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Research Article

Assessment of Heavy Metals in Surface and Groundwater Samples from The Vicinity of Kurudu Solid Waste Dumpsite, FCT, Abuja, Nigeria

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ABSTRACT
Given the documented threats posed by heavy metal contamination to environmental and public health, this study assessed heavy metal concentrations in surface and groundwater around the decommissioned Kurudu dumpsite in Abuja, FCT. Groundwater samples were collected from two boreholes (GW1 and GW2) and one hand-dug well (GW3) within the vicinity of the dumpsite. Surface water samples were obtained from Oja River at three points—upstream, midstream, and downstream - between February and March, from 8:00 a.m. to 12:00 p.m., using 500 mL specimen bottles. Data analysis was performed using Analysis of Variance (ANOVA), with mean separation by Duncan's Multiple Range Test, while metal concentrations were determined using Atomic Absorption Spectrometry. The results showed iron concentrations of 0.40±0.11, 0.09±0.02, and 0.15±0.01 mg/L in GW1, GW2, and GW3 respectively. Lead was not detected in GW1 and GW2 but recorded 0.001 mg/L in GW3. Zinc concentrations were 0.35±0.20, 0.21±0.04, and 0.15±0.01 mg/L, while copper concentrations ranged between 0.04 and 0.05 mg/L across groundwater samples. Magnesium values ranged from 6.00 to 7.50 mg/L, and manganese ranged from 0.09 to 0.62 mg/L. In Oja River, iron concentrations ranged from 0.02 to 0.81 mg/L, while lead levels (2.20-3.22 mg/L) exceeded FMEnv standards for irrigation water. Zinc levels also increased downstream. Overall, cadmium and manganese in groundwater exceeded permissible limits, indicating that the Kurudu dumpsite has negatively impacted groundwater quality and poses environmental and agricultural risks.

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1 Introduction

Water is needed to maintain and sustain human life, animals, and plants; this is because it constitutes, to a large extent, the major solvent in which many of the body's proteins and other constituents are dissolved. It assists many metabolic activities of the body to take place. Water is essential for growing food, for domestic uses, and is a serious factor in industries, tourism, and cultural purposes, as it helps in sustaining the earth's ecosystem (Ebraheem et al., 2018).

Water plays a critical role in sustaining human, animal, and plant life, serving as the primary solvent for bodily proteins and essential components, while facilitating metabolic processes. It is vital for agriculture, household needs, industrial operations, tourism, and cultural practices, underpinning the Earth's ecosystems (Ebraheem et al., 2018). As an irreplaceable resource, water is fundamental to economic development, second only to air in supporting life. In urban settings, access to piped water, boreholes, and wells underscores its indispensability. Groundwater, in particular, holds significant importance as a resource, extensively utilized for domestic, private, and industrial purposes (Dwivedi & Pathak, 2017).

Residents near the Kurudu dumpsite rely heavily on borehole water for daily needs such as cooking, drinking, and cleaning. However, these water sources are vulnerable to contamination. Oko (2018) identifies agricultural practices (fertilizers, soil treatments), septic systems, solid waste, and geological factors as key contributors to groundwater pollution. Human activities in urban and densely populated regions further heighten the risk of contamination in both surface water (rivers, streams, lagoons) and groundwater systems.

The Kurudu dumpsite in the Federal Capital Territory (FCT) was established as a temporary waste disposal site for Abuja and surrounding suburbs, including Karu, Nyanya, and Jikwoyi. Operational for eight years, it was eventually closed due to environmental and health hazards posed to nearby communities. While local scavengers have removed recyclable non-biodegradable materials, their activities, though economically beneficial, often exacerbate environmental degradation and pose health risks (Zheng et al., 2008).

Given the documented threats posed by heavy metal contamination to environmental and public health, this study underscores the urgency of assessing heavy metal levels in surface and groundwater samples collected near the decommissioned Kurudu dumpsite in Abuja. Such an evaluation is crucial for informing mitigation strategies and safeguarding water quality in the region.

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2 Materials and Methods

2.1 Study Area

Kurudu is in the Federal Capital Territory (FCT), which is located within the north-central geopolitical zone of Nigeria. It is located between Latitudes 9°14′38.28′′N and 9°20′01.41′′N and between Longitudes 7°21′44.5′′8E and 7°23′8.00′′E. The Area Council is located in the geographical center of Nigeria, bordering Nasarawa State, and covers a total land mass of 914km^2 (Figure 1).

