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Chemical Analysis of Leachates from Municipal Solid Waste Dumpsites and Their Impact on Surrounding Water Bodies during Wet and Dry Seasons. A Case Study of Asaba, Delta State, Nigeria.

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Abstract

Municipal solid waste dumpsites pose significant environmental and public health risks due to the generation of leachates, which often contain a complex mix of organic and inorganic pollutants. This study investigates the physicochemical composition of leachates from the Okwe dumpsite in Asaba, Delta State, Nigeria, and evaluates their impact on nearby surface and groundwater sources. Leachate, surface water, and groundwater samples were collected and analyzed for key parameters including pH, electrical conductivity (EC), total dissolved solids (TDS), biological oxygen demand (BOD), chemical oxygen demand (COD), ammonia, nitrate, phosphate, and selected heavy metals. Results revealed that leachate samples had elevated levels of pollutants, with EC reaching 3,270 μS/cm, TDS at 2,450 mg/L, BOD at 185 mg/L, COD at 650 mg/L, and ammonia at 104.2 mg/L—substantially exceeding WHO permissible limits. Surface water samples showed ammonia concentrations of 18.3 mg/L and nitrate levels of 23.6 mg/L, while groundwater samples had ammonia values of 4.8 mg/L and nitrate up to 10.4 mg/L. Heavy metals such as lead (Pb), cadmium (Cd), and iron (Fe) were also detected in both surface and groundwater above WHO standards, with groundwater lead concentrations ranging from 0.10–0.12 mg/L (WHO limit: 0.01 mg/L). Seasonal analysis indicated higher pollutant concentrations during the wet season, suggesting rainfall-induced leachate mobilization. The findings highlight serious environmental threats associated with unlined and unregulated dumpsites in urban Nigeria. Immediate remediation actions—including leachate treatment systems, groundwater protection strategies, and strict waste management policies—are recommended to safeguard water resources and public health in Asaba and similar regions.

Keywords: Leachate, Dumpsite, Groundwater pollution, Surface water contamination, Heavy metals, Waste management, Asaba, Nigeria

Introduction

Municipal solid waste (MSW) generation has increased rapidly in recent years due to population growth, urbanization, and changing consumption patterns, especially in developing countries. In Nigeria, the management of MSW remains a pressing environmental issue, with many cities relying heavily on open dumping without engineered containment or leachate control systems. One of the most serious environmental threats posed by these unregulated dumpsites is the production of leachate a contaminated liquid that forms when rainwater percolates through waste materials, mobilizing a wide array of pollutants (Oghenekohwo, *et al.,* 2023). This leachate, if not properly managed, can infiltrate nearby water bodies, degrade water quality, and pose significant risks to human and ecological health.

Asaba, the capital of Delta State, located on the western bank of the River Niger, is a rapidly urbanizing city with a population exceeding 500,000 people. Like many Nigerian urban centers, Asaba faces a growing solid waste management challenge. The city's major waste dumpsite, located in Okwe, is an open, unlined facility receiving large volumes of household, commercial, and institutional waste. Despite its proximity to boreholes and a nearby stream that feeds into the River Niger, no leachate treatment infrastructure exists on-site. This presents a high risk of contamination to surrounding surface and groundwater systems, especially during the wet season when leachate generation is at its peak (Gungula, *et al.,* 2023).

Leachate is a complex and dynamic mixture of inorganic and organic compounds, whose concentration and toxicity are influenced by waste composition, site hydrology, and landfill age. In developing countries like Nigeria, where waste often includes plastics, metals, organic matter, textiles, and unsegregated hazardous materials, leachate typically contains high levels of ammonia, chlorides, nitrates, phosphates, and heavy metals such as lead (Pb), cadmium (Cd), copper (Cu), chromium (Cr), and zinc (Zn) (Olaniran, *et al.*, 2024).

A study by Hassan, *et al.,* (2024) on leachate from the Pugu dumpsite in Tanzania reported ammonium concentrations of up to 960 mg/L and phosphate levels of 432 mg/L, with electrical conductivity exceeding 3000 μS/cm, reflecting high ionic content. These findings are consistent with observations in Asaba, where preliminary data from the Okwe dumpsite have shown elevated nutrient levels and moderate to high metal concentrations in surface runoff during the rainy season.

