

ORIGINAL RESEARCH ARTICLE

Physicochemical Characterization and Heavy Metal Contamination of Municipal Solid Waste from the Dogarawa, Nigeria: Implications for Environmental and Public Health

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ABSTRACT

This research examines the physicochemical properties and heavy metal levels in municipal solid waste (MSW) from the Dogarawa dumpsite in Zaria, Kaduna State, Nigeria. Due to increasing concerns about the environmental and public health impacts of open dumping, particularly in rapidly urbanizing areas, waste samples were collected at varying distances and depths for comprehensive characterization. Key parameters, including pH, moisture content, organic matter, and elemental composition, were determined using standard analytical techniques, including X-ray fluorescence (XRF), X-ray diffraction (XRD), and atomic absorption spectrometry (AAS). Quantitative determination of heavy metals by AAS was achieved using external calibration curves constructed from certified standard solutions, which showed excellent linearity ($R^2 > 0.995$), ensuring the accuracy and reliability of the analytical results. The findings revealed an alkaline pH of 7.6, low moisture content (2.5%), and moderate organic matter content (20%). Heavy metal concentrations, particularly zinc (166,970 mg/kg), copper (3,570 mg/kg), and lead (656 mg/kg), exceeded the permissible limits set by the World Health Organization (WHO) and Nigeria's National Environmental Standards and Regulations Enforcement Agency (NESREA). Iron (34,940 mg/kg) remained within acceptable limits, while cadmium was not detected. Mineralogical analysis identified quartz, graphite, anhydrite, muscovite, garnet, and sphalerite, reflecting contributions from both geogenic and anthropogenic sources. These elevated metal concentrations pose significant risks to soil quality, groundwater integrity, crop safety, and human health through food chain transfer. The study underscores the urgent need for improved waste management strategies and continuous environmental monitoring to mitigate ecological degradation and protect public health in Zaria and comparable urban environments.

ARTICLE HISTORY

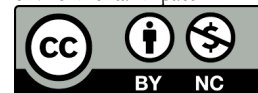
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KEYWORDS

Dogarawa dumpsite, Zaria, physicochemical characterization, heavy metals, soil contamination, environmental impact



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INTRODUCTION

Solid waste management is a growing challenge in many urban regions of Nigeria, with open dumping as the predominant method (Ogunleye *et al.*, 2014). The Dogarawa area in Zaria, Kaduna State, has a notable dumpsite that has grown significantly over the past two decades. This growth has raised environmental and health concerns among residents and environmental agencies alike. Physicochemical analysis of dumpsites is essential for understanding the environmental impacts of waste leachate and for informing remediation strategies (Olayinka, 2013).

Solid waste dumpsites can alter the physical and chemical properties of surrounding soils by leaching contaminants, such as heavy metals and organic compounds (Aluko *et al.*, 2003). Previous studies have revealed that soils in the vicinity of dumpsites exhibit reduced fertility, increased

salinity, and elevated levels of potentially toxic elements (Akinbile, 2006).

Soil pH influences the solubility and bioavailability of heavy metals. A study by Uba *et al.* (2008) indicated that leachates from open dumps can lower soil pH, creating acidic conditions that enhance metal mobility. Electrical conductivity is a key indicator of ionic concentration in soil and is used to assess the extent of salinity (Osibanjo and Oyewole, 2012).

Heavy metals like lead (Pb), cadmium (Cd), zinc (Zn), copper (Cu), and iron (Fe) have been consistently reported in elevated concentrations around waste dumpsites. According to Awokunmi *et al.* 2010, such metals can accumulate in soils and potentially enter the food chain through crops grown in contaminated areas. These

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contaminants pose significant health risks, including neurological, renal, and developmental disorders (WHO, 2010).

Multiple Studies have reported the impact of the physicochemical properties of municipal solid wastes on the environment. Suleiman *et al.* (2019) assessed the impact of urban waste on soil and groundwater from Kaduna, reporting high levels of lead and cadmium. Similarly, Musa *et al.* (2017) studied a dumpsite in Kano and observed significant changes in soil nutrient profiles and increased metal concentrations compared to control sites.

