Assessment of Physicochemical and Microbial Parameters in Groundwater Around Solid Waste Dumpsite at Egbelu, Rivers State, Nigeria

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Abstract
This study assessed the physicochemical and microbial quality of groundwater around a solid waste dumpsite at Egbelu, Rivers State, Nigeria. Groundwater from twelve boreholes (three per distance) was sampled once at 100 m, 300 m and 500 m from the dumpsite, with boreholes at 800 m as the control. Parameters analysed were pH, temperature, electrical conductivity (EC), total suspended solids (TSS), total dissolved solids (TDS), turbidity, nitrate, phosphate, total heterotrophic bacteria (THB) and total heterotrophic fungi (THF). Data were analysed using analysis of variance (ANOVA), Pearson correlation and principal component analysis (PCA). pH (6.35–6.69) remained within WHO and NSDWQ limits. Temperature declined from 29.60 °C at 100 m to 28.20 °C at 800 m, EC from 98.33 µS/cm (100 m) to 70.80 µS/cm (500 m). Nitrate and phosphate peaked near the dumpsite (5.31 and 2.61 mg/L). THB peaked at 706,667 ± 271,538.80 CFU/mL at 100 m, while THF declined from 60,000 ± 43,588.99 CFU/mL at 100 m to 3,333.33 ± 5,773.50 CFU/mL at the control. Distance correlated negatively with temperature ($r = -0.999$), phosphate ($r = -0.992$) and THF ($r = -0.83$). PCA showed that PC1 (49.88% of variance) was driven mainly by nitrate, EC, turbidity, pH, temperature and phosphate, while PC2 (38.84%) separated TSS and TDS, which were unrelated to distance, from temperature and phosphate. The findings suggest a dumpsite influence on groundwater quality, particularly at close range, although overall ANOVA differences across distances were not significant; the trends are therefore indicative and have potential public health implications.

Keywords: *Groundwater quality, Solid waste dumpsite, Physicochemical parameters, Microbial contamination, Borehole water, Distance-based variation, Multivariate statistical analysis, Public health risk.*

1.0 Introduction

Groundwater is a critical source of domestic water supply in many developing countries, particularly in rapidly urbanizing communities where surface water sources are limited or heavily polluted. In Nigeria, boreholes and hand-dug wells constitute the primary sources of drinking water for millions of people, making groundwater quality a major public health concern. However, poor solid waste management practices have increasingly exposed groundwater resources to contamination, especially in areas where waste is disposed of in uncontrolled open dumpsites.

Uncontrolled solid waste dumpsites represent major non-point sources of groundwater pollution. Leachate generated from decomposing waste contains dissolved organic matter, inorganic salts, nutrients, heavy metals, microplastics, and diverse microorganisms. This leachate can infiltrate surrounding soils and migrate into aquifers used for domestic supply, particularly in areas with permeable subsurface materials and high rainfall (Olagbemiro et al., 2025; Kamble et al., 2020; Oladiran et al., 2023; Naeem & Asam, 2024; Igboama et al., 2022). Consequently, assessing physicochemical and microbial parameters of groundwater around dumpsites is essential for determining water potability, ecological risk, and the need for remediation.

Physicochemical assessment of groundwater near dumpsites commonly involves parameters such as pH, electrical conductivity (EC), total dissolved solids (TDS), turbidity, hardness, major ions (Cl^-, NO_3^-, SO_4^{2-}, PO_4^{3-}), dissolved oxygen (DO), biochemical oxygen demand (BOD), chemical oxygen demand (COD), and occasionally total organic carbon (TOC) (Olagbemiro et al., 2025; Kamble et al., 2020; Oladiran et al., 2023; Kapelewska et al., 2019; Naeem & Asam, 2024; Saleh et al., 2020). Many studies report slightly acidic to near-neutral pH values around dumpsites, with several cases falling below recommended drinking water limits, rendering groundwater corrosive and unsuitable for consumption (Oladiran et al., 2023; Onwualu-John & Uzoegbu, 2022; Yahaya et al., 2024). Elevated EC, TDS, and hardness values further indicate enrichment with leachate-derived ions, although variations are often influenced by local geology and dumpsite age (Kamble et al., 2020; Oladiran et al., 2023; Naeem & Asam, 2024; Saleh et al., 2020).

