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Assessment of Physicochemical Properties and Heavy Metal Contamination of Soils from selected Dumpsites in Gwagwalada Area Council, Abuja, Nigeria

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Abstract
Soil contamination from indiscriminate waste disposal is a growing environmental challenge in developing regions such as Nigeria. This study assessed the physicochemical properties and heavy metal concentrations of soils from selected dumpsites Kuje Road, Abattoir, and Phase III in Gwagwalada Area Council, Abuja, with Passo serving as a control site. Soil samples were collected at a depth of 0–30 cm and analyzed for pH, moisture content, organic matter, total nitrogen, cation exchange capacity (CEC), and texture, following standard procedures. Heavy metals including cadmium (Cd), chromium (Cr), manganese (Mn), lead (Pb), and zinc (Zn) were determined using Atomic Absorption Spectrophotometry (AAS). Results revealed that soil pH ranged from 5.65 to 6.60, indicating slightly acidic conditions across all sites. All soils were classified as sandy loam. Organic matter and moisture content were highest at Kuje Road (2.20% and 2.60%, respectively), while Passo had the lowest values. Heavy metal analysis showed that Kuje Road had the highest concentrations of all measured metals Cd (3.00 mg/kg), Cr (218.25 mg/kg), Mn (240.75 mg/kg), Pb (79.75 mg/kg), and Zn (265.75 mg/kg) followed by Abattoir and Phase III, while Passo exhibited the lowest contamination levels. The elevated metal concentrations, particularly at Kuje Road and Abattoir, indicate significant anthropogenic influence from mixed solid waste and industrial effluents. These findings suggest potential ecological and health risks due to the accumulation of toxic metals in soils near active dumpsites. The study underscores the urgent need for improved waste management practices, soil remediation, and continuous environmental monitoring to safeguard public health and ensure sustainable land use in Gwagwalada and similar urban communities
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Keywords: Soil Contamination, Heavy Metals, Dumpsites, Environmental Pollution, Abuja

Introduction

Soil contamination by heavy metals is one of the most persistent environmental problems associated with indiscriminate waste disposal in developing countries (Mainimo et al., 2025). The continuous deposition of industrial, domestic, and abattoir waste into open dumpsites introduces various pollutants, including toxic metals such as cadmium (Cd), chromium (Cr), manganese (Mn), lead (Pb), and zinc (Zn), into the soil environment (Ama et al., 2025). These heavy metals are non-biodegradable and tend to accumulate in soil, posing long-term risks to soil fertility, plant growth, and human health through bioaccumulation and biomagnification in the food chain (Anuoluwa et al., 2025).

In Nigeria, improper waste management practices such as open dumping and uncontrolled burning remain the dominant methods of solid waste disposal (Omokaro et al., 2025). These practices have led to the contamination of both surface and subsurface environments, especially in urban and peri-urban areas where population growth and industrial activities are increasing. Dumpsites often receive mixed waste streams including plastics, metals, animal waste, and effluents, resulting in complex chemical interactions and leachate generation that alter soil physicochemical properties such as pH, cation exchange capacity, organic matter, and moisture content (Omo-Okoro et al., 2025).

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Heavy metal contamination of soil is of particular concern because it can degrade soil quality, reduce agricultural productivity, and pose serious health hazards to nearby communities. Lead and cadmium are known to cause neurological and renal disorders, while high chromium levels may be carcinogenic. The mobility and availability of these metals in soil depend largely on physicochemical parameters such as pH, organic matter, and texture (Chen et al., 2025; Hou et al., 2025; Sharafi&Salehi, 2025).

The Gwagwalada Area Council of the Federal Capital Territory (FCT), Nigeria, is a rapidly developing region that hosts several dumpsites including the Kuje Road, Abattoir, and Phase III waste sites receiving various forms of industrial, domestic, and abattoir waste. Despite the proximity of these sites to residential and agricultural areas, limited studies have evaluated the extent of soil contamination and its impact on soil quality in the region. The Passo layout area, which is relatively unpolluted, provides a suitable control site for comparative analysis.Therefore, this study aims to assess the physicochemical properties and heavy metal concentrations of soils from selected dumpsites in Gwagwalada Area Council, Abuja, Nigeria.

