

Physicochemical Characterization of Leachate and Groundwater at the Tam David-West Road Dumpsite, Port Harcourt, Nigeria: Nature, Magnitude and Spatial Distribution of Contaminant Loading

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Abstract

Uncontrolled municipal solid waste disposal remains a major source of subsurface contamination in rapidly urbanising Nigerian cities. This study characterised the physicochemical properties of leachate and groundwater within and around the Tam David-West Road dumpsite, Port Harcourt, Rivers State, Nigeria, in order to establish the nature, magnitude and spatial distribution of contaminant loading associated with the site. Leachate samples were collected from five points across the waste body and groundwater samples from five boreholes located within a 1000 m radius of the dumpsite, during both the dry and rainy seasons. Samples were analysed for pH, electrical conductivity (EC), total dissolved solids (TDS), total suspended solids (TSS), biochemical and chemical oxygen demand (BOD and COD), ammonia, chloride, nitrate, sulphate, phosphate, total hardness and the heavy metals iron, aluminium, copper, zinc, chromium, cadmium, lead and manganese, following American Public Health Association (APHA, 2017) procedures. Leachate was found to be near-neutral to slightly acidic (pH 6.1-6.6) and chemically aggressive, with mean BOD of 760 mg/L (dry) and 590 mg/L (rainy), COD of 785.4 mg/L (dry) and 606.6 mg/L (rainy), ammonia of 82.0 mg/L (dry) and 68.4 mg/L (rainy), and iron of 0.824 mg/L (dry) and 0.786 mg/L (rainy), all exceeding Federal Environmental Protection Agency (FEPA) effluent limits by wide margins. Cadmium (0.89-1.44 mg/L) and chromium (0.16-0.17 mg/L) were similarly elevated. Groundwater quality deteriorated markedly with proximity to the dumpsite, with the closest boreholes recording electrical conductivity up to 150 μ S/cm, total dissolved solids up to 105 mg/L, nitrate up to 35 mg/L and iron up to 6.10 mg/L (more than fifteen times the World Health Organization guideline of 0.3 mg/L), while the most distant boreholes approached background conditions. Concentrations of nearly all measured parameters were higher in the dry season than in the rainy season, reflecting reduced dilution during periods of low rainfall, while the spatial decline in contaminant concentration away from the dumpsite indicates a locally sourced, waste-derived contaminant loading rather than a regional geochemical signature. These findings confirm that the dumpsite continues to generate a chemically aggressive, spatially concentrated leachate plume that measurably influences the physicochemical quality of the surrounding shallow aquifer, and they provide a quantitative baseline for subsequent hydrogeophysical delineation of the plume and for groundwater protection planning in the study area.

Keywords: landfill leachate; groundwater contamination; physicochemical characterisation; heavy metals; contaminant loading; Niger Delta

