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Research article

PHYSICOCHEMICAL AND HEAVY METAL CHARACTERIZATION OF DUMPSITE LEACHATE AFFECTING SURFACE WATER INTAKE POINTS IN CROSS RIVER STATE, NIGERIA

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ABSTRACT

This study assessed the physicochemical, bacteriological, and heavy metal characteristics of dumpsite leachate affecting surface water quality in Cross River State, Nigeria. Mixed-method comparative cross-sectional design involving field sampling, laboratory analysis, and Geographic Information System (GIS) mapping was adopted. Water samples were collected from impact, intake, and control points in Ikom and Calabar during both wet and dry seasons and analyzed using standard World Health Organization (WHO) and Nigerian Industrial Standards (NIS) procedures. Data were analyzed using Analysis of Variance (ANOVA). The findings showed elevated concentrations of ammonia (4.16 mg/L), biochemical oxygen demand (18.25 mg/L), phosphate (3.81 mg/L), nitrate (60.50 mg/L), nitrite (0.18 mg/L), and sulfide (0.22 µg/L), exceeding permissible limits. Heavy metal analysis revealed high levels of copper (0.62 mg/L), chromium (1.16 mg/L), and manganese (1.05 mg/L), while other metals remained within acceptable standards. Total coliform and Escherichia coli counts were 600 CFU/100 mL and 311 CFU/100 mL, respectively. ANOVA indicated significant variations in water quality among sampling locations ($F = 5.42$, $p = 0.008$), confirming leachate influence on receiving waters. The study concludes that dumpsite leachate degrades surface water quality, poses environmental and public health risks, recommending stricter waste management, routine monitoring, and improved water treatment.

KEYWORDS

Dumpsite, leachate, surface water quality, heavy metals, physicochemical parameters, Bacteriological parameters, water contamination, water intake points.

Introduction

Dumpsites have become major sources of environmental pollution due to the continuous release of leachate into surrounding soils and nearby surface water bodies. Leachate is a contaminated liquid formed when rainwater passes through decomposing waste materials, dissolving harmful substances and transporting them into the environment. This liquid often contains dangerous physicochemical pollutants and heavy metals capable of degrading water quality and threatening both human health and aquatic ecosystems. Studies have revealed that dumpsite leachates commonly contain high levels of pH imbalance, total dissolved solids, chemical oxygen demand, biological oxygen demand, nitrates, sulphates, and toxic metals such as lead, cadmium, chromium, and nickel (Karagozoglu & Asar, 2023). According to Alao (2023), uncontrolled dumpsite leachates can severely contaminate surrounding soil and groundwater, especially in areas lacking proper waste management systems. Research conducted around the Idemili River in Nigeria also identified elevated concentrations of physicochemical pollutants and heavy metals in dumpsite leachates, showing their direct impact on nearby water resources (Dibua et al., 2025). Similarly, Koliyabandara et al. (2022) reported that leachate migration from open dumpsites significantly contributed to water pollution in surrounding environments. Furthermore, Alao et al. (2023) explained that leachate plumes can spread through both surface and groundwater systems, increasing the risk of ecological damage and public exposure to toxic substances. As urbanization, industrialization, and population growth continue to increase waste generation, the physicochemical and heavy metal characterization of dumpsite leachate has become essential for assessing pollution levels, protecting surface water quality, and promoting sustainable environmental management.

The contamination of surface water by dumpsite leachate has become a serious environmental issue due to rapid urbanization, industrial growth, and poor waste disposal practices. In many developed nations, extensive studies have shown that leachates from landfills and open dumpsites contain hazardous physicochemical pollutants and heavy metals capable of altering the quality of nearby rivers, streams, and water intake points used for domestic and industrial purposes. Research in Iraq revealed significant seasonal variations in leachate composition, with elevated levels of dissolved solids, organic pollutants, and toxic metals affecting surrounding groundwater and surface water systems (Rashid et al., 2022). Similarly, studies from Ethiopia demonstrated that unmanaged dumping sites possess high pollution potentials capable of severely degrading surface water quality through leachate infiltration and runoff (Tesseme et al., 2022). In addition, investigations into e waste disposal sites have shown that landfill leachates are important sources of heavy metal pollution, especially lead, cadmium, chromium, and mercury, which pose long term ecological and public health risks (Adu & Aneke, 2025). According to Alao et al. (2023), leachate plumes can spread through both surface and groundwater systems, increasing the exposure of nearby communities to toxic contaminants and waterborne diseases.