Nigerian cities, where uncontrolled open dumping is still widely practiced. In places such as Zaria, the expansion of informal dumpsites over time has intensified concerns regarding soil degradation, groundwater contamination, and associated health risks. Open dumpsites generate leachates rich in dissolved organic matter and inorganic contaminants, which can infiltrate surrounding soils and water systems, thereby altering their physicochemical characteristics (Ogunleye *et al.*, 2014).

Evidence from northern Nigeria indicates that dumpsite leachates significantly influence soil chemistry. A study conducted by Uba *et al.* (2008) demonstrated that prolonged exposure to leachates can lower soil pH, creating acidic conditions that enhance the solubility and mobility of heavy metals. This process increases the likelihood of metal uptake by plants and subsequent entry into the food chain. Soil acidity has been widely recognized as a controlling factor in metal speciation and bioavailability (Alloway, 2013).

In a related investigation, Suleiman *et al.* (2019) evaluated the impact of urban waste disposal on soil and groundwater quality in Kaduna metropolis. Their findings revealed elevated concentrations of toxic metals, including lead (Pb) and cadmium (Cd), exceeding permissible limits in some cases. These contaminants pose significant public health concerns, particularly in communities that depend on shallow groundwater sources for domestic use. Similar observations have been reported in other parts of Nigeria, reinforcing the link between waste mismanagement and environmental pollution (Akinbile and Yusoff, 2011).

Beyond Kaduna State, comparable studies in northern Nigeria further highlight the environmental implications of open dumping. For instance, Musa *et al.* (2017) reported substantial alterations in soil nutrient composition and elevated heavy metal concentrations in soils surrounding dumpsites in Kano. These findings are consistent with earlier reports emphasizing that parameters such as electrical conductivity (EC) serve as indicators of ionic enrichment and salinity resulting from leachate infiltration (Osibanjo and Oyewole, 2012).

Despite these contributions, most previous studies have concentrated on secondary environmental compartments, such as soil and groundwater, with limited attention given to the primary waste material itself. This represents a critical knowledge gap, as the physicochemical

characteristics of municipal solid waste largely determine the composition and behavior of leachates generated during decomposition. Furthermore, earlier investigations often assessed individual parameters in isolation, rather than adopting a comprehensive approach that integrates physicochemical properties with heavy metal distribution.

The present study addresses these limitations by focusing on the Dogarawa dumpsite, a long-established disposal site that has undergone significant expansion over the past two decades. This research provides a detailed characterization of municipal solid waste, including pH, electrical conductivity, moisture content, and organic matter, as well as quantification of key heavy metals (Pb, Cd, Cr, Zn, Cu, and Fe). In addition, the study advances existing knowledge by incorporating comparative evaluation against regulatory standards and examining the potential risks to human health and ecological systems, particularly through food chain transfer. By directly analyzing the waste matrix rather than relying solely on surrounding environmental samples, this work offers a more comprehensive understanding of contamination sources and pathways, thereby contributing to improved waste management strategies and environmental protection in Kaduna State and beyond.

The main aim of this study is to analyze the physicochemical properties of Municipal solid wastes obtained from Dogarawa dumpsite in order to assess the pH, electrical conductivity (EC), organic matter content, moisture content, and concentrations of key heavy metals (Pb, Cd, Cr, Zn, Cu, and Fe) to determine if it conforms to regulatory bodies as well as determine the potential dangers it may have on both animals and human around the waste dump site and possible effects through food chain.

MATERIALS AND METHODS

Sample collection

Composite samples were collected at varying distances from the diagonal and center of (0 m, 20 m, 50 m, 100 m, and 200 m) and at depths of 0–15 cm weekly for a period of one month from an open waste dump site in Dogarawa (Figure 1), Zaria L.G.A., Kaduna State, Nigeria.