1. Introduction

The accelerating pace of urbanisation, population growth and industrial activity in Nigerian cities has increased both the volume and chemical complexity of municipal solid waste (Kjeldsen *et al.*, 2002). Where such waste is disposed of without engineered containment, rainfall infiltration and the decomposition of organic material generate leachate, a chemically variable liquid whose composition depends on waste characteristics, landfill age, climate and hydrogeological setting (Kjeldsen *et al.*, 2002; Christensen *et al.*, 2001). Once generated, leachate can mobilise dissolved organic matter, inorganic macro-components and heavy metals into the unsaturated zone and, under favourable hydrogeological conditions, into underlying groundwater (Öman & Junestedt, 2008). The physicochemical characterisation of leachate and of groundwater in the vicinity of a dumpsite is the essential first step in any environmental assessment of contaminant loading, because it establishes both the pollution strength of the source and the extent to which that pollution has already been transmitted to a receptor. Physicochemical parameters such as pH, electrical conductivity, total dissolved and suspended solids, biochemical and chemical oxygen demand, major ions and heavy metals are widely used to characterize the nature and magnitude of contaminant loading in landfill-affected environments (Renou *et al.*, 2008; Mor *et al.*, 2006). Comparing these parameters across sampling locations and seasons further reveals the spatial distribution of contamination and its sensitivity to rainfall-driven dilution and recharge. Port Harcourt, a rapidly developing city in the Niger Delta, provides an important setting for such an investigation because of its extensive waste generation, high community dependence on groundwater, and the presence of numerous dumpsites operating without engineered liners or leachate management infrastructure. The Tam David-West Road dumpsite, despite its reported decommissioning, continues to receive waste and has been in continuous operation for over ten years, accommodating a heterogeneous mixture of municipal, industrial, biomedical and electronic waste. The site is underlain by the highly permeable, unconsolidated sands of the Benin Formation, with a shallow water table and high annual rainfall, conditions that collectively favour rapid downward and lateral migration of leachate-derived contaminants. Although the general risks associated with unmanaged dumpsites in the Niger Delta are increasingly recognised, site-specific quantitative evidence on the physicochemical characteristics of leachate and groundwater at the Tam David-West Road dumpsite, and on how contaminant loading varies with distance from the dumpsite and with season, has remained limited. This gap constrains effective environmental monitoring and informed groundwater protection planning. The present article addresses this gap by reporting the physicochemical and heavy metal characteristics of leachate and groundwater sampled within and around the dumpsite during both the dry and rainy seasons, corresponding to the first objective of a wider hydrogeological investigation of leachate plume dynamics and aquifer vulnerability at the site. Specifically, the article aims to establish the nature of the contaminants present, their magnitude relative to regulatory guideline values, and the pattern of their spatial and seasonal distribution around the dumpsite.

2. Materials and Methods

2.1 Study Area

The Tam David-West Road dumpsite is located within Obio/Akpor Local Government Area of Rivers State, Nigeria, approximately 2.72 km from Rumuokoro Junction within the Greater Port Harcourt metropolis. The site lies at an elevation of approximately 24 m above mean sea level, on a gently sloping terrain (average slope ~11%), with drainage oriented generally towards the southwest. The area falls within the humid tropical climate of the Niger Delta, with

a bimodal rainfall pattern, annual precipitation exceeding 2,200 mm concentrated mainly between April and October (wet season), and a comparatively drier period from November to March (dry season) associated with the Harmattan.

Geologically, the shallow subsurface is dominated by the Benin Formation, consisting of unconsolidated, medium- to coarse-grained sands with localised clay interbeds and high porosity and permeability. This formation hosts the shallow, unconfined aquifer that supplies domestic groundwater to surrounding communities, typically at depths of 30-45 m. The combination of high rainfall, shallow water table, permeable sandy soils and the absence of engineered containment at the dumpsite creates conditions that are highly favourable for the generation and downward migration of leachate.

2.2 Sampling Procedure

Leachate and groundwater sampling were structured to capture both spatial and seasonal variability in contaminant concentrations, in line with the first objective of characterising the nature, magnitude and spatial distribution of contaminant loading. Five composite leachate samples (LS1-LS5) were collected at intervals of 20-50 m across the dumpsite from surface pools and seepage points, using 1-litre acid-washed polyethylene bottles preserved at 4 °C. Five groundwater samples were collected from boreholes (BH1-BH5) located at increasing distance within a 1000 m radius of the dumpsite, along transects representing up-gradient, mid-gradient and down-gradient positions relative to the waste body, so as to evaluate the influence of proximity on groundwater quality. Each borehole was purged for 5-10 minutes before sampling to remove stagnant water. Sampling was repeated in both the dry and rainy seasons over a twelve-month monitoring period to capture seasonal variation in leachate generation, contaminant concentration and groundwater response. On-site parameters (pH, temperature, electrical conductivity and total dissolved solids) were measured immediately using a calibrated Hanna HI9810-5 multi-parameter meter, while samples for laboratory analysis were transported under refrigeration.