The problem of dumpsite leachate contamination has intensified due to inadequate waste management infrastructure, weak environmental monitoring systems, and increasing population pressure. In several African cities, open dumpsites are commonly located close to rivers, streams, and residential communities, making nearby surface water intake points highly vulnerable to contamination. Research conducted around the Iringa municipal dumpsite in Tanzania identified alarming concentrations of heavy metals in leachates and surrounding groundwater, demonstrating the direct influence of waste disposal activities on water quality and environmental health (Sanga et al., 2023). In Nigeria, studies have consistently reported elevated levels of physicochemical pollutants and heavy metals in leachates surrounding major dumpsites. Investigations carried out in Rivers State revealed high concentrations of parameters such as total dissolved solids, biochemical oxygen demand, chlorides, sulphates, and toxic metals in both leachate and groundwater samples collected around solid waste dumpsites (Onwualu John & Ugbena, 2022). Similarly, Olagbemiro et al. (2025) observed that leachate contamination around dumpsites in Onne significantly affected surrounding groundwater quality and increased the risk of environmental pollution and microbial contamination.

Increasing urban growth, population expansion, and poor waste management practices have heightened concerns regarding the contamination of surface water intake points by dumpsite leachates in Cross River State (Omang et al., 2023). Many communities in the state depend heavily on rivers, streams, and boreholes for domestic water supply, making water quality protection extremely important. However, the indiscriminate disposal of solid waste near drainage channels and water bodies has created conditions for leachate migration into nearby surface water systems (Isong et al., 2025). Recent findings by Edet et al. (2025) revealed significant deterioration in both surface water and groundwater quality around dumpsites in Cross River State, with detectable levels of heavy metals and pollutants capable of posing serious human health risks. These pollutants can accumulate in aquatic organisms, reduce water quality, and expose residents to diseases associated with toxic metal consumption. The physicochemical and heavy metal characterization of dumpsite leachate affecting surface water intake points in Cross River State is therefore essential for evaluating contamination levels, understanding environmental risks, and developing effective waste management and water protection strategies for sustainable public health and environmental safety.

The increasing generation of solid waste and the continued reliance on open dumpsites in many parts of Nigeria have raised serious environmental concerns, particularly regarding the quality of nearby water resources (Amuyo et al., 2013). Leachate produced from these dumpsites often contains a mixture of physicochemical pollutants and heavy metals that can migrate into surrounding surface and groundwater systems. Studies have shown that such contamination is not limited to isolated locations but is widespread across different regions (Eneyo et al., 2023). For instance, investigations around dumpsites in Rivers State revealed elevated levels of physicochemical parameters and heavy metals in both leachate and groundwater, indicating strong interactions between waste disposal sites and surrounding water bodies (Onwualu John & Ugbena, 2022). Similarly, Olagbemiro et al. (2025) reported that dumpsite leachates contain significant concentrations of toxic metals and microbial contaminants capable of degrading water quality and increasing environmental health risks. Despite these findings, surface water intake points in many communities continue to serve as primary sources of domestic water supply without adequate protection from contamination sources.

Surface water bodies remain highly vulnerable due to their proximity to uncontrolled dumpsites in Cross River State, yet systematic assessment of leachate influence on these intake points is still limited. Existing evidence suggests that water resources around dumpsites in the state are already experiencing varying levels of pollution. Edet et al. (2025) observed that both surface water and groundwater around dumpsites in Cross River State show signs of contamination, with associated human health risks linked to prolonged exposure to polluted water sources. However, most studies tend to focus broadly on groundwater or general water quality, with less emphasis on the specific contribution of dumpsite leachate to surface water intake points that communities directly depend on. This creates a knowledge gap in understanding the extent to which physicochemical and heavy metal contamination from leachate is influencing surface water used for domestic consumption.