Kurudu has two main seasons, wet (April to October) and dry (November to March). During the dry season, the typical month being February, the temperature varies between 30°C and about 37°C. Annual rainfall is reported to exceed 1,600 mm, most of it occurring during the rainy season. The mean total annual rainfall is between 1,100 and 1,600 mm, with about 80% of it occurring between May and October during the peak of the rainy season. Rainfall is heavy, and an event can last more than 6 hours. Rainfall rates of about 50mm/hr are common between July and August. The annual rainfall regime consists of two peaks occurring in July and September, as exemplified in the data for mean monthly rainfall for Abuja. In general, the area experiences a bimodal pattern of rainfall. (FCT Secretariat, 2020).

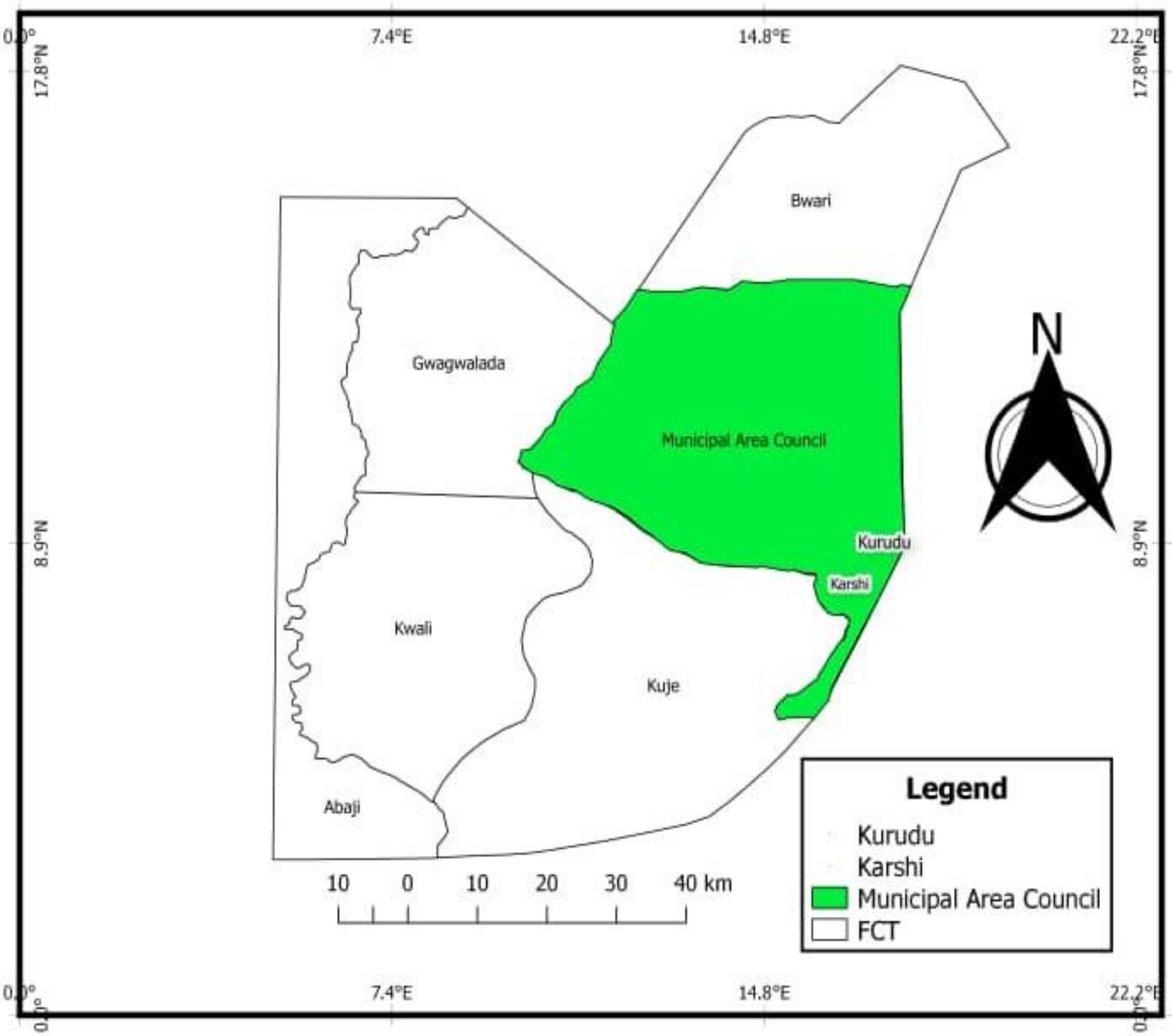

Figure 1: FCT showing the study site

The Kurudu region and surrounding areas within the Federal Capital Territory (FCT) are primarily underlain by high-grade metamorphic and igneous rocks dating to the pre-Cambrian era. These formations include gneiss, migmatites, and granites, which exhibit significant shearing and are categorized into four major groups:

a) **Metamorphosed Supracrustal (Exogenetic) Rocks**: Comprising mica schist (sh), marble (m), amphibolite, amphibole schist (a), and fine to medium-grained gneiss.

b) **Migmatitic Complex**: Encompassing migmatite (mi), migmatitic gneiss (mg), granite gneiss (gg), porphyroblastic granite-gneiss (pg), and leucocratic granite gneiss (lg).

c) **Intrusive Granite**: Represented by coarse-grained granite (eg, FCT Secretariat, 2020).

The soils in the study area are typically shallow and sandy, with high erodibility due to their granular composition. The limited soil depth is attributed to the presence of stony subsoil layers. Vegetation in the area is characterized by tropical Guinea savannah, dominated by annual grasses, scattered trees, and dense shrub patches. Riparian forests fringe watercourses, though tree and shrub cover remains sparse, failing to form a continuous canopy (FCT Secretariat, 2020).

2.2 Sample Collection

The groundwater samples were collected from three boreholes situated around the vicinity of the Kurudu dumpsite, FCT, Abuja. Borehole water samples were obtained directly from the water pump in the various borehole locations after allowing the water to run for at least five minutes, and each sample bottle and its cap were rinsed three times with the water sample. These samples were subsequently stored at 4°C for as short a time as possible before analysis to minimize physicochemical changes.

Surface Water samples were collected in February and March (when the need for water is high for both man and animals and activities center on the Oja River), between 8:00 am and 12 pm of the day from the three sampling points (Upstream, Downstream, and Mid-Stream) using 500 ml capacity specimen bottles. The water samples were acidified with nitric acid and placed in an ice chest immediately, based on the standard procedure of America Public Health Association (APHA 2015), before being takens to the laboratory for further analysis.

2.3 Data Analysis

Equipment used for in-situ measurement was pre-calibrated by approved organizations. Necessary quality controls were observed, which included avoidance of contamination at all stages using gloves where necessary, as well as following the chain of custody procedures. An atomic absorption spectrometer (AAS) was used to analyze the heavy metals.

Data collected were analyzed using Analysis of Variance (ANOVA); ANOVA was used to determine whether the variations in the water parameters were caused by real environmental differences or just random variations. Means were separated using Duncan's Multiple Range Test. All the ANOVA assumptions were met, which include independent observations, normality, and homogeneity of variances, among others.

3 Results

3.1 Heavy Metal Content of Ground Water Samples

Table 1 presents the results of the heavy metal content in groundwater samples collected in Kurudu.

Table 1: Results of Heavy Metal Content of Ground Water Samples

Heavy Metals	GW1	GW2	GW3	FMEnv Standard For Drinking Water	NSDWQ	WHO
Fe^{2+} mg/l	$0.40^{a} \pm 0.11$	$0.09^{c} \pm 0.02$	$0.15^{b} \pm 0.01$	0.3	0.3	0.3
Pb^{2+} mg/l	ND	ND	0.001	0.05	0.01	0.01
Zn^{2+} mg/l	$0.35^{a} \pm 0.2$	$0.21^{b} \pm 0.04$	$0.15^{c} \pm 0.01$	5.0	3.0	3.0
Cu^{2+} mg/l	$0.05^{a} \pm 0.11$	$0.04^{ab} \pm 0.13$	$0.04^{ab} \pm 0.02$	0.1	1.0	2.0
Mg^{2+} mg/l	$6.10^{ab} \pm 0.04$	$6.00^{ab} \pm 0.02$	$7.5^{a} \pm 0.04$	-	20	50
Mn^{2+} mg/l	$0.62^{a} \pm 0.14$	$0.09^{c} \pm 0.11$	$0.19^{b} \pm 0.04$	0.05	0.2	0.4
As mg/l	NiL	Nil	0.001±0.07	0.2	0.01	0.01
Cd mg/l	$2.10^{a} \pm 0.12$	$2.10^{a} \pm 0.14$	$3.10^{b} \pm 0.03$	0.01	0.03	0.03

Data are presented as mean ± standard deviation of three replicates. Means within a row with the same superscript were not significantly different ($p>0.05$).