Determination of moisture content

A 10 g sample of municipal solid waste was first air-dried and then precisely weighed into a pre-weighed crucible. The crucible was heated in an oven set at 105 °C for 24 hours to remove all residual moisture. After drying, it was transferred to a desiccator and allowed to cool to room temperature before being weighed again. The decrease in mass, which indicates the moisture content, was calculated using the equation shown below.

$$\text{Moisture content (\%)} = \frac{W_1 - W_2}{W_1} \times 100$$

Where: W_1 is the mass before oven drying.
 W_2 is the mass after oven drying, Ideriah *et al.* (2010), Omola *et al.* (2022).

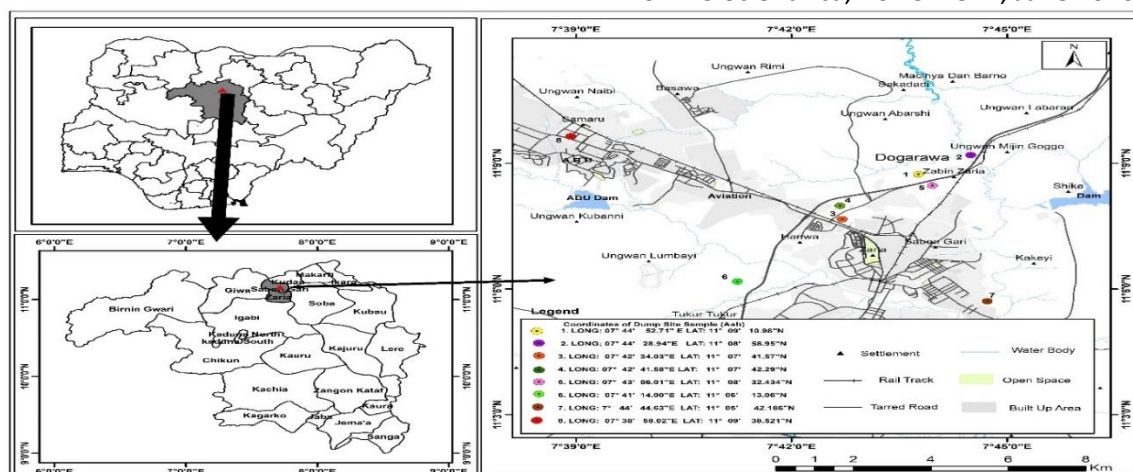


Fig. 1: Map showing the sampling site

Determination of organic matter content (OM)

10g of the municipal solid waste sample collected was oven-dried, quantitatively transferred into a pre-weighed crucible, and placed in a muffle furnace at 550 °C for 2 hours. After this, the crucible was removed and transferred into a desiccator to cool. The sample obtained after cooling was re-weighed and the loss of mass on ignition calculated using the equation below (Irabor, 2023).

$$\%OM = \frac{AC - BC}{AC} \times 100$$

Where OM = Organic matter, AC = mass before roasting, and BC = mass after roasting (Omoniyi, 2015).

pH determination:

A 5.0 g portion of the sample was weighed into a 250 cm³ beaker, after which 25.0 cm³ of distilled water was added. The suspension was stirred thoroughly for approximately five minutes and then left to attain equilibrium. The pH of the resulting supernatant was determined using a calibrated pH meter, and measurements were recorded daily over a period of 1 week (Ojonimi et al., 2025).

Conductivity determination

5.0 g of the sample was placed inside a 250 cm³ beaker. Then 25.0 cm³ distilled water was added, and the mixture was stirred vigorously for about 5 minutes, then allowed to equilibrate. The electrical conductivity of the supernatant solution was measured using a conductivity meter. The conductivity was monitored daily for 1 week (Ogunmodede and Aladejana, 2014).

Sample Characterization

Elemental Composition of the Sample (X-ray Fluorescence)

The elemental composition of the sample was determined using an X-ray fluorescence (XRF) spectrometer at the National Geological Survey Agency, Kaduna, Nigeria. XRF is a well-established, non-destructive analytical technique widely employed for the qualitative and quantitative determination of major and trace elements in

geological and waste-derived materials (Jenkins, 1999; Beckhoff et al., 2006).