2.3 Laboratory Analysis

Physicochemical analyses followed American Public Health Association (APHA, 2017) standard methods. pH and electrical conductivity were determined using a calibrated Hanna HI9810-5 multi-parameter meter; total dissolved solids were derived from conductivity using the instrument's internal conversion; total suspended solids were determined gravimetrically after filtration and oven-drying; biochemical oxygen demand was determined by the five-day Winkler titrimetric method; chemical oxygen demand was determined by the closed-reflux colorimetric method; and chloride, sulphate, nitrate and phosphate were determined by UV-Visible spectrophotometry (Jenway 6715) following appropriate colour-development procedures. Total hardness was determined by EDTA complexometric titration.

Heavy metals (iron, aluminium, copper, zinc, chromium, cadmium, lead and manganese) were determined by Atomic Absorption Spectrophotometry (Buck Scientific Model 205) following acid digestion of filtered (0.45 µm), nitric-acid-preserved samples using USEPA Method 3010B, with hydrogen peroxide added to complete oxidation of residual organic matter.

2.4 Quality Assurance and Quality Control

Analytical reliability was maintained through equipment calibration, the use of reagent blanks and duplicate samples, triplicate field sampling, and chain-of-custody documentation. Instrument calibration (Hanna HI9810-5 multi-parameter meter, Jenway 6715 UV-Visible spectrophotometer and Buck Scientific Model 205 atomic absorption spectrophotometer) was performed daily using standard reference solutions traceable to the National Institute of Standards and Technology (NIST), with buffer solutions of pH 4.0, 7.0 and 10.0 used for pH

standardisation. Reagent blanks, field and analytical duplicates, and certified standard reference materials were analysed alongside every batch of environmental samples to check for contamination, instrument drift and analytical accuracy. Analytical precision was accepted where the relative standard deviation between duplicates was below 10%.

2.5 Data Analysis

Laboratory results were organised in Microsoft Excel 2021 and summarised using descriptive statistics (mean, minimum and maximum) for each parameter, by season and by sampling location, to characterise the magnitude and spatial distribution of contaminant loading. Mean concentrations were compared against Federal Environmental Protection Agency (FEPA, 1991) effluent limits, for leachate, and World Health Organization (WHO, 2022) drinking-water guideline values, for groundwater, to evaluate the environmental significance of the observed concentrations.

3. Results

3.1 Physicochemical Characteristics of Leachate

The physicochemical characteristics of leachate sampled across the five leachate points (LS1-LS5) in the dry and rainy seasons are summarised in Table 1. Leachate pH ranged from acidic in the dry season (mean ~6.1) to near-neutral in the rainy season (mean ~6.6), indicating a system transitioning from the acidogenic towards the methanogenic phase of waste stabilisation. Organic pollution indicators were markedly elevated in both seasons: mean BOD was 760 mg/L (dry) and 590 mg/L (rainy), while mean COD was 785.4 mg/L (dry) and 606.6 mg/L (rainy), giving a BOD/COD ratio of approximately 0.97 in both seasons, indicative of an unusually fresh and highly biodegradable waste mass. Ammonia averaged 82.0 mg/L (dry) and 68.4 mg/L (rainy), while chloride, nitrate, sulphate and phosphate were all higher in the dry season than in the rainy season, consistent with reduced dilution during periods of low rainfall. Figure 1 illustrates the seasonal contrast in the principal organic and nutrient parameters.

Table 1: Mean physicochemical characteristics of leachate, Tam David-West Road dumpsite (n = 5 points per season)

Parameter	Unit	Dry season (mean)	Rainy season (mean)	FEPA limit
pH	-	6.11	6.60	6-9
BOD	mg/L	760.0	590.0	-
COD	mg/L	785.4	606.6	-
Ammonia	mg/L	82.0	68.4	-
Chloride	mg/L	59.3	20.9	600
Nitrate	mg/L	27.2	14.3	20
Sulphate	mg/L	47.1	16.8	-
Phosphate	mg/L	3.7	1.8	50