There is limited integrated data linking leachate composition directly to the quality of surface water intake points in the study area, making it difficult for environmental managers and policymakers to design effective intervention strategies. While previous research has confirmed the presence of pollutants in dumpsite environments, the pathways through which these contaminants affect downstream water sources remain insufficiently quantified. This gap is critical because surface water intake points are often unprotected and highly exposed to runoff during rainfall events, increasing the risk of contamination. Therefore, there is a need for a detailed physicochemical and heavy metal characterization of dumpsite leachate and its influence on surface water intake points in Cross River State to provide scientific evidence for environmental monitoring, risk assessment, and sustainable water resource management.

Literature review

Physicochemical characteristics and heavy metal concentrations of dumpsite leachates on surface water quality

Studies have consistently shown that dumpsite leachates possess complex physicochemical properties and elevated heavy metal concentrations that significantly influence surrounding water systems. Research conducted in Nigeria revealed that leachates around solid waste dumpsites contain high levels of parameters such as electrical conductivity, chemical oxygen demand, biological oxygen demand, total dissolved solids, and major ions, alongside toxic metals like lead, cadmium, chromium, and nickel, all of which indicate severe pollution potential (Onwualu John & Ugbena, 2022). Similarly, Dibua et al. (2025) reported that leachates collected near the Idemili River exhibited elevated physicochemical loads and heavy metal concentrations, suggesting strong contamination pathways into adjacent water bodies. In Turkey, Karagozoglu and Asar (2023) observed that landfill leachates significantly alter surface water quality through increased organic pollution and metal enrichment, particularly during rainfall events that enhance leachate migration. Comparable findings in Tanzania showed that heavy metal accumulation in leachates poses a serious threat to groundwater and nearby aquatic environments, with contamination levels influenced by waste composition and environmental conditions (Sanga et al., 2023). Furthermore, studies on landfill ash and waste by Li et al. (2022) reinforce the fact that waste-derived materials contribute significantly to metal leaching processes, thereby intensifying environmental contamination risks. Additionally, research in Tehran demonstrated that landfill age influences the concentration and intensity of heavy metal pollution, with older sites generally producing more stable but persistent contamination loads (Beinabaj et al., 2023). These findings collectively indicate that physicochemical and heavy metal characteristics of dumpsite leachates are key determinants of surface water quality deterioration.

Further evidence highlights the direct influence of leachate composition on surface water systems, particularly in areas lacking engineered waste containment structures. Studies in Nigeria have shown that open dumpsites without proper lining systems allow leachate to infiltrate surrounding environments, leading to measurable degradation of nearby water bodies. For instance, Onwualu John and Ugbena (2022) found that leachate from Mbodo dumpsite significantly affected both groundwater and nearby surface water quality through elevated pollutant loads. Similarly, Karagozoglu and Asar (2023) emphasized that surface water bodies in proximity to landfills are highly vulnerable to contamination, especially during periods of heavy rainfall when leachate runoff increases. Dibua et al. (2025) also confirmed that physicochemical instability in leachate composition directly correlates with the deterioration of receiving water quality, particularly in riverine environments. Collectively, these studies establish a clear empirical link between leachate physicochemical properties, heavy metal concentration, and surface water quality degradation, demonstrating that unmanaged dumpsites remain a persistent environmental threat to aquatic systems.

Contamination and potential environmental and health risks associated with dumpsite leachate impact on surface water quality

Evidence has shown that dumpsite leachate contamination presents significant environmental and public health risks through its impact on surface water systems. Studies have demonstrated that leachate plumes can migrate through soil and water pathways, transporting toxic substances into rivers and streams used for domestic water supply. Alao (2023) reported that open dumpsite leachates contribute to the deterioration of both soil and groundwater quality, with contaminants often persisting in the environment for long periods due to their non degradable nature. In a related study, Alao et al. (2023) highlighted that leachate plumes significantly affect surface and groundwater systems, increasing exposure risks to toxic metals and organic pollutants among nearby populations. Furthermore, Aromolaran et al. (2023) observed that unlined municipal landfills in Nigeria led to measurable contamination of both surface and groundwater sources, thereby posing serious environmental safety concerns. Similarly, Tesseme et al. (2022) reported that dumping sites have high pollution potential, with surface water bodies near waste disposal areas showing elevated contamination indices that exceed safe environmental thresholds.