In addition to chemical deterioration, microbial contamination poses a serious health risk. Groundwater around dumpsites frequently exhibits high counts of total coliforms, faecal coliforms such as *Escherichia coli*, total heterotrophic bacteria, and fungi, often exceeding drinking water limits (Olagbemiro et al., 2025; Oladiran et al., 2023; Ape et al., 2025; Yahaya et al., 2024; Simon-Oke et al., 2023). While some studies report acceptable microbial levels despite chemical contamination, hydrogeological conditions, well construction, and distance from dumpsites strongly influence microbial transport (Onwualu-John & Uzoegbu, 2022; Saleh et al., 2020). Recent molecular studies further show that leachate intrusion alters groundwater microbial community structure, increasing diversity and introducing landfill-derived bacteria (Sha et al., 2023; Liu et al., 2024). Egbelu, Rivers State, is characterized by intense urban growth, widespread reliance on groundwater for domestic use, and the presence of unmanaged solid waste dumpsites. Despite these vulnerabilities, comprehensive data on the combined physicochemical and microbial quality of groundwater in the area remain limited. This study is therefore justified to provide site-specific evidence of dumpsite-related groundwater contamination in Egbelu, support public health protection, and inform sustainable waste management and groundwater monitoring strategies in Rivers State.

2.0 Methodology

2.1 Study Area

The study was conducted around the Ogbogoro dumpsite (hereafter referred to as the Egbelu dumpsite), located at the intersection of the Egbelu and Ogbogoro communities in Obio/Akpor Local Government Area, Rivers State, Nigeria (approximately 4°50′48″ N and 6°55′50″ E). The dumpsite, originally a borrow pit, has been in continuous use for over a decade and receives mixed municipal wastes. A slaughterhouse (abattoir) and market are situated in close proximity to the dumpsite and are separated from it by a lotic stream. The surrounding environment comprises residential, commercial, and industrial activities, with the nearest building located approximately 15 m from the dumpsite, raising concerns about potential groundwater contamination (Fig 1).