GW1 = Borehole at New AMAC Market; GW2= Central Borehole at Shelter Origin Estate; GW3= Hand-dug Well at Karshi Town. NSDWQ (2017) = Nigerian Standard for Drinking Water Quality. WHO (2022) Guideline for Drinking Water Quality.

The Iron readings were 0.40mg/L at GW1, 0.09mg/l at GW2, and 0.15mg/l at GW3. However, the highest value recorded was 0.40 mg/L at GW1. The iron content of GW1 was significantly ($p<0.05$) higher than that of GW2 and GW3. The iron content of the water samples from GW2 and GW3 was low compared to the WHO and NSDWQ allowable limit of 0.3 mg/L. With these results, GW2 and GW3 are suitable for drinking. On the other hand, the iron content of water samples from GW1 was high compared to the WHO and NSDWQ allowable limit of 0.3 mg/L.

Iron (Fe):

Bassey and Akanimoh (2022) reported variable iron levels in Cross River State's groundwater, attributing elevated concentrations in some boreholes (e.g., GW1) to corroded casing pipes. Bacterial activity may further influence iron dynamics in water systems. Excessive iron imparts a metallic taste, stains surfaces, and fosters iron bacteria growth, which clogs pipes (Oko, 2018). While not acutely toxic, prolonged exposure can cause gastrointestinal distress and interfere with mineral absorption, worsening conditions like hemochromatosis (Akpoborie et al., 2018).

Lead (Pb):

Lead was undetected in GW1 and GW2 but measured at 0.001 mg/L in GW3. All values fell below the WHO (2022) and NSDWQ (2017) thresholds (0.01 mg/L). However, Nair et al. (2020) warn that even trace lead poses risks, as it bio-accumulates and can poison water at concentrations exceeding 0.1 mg/dm³. The current levels suggest minimal immediate risk, aligning with findings by Aboyeji and Eigbokhan (2016).

Zinc (Zn):

Zinc concentrations (GW1: 0.35 mg/L; GW2: 0.21 mg/L; GW3: 0.15 mg/L) were significantly different ($p<0.05$) but well below NSDWQ (3.00 mg/L), WHO, and FMEnv (5.00 mg/L) limits. The low levels imply limited zinc-containing waste (e.g., batteries, electronics) in the dumpsite, as noted by Aboyeji and Eigbokhan (2016) and Okpanachi (2015).

Copper (Cu):

Mean copper levels in GW1 (0.05 mg/L) fall within the FMEnv's limit (0.1 mg/L), as well as GW2 and GW3 (0.04 mg/L each). Chronic exposure to elevated copper, if observed, may impair neurological function and cause gastrointestinal disorders (Okpanachi, 2015).

Magnesium (Mg):

Concentrations (GW1: 6.10 mg/L; GW2: 6.00 mg/L; GW3: 7.5 mg/L) were far below WHO (50 mg/L) and NSDWQ (20 mg/L) guidelines. These values suggest negligible magnesium contamination, contrasting with higher levels reported by Yerima and Fidi (2018) and Ojo et al. (2012).

Manganese (Mn):

GW1 (0.62 mg/L) exceeded WHO/NSDWQ (0.2 mg/L) and FMEnv (0.05 mg/L) limits, while GW2 (0.09 mg/L) and GW3 (0.19 mg/L) surpassed only FMEnv's threshold but remained within the WHO/NSDWQ guidelines. Elevated manganese is linked to neurological and gastrointestinal disorders (Abolude et al., 2020), mirroring findings in Cross River State by Bassey and Akanimo (2022).

Arsenic (As):

Arsenic was undetected in GW1/GW2 and measured at 0.001 mg/L in GW3—well below FMEnv (0.2 mg/L), NSDWQ (0.01 mg/L), and WHO (0.01 mg/L) standards. This aligns with Ojo et al. (2012) and Okpanachi (2015), who found no arsenic contamination. Potential sources include agricultural pesticides, which can infiltrate groundwater via runoff (Karbassi et al., 2019; Sekabira et al., 2022).