Additional studies have emphasized the broader health implications associated with long term exposure to leachate contaminated water sources. Alao (2025) explained that the movement of landfill leachate contaminants through environmental media is influenced by geophysical and geochemical factors, which in turn determine the extent of human exposure risks. This suggests that communities located near dumpsites are at continuous risk of ingesting harmful substances through contaminated surface water. Alao et al. (2025) further noted that environmental contaminants from dumpsite leachates are associated with a wide range of public health implications, including waterborne diseases, heavy metal toxicity, and chronic health disorders. These findings are supported by evidence showing that prolonged exposure to contaminated water bodies can lead to bioaccumulation of heavy metals in humans and aquatic organisms, thereby increasing long term ecological and health burdens. Collectively, these studies establish that dumpsite leachate not only degrades surface water quality but also poses significant environmental and public health threats, particularly in communities dependent on untreated surface water sources.

Methodology

The study adopted a mixed-method research design combining comparative cross-sectional comparative survey, laboratory analysis, and Geographic Information System (GIS) spatial mapping. This design was appropriate as it allowed for the identification, quantification, and spatial assessment of dumpsite leachate influence on surface water intake points in Calabar and Ikom. Surface water samples were collected from Qua River and Ikom River across three functional zones: the leachate impact point, the water abstraction point and a control point away from potential contamination sources. Sampling was conducted during both wet (September 2025) and dry (January 2026) seasons to capture seasonal variability. Triplicate samples were collected at each location, preserved at approximately 4°C, and transported to the laboratory for analysis. However, samples for BOD, COD, and microbiological analyses were not subjected to extended storage periods in order to minimize post-collection changes, and all analyses were carried out promptly in accordance with WHO and NSDWQ guidelines. Laboratory analysis covered physicochemical parameters including pH, temperature, turbidity, electrical conductivity, total dissolved solids, BOD, COD, nutrients, and selected heavy metals (lead, cadmium, chromium, zinc, nickel, copper, iron, manganese, mercury, and arsenic). Microbiological indicators such as total coliforms and Escherichia coli were also assessed using standard culture techniques. Heavy metal concentrations were determined using atomic absorption spectrophotometry, following appropriate sample digestion procedures and calibration with standard reference solutions to ensure accuracy, although detailed detection limits are not reported. Physicochemical parameters were measured using standard HACH methods.

GIS analysis was carried out using ArcMap 10.7 and Shuttle Radar Topography Mission (SRTM) digital elevation data to examine terrain characteristics and elevation patterns. While spatial maps were generated to illustrate site locations and topography, it did not include detailed hydrological modelling outputs such as flow direction, contour-based runoff modelling, or buffer distance analysis; therefore, interpretations of leachate movement were based primarily on elevation proximity rather than full hydrological simulation. GPS coordinates were used to georeference sampling points and produce location maps. Data from field sampling, laboratory analysis, and spatial mapping were analyzed using descriptive and inferential statistics. Mean, standard deviation, and range were used to summarize pollutant concentrations across sampling points, while one-way Analysis of Variance (ANOVA) was used to test for significant differences among impact, intake, and control points. Statistical analysis was performed using SPSS version 24, with significance set at $p < 0.05$. In addition, key informant interviews were conducted with stakeholders from the Cross River State Water Board and waste management agencies to obtain qualitative insights into waste handling practices, contamination pathways, and water treatment challenges.

Results and discussion

In Table 1, five sampling points were identified in Calabar, including a water intake point, an impact point representing leachate entry, a control point within the water system, and two dumpsite related locations along Ikot Omin–Idundu Road. The coordinates show that the water intake point, impact point, and control point share identical geographical positions at latitude 5.03038 and longitude 8.37289, indicating a very close spatial relationship between abstraction and potential contamination zones. The elevation at these points is 19 metres or 62 feet above sea level, while nearby dumpsite locations are slightly higher at 23 metres or 75 feet, suggesting a possible downhill movement of leachate toward the water system due to gravity driven surface runoff.

