Golzay et al., 2023). However, in many developing countries, MSW management is hindered by limited awareness, inadequate technology, financial constraints, and weak governance. Globally, landfilling remains the most common and cost-effective method for MSW disposal, as landfills can naturally attenuate various contaminants (Njewa et al., 2025).

Soil formation is influenced by factors such as climate, topography, organisms, and parent material, and it develops through a combination of physical, chemical, and biological processes, including weathering and erosion. Due to its complexity and interconnectedness, soil is recognized as a vital ecosystem (Ponge, 2015; Abdu et al., 2016). Heavy metals are widespread in the environment, originating from both natural processes and anthropogenic activities such as industrialization and intensive agriculture (He et al., 2013; Shah et al., 2013). These elements, characterized by densities greater than 5 g/cm³ and atomic masses above 20, include arsenic (As), cadmium (Cd), chromium (Cr), copper (Cu), mercury (Hg), lead (Pb), and zinc (Zn) (Donald et al., 2022). The presence and distribution of heavy metals in soils can be mapped through soil delineation, while environmental assessments provide insights into contamination sources, health risks, and remediation options (Wuana & Okieimen, 2011). Addressing heavy metal contamination in soils is a pressing global challenge requiring coordinated scientific and governmental action.

Previously reported works such as the presence of toxic metals, related health and ecological risks, and impact of industrial with agricultural activities have been carried out in Oyo State and neighboring regions (Talabi et al., 2023; Odunjo & Thomas, 2021), but a study combining all these factors specifically in the tropical ecosystem of Akinyele LGA with the detailed pollution and ecological risk evaluation proposed is still relatively novel and underrepresented.

Soil contamination by potentially toxic heavy metals poses a significant threat to tropical ecosystems and human health. In Akinyele Local Government, Oyo State, Nigeria, the presence of Chromium (Cr), Copper (Cu), Lead (Pb), Manganese (Mn), and Zinc (Zn) in soils raises concerns about environmental quality and ecological safety. Despite the persistence of these metals throughout the year, influenced by local industrial and agricultural activities, there is limited information on the extent of contamination, seasonal variations, and associated ecological risks in this region. This study addresses the urgent need to assess heavy metal contamination levels, evaluate ecological risks, and identify sites with deteriorated soil quality to inform ongoing monitoring and remediation strategies.

Materials and Methods

Map Showing the Study Sites (Figure 1)

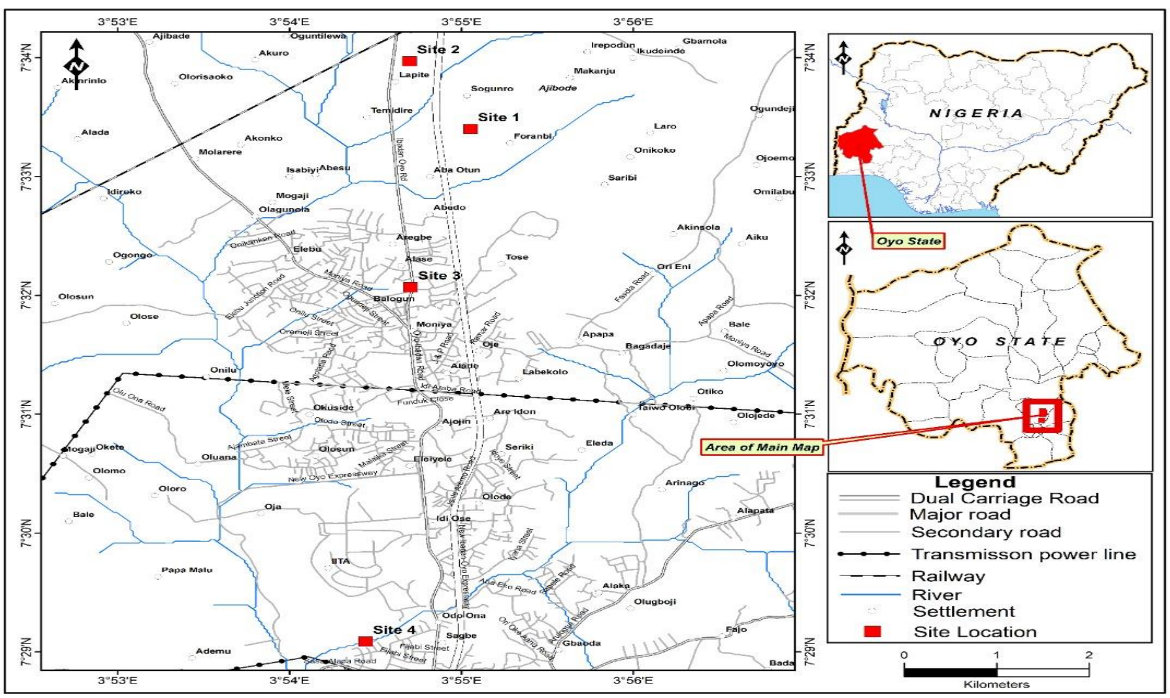

Fig 1: Study sites and sampling locations.