Materials and Methods

Study Site

The study was carried out in mechanic workshop dumpsite at Kuje road, Abbatoir dump site, Phase III dump site and the unpolluted Passo layout which is 2km away from the dumping sites will use as the control site at Gwagwalada area council. Gwagwalada Area Council is located in the Federal Capital Territory (FCT), Nigeria. The coordinates for Gwagwalada are 8.874^0N, 7.135^0E. it is about 32 kilometers away from the central area of Abuja. Phase 3 dumpsite lies between latitude $8^0$58·14.20212" and longitude $7^0$3·22.8006", Abbatoir dumpsite latitude $8^0$55·56.73216" and longitude $7^0$4·52.81896", Kuje road dumpsite latitude $8^0$55·37.53588" and longitude $7^0$6·7.40412" and Passo control latitude $8^0$57·23.65884" and longitude $7^0$3·59.44644". The soil type is predominantly lateritic soils. These soils are rich in iron and aluminum oxides and are well drained and suitable for agriculture and forestry

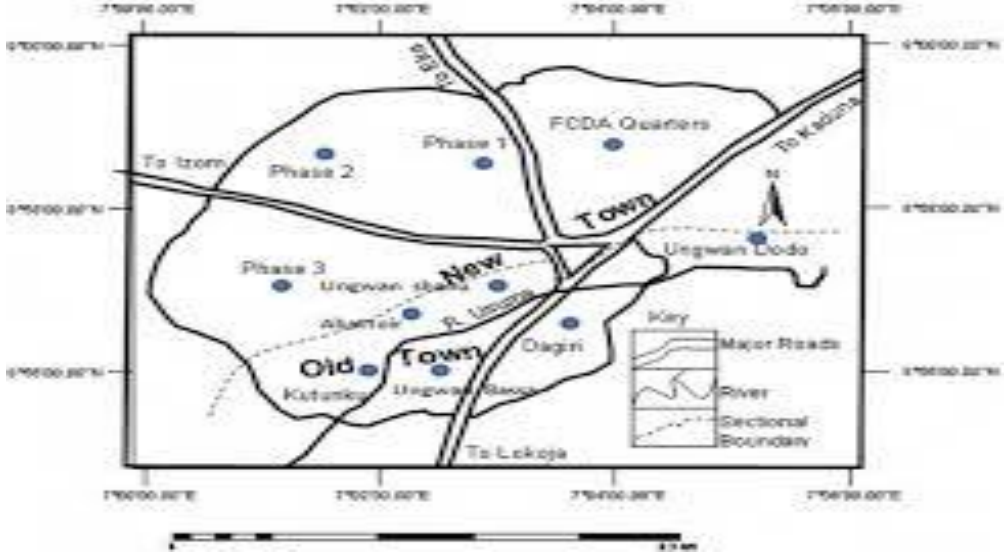

Fig 1: Map of Gwagwalada area council Abuja, Nigeria

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Soil sampling and preparations

Samples of soils from these sites was taken at a uniform depth of 0-30 cm with the aid of a soil auger. 5 (five soil samples) was collected each to make a good representation of the area. The collected soil samples were bulked together to form a composite sample from each zone. Composite samples was thoroughly mixed, then sub samples was collected into plastic bags for laboratory analysis. Soil sample was collected 1000m away from the dump sites were no dumping activities was being carried out. The soil samples was air dried for 48 hours, ground and sieved using a 0.5 mm mesh size sieve to have uniform particle size. Each sample was labelled and stored in a dry plastic container that had been pre-cleaned with concentrated Nitric acid prior to analysis.

Particle Size Analysis

Particle size analysis was determined according to the method of Bouyoucos (1962). 50 milliliters of cagon solution were used to soak 50 grams of the soil sample overnight. After that, the mixture was mixed up to the mark and put into a 1000 ml measuring cylinder. After shaking, the mixture was left for forty seconds. prior to plunging the hydrometer into it to measure the amount of sand, and the same procedure was used to measure the amount of clay and silt after three hours (to allow the mixture to settle). After that, the temperatures were simultaneously recorded. The percentages of sand, clay, and silt were computed as follows: H1 and H2 are hydrometer measurements at 40 seconds and three hours, respectively, at corresponding temperature readings T1 and T2 (Bouyoucos, 1962).

Determination of the Soil Physico-Chemical Properties

The Black (1965) method was employed to assess the soil pH in the suspension; Ogunfowakan (2009) used the textural class approach; Walkley and Black (1997) used the standard method to determine the organic carbon, organic matter, and moisture contents.