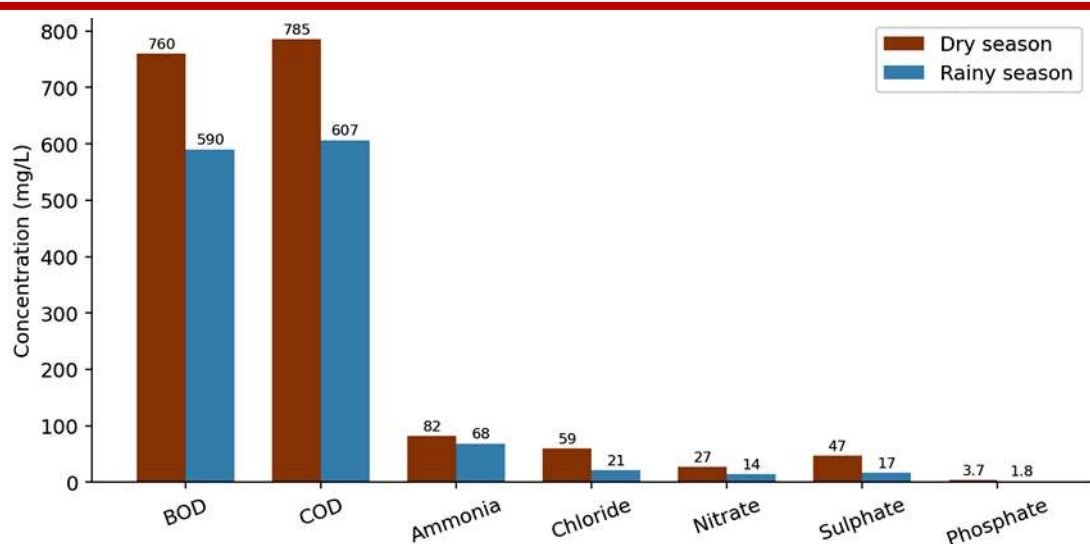


Figure 1: Seasonal variation in organic and nutrient loading of leachate

3.2 Heavy Metal Concentrations in Leachate

Table 2 presents the heavy metal concentrations recorded in leachate. Iron averaged 0.824 mg/L (dry) and 0.786 mg/L (rainy), exceeding the FEPA effluent limit of 0.05 mg/L by more than fifteen-fold in both seasons. Cadmium was the most environmentally concerning metal detected, averaging 0.894 mg/L (dry) and rising to 1.440 mg/L (rainy), well above levels considered safe for aquatic and human exposure. Chromium (0.164-0.170 mg/L) approached or slightly exceeded typical regulatory guidance, while copper (1.762-1.806 mg/L) and zinc (1.710-1.858 mg/L) were also elevated, consistent with inputs from metal scraps, batteries and electrical waste within the mixed waste stream. Figure 2 compares these concentrations with applicable FEPA limits.

Table 2: Mean heavy metal concentrations in leachate, Tam David-West Road dumpsite (n = 5 points per season)

Metal	Unit	Dry season (mean)	Rainy season (mean)	FEPA limit
Iron (Fe)	mg/L	0.824	0.786	0.05
Copper (Cu)	mg/L	1.806	1.762	2.0
Zinc (Zn)	mg/L	1.710	1.858	1.53-1.66
Chromium (Cr)	mg/L	0.164	0.170	0.20
Cadmium (Cd)	mg/L	0.894	1.440	0.003-<1