Prior to analysis, representative portions of the zinc-rich sample were oven-dried at 105 °C for 2 h to remove moisture and subsequently ground to a fine powder (<75 μm) using an agate mortar and pestle to ensure homogeneity and minimize matrix effects (Jenkins, 1999). Approximately 5 g of the powdered sample was pressed into a 32 mm diameter pellet using a hydraulic press at 20 t cm⁻².

The prepared pellets were analyzed using an energy-dispersive X-ray fluorescence (ED-XRF) spectrometer equipped with a rhodium anode X-ray tube operated at 40 kV and 30 mA. Instrument calibration and analytical accuracy were ensured through the use of appropriate certified reference materials and established quality-assurance procedures, as recommended in standard XRF analytical protocols (Potts et al., 1997; Beckhoff et al., 2006).

During measurement, the sample surface was irradiated with primary X-rays, which produced characteristic secondary (fluorescent) X-rays corresponding to the sample's elemental composition. A solid-state detector detected the emitted radiation, and spectral data were processed using fundamental parameter quantification methods to compute elemental concentrations (Beckhoff et al., 2006). All analyses were conducted under controlled laboratory conditions to minimize contamination and background interference.

Mineralogical Characteristics of the Raw Sample (X-ray Diffraction)

The mineralogical composition of the municipal solid waste (MSW) sample was determined using X-ray diffraction (XRD) with an Ultima IV Rigaku automatic powder diffractometer at the National Geological Survey Agency, Kaduna, Nigeria. XRD is a widely accepted technique for phase identification and structural analysis of crystalline materials in heterogeneous systems (Klug and Alexander, 1974).

Representative sample aliquots were oven-dried at 105 °C for 2 h to remove adsorbed moisture, then ground to a

fine powder (<75 μm) using an agate mortar and pestle to enhance sample homogeneity and reduce preferred orientation effects (Klug and Alexander, 1974). The powdered samples were mounted on glass holders and gently pressed to obtain flat, uniformly packed surfaces.

The diffractometer was operated using Cu Kα radiation (λ = 1.5406 Å) at 40 kV and 30 mA. Diffraction patterns were collected over a 2θ range of 5°–80°, with a step size of 0.02° and a scan rate of 2° min⁻¹, consistent with established best practices for multiphase material analysis (Klug and Alexander, 1974).

Phase identification was performed by comparing the measured diffraction patterns with standard reference data from established crystallographic databases. For semi-quantitative phase analysis, the Rietveld refinement method was employed to fit the entire diffraction profile and estimate relative phase abundances (Rietveld, 1969; Bish and Post, 1993). All measurements were carried out in triplicate to ensure reproducibility and data reliability.

HCl and HNO₃ in the 3:1

A 1.0 g sample of the waste material was carefully weighed and placed into a digestion flask. Thereafter, 20 mL of freshly prepared aqua regia was added, and the mixture was heated on a heating mantle in a fume hood. The temperature gradually increased with occasional agitation until the solution volume was reduced to about 5 mL. To prevent excessive evaporation, the flask was covered with a watch glass during digestion. The resulting digest was filtered and rinsed thoroughly with deionized and double-distilled water, then quantitatively transferred into a 50 mL volumetric flask and diluted to the calibration mark with distilled water. Heavy metal concentrations in the final solution were analyzed using an Atomic Absorption Spectrophotometer (AAS), Buck Scientific Model 210VGP, following the method described by Abegunde et al. (2018).

RESULTS AND DISCUSSION

Physicochemical properties of the municipal solid waste (MSW)

The results of the physicochemical tests on municipal solid waste (MSW) for this research are reported in Table 1. The pH is 7.6, while the moisture content is 2.5 ± 0.005.

The pH value in this study falls within the range of 6.04–8.17 reported by Ortabor et al. (2018) in their study on the impact of municipal solid waste on soil in dumpsites. The moisture content in this study falls below 20–20%, which corresponds to the report by Kumar on research conducted on municipal solid waste. Similarly, the Organic matter content of 20±0.005 reported in this research falls within the values obtained by Ahmed and Onyidoh (2018) from Municipal Solid Wastes (MSW) Management in High Population Density Areas of Zaria and Kaduna Metropolis in Kaduna State, Nigeria. The Organic matter, which is a measure of the combustible content of the sample, is low. This low value implies a

high mineral content, hence confirming the high values of heavy metals recorded.