Determination of the Physicochemical Properties of Soil

Soil Moisture Content

A beaker with a known mass was filled with soil samples, which were then measured. The samples were oven-dried at 105°C for a whole day in order to achieve a uniform bulk. After the samples were dried and allowed to cool in a desiccator, their final mass was calculated (Ukpong et al., 2013).

$$\text{Calculation : \% Mass} = = \left(\frac{\text{Air dried} - \text{Oven dried}}{\text{Oven-dried}} \right) \times 100\ \%.$$

Soil pH

In a beaker, 1.0 g of a soil sample from each site was measured and stirred with 10 mL of deionized water (1:10 soil: distilled water mixture). The digital pH meter was calibrated using a standard buffer solution at pH values of 4.01 and 7.00 before the pH was measured. The glass electrode/probe was submerged in the solution to get the pH measurements, which were then recorded (Chen et al., 2019).

Soil Electrical Conductivity (Salinity)

A measuring cylinder was filled with 10 milliliters of thoroughly mixed water. A previously prepared soil sample was added to the water until the contents increased by 5 mL, bringing the container's volume to 15 mL. More water was added to the mixture until its total volume reached 30 mL. The material was shaken intermittently for five minutes before being allowed to settle for another five. An EC probe would be dipped into the solution to detect the electrical conductivity (Motsara and Roy 2008).

Temperature

The temperature of the soil was tracked in situ using a mercury thermometer. The thermometer was left in the ground until a consistent temperature was noted (Edori and Iyama, 2017).

Soil Organic Carbon

After treating a 1 g soil sample for four hours with 5 mL of concentrated H2SO4, 5 mL of 0.5 M $K_2Cr_2O_7$ was added. The mixture was heated to 150–160 degrees Celsius for five minutes before being allowed to cool to room temperature. A conical $K_2Cr_2O_7$ will be identified by titrating with 0.25 M $FeSO_4$. Chen et al. (2019) state that when the hue of the solution shifted from dark green to blue to reddish-brown, the endpoint was attained.

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$$\text{Organic carbon } (\%) = M \times \left(\frac{V1 - V2}{\text{Mass of soil}} \right) \times 0.39.$$

Where
M=concentration of $FeSO_4$,V1=Volume of blank, V2=Volume of $FeSO_4$, 0.39=constant.

Cation Exchange Capacity

The technique outlined by Raman and Sathiyanarayanan (2009) was used to calculate cation exchange capacity (CEC). The centrifuge tube was filled with 1.3 g of soil. The centrifuge tube was filled with 11 milliliters of 1 N sodium acetate solution. It was centrifuged after being well shook. We'll decant the liquid supernatant. The centrifuge tube was filled with 11 milliliters of isopropyl alcohol. After giving the centrifuge tube a good shake, it was centrifuged. We'll decant the liquid supernatant. The centrifuge tube was filled with 11 milliliters of 1 N ammonium acetate solution. After giving the centrifuge tube a good shake, it was centrifuged. The 100 ml flask was filled with the liquid supernatant. The 100 ml standard measuring flask was filled with the solution. A standard sodium solution was used to calibrate the flame photometer. After injecting the prepared solution into the device, a reading was obtained (Raman and Sathiyanarayanan, 2009). The formula was then used to calculate the CEC value (Herk, 2012).

$$\text{CEC, cmol(+) kg-1 soil} = \frac{10 * \text{Na concentration in meq L}-1}{\text{Mass of sample (g)}}$$

Soil analysis for Heavy Metals

The following Regular Macro-Kjeldahl Methods were used to calculate the Total Nitrogen in Soil: A dry 500 ml Macro-Kjeldahl flask was filled with 5–10 g of air-dried, ground soil sample (containing around 10 mg of nitrogen and passed through a 0.5 mm sieve), followed by the addition of 20 ml of distilled water. After a few minutes of swirling, the mixture was left to stand for half an hour. Following the addition of 10 g of K_2SO_4 and one tablet of mercury catalyst (or 1 g of K_2SO_4 + HgO catalyst combination), 30 ml of concentrated H_2SO_4 was added using an automated pipette. After that, the flask was gently heated on a digestion stand until the digest cleared and the frothing stopped. It was then boiled for five hours while keeping the acid condensation halfway up the flask's neck. Following digestion, 100 milliliters of distilled water were gradually added to the flask while it cooled. In order to avoid bumping during distillation, the digest was carefully placed into a clean 750 ml Macro-Kjeldahl flask, making sure that sand particles stayed in the digestion flask. Four 50 ml amounts of distilled water were used to wash the residue, and each washing was moved to the same distillation flask.