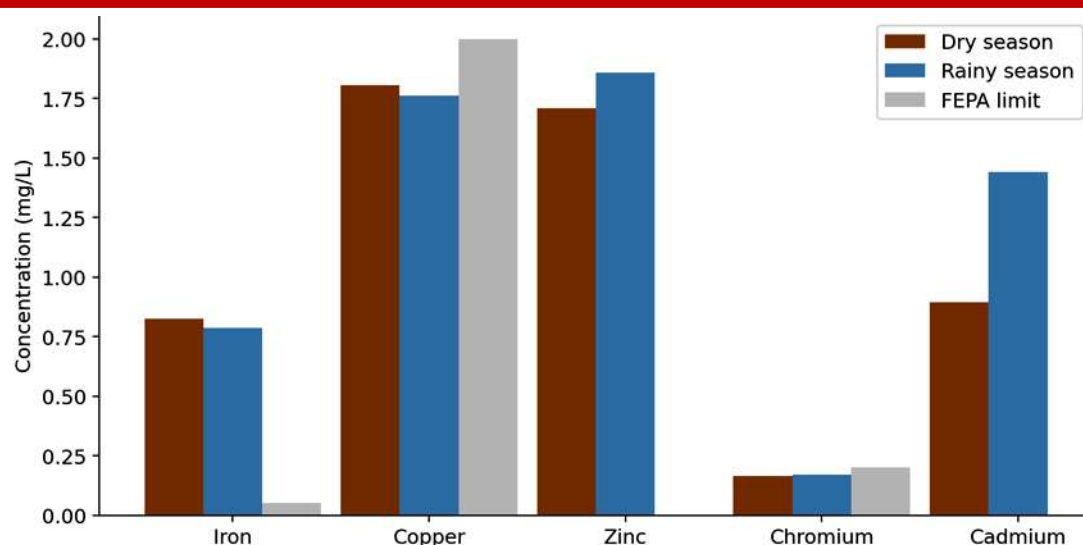


Figure 2: Seasonal heavy metal concentrations in leachate compared with FEPA limits

3.3 Physicochemical Characteristics of Groundwater

Table 3 summarises groundwater physicochemical characteristics from the five boreholes (BH1-BH5), arranged in order of increasing distance from the dumpsite. A clear spatial gradient was evident: BH1, the closest borehole, recorded the highest electrical conductivity (150 $\mu\text{S}/\text{cm}$ dry; 12 $\mu\text{S}/\text{cm}$ rainy), total dissolved solids (105 mg/L dry), total hardness, chloride (69.4 mg/L) and nitrate (34-35 mg/L), while values declined progressively towards BH4 and BH5, the most distant boreholes, which approached background conditions. Mean electrical conductivity across all boreholes was 90.6 $\mu\text{S}/\text{cm}$ (dry) and 21.6 $\mu\text{S}/\text{cm}$ (rainy); mean total dissolved solids were 63.4 mg/L (dry) and 11.0 mg/L (rainy); and mean nitrate was 27.4 mg/L (dry) and 6.9 mg/L (rainy). Groundwater pH was slightly acidic overall (mean 5.25 dry; 5.93 rainy), falling below the WHO/NSDWQ range of 6.5-8.5 in several boreholes, particularly during the dry season. As with the leachate, nearly every parameter was higher in the dry season than in the rainy season, reflecting reduced recharge-driven dilution. Figure 3 illustrates these seasonal contrasts.

Table 3: Mean physicochemical characteristics of groundwater, boreholes within 1000 m of the dumpsite (n = 5 boreholes per season)

Parameter	Unit	Dry season (mean)	Rainy season (mean)	WHO limit
EC	$\mu\text{S}/\text{cm}$	90.6	21.6	382-512
TDS	mg/L	63.4	11.0	1000
pH	-	5.25	5.93	6.5-8.5
Turbidity	FAU	1.6	2.4	<5
Total Hardness	mg/L CaCO_3	40.8	10.4	<200
Chloride	mg/L	52.9	11.4	250
Nitrate	mg/L	27.4	6.9	50
Sulphate	mg/L	2.1	0.2	250
Phosphate	mg/L	6.7	1.4	0.1