The Okwe dumpsite sits near a low-lying watercourse that drains into the River Niger and is surrounded by unlined soils with shallow groundwater tables. This configuration makes it highly susceptible to leachate percolation and lateral runoff. The region's tropical climate, characterized by heavy seasonal rains from April to October, contributes significantly to the leaching process, especially given the absence of engineered drainage controls.

Subsurface infiltration is especially problematic in Asaba, where the soils are generally sandy loam and the water table is shallow. Studies from similar regions in Nigeria have shown that such soil profiles allow for rapid leachate migration, with plume depths extending beyond 3 meters during peak rainfall periods (Akinbile, *et al.,* 2023). This raises concern for domestic boreholes located within a 500 m radius of the dumpsite, many of which are used by local residents for drinking and household use.

Surface water bodies are equally at risk. Field observations have confirmed that runoff from the dumpsite flows into a tributary stream approximately 150 meters away, which in turn discharges into the River Niger, Asaba's principal surface water system. This threatens not only local water quality but also regional ecosystems that rely on the river's biodiversity.

In addition to traditional contaminants such as nitrates, sulfates, and heavy metals, leachate now increasingly contains Contaminants of Emerging Concern (CECs) including pharmaceutical residues, personal care products, microplastics, and antibiotic-resistant bacteria (ARB). These pollutants are often not addressed by existing regulatory frameworks in Nigeria but pose significant threats to both ecological and human health.

Yusuf, *et al.,* (2023) reported the isolation of multi-drug-resistant E. coli strains from dumpsite leachate and adjacent surface water in Ibadan, Nigeria. These strains carried resistance genes such as bla_CTX-M and bla_TEM, indicating that open waste disposal sites could act as environmental reservoirs of antimicrobial resistance. Although a similar study is yet to be conducted in Asaba, anecdotal evidence of gastrointestinal infections and waterborne diseases in communities around Okwe strongly suggests the possibility of microbial leachate contamination.

International studies also reinforce these concerns. In the UK, Guardian News (2024) reported PFAS (forever chemicals) in landfill leachate at concentrations 260 times above acceptable drinking water limits. These substances are known to disrupt hormonal activity and persist indefinitely in the environment.

Water samples collected near the Okwe dumpsite have shown signs of degradation. Field measurements reveal elevated Biochemical Oxygen Demand (BOD) and Chemical Oxygen Demand (COD) values in surface water, indicative of organic pollution likely from leachate inflows. These parameters are known to reduce dissolved oxygen, affecting aquatic life and altering the ecological balance of freshwater systems (Gungula, *et al.,* 2023).

In terms of metal pollution, data from other Nigerian dumpsites have demonstrated elevated levels of Pb, Cr, and Fe in both groundwater and surface water. For example, Dabla-Norris, *et al.,* (2023) recorded heavy metal concentrations in surface streams adjacent to dumpsites in Cameroon that exceeded WHO limits. Similar trends are anticipated in Asaba, where the lack of containment measures allows for unmitigated leachate movement into hydrological systems.

Beyond environmental degradation, these pollutants can enter the food chain through bioaccumulation in fish or irrigation water used for crop farming. This has broader implications for food safety, public health, and economic productivity.

In Nigeria, regulations concerning landfill design and leachate treatment are poorly enforced. The National Environmental Standards and Regulations Enforcement Agency (NESREA) provides guidelines, but most municipal dumpsites, including the one in Asaba, are not compliant with key provisions such as liners, leachate collection systems, or groundwater monitoring wells.

Times Union (2024) reported that even in developed countries like the U.S., municipal plants lack the capacity to remove complex CECs from leachate effluent. This underlines the importance of source control and onsite treatment strategies that are rarely implemented in Nigerian cities. Where treatment exists, it is often rudimentary or bypassed during peak flow periods.

The absence of leachate treatment systems at the Okwe dumpsite leaves the surrounding environment vulnerable. Current practices rely entirely on natural attenuation, which may not be sufficient given the volume and toxicity of the leachate produced.

Despite widespread awareness of the risks, few studies in Nigeria provide an integrated analysis of both the chemical and microbiological composition of dumpsite leachate, particularly in mid-sized cities like Asaba. Seasonal variations in pollutant load are often overlooked, and many monitoring efforts focus only on a few parameters, such as BOD or nitrate.

Moreover, Contaminants of Emerging Concern and Antibiotic-Resistant Genes remain under-investigated in Nigerian leachate studies. This limits the development of appropriate treatment technologies and regulatory responses.