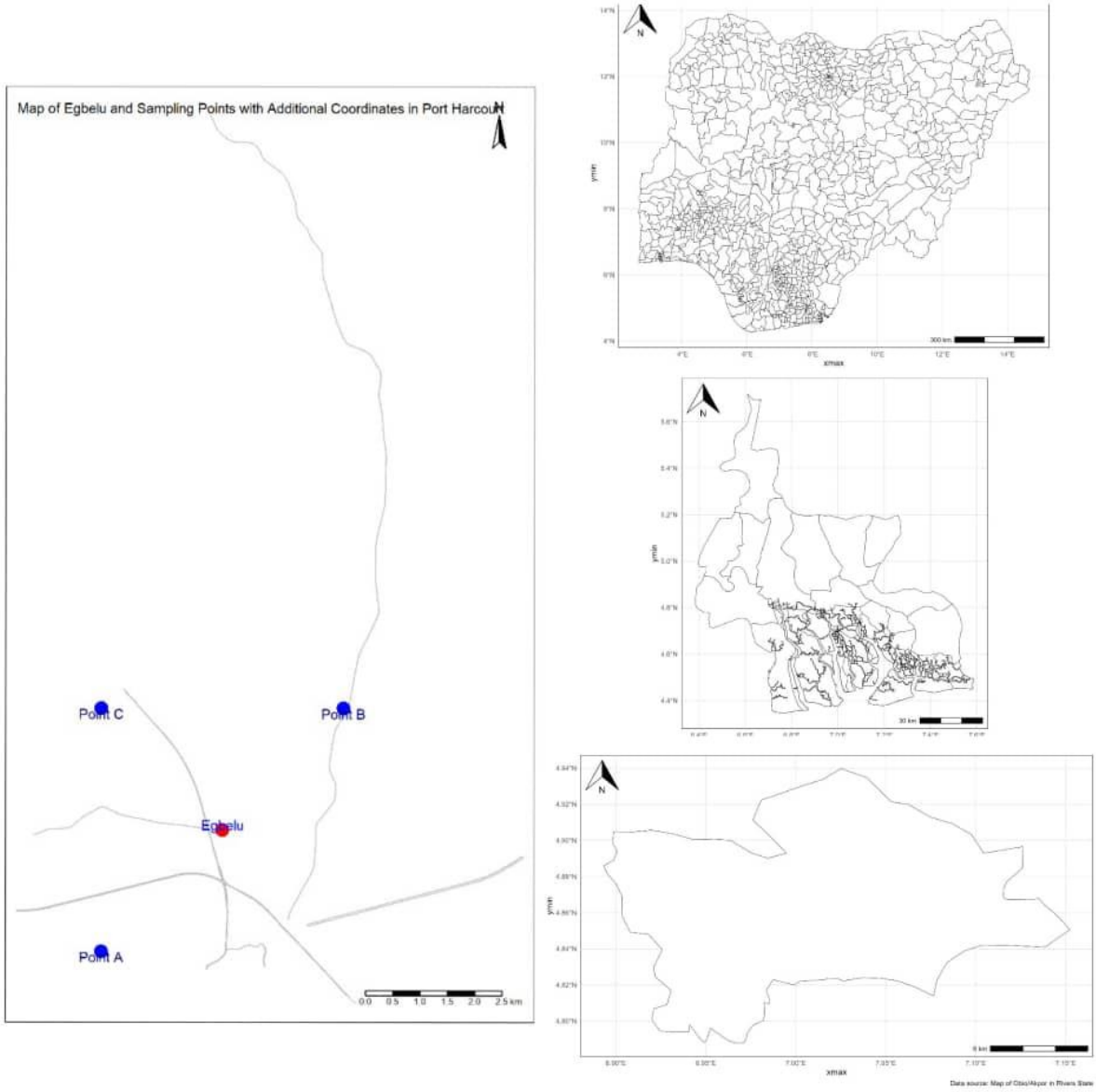


Fig 1: Map of the study area showing the various distances away from the dumpsite

2.1.1 Station A: 100 m Away from the Dumpsite

Station A comprised boreholes located approximately 100 m away from the dumpsite and represents the zone of highest potential influence from leachate migration due to proximity.

2.1.2 Station B: 300 m Away from the Dumpsite

Station B consisted of boreholes situated 300 m away from the dumpsite and represents an intermediate impact zone.

2.1.3 Station C: 500 m Away from the Dumpsite

Station C included boreholes located 500 m away from the dumpsite and represents a reduced impact zone based on distance.

2.1.4 Control: 800 m Away from the Dumpsite

The control station comprised boreholes located 800 m away from the dumpsite and was assumed to be minimally influenced by dumpsite-derived contamination.

2.2 Groundwater Sampling

Groundwater samples were collected from twelve boreholes distributed across the four sampling distances, with three boreholes sampled at each distance (100 m, 300 m, 500 m, and 800 m). Sampling was conducted once during the study period. Water samples were collected in clean 50 cl plastic containers, properly labeled, and immediately placed in an ice chest for preservation. Three replicate samples were obtained per distance and transported to the Biology Laboratory, Ignatius Ajuru University of Education, for physicochemical and microbiological analyses.

2.3 Determination of Physicochemical Parameters in Groundwater Samples

Physicochemical parameters analyzed included pH, temperature, electrical conductivity, total suspended solids, total dissolved solids, turbidity, nitrate, and phosphate. All analyses were carried out using standard procedures recommended by the American Public Health Association (APHA, 2005). Temperature was measured in situ using a calibrated mercury-in-glass thermometer. pH was determined using a calibrated digital pH meter, while electrical conductivity and turbidity were measured using a Horiba water checker. Total dissolved solids were estimated using a conductivity meter, and total suspended solids were determined following standard procedures (APHA, 2005). Nitrate concentration was determined spectrophotometrically using the brucine method at 420 nm, while phosphate was analyzed using the ammonium molybdate-stannous chloride method with absorbance measured at 690 nm.

2.4 Estimation of Total Heterotrophic Bacteria and Total Heterotrophic Fungi in Groundwater Samples

Total heterotrophic bacteria (THB) were enumerated using the spread plate technique on nutrient agar following serial dilution of the groundwater samples with sterile normal saline. Plates were incubated at 37 °C for 24 h, after which colonies were counted and expressed as colony-forming units per milliliter (CFU/mL). Bacterial isolates were further characterized based on colony morphology, Gram reaction, and standard biochemical tests including indole, methyl red, Voges–Proskauer, citrate utilization, oxidase, catalase, motility, and sugar fermentation tests.

Total heterotrophic fungi (THF) were isolated using Sabouraud dextrose agar. Aliquots of the samples were spread on agar plates and incubated at 37 °C for 7 days (Simon-Oke et al. 2023).

Fungal isolates were identified based on macroscopic colony characteristics and microscopic features following lactophenol blue staining.

2.5 Statistical Analysis

Descriptive statistics were used to summarize groundwater quality parameters across distances away from the dumpsite. Differences among distances were evaluated using analysis of variance (ANOVA), followed by Tukey's HSD post-hoc test for multiple comparisons. Pearson correlation analysis was performed to assess relationships between physicochemical parameters and distance, microbiological parameters and distance, and combined physicochemical–microbiological interactions with distance. Multivariate analysis was conducted using principal component analysis (PCA) on the standardised physicochemical variables (mean values per distance) to identify dominant factors influencing groundwater quality. Heat maps and line graphs were generated to visualize spatial trends and relationships. All statistical analyses and graphical outputs were performed using R and Python (pandas, NumPy and Matplotlib) software.