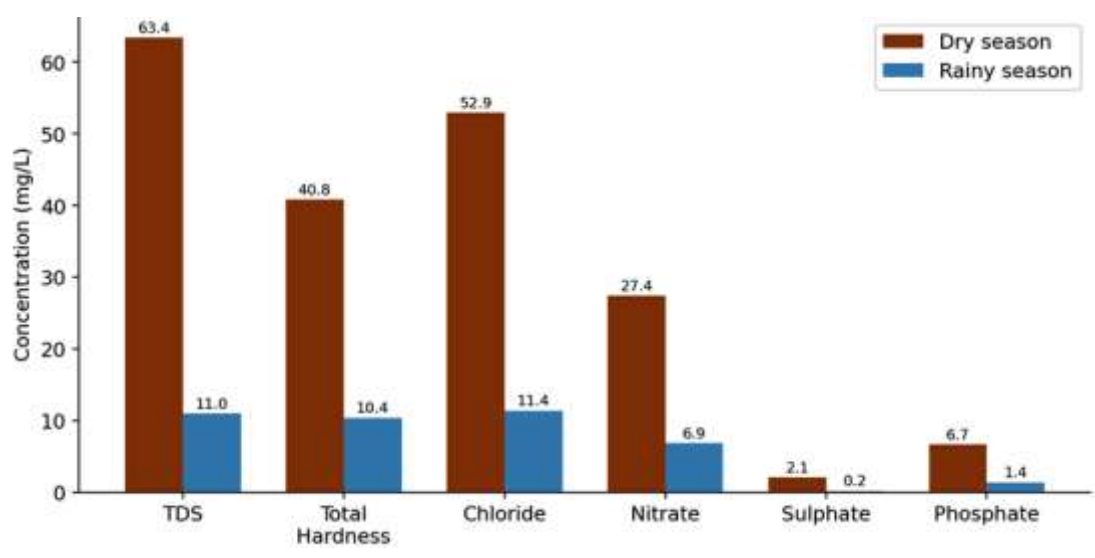


Figure 3: Seasonal variation in borehole (groundwater) physicochemical parameters

3.4 Heavy Metal Concentrations in Groundwater

Table 4 presents groundwater heavy metal concentrations. Iron was the only metal to exceed its guideline value at every borehole, averaging 4.55 mg/L in the dry season and 1.25 mg/L in the rainy season, more than fifteen times the WHO limit of 0.3 mg/L even during the wetter, more dilute season, and reaching a maximum of 6.10 mg/L at BH2 in the dry season (Figure 4). Copper, lead, manganese and zinc were present at low concentrations, generally below or only marginally above guideline values, while aluminium was not detected in any sample. Lead exceeded the WHO limit of 0.01 mg/L only in isolated dry-season samples (maximum 0.02 mg/L at BH4), suggesting early-stage, spatially limited impact rather than widespread contamination.

Table 4: Mean heavy metal concentrations in groundwater, boreholes within 1000 m of the dumpsite ($n = 5$ boreholes per season)

Metal	Unit	Dry season (mean)	Rainy season (mean)	WHO limit
Iron (Fe)	mg/L	4.550	1.252	0.3
Aluminium (Al)	mg/L	0.000	0.000	0.05-0.2
Copper (Cu)	mg/L	0.066	0.009	2
Lead (Pb)	mg/L	0.010	0.003	0.01
Manganese (Mn)	mg/L	0.004	0.001	0.4
Zinc (Zn)	mg/L	0.018	0.003	5