Table 1: Sampling Locations and Coordinates

Sample Location	Latitude	Longitude	Site description
Site A	N 7°36’24.0618	E3°55’3.1686	Akinyele Kara Oni-malu
Site B	N7°33’58.3122	E3°54’41.8962	Akinyele Abaodo Express
Site C	N7°32’4.1598	E3°54’42.2958	Lapite Old Road, Opposite Railway Akinyele
Site D	N7°29’5.2999	E3°54’26.554	Sasa Market, Akinyele

Sample Collection and Preservation

Soil sampling was conducted across two seasonal periods: dry season (November 2021–January 2022) and wet season (February–April 2022). A total of 24 composite samples (12 per season) were collected from four designated sites. Samples were placed in sterile transparent polyethylene bags, sealed to prevent contamination, and transported to the laboratory. Samples were air-dried at ambient temperature, homogenized, and sieved through a 2-mm mesh. Processed samples were stored in labeled polyethylene bags prior to analysis. Samples underwent acid digestion using a 1:3 (v/v) HNO_3:HCl mixture. Digested solutions were transferred to 100 ml volumetric flasks and analyzed via Flame Atomic Absorption Spectrophotometry (FAAS) specifically the Buck Scientific Model 210, was used to determine the concentrations of target metals for quantification of Cr, Cu, Pb, Mn, and Zn. Pollution levels were evaluated using four indices which are: Pollution Load Index (PLI); Contamination Factor (CF); Hazard Quotient (HQ) and Risk Quotient (RQ) respectively.

Results and Discussion

The analytical results indicate the presence of various heavy metal contaminants in the soil samples, specifically Mn, Cu, Zn, Cr, and Pb. Across both seasons, Mn and Zn were the most prevalent metals detected. During the dry season, their mean concentrations were 6.160 mg/kg and 10.027 mg/kg, respectively, while in the wet season, the average means decreased to 5.008 mg/kg for Mn and 3.738 mg/kg for Zn. As shown in Table 1, there is a general decline in mean metal concentrations from the dry to the wet season, except for Cr, which exhibits a slight increase during the wet season.

The Contamination Factor (CF) data in Table 2 indicate low contamination levels for most metals, except for Zn, which shows considerable contamination at sites B, C, and D. The Pollution Load Index (PLI), presented in Table 3, varies across the different sites and serves as a rapid assessment tool to compare pollution status. Site A recorded the lowest PLI value of 1.57, which is relatively lower than the other sites. Site C and Site B have PLI values of 2.76 and 3.03, respectively, while Site D exhibits the highest PLI of 8.20, significantly exceeding values at other locations. All sites indicate a deterioration in soil quality. According to Table 4, the Hazard Quotient (HQ) values for all sampling locations are below one, suggesting that no adverse health effects are expected from exposure to the measured metals. The hazard ranking follows the order Zn > Pb > Cu > Mn > Cr, indicating that zinc poses the highest potential hazard, while chromium poses the lowest. The Risk Quotient (RQ) values in Table 5 show manganese (Mn) with the highest value of 0.186, indicating a moderate environmental risk, whereas chromium (Cr) has the lowest value of 0.001, reflecting minimal risk. The overall risk sequence is Mn > Cu > Zn > Pb > Cr.

Table 2: Result for Mean Value for Heavy Metals for Dry and Wet Season

Heavy Metals	Dry	Wet
Mn mg/kg	6.160	5.008
Cu mg/kg	2.417	0.445
Zn mg/kg	10.027	3.738
Cr mg/kg	0.225	0.268
Pb mg/kg	1.154	0.530