3.0 Results

3.1 Physicochemical parameters in Groundwater

The results revealed spatial variation in groundwater quality with increasing distance away from the dumpsite. pH values ranged from 6.35 at 500 m away from the dumpsite to 6.69 at 300 m away, remaining within WHO and NSDWQ permissible limits, while temperature showed a gradual decline with increasing distance, recording a minimum of 28.20 °C at 800 m away from the dumpsite and a maximum of 29.60 °C at 100 m away. Electrical conductivity was higher closer to the dumpsite, varying from 70.80 µS/cm at 500 m away to 98.33 µS/cm at 100 m away. Total suspended solids and total dissolved solids exhibited limited spatial variability and remained low across all distances. Turbidity values were uniformly low, whereas nitrate and phosphate concentrations were elevated closer to the dumpsite, reaching maximum values of 5.31 mg/L and 2.61 mg/L, respectively, and decreased with increasing distance. Two-way ANOVA indicated statistically significant differences among the measured parameters ($p < 0.05$), reflecting heterogeneity in groundwater physicochemical characteristics, while no significant differences were observed across distances away from the dumpsite ($p > 0.05$). Further analysis showed that pH, temperature, total dissolved solids, and total suspended solids did not vary significantly with distance, indicating relative stability of these parameters, whereas electrical conductivity, turbidity, nitrate, and phosphate exhibited statistically significant differences ($p < 0.05$), highlighting the influence of localized dumpsite-derived inputs on groundwater quality (Table 1).

Table 1. Physicochemical characteristics of groundwater samples collected at varying distances from the Egbelu solid waste dumpsite, Rivers State, Nigeria, compared with WHO drinking water guidelines.

Parameter	100 m	300 m	500 m	800 m (Control)	WHO Limit
pH	6.66 ± 0.05^{a}	6.69 ± 0.12^{a}	6.35 ± 0.24^{a}	6.65 ± 0.01^{a}	6.5 – 8.5
Temperature (°C)	29.60 ± 0.06^{a}	29.17 ± 0.32^{a}	28.82 ± 0.17^{a}	28.20 ± 0.10^{a}	22 – 30
Electrical Conductivity (µS/cm)	98.33 ± 0.15^{a}	72.67 ± 0.20^{b}	70.80 ± 0.46^{b}	84.07 ± 0.32^{ab}	250 – 500
TSS (mg/L)	1.90 ± 0.01^{a}	1.70 ± 0.04^{a}	1.51 ± 0.05^{a}	2.23 ± 0.01^{a}	Not specified
TDS (mg/L)	73.11 ± 0.34^{a}	69.62 ± 0.86^{a}	66.82 ± 1.80^{a}	76.28 ± 0.02^{a}	≤500
Turbidity (NTU)	0.70 ± 0.15^{a}	0.35 ± 0.15^{b}	0.44 ± 0.20^{ab}	0.33 ± 0.12^{b}	≤5
Nitrate (mg/L)	5.31 ± 0.01^{a}	4.78 ± 0.13^{ab}	3.63 ± 0.40^{b}	4.30 ± 0.05^{ab}	≤50
Phosphate (mg/L)	2.61 ± 0.11^{a}	2.40 ± 0.13^{a}	1.89 ± 0.03^{b}	1.39 ± 0.06^{c}	≤5*

Values are presented as mean ± standard deviation. Values with the same superscript along a row are not significantly different ($p > 0.05$), while values with different superscripts differ significantly ($p < 0.05$).

3.1.1 Correlation of the physicochemical properties with the distance to the dumpsite

Distance from the dumpsite showed very strong negative correlations with temperature (r = −0.999) and phosphate (r = −0.992), as well as strong to moderate negative correlations with turbidity (r = −0.751), nitrate (r = −0.685), and electrical conductivity (r = −0.370), indicating a pronounced decline in thermal load, nutrient enrichment, particulate matter, and ionic content with increasing distance. In contrast, distance exhibited weak positive correlations with total suspended solids (r = 0.433) and total dissolved solids (r = 0.313), and a weak negative correlation with pH (r = −0.216), suggesting that proximity to the dumpsite was a major influence on key water quality parameters, while pH and background solids remained relatively stable across the sampling gradient (Fig 2).