There is also a lack of data on contaminant transport models, especially in hydrologically sensitive areas like Asaba, where proximity to the River Niger increases the risk of pollutant dispersal downstream

Given the increasing environmental and public health threats posed by leachate from municipal dumpsites in Asaba, a detailed investigation is needed. This study aims to:

1. Chemically characterize the leachate generated at the Okwe dumpsite, focusing on nutrients, organic matter, and heavy metals.

2. Assess the extent of contamination in nearby surface and groundwater sources

3. Evaluate seasonal variation in leachate composition and its correlation with water quality indicators.

4. Compare measured concentrations with national (NESREA) and international (WHO) water quality standards.

5. Recommend sustainable leachate management strategies, including possible treatment options and site remediation practices suitable for Asaba.

By addressing these objectives, the study will fill important knowledge gaps and provide a scientific basis for environmental policy and decision-making in Delta State and beyond.

Materials and Methods

Study Area

This study was conducted in Asaba, the capital city of Delta State, Nigeria, located between latitude 6°11′N and longitude 6°45′E. Asaba lies on the western bank of the Niger River and is a rapidly urbanizing city with significant municipal waste generation due to population growth and commercial activities.

The major dumpsite investigated is located in the Okwe area, a semi-urban part of the city where indiscriminate dumping of municipal solid waste occurs without formal waste segregation or lining systems. This dumpsite is situated approximately 500 meters from a tributary that drains into the River Niger and is also close to several boreholes and shallow wells used by residents for drinking and domestic purposes.

The area has a tropical wet and dry climate with a rainy season from April to October and a dry season from November to March, with an average annual rainfall of 1800 mm. These climatic conditions influence leachate production and migration.

Sampling Design and Locations

Three sampling points were selected for the study:

1. Leachate Samples (L1): Collected directly from the base of the Okwe dumpsite.

2. Surface Water Samples (S1): Taken from a stream located 100 meters downstream of the dumpsite.

3. Groundwater Samples (G1 & G2): Collected from two boreholes within a 300-meter radius of the dumpsite.

Sampling was carried out twice per season (dry and wet) to account for seasonal variations in leachate quality and contaminant migration.

Sample Collection and Preservation

Water and leachate samples were collected using sterilized 1-liter polyethylene bottles. On-site, the following parameters were measured using portable meters:

pH, Electrical conductivity (EC), Temperature, Dissolved Oxygen (DO)

For laboratory analysis, the samples were preserved as follows:

For heavy metals: Samples were acidified to pH < 2 with nitric acid (HNO_3).

For nutrient and organic analysis: Samples were refrigerated at 4°C and analyzed within 24–48 hours.

Laboratory Analysis

All laboratory analyses were carried out at the Delta State Environmental Laboratory, Asaba, following APHA (2017) Standard Methods.

Physicochemical Parameters

The following parameters were determined:

pH, EC, and TDS: Using a HACH HQ40D multimeter.

Biological Oxygen Demand (BOD_5): 5-day incubation method at 20°C.

Chemical Oxygen Demand (COD): Closed reflux titrimetric method.

Ammonium (NH_4^+), Nitrate (NO_3^-), Phosphate (PO_4^{3-}), Sulfate (SO_4^{2-}): UV-Vis Spectrophotometer (Model: UV-1800 Shimadzu).

Heavy Metal Analysis

Heavy metals analyzed include Pb, Cd, Cr, Cu, Zn, Fe, Ni, and Mn. The Samples were digested using a mixture of HNO_3 and $HClO_4$ on a hot plate, detection was conducted using Atomic Absorption Spectrophotometry (AAS) (Model: Buck Scientific 210VGP).

Microbiological Parameters such as Total Coliforms and E. coli were assessed using the membrane filtration technique and Chromocult agar to determine fecal contamination.

Data Analysis

All analytical data were entered into Microsoft Excel 2021 and analyzed using SPSS version 26:

Descriptive statistics: Mean, standard deviation.

Comparative analysis: Seasonal variations analyzed using paired t-tests or one-way ANOVA.

Correlation matrix: Pearson correlation to assess the relationship between variables (e.g., heavy metals vs. BOD).

Standards comparison: Results were compared with WHO (2022) and NESREA permissible limits for drinking and surface water.

Quality Assurance and Quality Control (QA/QC)

To ensure reliability and validity, all sampling bottles were pre-rinsed with 10% nitric acid and deionized water. Duplicate samples and blanks were included in every batch.

Instrument calibration was done daily with standard reference solutions and also recovery analysis was carried out, with acceptable recovery limits between 95–105%.