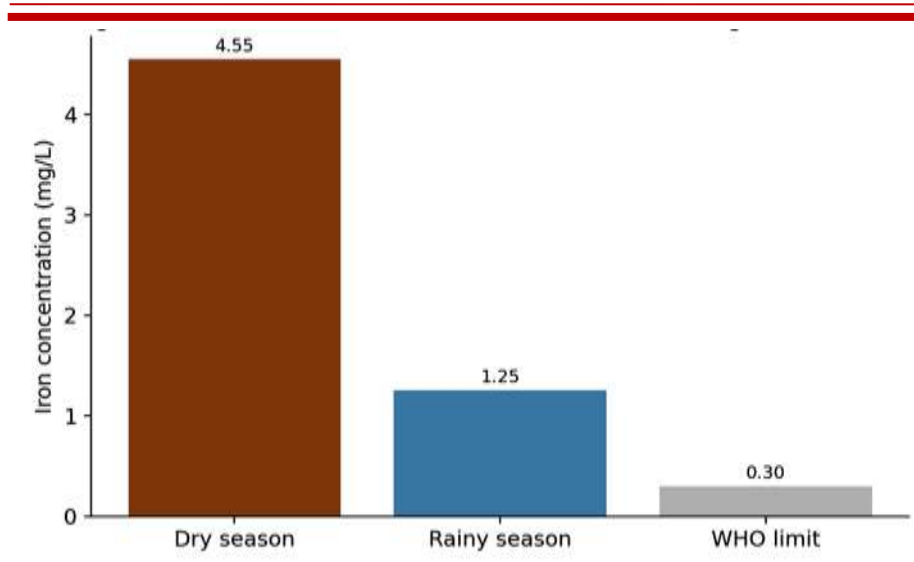


Figure 4: Mean borehole iron concentration versus WHO guideline value

4. Discussion

4.1 Nature and Magnitude of Contaminant Loading in Leachate

The physicochemical characteristics of the leachate confirm that the Tam David-West Road dumpsite continues to function as an active source of contaminant generation. The slightly acidic to near-neutral pH range observed indicates a system in transition from the acidogenic towards the methanogenic phase of landfill stabilisation, during which organic acids produced by decomposition progressively give way to more neutral conditions as methanogenic microorganisms become dominant (Christensen *et al.*, 2001). Similar acidic leachate conditions have been reported in other active African dumpsites undergoing anaerobic decomposition (Nyirenda & Mwansa, 2022). This acidity is environmentally significant because lower pH enhances the solubility and mobility of heavy metals, thereby increasing the potential for their transfer into groundwater. The high BOD and COD values, and the resulting BOD/COD ratio of approximately 0.97, indicate that the leachate is unusually fresh and highly biodegradable, more characteristic of a young, actively tipped waste mass than of a site that has progressed substantially towards stabilisation. This finding is consistent with Reddy *et al.* (2026), who reported comparable biodegradability characteristics in actively decomposing tropical landfill systems, and reflects the continuous, unmanaged addition of fresh municipal waste onto older material at the dumpsite. Elevated ammonia concentrations further confirm extensive degradation of nitrogen-containing organic matter; ammonia is widely recognised as one of the dominant nitrogen species in landfill leachate arising from anaerobic decomposition of proteins and amino acids (Kjeldsen *et al.*, 2002). Chloride, nitrate, sulphate and phosphate concentrations were all higher in the dry season than in the rainy season, a pattern attributable to reduced dilution when infiltration and recharge are lower. Chloride is widely regarded as a conservative tracer of leachate contamination because it is highly soluble and undergoes limited chemical transformation in the subsurface (Freeze & Cherry, 1979); its elevated concentration in the leachate therefore signals substantial potential for downstream groundwater impact. Elevated nitrate is consistent with nitrification of ammonium and decomposition of organic nitrogen (Ezeikpe, 2024), and elevated phosphate with the decomposition of food waste and domestic refuse components (Mor *et al.*, 2006); by contrast, the comparatively low sulphate concentrations recorded may reflect sulphate reduction under the anaerobic conditions typical of an actively decomposing waste mass (Christensen *et al.*, 2001).

4.2 Heavy Metal Composition and Environmental Significance

The heavy metal composition of the leachate confirms that the dumpsite receives mixed waste inputs, consistent with common sources such as batteries, electronic waste, paints and metal scraps (Alloway, 2013). Iron concentrations, although environmentally significant, may partly reflect natural weathering of lateritic soils in addition to corrosion of metallic waste, a pattern also reported in other tropical lateritic landfill settings (Odukoya & Abimbola, 2010). Copper and zinc were relatively elevated in both leachate and, to a much lesser extent, groundwater, and are commonly associated with galvanised materials, batteries and electrical components; while both are essential micronutrients at trace concentrations, excessive accumulation can become toxic to aquatic organisms and to humans (Alloway, 2013).