Table 1. Coordinates of Dumpsite and Water Intake Points in Calabar

S/N	Date / Time	Latitude	Longitude	Location Description	Address / Area Description	Elevation (m)	Elevation (ft)
1	2/8 – 1:29 PM	5.03038	8.37289	Water intake point 1	29JC+6P, Calabar 541102, Cross River State, Nigeria	19.0	62

S/N	Date / Time	Latitude	Longitude	Location Description	Address / Area Description	Elevation (m)	Elevation (ft)
2	2/8 – 1:33 PM	5.03038	8.37289	Impact point 1 (leachate entry)	29JC+6P, Calabar 541102, Cross River State, Nigeria	19.0	62
3	2/8 – 1:36 PM	5.03038	8.37289	Control point (water system)	29JC+6P, Calabar 541102, Cross River State, Nigeria	19.0	62
4	2/8 – 1:52 PM	5.0331686	8.3651883	Dumpsite control point	Ikot Omin–Idundu Road (29M8+566), Calabar, Cross River State	23.0	75
5	2/8 – 1:54 PM	5.0331686	8.3651883	Dumpsite sampling point 2	Ikot Omin–Idundu Road (29M8+566), Calabar, Cross River State	23.0	75

Source: Author's research, 2026.

Table 2 presents the sampling points along the Ikom River at the Cross River State Water Board intake site under Head Bridge. The study identified one water intake point, one impact point, and two control points for comparative assessment. The coordinates fall within a narrow spatial range around latitude 5.944807 to 5.948118 and longitude 8.702315 to 8.703160, indicating clustered sampling within the same hydrological environment. Elevation values range from 31 metres to 38 metres above sea level, showing a gentle slope that can influence flow direction and potential leachate migration into the river system.

Table 2. Coordinates of Sampling Points at Ikom River

S/N	Latitude (DMS)	Longitude (DMS)	Latitude (Decimal)	Longitude (Decimal)	Elevation (m)	Location Description
1	N 5°56'41.5788"	E 8°42'8.4348"	5.944883	8.702343	Not available	Water intake point 1
2	N 5°56'41.3052"	E 8°42'8.3340"	5.944807	8.702315	32.0	Impact point 1 (leachate entry zone)
3	N 5°56'41.5392"	E 8°42'8.3412"	5.944872	8.702317	31.0	Control point 1
4	N 5°56'53.2248"	E 8°42'11.3760"	5.948118	8.703160	38.0	Control point 2

Source: Author's research, 2026.

The maps present the spatial distribution of dumpsites and surface water systems, with the dumpsites indicated in brown and the Great Kwa River and related water bodies shown in blue. They also illustrate the likely pathways through which leachate may travel from waste disposal sites towards surface water intake points. Specifically, FIGURE 1. presents the digital elevation map showing the surface water intake point at Ikom, while FIG 2 presents the digital elevation map showing the surface water intake point at Lemna in Calabar. The spatial analysis indicates that both surface runoff and possible subsurface migration could facilitate the movement of leachates towards these intake locations, which are situated within close proximity to dumpsite influence zones. This proximity increases the likelihood of contamination of raw water sources used for treatment and public supply.

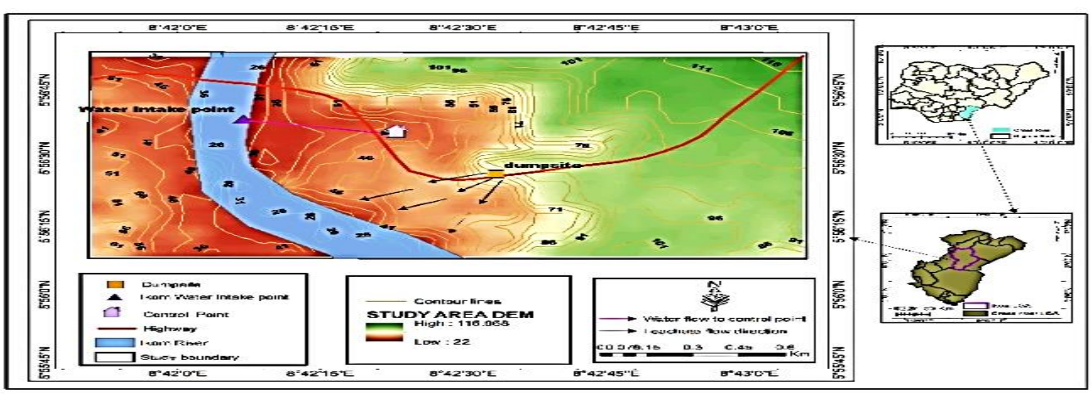

FIGURE 1.: Digital Elevation Map showing Surface Water Intake Point at Ikom

Source: GIS Laboratory Unit Geography Department UNICAL (2026).