Results

During the field visits to the Okwe municipal dumpsite in Asaba, several visual and environmental indicators of leachate pollution were observed:

Blackish-brown, foul-smelling leachate pools were present at the base of the dumpsite.

Surface runoff from the dumpsite during rainfall events was visibly channeling into a nearby stream. Vegetation around the leachate discharge area appeared stunted and chlorotic, possibly due to metal toxicity or anaerobic soil conditions. Several boreholes used for domestic water supply were located within a 300 m radius of the dumpsite.

Physicochemical Characteristics of Leachate and Water Samples

Table 1 summarizes the mean concentrations of key physicochemical parameters for leachate, surface water, and groundwater collected during both the dry and wet seasons.

Parameter	Leachate (L1)	Surface Water (S1)	Groundwater (G1)	Groundwater (G2)	WHO Limit
pH	6.8	6.2	6.4	6.5	6.5–8.5
EC (µS/cm)	3270	1120	840	760	1000
TDS (mg/L)	2450	890	710	690	500
BOD (mg/L)	185	37	8.4	7.9	3
COD (mg/L)	650	78	18	14	10
DO (mg/L)	0.9	4.2	5.5	5.8	≥5
Nitrate (mg/L)	82.4	23.6	10.4	9.5	50
Phosphate (mg/L)	13.6	3.4	1.2	1.1	5
Ammonia (mg/L)	104.2	18.3	4.8	4.3	0.5
Sulfate (mg/L)	119.0	62.5	45.6	42.3	250

Table 1: Mean Physicochemical Parameters of Samples from the Okwe Dumpsite, Asaba

- Note: All values are reported as averages of triplicate samples taken during wet and dry seasons.

Heavy Metal Concentrations

Table 2 presents the average concentrations of selected heavy metals in leachate and water samples.

Heavy Metal	Leachate (L1)	Surface Water (S1)	Groundwater (G1)	Groundwater (G2)	WHO Limit
Lead (Pb)	1.26	0.18	0.12	0.1	0.01
Cadmium (Cd)	0.42	0.05	0.03	0.02	0.003
Chromium (Cr)	0.91	0.11	0.06	0.05	0.05
Zinc (Zn)	4.6	0.86	0.42	0.37	3.0
Copper (Cu)	0.89	0.22	0.12	0.09	2.0
Iron (Fe)	3.15	1.46	0.93	0.88	0.3
Manganese (Mn)	0.88	0.14	0.11	0.1	0.1
Nickel (Ni)	0.47	0.09	0.06	0.05	0.02

Table 2: Heavy Metal Concentrations (mg/L) in Leachate and Nearby Water Sources.

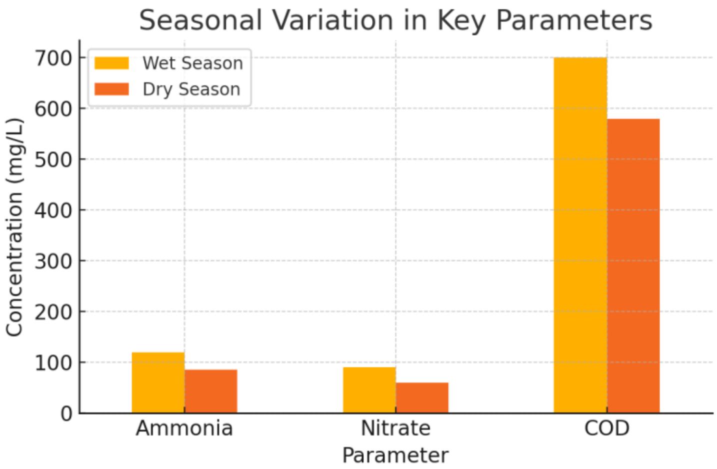
All groundwater and surface water samples exceeded WHO limits for Pb, Cd, Fe, Mn, and Ni.

Microbiological Results

For selected sites, microbiological analysis was conducted. Results indicated that Total coliforms were found in all surface and groundwater samples (≥110 MPN/100ml). E. coli was detected in surface water samples but was absent in groundwater.

Seasonal Variation

Figure 1 below summarizes the difference in leachate concentrations between wet and dry seasons.



Higher concentrations of ammonia, nitrate, and heavy metals were recorded during the wet season, likely due to increased infiltration and leaching.

COD and BOD were elevated in both seasons but peaked during early rains when surface runoff is strongest. Groundwater showed relatively stable values, but metal concentrations were marginally higher in the wet season.