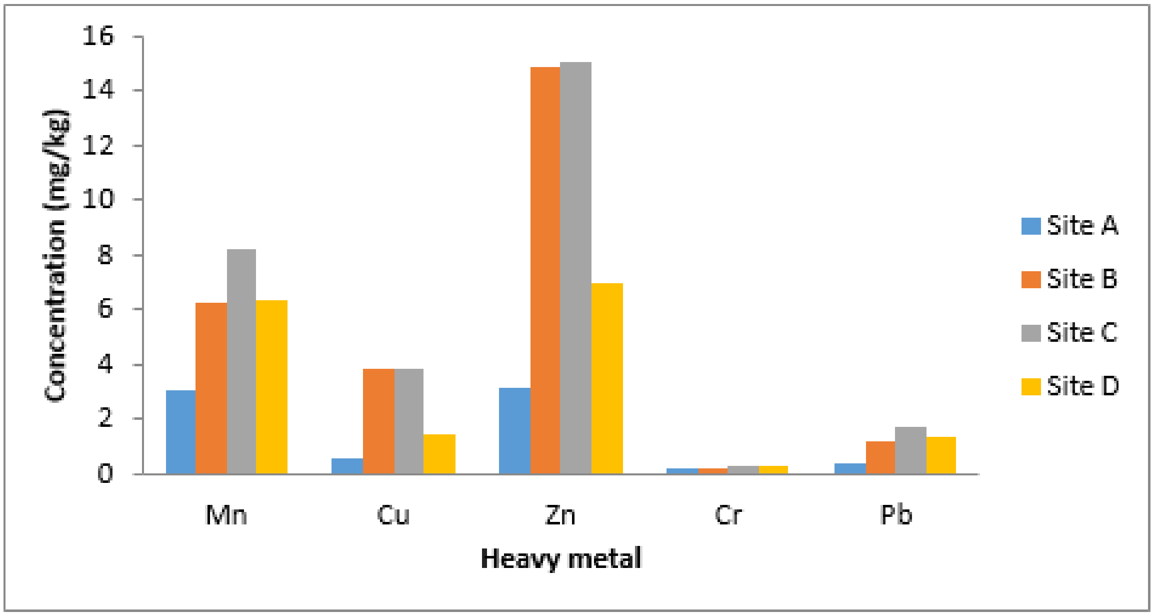

Fig. 2: Seasonal variations in potentially toxic metal loadings of soil samples.

Table 3: Contamination Factor (CF) Values for Heavy Metals in Soil Samples

CF	Cr	Cu	Pb	Mn	Zn
Site A	0.00016	0.17	0.058	0.011	0.19
Site B	0.007	0.13	0.63	0.014	4.59
Site C	0.008	0.13	0.13	0.020	2.89
Site D	0.008	0.08	0.68	0.015	3.09

Table 4: Pollution Load Index Values for Metals in Soil Samples

Sampling sites	PLI (metals)	CLASS	QUALITY
Site A	1.57	>1	Polluted
Site B	3.03	>1	Polluted
Site C	2.76	>1	Polluted
Site D	8.20	>1	Polluted

Ecological Risk Assessment Indices

Table 5: Hazard Quotient (HQ) Values for Heavy Metals of Soil Samples

HQ	Cr	Cu	Pb	Mn	Zn
Site A	0.0028	0.012	0.024	0.0056	0.095
Site B	0.0036	0.065	0.052	0.0071	0.483
Site C	0.0039	0.064	0.063	0.0098	0.389
Site D	0.0040	0.038	0.071	0.0072	0.411
Mean	0.036	0.045	0.053	0.0074	0.345

Table 6: Risk Quotient (RQ) Values for Heavy Metals of Soil Samples

RQ	Cr	Cu	Pb	Mn	Zn
Site A	0.0079	0.025	0.010	0.141	0.017
Site B	0.010	0.129	0.021	0.178	0.088
Site C	0.011	0.127	0.025	0.245	0.071
Site D	0.011	0.077	0.029	0.180	0.075
Mean	0.001	0.090	0.021	0.186	0.063

Conclusion

Heavy metal concentrations in soil were measured during both dry and wet seasons. Some parameters exhibited higher levels in the dry season, while others were elevated during the wet season. Zinc showed the highest values in several risk assessments, including a Risk Quotient of 0.28, a degree of contamination with elevated values at sites B, C, and D (4.59, 2.89, and 3.09 respectively), and the highest Hazard Quotient of 0.344. The elevated zinc levels in the soil may pose toxic effects on soil organisms such as plants, invertebrates, and microorganisms.

Acknowledgments

The authors appreciate Department of Chemical Sciences Laboratory, KolaDaisi University, Ibadan.

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HOW TO CITE

Akintade, O. O., Adeleke, I. E., Odujebe, F. O., & Ayorinde, G. O. (2025). Analysis of Potentially Toxic Metals Contamination in Akinyele Local Government, Oyo State, Nigeria using Ecological Risk Indices. KolaDaisi University Journal of Applied Sciences, 2, 31-36. https://doi.org/10.5281/zenodo.17437871