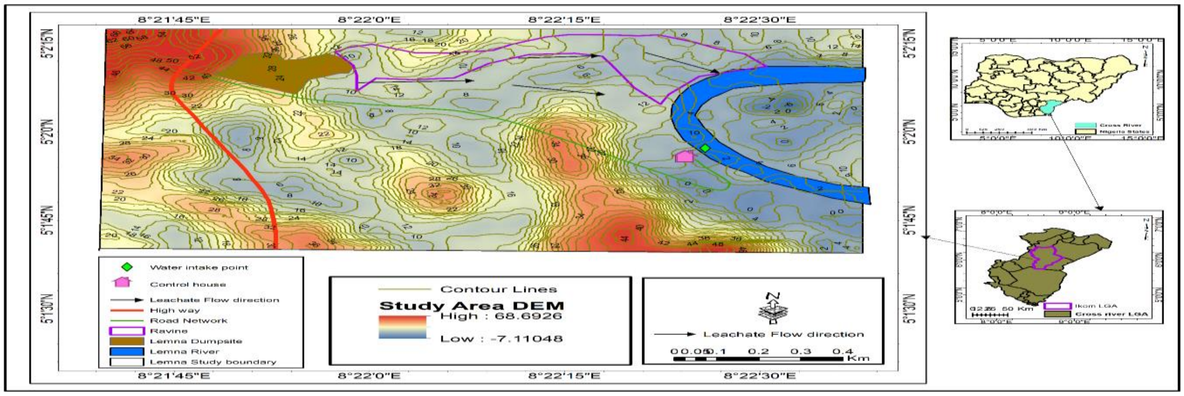

FIG 2: Digital Elevation Map showing surface water intake point at Lemna, Calabar

Source: GIS Laboratory Unit Geography Department UNICAL

Table 3 presents the quality characteristics of leachate at the water impact point in Ikom and compares the measured values with the Nigerian Industrial Standards (NIS) and World Health Organization (WHO) guidelines. The results indicate that several physicochemical parameters exceeded permissible limits, suggesting significant contamination. Ammonia (4.16 mg/L), biochemical oxygen demand (18.25 mg/L), phosphate (3.81 mg/L), nitrate (60.50 mg/L), nitrite (0.18 mg/L), and sulfide (0.22 µg/L) were all above recommended standards, reflecting high organic and nutrient loads in the leachate. In contrast, temperature (31.50°C), electrical conductivity (158.00 µS/cm), chemical oxygen demand (22.10 mg/L), total dissolved solids (94.80 mg/L), pH (6.80), alkalinity (18.30 mg/L), and turbidity (4.28 NTU) remained within acceptable limits. The elevated dissolved oxygen concentration (12.60 mg/L) indicates substantial oxygen availability despite the high organic pollution levels.

The bacteriological analysis revealed severe microbial contamination, with total coliforms (600 CFU/100 mL) and Escherichia coli (311 CFU/100 mL) far exceeding the allowable limits for water quality. Heavy metal assessment showed elevated concentrations of copper (0.62 mg/L), chromium (1.16 mg/L), and manganese (1.05 mg/L), all above NIS and WHO standards, indicating potential risks to aquatic ecosystems and human health. However, aluminium (0.125 mg/L), cadmium (0.001 mg/L), iron (0.25 mg/L), lead (0.001 mg/L), magnesium (30.10 mg/L), and zinc (2.18 mg/L) were within permissible limits. The ANOVA result ($F = 5.42$, $p = 0.008$) indicates a statistically significant variation in water quality parameters, confirming that leachate contamination has a measurable influence on the quality of water at the impact point.