Cadmium (Cd):

Alarmingly, cadmium concentrations detected in the groundwater samples (GW1/GW2: 2.10 mg/L; GW3: 3.10 mg/L) were far above the permissible limits established by the World Health Organization (WHO), Federal Ministry of Environment (FMEnv), and the Nigerian Standard for Drinking Water Quality (NSDWQ), all of which prescribe a maximum allowable concentration of 0.07 mg/L for potable water. These concentrations indicate severe heavy metal contamination and represent a major public health concern for communities relying on the affected groundwater sources for drinking, cooking, and domestic use.

Cadmium is a highly toxic and non-biodegradable heavy metal that can accumulate progressively in human tissues over prolonged exposure. Continuous consumption of cadmium-contaminated water may result in chronic kidney dysfunction, renal failure, skeletal deformities, bone demineralization, and increased risk of fractures (Ndu, 2020; Loizidou & Kapetanios, 1993). Long-term exposure has also been associated with hypertension, liver damage, reproductive disorders, weakened immune response, and increased risk of certain cancers. Vulnerable populations such as children, pregnant women, and the elderly are particularly at risk because cadmium bioaccumulates in the body over time.

The extremely elevated concentrations observed in this study strongly suggest active leachate infiltration from the nearby dumpsite into the groundwater system. As waste materials decompose, toxic leachates containing dissolved heavy metals migrate through the soil profile into surrounding aquifers, especially in areas with poor waste containment systems (Loizidou & Kapetanios, 1993). The persistence of cadmium in soils and aquatic ecosystems further aggravates the situation because the metal remains environmentally stable for long periods and may continue contaminating groundwater even after waste disposal activities have ceased.

3.2 Heavy Metal Content of Surface Water Samples

Table 2 presents the heavy metal content in surface water samples in Oja River.

Table 2: Heavy Metal Content of Surface Water Samples (Oja River)

Parameters and Units	Upstream	Midstream	Downstream	FMEnv Standard for Irrigation Water	WHO Standard for Potable (Drinking) Water
Fe^{2+} mg/l	0.02±0.01	0.03^{b}±0.11	0.81^{a}±0.09	5.0	0.3 mg/l
Pb^{2+} mg/l	2.2^{c}±0.11	2.29^{b}±0.02	3.22^{a}±0.01	0.2	0.01
Zn^{2+} mg/l	0.31^{c}±0.09	0.4^{b}±0.01	5.33^{a}±0.11	5.0	3.0
Cu^{2+} mg/l	0.01^{b}±0.02	0.01^{b}±0.09	0.02^{a}±0.01	0.2	5.0 mg/l
Mg^{2+} mg/l	2.2^{b}±0.01	2.29^{c}±0.11	3.22^{a}±0.09	3.5	
Mn^{2+} mg/l	0.01^{b}±0.09	0.12^{b}±0.01	1.43^{a}±0.11	NS	0.1 mg/l
Ca^{2+} mg/l	7.10^{c}±0.08	8.19^{b}±0.11	10.12^{a}±0.01	NS	
As mg/l	ND	ND	ND	0.1	0.01
Cd mg/l	0.001±0.11	0.001 ^{b}±0.01	0.92^{a} ±0.09	0.01	0.003

Iron (Fe):

Mean iron levels in the Oja River were 0.02 mg/L (upstream), 0.03 mg/L (midstream), and 0.81 mg/L (downstream), with upstream concentrations significantly lower (p <0.05) than midstream and downstream. All values fell below the FMEnv irrigation standard of 5.0 mg/L. Low iron levels support soil health and crop productivity by preventing acidification and structural degradation (McBride, 2017). Clean irrigation water minimizes ecosystem disruption and ensures sustainable agricultural output (Yap et al., 2020).

Lead (Pb):

Lead concentrations increased downstream, with readings of 2.2 mg/L (upstream), 2.29 mg/L (midstream), and 3.22 mg/L (downstream). All values exceeded the FMEnv irrigation threshold (0.2 mg/L). Aboyeji and Eigbokhan (2016) attribute the elevated lead to sedimentation of lead-bearing particles during the dry season. These levels endanger aquatic life and human consumers, particularly low-income communities reliant on the river for fish.

Zinc (Zn):

Zinc levels were 0.31 mg/L (upstream), 0.4 mg/L (midstream), and 5.33 mg/L (downstream), with downstream concentrations significantly higher (p >0.05). While upstream and midstream values adhered to FMEnv's 5.0 mg/L irrigation limit, downstream values exceeded it. Low zinc levels upstream suggest minimal disposal of zinc-containing waste (e.g., batteries, electronics) near the river (Aboyeji & Eigbokhan, 2016).