Table 1: physicochemical analysis of the sample

Parameter	Value
pH	7.6
Moisture content (%)	2.5±0.005
Organic content (%)	20±0.005

Mineralogical Compositions of the Municipal Solid Waste Sample

The physicochemical properties of municipal solid waste were assessed, and the outcomes are summarized in the following tables and figures. The subsequent discussion offers an interpretation of these findings and emphasizes their significant implications.

The result of the mineralogical characterization using XRD is provided in Figure 2. The result reveals that the sample includes quartz, graphite, anhydrite, garnet, muscovite, and sphalerite. Weibel et al., (2017) reported similar phases (quartz, iron oxides, and Zn-bearing minerals) on municipal solid waste incinerated fly ash.

Also, the results of the elemental analysis of the sample using XRF are shown in Table 2. The result showed that the sample contains 20.239% Zn, 0.078% Si, 4.235% Fe, 0.082% Al, 0.426% Cu, 0.025% S, and 17.470% V. The value of zinc recorded in this research is very high compared to 3.2% reported by Oke et al., (2024) from the XRF analysis of brunt tyre ash.

Table 3 presents the levels of heavy metals detected in the municipal solid waste (MSW) sample under consideration. A comparison with regulatory standards clearly reveals that these concentrations are alarmingly high. The Dogarawa dumpsite in Zaria is highly contaminated, posing substantial threats to environmental quality, agricultural sustainability, and public health. Zinc (Zn) was found at 166,970 mg/kg, more than 550 times the World Health Organization (WHO) guideline. Copper (Cu) was measured at 3,570 mg/kg, exceeding limits by more than 35 times. These values far surpass those reported in similar studies across Nigeria; for instance, Oladeji et al. (2017) reported Zn and Cu levels of 1,465 mg/kg and 315 mg/kg, respectively, in MSW samples from Ibadan.

Such elevated concentrations can pollute soil and nearby water bodies, deteriorate soil structure, and disrupt microbial activity. Lead (Pb) was also recorded at a concerning level of 656 mg/kg, exceeding both the WHO and National Environmental Standards and Regulations Enforcement Agency (NESREA) thresholds. Pb contamination is especially problematic due to its persistence in the environment and potential to bioaccumulate (Onuh et al., 2021).

From an agricultural perspective, the use of untreated MSW as a soil amendment may facilitate the transfer of toxic metals into crops. Studies in Zaria have shown that vegetables such as *Amaranthus hybridus* and spinach cultivated on MSW-affected soils accumulate unsafe levels

of Pb, Zn, and Cu (Onuh *et al.*, 2021). Similar research conducted in Kaduna also revealed that vegetables grown

near dumpsites absorbed Pb and Zn levels beyond acceptable health limits (Gana and Akinyemi, 2022).

Table 2: Elemental Analysis by X-ray Fluorescence (XRF) of the Sample.

Element	Zn	Fe	Cd	Al	Cu	Pb
Composition(wt.%)	20.239	4.235	-	0.082	0.426	0.067

Table 3: Heavy Metal Concentrations

Heavy metal	Concentration (mg/Kg)	WHO limit (mg/Kg)	NESREA limit (mg/Kg)
Lead (Pb)	656	100	164
Cadmium (Cd)	Not Detected	3	1.0
Zinc (Zn)	166,970	300	140
Copper (Cu)	3,510	100	36
Iron (Fe)	34,940	50,000	-