Table 3. Leachate Quality and ANOVA Analysis at Water Impact Point (Ikom)

Category	Parameter	Unit	NIS Guideline	WHO Standard	Measured Value	Remark	ANOVA Result (F, Sig.)
Physico-chemical	Ammonia (NH_3-N)	mg/L	2.0	2.0	4.16	High	F = 5.42, Sig. = 0.008
Physico-chemical	BOD	mg/L	6.0	6.0	18.25	High	
Physico-chemical	DO	mg/L	4.0	4.0	12.60	High	
Physico-chemical	Temperature	°C	Ambient	N/A	31.50	Within Limit	
Physico-chemical	Electrical Conductivity	µS/cm	1000	1000	158.00	Within Limit	
Physico-chemical	COD	mg/L	30	30	22.10	Within Limit	
Physico-chemical	Total Dissolved Solids	mg/L	500	500	94.80	Within Limit	

Category	Parameter	Unit	NIS Guideline	WHO Standard	Measured Value	Remark	ANOVA Result (F, Sig.)
Physico-chemical	pH	-	6.5–8.5	6.5–8.5	6.80	Within Limit	
Physico-chemical	Phosphate	mg/L	3.5	3.5	3.81	High	
Physico-chemical	Nitrate	mg/L	40	40	60.50	High	
Physico-chemical	Nitrite	mg/L	0.08	0.08	0.18	High	
Physico-chemical	Sulfide	µg/L	0.1	0.1	0.22	High	
Physico-chemical	Alkalinity ($CaCO_3$)	mg/L	100	100	18.30	Within Limit	
Physico-chemical	Turbidity	NTU	<5	<5	4.28	Within Limit	
Bacteriological	Total Coliforms	CFU/100 mL	100	100	600	High	
Bacteriological	E. coli	CFU/100 mL	10	10	311	High	
Heavy Metals	Aluminium	mg/L	0.20	0.125	0.125	Within Limit	
Heavy Metals	Cadmium	mg/L	0.003	0.001	0.001	Within Limit	
Heavy Metals	Copper	mg/L	0.01	0.01	0.62	High	
Heavy Metals	Chromium	mg/L	0.50	0.50	1.16	High	
Heavy Metals	Iron	mg/L	0.50	0.30	0.25	Within Limit	
Heavy Metals	Lead	mg/L	0.01	0.01	0.001	Within Limit	
Heavy Metals	Manganese	mg/L	0.50	0.50	1.05	High	
Heavy Metals	Magnesium	mg/L	40	40	30.10	Within Limit	
Heavy Metals	Zinc	mg/L	5.0	5.0	2.18	Within Limit	

Source: Author's research, 2026.

Table 4 presents the physicochemical quality of surface water at the Great Kwa River intake point in Calabar, comparing abstraction and control locations against NIS and WHO standards. The results show that several key parameters exceeded permissible limits, indicating notable water quality degradation. Ammonia (4.42 mg/L), biochemical oxygen demand (8.16 mg/L at abstraction point and 2.00 mg/L at control, giving an average of 5.08 mg/L), nitrate (59.5 mg/L), nitrite (0.26 mg/L), sulfide (0.29 µg/L), and turbidity (6.25 NTU) were all above recommended standards, suggesting nutrient enrichment and organic pollution. Dissolved oxygen levels (16.50–16.80 mg/L) were unusually high, while temperature (31.2°C), electrical conductivity (236.2 µS/cm), total dissolved solids (148.8 mg/L), pH (6.15), alkalinity (19.6 mg/L), and chemical oxygen demand (22.1 mg/L) remained within acceptable limits.

The results also highlight spatial variation between abstraction and control points, particularly in ammonia and BOD concentrations, which indicate localized pollution influences at the intake zone. Heavy nutrient loading and elevated turbidity further suggest the presence of anthropogenic inputs affecting water quality. The ANOVA result ($F = 4.85$, $p = 0.012$) confirms a statistically significant difference in water quality between sampling locations, indicating that the observed variations are not due to chance. The findings suggest that while some parameters remain within regulatory limits, several key indicators of organic and microbial pollution exceed safe thresholds, posing potential risks to water quality and public health at the Great Kwa River intake point.