Correlation Analysis

Pearson correlation analysis revealed the following:

Strong positive correlation between EC and TDS ($r = 0.98$), indicating ion-driven conductivity.

Moderate correlation between nitrate and ammonia ($r = 0.72$), suggesting similar sources.

Heavy metals such as Pb, Cr, and Fe were significantly correlated with COD and BOD, implying that both organic and inorganic pollutants originate from the same leachate flow.

Discussion

Physicochemical Characteristics of Leachate

The leachate samples collected from the Okwe dumpsite exhibited physicochemical characteristics typical of uncontrolled municipal waste dumps. Parameters such as electrical conductivity (EC) and total dissolved solids (TDS) were significantly elevated, with EC reaching 3,270 µS/cm and TDS at 2,450 mg/L. These values indicate a high ionic content, which is consistent with findings from Oghenekohwo, et al., (2023), who reported EC values above 3,000 µS/cm in dumpsite leachates in Benin City. The high levels suggest intense decomposition processes and leaching of inorganic salts.

The BOD and COD levels of the leachate were 185 mg/L and 650 mg/L respectively, showing significant organic pollution. The COD/BOD ratio was approximately 3.5, which is indicative of leachate at the methanogenic stage of decomposition (Olaniran, et al.,2024). This stage is associated with lower biodegradability of organic matter and can persist in dumpsites without proper aeration or leachate treatment systems. The implications are twofold: first, this leachate is persistent and less likely to be naturally attenuated; second, it poses long-term risks to nearby aquatic ecosystems.

Ammonia and nitrate levels were notably high in leachate and surface water samples. The ammonia concentration in leachate (104.2 mg/L) far exceeds WHO's safe drinking water limit (0.5 mg/L), confirming that nitrogen pollution from the dumpsite is severe. High ammonia levels can lead to eutrophication and oxygen depletion in receiving water bodies, thus affecting aquatic organisms. Similar ammonia levels have been documented in the Pugu dumpsite in Tanzania by Hassan, et al., (2024), validating this pattern in sub-Saharan African cities with inadequate waste segregation.

Impact on Surface and Groundwater

The leachate clearly affected nearby water bodies. The stream adjacent to the Okwe dumpsite exhibited elevated EC (1,120 µS/cm), BOD (37 mg/L), and nitrate (23.6 mg/L). These values suggest that the stream is receiving significant leachate runoff, especially during the rainy season. The presence of phosphate (3.4 mg/L) and ammonia (18.3 mg/L) further supports this inference. These nutrients are precursors to algal blooms and can degrade water quality rapidly, consistent with findings by Gungula and Inim (2023) on leachate-induced stream pollution in Akwa Ibom State.

Groundwater samples (G1 and G2) also showed contamination, although at lower concentrations than surface water. Notably, the concentrations of nitrate (10.4 and 9.5 mg/L), ammonia (4.8 and 4.3 mg/L), and TDS (710 and 690 mg/L) exceeded permissible limits in several cases. These findings point to vertical leachate infiltration through unlined soils—a scenario expected in Asaba's sandy loam terrain, especially during heavy rains. Akinbile , *et al.,* (2023) documented similar subsurface pollution in shallow aquifers in Nigeria, warning that such contamination poses chronic risks to human health.

The low dissolved oxygen (DO) in the stream (4.2 mg/L) compared to WHO's standard of ≥5 mg/L also indicates stress in the aquatic environment due to organic loading from the leachate.

Heavy Metal Contamination

Heavy metals detected in both surface and groundwater particularly lead (Pb), cadmium (Cd), iron (Fe), chromium (Cr), and manganese (Mn) were consistently above WHO safe drinking water limits. For example, lead concentrations in groundwater (0.10–0.12 mg/L) exceeded the permissible limit of 0.01 mg/L by up to tenfold. This poses significant health hazards such as neurotoxicity, kidney dysfunction, and developmental disorders in children, as emphasized by Dabla-Norris, *et al.,* (2023) in a similar context in Cameroon.

Cadmium, a known carcinogen, was present in both leachate and water sources at levels (0.02–0.05 mg/L) exceeding the WHO limit (0.003 mg/L). Zinc and copper, while essential in trace amounts, also showed elevated values, although they remained within or near permissible limits.