Cadmium was the most concerning metal identified, exceeding permissible environmental limits in the leachate in both seasons and increasing further in the rainy season. Cadmium is highly toxic even at low concentrations and is recognised for its persistence and bioaccumulative behaviour; prolonged exposure has been associated with kidney dysfunction, skeletal disorders and carcinogenic effects (WHO, 2022). Similarly elevated cadmium levels have been reported at other unmanaged dumpsites in developing countries where waste segregation is poorly practised (Ezeikpe, 2024). Chromium concentrations approached or slightly exceeded recommended limits, plausibly reflecting inputs from paints, dyes and leather-related waste; because chromium mobility is strongly influenced by pH, the slightly acidic conditions recorded in the leachate may enhance its solubility and transport (Alloway, 2013). The coexistence of elevated organic matter and heavy metals is itself significant, since dissolved organic matter can enhance heavy metal mobility through complexation, increasing the persistence and migration potential of metals within groundwater systems (Duan *et al.*, 2024).

4.3 Spatial and Seasonal Distribution of Groundwater Contamination

The clear decline in electrical conductivity, total dissolved solids, chloride, nitrate and iron with increasing distance from the dumpsite provides direct evidence that the observed groundwater quality deterioration is attributable to a locally sourced, waste-derived contaminant loading rather than a regional geochemical background. Boreholes located closer to the dumpsite consistently recorded the most degraded water quality, a spatial pattern that has also been documented at other Nigerian dumpsites (Akinbile & Yusoff, 2011; Odukoya, Arowolo & Bamgbose, 2019). The slightly acidic pH recorded in both leachate and nearby groundwater further supports the interpretation that contaminant migration is actively influencing groundwater chemistry, since acidic conditions increase the dissolution potential of heavy metals and enhance their persistence within the aquifer.

The consistently higher concentrations recorded in the dry season across almost every parameter, in both leachate and groundwater, demonstrate the dominant control that rainfall-driven dilution exerts on measured contaminant concentrations at this site: reduced recharge during the dry season concentrates dissolved constituents, while increased infiltration during the rainy season dilutes them even as it may simultaneously increase the total mass of contaminant flux into the subsurface. This has practical implications for any future monitoring programme, which should sample across both seasons to avoid misrepresenting either the peak contaminant concentrations reached in the dry season or the greater hydraulic loading that occurs during the rains. The detection of iron at concentrations exceeding the WHO guideline value at every borehole, together with more localised and lower-magnitude impacts from lead, copper, manganese and zinc, indicates a groundwater system that is already measurably impacted by the dumpsite, with the potential for further deterioration should waste disposal continue without engineered containment. Because groundwater remains the principal source of domestic water for many peri-urban communities in this part of Port Harcourt, these findings

carry direct implications for public health, particularly given the tendency of iron and other metals to persist and, in the case of nitrate and heavy metals, to pose specific risks such as methemoglobinemia in infants and chronic accumulation-related disease (WHO, 2022).

5. Conclusion

This study characterised the physicochemical properties of leachate and groundwater within and around the Tam David-West Road dumpsite, Port Harcourt, in order to establish the nature, magnitude and spatial distribution of contaminant loading associated with the site. The leachate was found to be chemically aggressive, near-neutral to slightly acidic, and heavily loaded with biodegradable organic matter, ammonia and heavy metals, particularly iron and cadmium, at concentrations that greatly exceeded applicable FEPA effluent limits in both the dry and rainy seasons. Groundwater quality declined systematically with proximity to the dumpsite, with the closest boreholes recording markedly elevated conductivity, dissolved solids, nitrate and iron relative to more distant locations, and iron exceeded the WHO guideline value at every borehole sampled. Concentrations of nearly all parameters were higher in the dry season than in the rainy season, reflecting the strong control exerted by rainfall-driven dilution and recharge on contaminant concentration at this site. Collectively, these findings establish a robust, quantitative baseline confirming that the dumpsite generates a chemically aggressive and spatially concentrated contaminant load capable of measurably degrading the physicochemical quality of the surrounding shallow, unconfined aquifer. This baseline provides the essential physicochemical foundation for the subsequent hydrogeological and hydrogeophysical delineation of the leachate plume, and underscores the urgency of engineered leachate containment, groundwater protection zoning and continued seasonal monitoring at the site.

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