Table 4. Surface Water Quality and ANOVA Results at Great Kwa River Intake Point (Calabar)

Category	Parameter	Unit	NIS Guideline	WHO Standard	Abstraction Point	Control Point	Average	Remark	ANOVA (F, Sig.)
Physico-chemical	Ammonia NH_3-N	mg/L	2.0	2.0	4.21	4.62	4.42	High	F = 4.85, Sig = 0.012
Physico-chemical	BOD	mg/L	6.0	6.0	8.16	2.00*	5.08*	High	
Physico-chemical	DO	mg/L	4.0	4.0	16.50	16.80	16.65	High	
Physico-chemical	Temperature	°C	Ambient	Ambient	31.2	31.2	31.2		
Physico-chemical	Electrical Conductivity	µS/cm	1000	1000	225.6	246.8	236.2		
Physico-chemical	COD	mg/L	30	30	22.1	22.1	22.1		
Physico-chemical	Total Dissolved Solids	mg/L	500	500	148.8	148.8	148.8		
Physico-chemical	pH	-	6.5–8.5	6.5–8.5	6.2	6.1	6.15		
Physico-chemical	Phosphate	mg/L	3.5	3.5	3.25	3.81	3.53		
Physico-chemical	Nitrate	mg/L	40	40	59.5	59.5	59.5	High	
Physico-chemical	Nitrite	mg/L	0.08	0.08	0.26	0.26	0.26	High	
Physico-chemical	Sulfide	µg/L	0.1	0.1	0.29	0.28	0.29	High	
Physico-chemical	Alkalinity ($CaCO_3$)	mg/L	100	100	19.6	19.6	19.6		
Physico-chemical	Turbidity	NTU	<5	<5	6.25	6.25	6.25	High	

Source: Author's research, 2026.

Conclusion

The study on physicochemical and heavy metal characterization of dumpsite leachate affecting surface water intake points in Cross River State reveals clear evidence of environmental degradation linked to waste disposal activities. Both Ikom and Calabar water systems showed elevated concentrations of key physicochemical parameters such as ammonia, biological oxygen demand, nitrates, nitrites, and sulfides, indicating strong organic and nutrient pollution inputs from nearby dumpsites. Although some parameters remained within acceptable standards, the overall pattern reflects a consistent deterioration of water quality in areas influenced by leachate movement. Spatial analysis further confirmed that the proximity of dumpsites to water intake points increases vulnerability, with runoff and possible subsurface flow acting as major pathways of contamination.

The bacteriological and heavy metal results strengthen the conclusion that dumpsite leachates significantly compromise surface water quality in the study area. High levels of coliforms and E. coli suggest faecal contamination, while elevated concentrations of metals such as copper, lead, manganese, and chromium present long term toxicological risks to human health and aquatic ecosystems. The statistically significant ANOVA results further confirm that the observed differences in water quality are not incidental but shows a link with dumpsites. The study establishes that surface water intake points in Cross River State are at considerable risk of contamination, highlighting the urgent need for improved waste management systems, strict environmental regulation, and continuous monitoring of water quality to safeguard public health. The study recommends strict enforcement of waste management regulations, including proper siting and lining of dumpsites to prevent leachate escape into nearby water bodies. Regular monitoring of surface water intake points should be carried out by relevant agencies, with routine testing for physicohemical, microbial, and heavy metal contaminants. It is also important that buffer zones are established between dumpsites and water sources, while public water supply authorities adopt advanced treatment processes to reduce contamination risks. Public awareness campaigns should further educate communities on the health risks associated with improper waste disposal and polluted water sources.

Declarations

Ethics approval and consent to participate: The study involved field survey and analysis. Permission was obtained from the relevant authorities before fieldwork, and the study was conducted according to accepted research procedures.
Consent for publication: All authors approved the manuscript for journal submission and publication.
Availability of data and materials: The datasets generated and analysed during the study are available from the corresponding author on reasonable request.
Competing interests: The authors declare that they have no competing interests.
Funding: No external funding was declared for this study.
Authors' contributions: The authors contributed to the conception of the study, field sampling, laboratory analysis, data interpretation, manuscript drafting, revision and final approval of the article.
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