A 500 ml Erlenmeyer flask was positioned beneath the condenser of the distillation apparatus, with the condenser tip approximately 4 cm above the solution surface, and a 50 ml boric acid (H3BO3) indicator solution was added.Distil lation was started by adding 150 ml of 10 N NaOH through the funnel and attaching the 750 ml Kjeldahl flask to the distillation machine.

Heat was controlled to reduce frothing and avoid suckback, and a constant flow of cold water was used to keep the c ondenser below 30°C.After collecting a 150 cc distillate, the distillation process was halted. By titrating with 0.01 N standard HCl or H_2SO_4 using a 25 ml burette graduated at 0.1 ml intervals and detecting a color change from green to pink at the endpoint, the amount of ammonium nitrogen (NH_4–N) in the distillate was ascertained. Lastly, the soil's percentage nitrogen content was determined.

Digestion of soil samples

Concentrated HNO3 (70%, SigmaAldrich Corp, Germany) was used to digest soil samples (Hseu, 2004). To get rid of any big particles, the soil sample was first air-dried and sieved through a 2-mm mesh screen. For digestion, a subsample of roughly 0.5 g was collected. A digestion solution comprising concentrated nitric acid (HNO3) and hydrogen peroxide (H2O2) was combined with the sub-sample. On a hot plate, the mixture was cooked until it began to boil, at which point the heat was lowered to maintain a gentle boil. Until the material has entirely dissolved, the digestion procedure is carried out for roughly two hours.

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After being digested, the sample was placed in a crucible and heated to 500°C for four hours in a muffle furnace. Whatman No. 42 filter paper was used to filter the extraction and digestion solutions, which were then diluted with 25 milliliters of deionized water.

3.6.2 Determination of concentration of heavy metals

Using the AAS Peckin Elmer A Analyst 200, heavy metal analysis for (Cd), chromium (Cr), manganese (Mn), lead (Pb), and zinc (Zn) was performed using the Atomic Absorption Spectrophotometry method.

Statistical Analysis

One-way analysis of variance (ANOVA) was used to evaluate the significant differences in the mean values of physicochemical parameters among groups of soils.The correlation between the physicochemical properties of soil samples will also be tested using Pearson's correlation analysis. A statistically significant probability threshold was defined as $P<0.05$. SPSS version 16.0 for Windows was used for all statistical analyses. Five duplicate experiments' mean±standard deviation (SD) was used to express the data.

Physicochemical Parameters of Soil obtained from Abbatoir, Phase III, Kuje road dumpsites and Passo

Table 1 Indicates the physicochemical parameters of soil obtained from Abbatoir, Phase III, Kuje road dump sites and Passo. The soil pH in water was 5.65 at Abattoir, 6.20 at Phase III, 6.55 at Kuje Road, and 6.60 at Passo. The soil pH measured in calcium chloride solution was 5.25 at Abattoir, 5.90 at Phase III, 5.99 at Kuje Road, and 5.40 at Passo, The sand content of the soil was highest at Kuje Road (82%), followed by Abattoir (72%), Passo (54%), and lowest at Phase III (53%).Clay content was highest at Phase III (20%), followed by Passo (10%), while both Abattoir and Kuje Road had the lowest clay content at 6%.The silt content was 38% at Phase III, 36% at Passo, 22% at Abattoir, and 12% at Kuje Road, indicating a relatively higher presence of fine particles in Phase III and Passo soils.Despite the differences in sand, silt, and clay percentages, the textural class of all soil samples was classified as sandy loam, indicating that sand is the dominant particle across the sites.The organic matter content was 2.01% at Abattoir, 1.91% at Phase III, 2.20% at Kuje Road, and 1.48% at Passo. Kuje Road had the highest organic matter, while Passo had the lowest.Moisture content was highest at Kuje Road (2.60%), followed by Phase III (1.68%), Abattoir (1.42%), and lowest at Passo (1.32%).Total nitrogen levels were 0.10% at Abattoir, 0.17% at Phase III, 0.18% at Kuje Road, and 0.19% at Passo.Cation exchange capacity (CEC) was 10.50 cmol/kg at Abattoir, 10.34 cmol/kg at Phase III, 9.80 cmol/kg at Kuje Road, and 8.79 cmol/kg at Passo. There's no significant difference between the physicochemical properties of soil at the study site and the control site.