Copper (Cu):

Copper concentrations were consistent across the river: 0.01 mg/L (upstream/midstream) and 0.02 mg/L (downstream), well within FMEnv's 0.2 mg/L irrigation limit. Though essential for haemoglobin production, excessive copper can cause anaemia and organ damage (Kabata, 2019). Current levels pose no risk for agricultural use.

Manganese (Mn):

Manganese levels rose downstream, measuring 2.2 mg/L (upstream), 2.29 mg/L (midstream), and 3.22 mg/L (downstream), with downstream values significantly higher (p >0.05). While vital in trace amounts, elevated manganese from fossil fuels or sewage sludge (Begnum et al., 2013) can harm respiratory and neurological health (Boyd & Tucker, 2020).

Arsenic (As):

Arsenic was undetected in surface water samples, aligning with findings by Ojo et al. (2012) and Okpanachi (2015). This absence indicates negligible arsenic-contaminated waste in the dumpsite, making the water safe for irrigation and aquatic ecosystems.

Cadmium (Cd):

Cadmium levels were 0.001 mg/L (upstream/midstream) and 0.92 mg/L (downstream). Downstream concentrations exceeded both the FMEnv's 0.001 mg/L irrigation limit and the WHO's potable water limit of 0.003. This is likely due to leaching from waste or human activity. Upstream/midstream values remain suitable for irrigation, consistent with Unanam and Akpan's (2006) findings of (0.0148–0.0158 mg/L).

3.3 Environmental and Health Implications

Almafrachi et al. (2025) and Bawuro et al. (2018) believe that bioaccumulation leads to biomagnification along the food chain, increasing metal concentrations at higher trophic levels. Consumption of contaminated fish and crops exposes humans to serious health risks, including neurological disorders, kidney damage, developmental problems, and cancer. Therefore, monitoring heavy metals in aquatic systems, soils, crops, and food products is essential to protect ecosystem integrity and public health.

4 Limitations

Groundwater samples were collected from selected sampling points within the study area. Consequently, the findings may not fully represent the hydrochemical conditions of the entire region or all groundwater sources surrounding the dumpsite.

Sampling was conducted within a limited period and may not adequately capture seasonal variations in groundwater quality. Heavy metal concentrations and physicochemical parameters can fluctuate between the wet and dry seasons due to dilution, runoff, and leachate migration dynamics.

Groundwater movement and contaminant transport are influenced by complex hydrogeological factors such as soil permeability, aquifer characteristics, groundwater flow direction, and geological formations. Detailed subsurface investigations were beyond the scope of this study.

The study primarily evaluated contamination levels and inferred possible health risks from established standards and literature. Clinical or epidemiological investigations involving affected residents were not conducted to directly establish health outcomes associated with exposure.

Despite these limitations, the study provides valuable baseline data on groundwater contamination, heavy metal distribution, and potential public health risks associated with dumpsite activities within the study area. The findings can serve as a foundation for future detailed hydrogeological and environmental health investigations.

5 Conclusion

This study evaluated the concentration of selected heavy metals in surface and groundwater sources within the vicinity of the Kurudu dumpsite, Federal Capital Territory, Abuja, in order to determine the impact of the dumpsite on water quality. The findings clearly indicate that the presence of the dumpsite has adversely affected both groundwater and surface water systems in the study area. Elevated concentrations of cadmium and manganese were recorded in borehole and well water samples, as well as excessive iron levels in GW1, which exceeded permissible limits for potable water, rendering these sources unsuitable for direct human consumption without adequate treatment. These elevated metal levels suggest leachate infiltration from the dumpsite into surrounding groundwater aquifers, likely facilitated by subsurface permeability and prolonged waste deposition.

Although most heavy metals in the surface water samples from the Oja River were within acceptable limits, the concentration of lead exceeded the Federal Ministry of Environment (FMEnv) standard for irrigation water. This raises serious concerns regarding the suitability of the river for agricultural use, as continuous irrigation with lead-contaminated water could result in soil contamination, crop uptake, and eventual entry of toxic metals into the food chain through bioaccumulation. Such conditions pose long-term risks to food safety, ecosystem health, and public well-being.

Overall, the study reveals that the proximity of the Kurudu Dumpsite to surrounding water resources poses serious environmental risks, especially to groundwater quality. The findings underscore the urgent need for sustainable waste management practices, regular groundwater quality assessment, strict enforcement of environmental protection regulations, and the provision of safe and reliable alternative water sources for communities located within the impacted area.

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