The strong correlation between heavy metals and COD/BOD values ($r > 0.75$) suggests that metal pollutants are likely co-transported with organic matter during leachate migration. This reinforces the concern that untreated leachate is a major vector of both organic and inorganic contaminants, as observed in leachate studies across Asia and sub-Saharan Africa (Khan, *et al.,* 2021).

Seasonal Variations in Pollution

Seasonal analysis revealed that concentrations of key pollutants ammonia, nitrate, and COD—were higher during the wet season than the dry season. This trend is attributed to increased percolation and runoff caused by heavy rainfall, which accelerates the transport of leachate into nearby water sources. Figure 1 illustrated this pattern clearly.

These seasonal fluctuations align with studies by Yusuf, *et al.,* (2023), who also observed that wet season sampling yielded higher microbial and chemical contaminant loads in water sources near dumpsites. In Asaba, this indicates a critical period when intervention measures such as diversion channels or temporary liners may be most effective in reducing leachate movement.

Environmental and Public Health Implications

The data present compelling evidence that the Okwe dumpsite poses serious threats to the environment and public health. Chronic exposure to contaminated groundwater, especially through boreholes within 300 meters of the dumpsite, could lead to long-term health issues, including cancer, liver damage, reproductive disorders, and neurological diseases.

Moreover, the stream draining the site ultimately connects to the River Niger, raising concerns about wider ecological impacts, including bioaccumulation of toxins in fish and subsequent entry into the food chain. This could affect not only the local population but also downstream communities relying on the river for domestic and agricultural use.

Additionally, elevated nutrient loads and organic pollution in surface water contribute to eutrophication, algal blooms, and depletion of aquatic biodiversity. These environmental changes disrupt natural ecosystems and reduce the sustainability of freshwater resources.

Gaps in Regulation and Site Management

The findings underscore major deficiencies in waste and water resource management in Asaba. The lack of a leachate collection and treatment system, absence of groundwater monitoring wells, and proximity of residential areas to the dumpsite contravene national guidelines issued by NESREA.

This situation is not unique to Asaba. Across Nigeria, most dumpsites are neither engineered nor regulated, functioning as open, uncontained landfills. As observed by Times Union (2024) in the context of developed countries, even advanced landfill systems may fail to address all contaminants further emphasizing the urgency for structured landfill upgrades in Nigeria.

Currently, enforcement of environmental standards is weak, and budgetary allocations for waste management are insufficient to implement modern systems like liner installations, leachate ponds, or constructed wetlands.

Conclusion

This study investigated the chemical characteristics of leachate generated from the Okwe municipal solid waste dumpsite in Asaba, Delta State, and assessed its impact on nearby surface and groundwater resources. The findings provide compelling evidence that leachate from the dumpsite is severely polluting the surrounding aquatic environment with both organic and inorganic contaminants.

Leachate samples were found to contain high levels of electrical conductivity (EC), total dissolved solids (TDS), biological oxygen demand (BOD), chemical oxygen demand (COD), and ammonia, indicating significant organic and ionic pollution. Additionally, dangerous concentrations of heavy metals notably lead (Pb), cadmium (Cd), iron (Fe), and chromium (Cr) were recorded, far exceeding the safe limits prescribed by the World Health Organization (WHO).

Both surface water (a nearby stream) and shallow groundwater wells within 300 meters of the dumpsite showed signs of contamination, suggesting that leachate percolation and runoff are active and seasonal mechanisms of pollutant transport. Seasonal analysis revealed that pollutant concentrations peaked during the wet season, driven by increased leaching and infiltration during heavy rainfall.

These results reveal a critical public and environmental health concern in Asaba and underscore the inadequacy of existing waste management practices. Without engineered barriers, leachate collection systems, or monitoring wells, dumpsites like Okwe pose chronic threats to human health, biodiversity, and water resource sustainability.

In conclusion, if immediate intervention is not taken, the persistence of toxic pollutants in drinking water sources and surface ecosystems will continue to escalate, leading to long-term health burdens and ecological degradation in the region.

Scientific and Policy Recommendations

The results point to the urgent need for:

- Installation of engineered liners and leachate treatment systems at the Okwe dumpsite.
- Establishment of buffer zones and relocation of boreholes at least 500 m from the site.
- Continuous groundwater and surface water monitoring using advanced analytical methods.
- Public awareness campaigns on the risks of consuming untreated water near dumpsites.
- Policy development for segregated waste collection, especially for hazardous and e-waste.

Declaration of Conflicting Interests

The authors declare no potential conflicts of interest with respect to the research, authorship and publication of this article.

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