Table 1: Physicochemical Parameters of Soil obtained from Abbatoir, Phase III, Kuje road dump sites and Passo

Soil property	Abattoir	PhaseIII	Kuje Road	Passo
pH (H_20)	5.65	6.20	6.55	6.60
pH($CaCl_2$)	5.25	5.90	5.99	5.40
% sand	72	53	82,	54
% clay	6,	20	6	10
%silt	22	38	12	36
Textural Class	Sandy loam	Sandy loam	Sandy loam	Sandy loam
Organic Matter (%)	2.01	1.91	2.20	1.48
Moisture Content (%)	1.42	1.68	2.60	1.32
Electrical conductivity(dcm)	0.10	0.15	0.08	0.06
Cation Exchange Capacity (cmol/kg)	10.50	10.34	9.80	8.79
Total Nitrogen(%)	0.17	0.18	0.19	0.16

Heavy Metal Concentration (mg/kg) in Soil Samples obtained from Abbatoir, Phase III,Kuje road dump sites and Passo

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Table 2 indicates the concentrations of heavy metals in soil samples varied across the four dump sites Abattoir, Phase III, Kuje Road, and Passo. Kuje Road recorded the highest levels of all the measured heavy metals, with cadmium (Cd) at 3.00 mg/kg, chromium (Cr) at 218.25 mg/kg, manganese (Mn) at 240.75 mg/kg, lead (Pb) at 79.75 mg/kg, and zinc (Zn) at 265.75 mg/kg. The Abattoir site had the second-highest levels for most heavy metals, with Cd at 2.50 mg/kg, Cr at 211.50 mg/kg, Mn at 212.25 mg/kg, Pb at 57.50 mg/kg, and Zn at 222.00 mg/kg.Phase III followed closely, especially in lead concentration (62.00 mg/kg) which was higher than at the Abattoir, despite lower levels of other metals: Cd at 2.00 mg/kg, Cr at 185.25 mg/kg, Mn at 185.00 mg/kg, and Zn at 141.25 mg/kg.Passo consistently showed the lowest concentrations of all heavy metals, with Cd at 1.25 mg/kg, Cr at 100.00 mg/kg, Mn at 145.00 mg/kg, Pb at 40.50 mg/kg, and Zn at 90.50 mg/kg, indicating comparatively lower contamination levels at this site.

Table 2: Heavy Metal Concentration (mg/kg) in Soil Samples obtained from Abbatoir, PhaseIII, Kuje road dump sites and Passo

	Heavy Metal Concentrations (mg/kg)				
Dump Sites	**Cadmium (Cd)**	**Chromium (Cr)**	**Manganese (Mn)**	**Lead (Pb)**	**Zinc (Zn)**
Abattoir	2.50	211.50	212.25	57.50	222.00
Phase III	2.00	185.25	185.00	62.00	141.25
Kuje Road	3.00	218.25	240.75	79.75	265.75
Passo	1.25	100.00	145.00	40.50	90.50

Discussion

The soils across all sites are slightly acidic. This trend is consistent with the findings of Ale et al., (2024), who reported similar acidic conditions in soils around waste disposal sites in southwestern Nigeria, attributing the acidity to the decomposition of organic materials and leachate generation from waste dumps. The acidity may be due to microbial decomposition of organic wastes and the release of organic acids and CO_2. Passo had a relatively higher pH, suggesting less decomposition or a lower concentration of acidic leachates compared to the Abattoir. This may be because the Abattoir site experiences regular dumping of animal waste which decomposes quickly and produces acids.

All soils are classified as sandy loam, indicating a predominance of sand with varying proportions of silt and clay. Kuje Road had the highest sand content, while Phase III had the highest silt and clay. This pattern aligns with the results of Okunsebor et al. (2024), who reported sandy loam textures in soils from coastal plain sands origin in Edo State, Nigeria, indicating a naturally sandy parent material in the region. The variability in silt and clay may be influenced by the type of waste dumped. For example, finer particles at Phase III and Passo could result from domestic or construction waste that contributes more fines compared to Abattoir and Kuje Road.

Organic matter ranged from 1.48% at Passo to 2.20% at Kuje Road. This agrees with Akintola et al. (2021), who found higher organic matter in soils near active waste sites due to continuous organic waste input. Passo had the lowest organic matter despite relatively higher silt content. This could be due to less frequent waste deposition or a higher presence of non-biodegradable materials.