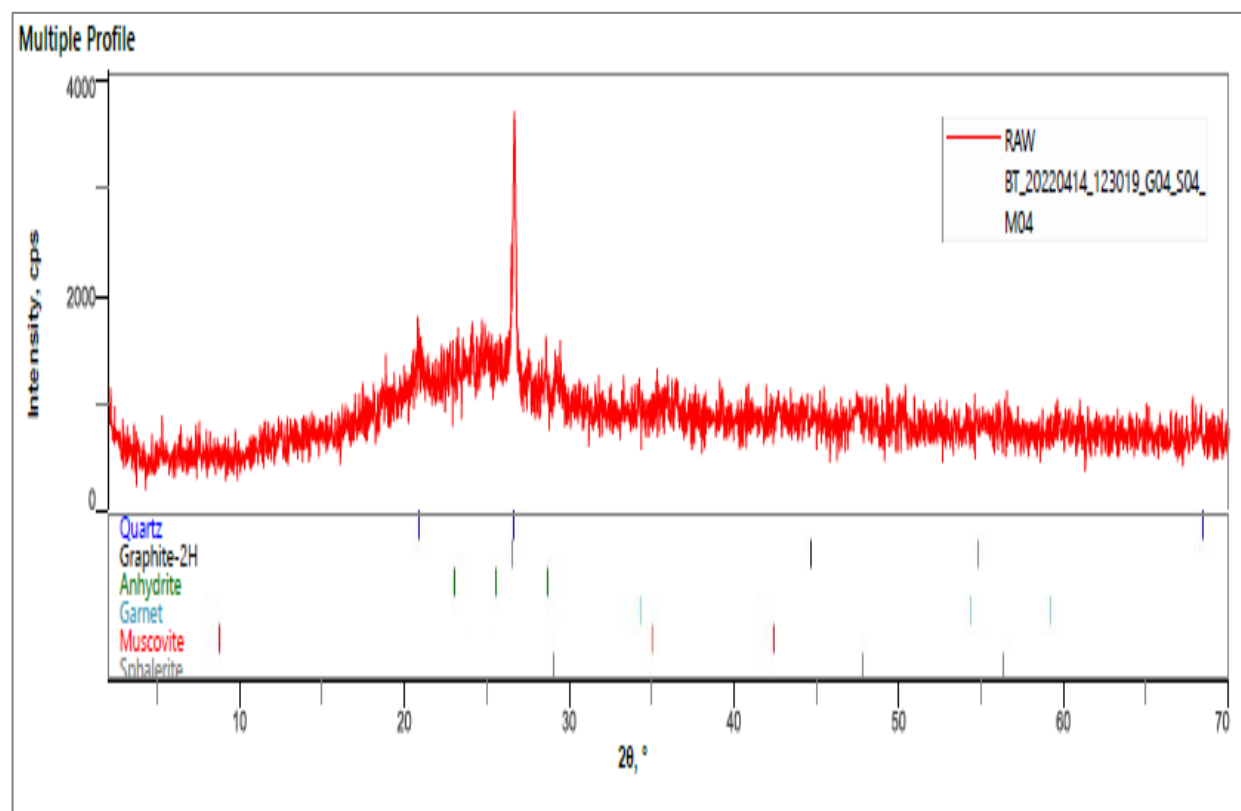


Figure 2: Mineralogical phase analysis results of the sample

Iron (Fe) was detected at 34,940 mg/kg. Although this falls within the WHO’s maximum permissible limit of 50,000 mg/kg, elevated Fe levels can reduce plant access to other key nutrients, such as phosphorus and manganese, thereby impacting plant health and productivity (Nwaedozie, 2018).

Human exposure through the food chain is another critical issue. Lead is highly toxic and has been linked to developmental and neurological disorders in children, as well as kidney damage in adults. Adie and Osibanjo (2009) reported excessive Pb accumulation in leafy vegetables such as lettuce and spinach grown on Nigerian waste dumps, consistent with findings from Zaria. While zinc is an essential micronutrient, consuming it in excess through contaminated produce may cause gastrointestinal discomfort and suppressed immune function. This was confirmed in Ogbomoso, where tomatoes and okra grown on MSW-impacted soils contained Zn concentrations above safe levels (Akinbile *et al.*, 2016).

Although cadmium (Cd) was not detected in the Zaria samples, it remains a concern. Cd is highly mobile in the environment and can be taken up by crops even when present at trace levels. Ogunfowokan *et al.* (2013) emphasized the potential for Cd accumulation in leafy vegetables, underscoring the latent risk posed by waste-contaminated soils.

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