The moisture content was highest at Kuje Road (2.60%), which is in line with its high organic matter and sandy texture that allows quick infiltration but limited water retention. The low moisture at Passo (1.32%) may be due to low organic matter and high silt, which can compact and reduce infiltration. These findings are consistent with Akinro and Oni, (2022), who observed that moisture retention in dump soils is influenced by both organic matter and particle size.

Nitrogen levels ranged from 0.10% at Abattoir to 0.19% at Passo. These values fall within the low to moderate range for tropical soils, as reported by Akintola et al. (2021), who emphasized that organic matter directly contributes to nitrogen availability. The relatively low nitrogen at the Abattoir may be due to nitrogen losses via ammonia volatilization, typical in soils with high animal waste input. Passo had the highest nitrogen despite the lowest organic matter, possibly indicating fertilizer presence.

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Cation Exchange Capacity values are moderate, reflecting the sandy loam texture and moderate organic matter levels. High CEC at the Abattoir may be due to organic colloids and decomposed animal waste acting as ion exchangers. Azuka and Ezeme (2023) also reported similar trends in CEC, noting that waste-rich sites with more clay and organic material tend to have higher CEC values.

The analysis of soil samples from four dump sites Kuje Road, Abattoir, Phase III, and Passo revealed varying levels of heavy metal contamination, with significant implications for environmental health and waste management practices. The results showed that Kuje Road had the highest concentrations of all assessed metals, followed by Abattoir, Phase III, and Passo, which had the lowest contamination levels.The elevated levels of cadmium, chromium, manganese, lead, and zinc at Kuje Road and Abattoir suggest intense anthropogenic activity, including improper waste disposal, possibly involving industrial, electronic, or slaughterhouse waste. This finding is consistent with studies byOnyedika (2015) and Nwaogu et al. (2017), which observed high levels of heavy metals in soils near urban dumpsites in Nigeria, attributed to mixed solid waste and lack of proper waste sorting.

The cadmium concentration at Kuje Road (3.00 mg/kg) exceeds background values reported by WHO (2007) and is in line with findings by Orisakwe et al. (2014), who reported Cd levels ranging from 7.605–24.194 mg/kg in soils near open dumps in south soutth Nigeria. Similarly, chromium levels at Kuje Road (218.25 mg/kg) and Abattoir (211.50 mg/kg) are within the range observed by Aliyua et al., (2024) in Duste abbatoir dump site in Jigawa state, Nigeria., indicating potential pollution from metal-containing wastes or dyes.
In contrast, Passo exhibited consistently lower levels of heavy metals across all parameters, suggesting less exposure to industrial or hazardous waste. The cadmium concentration of 1.25 mg/kg and lead concentration of 40.50 mg/kg are closer to values reported in less industrialized or semi-rural areas, aligning with findings from Onyekachi et al. (2020), who recorded lower heavy metal loads in remote soil samples compared to urban locations.

One notable difference is the higher lead concentration at Phase III (62.00 mg/kg) compared to the Abattoir (57.50 mg/kg), despite Phase III generally having lower levels of other metals. This anomaly could be attributed to specific localized activities, such as battery dumping or the use of lead-based paints, as suggested by Zafar et al. (2025), who linked elevated Pb levels to household and electronic waste in residential areas.

Across all sites, zinc showed the highest concentrations, particularly at Kuje Road (265.75 mg/kg) and Abattoir (222.00 mg/kg), possibly due to its widespread use in galvanized materials, tires, and batteries. This trend is consistent with observations made by Olorundare et al. (2011), who noted that zinc is commonly found in high concentrations in soils receiving urban waste due to its ubiquity in both household and industrial products.

Despite differences in absolute values, a common pattern across all sites is the detectable presence of all five heavy metals, highlighting the pervasive nature of soil contamination in urban and peri-urban dumpsites in Nigeria. These similarities reflect broader regional findings where poor waste management systems contribute to long-term accumulation of toxic metals in soil, as emphasized by Jayakumar et al., (2021).

Conclusion

Indiscriminate waste disposal significantly contributes to soil contamination in Gwagwalada, Abuja. The study revealed slightly acidic, sandy loam soils with elevated heavy metal concentrations, especially at Kuje Road and Abattoir, indicating strong anthropogenic impact. These findings highlight potential environmental and health risks, underscoring the need for improved waste management, site remediation, and continuous monitoring to ensure sustainable land use.

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