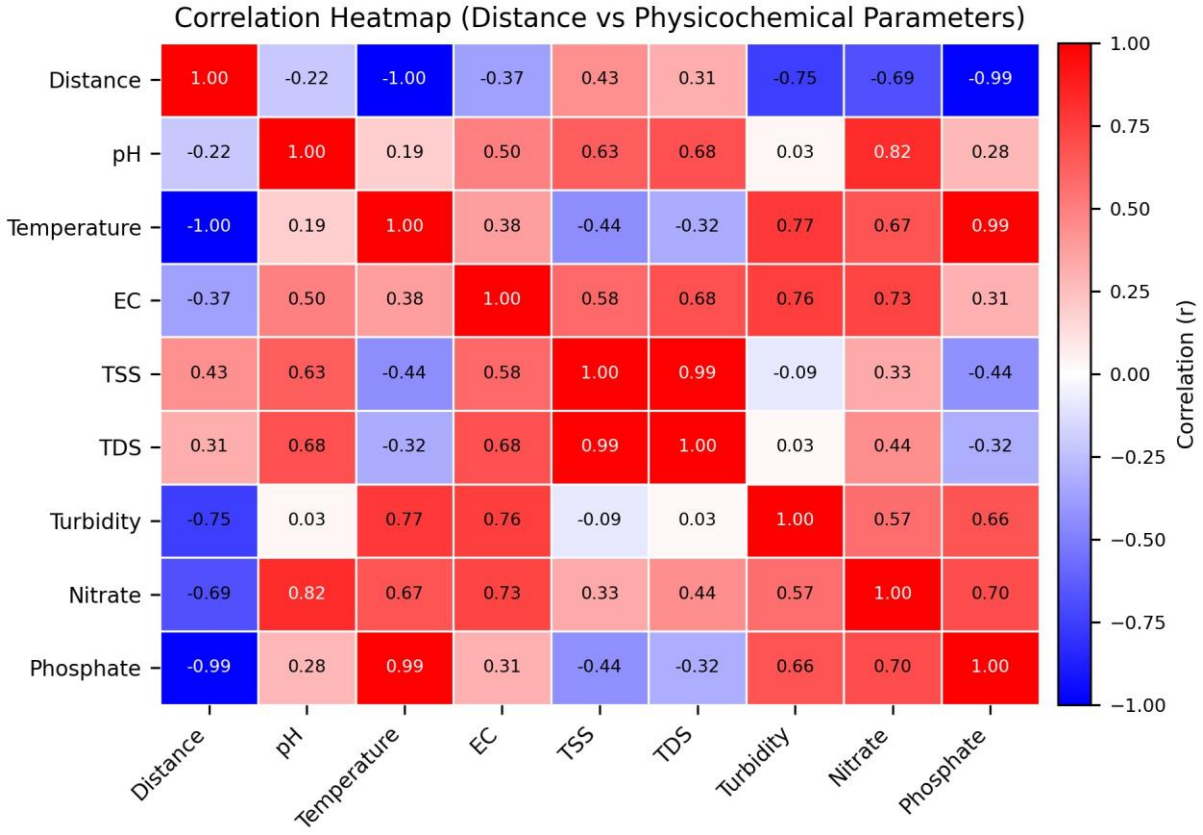


Fig. 2: Correlation of the physicochemical properties with the distance to the dumpsite

3.1.2 Principal Component Loadings and Dominant Gradients

PC1 (eigenvalue = 3.991; 49.88% of the variance) exhibited strong positive loadings for nitrate (0.967), electrical conductivity (0.874), turbidity (0.723), pH (0.715), temperature (0.667), and phosphate (0.657), identifying nutrient enrichment and ionic content as the dominant contributors to the primary variance and indicating a common gradient associated with dumpsite-derived inputs, whereas TDS (0.492) and TSS (0.374) showed weaker influence on this axis. PC2 (eigenvalue = 3.107; 38.84% of the variance) was strongly controlled by total suspended solids (0.924) and total dissolved solids (0.865), with strong negative loadings for temperature (−0.742) and phosphate (−0.718), separating the solids from the thermal and phosphate signal, while PC3 (eigenvalue = 0.902; 11.27% of the variance) displayed generally weak to moderate loadings (pH

−0.546, turbidity 0.537, EC 0.424), reflecting residual or site-specific variability rather than a dominant environmental process (Table 2 and Fig 3).

Table 2: Principal Component Loadings and Dominant Gradients

Parameter	PC1 (Dim.1)	PC2 (Dim.2)	PC3 (Dim.3)
pH	0.715	0.437	−0.546
Temperature	0.667	−0.742	−0.070
Electrical Conductivity	0.874	0.239	0.424
TSS	0.374	0.924	0.075
TDS	0.492	0.865	0.095
Turbidity	0.723	−0.435	0.537
Nitrate	0.967	−0.012	−0.255
Phosphate	0.657	−0.718	−0.229
Eigenvalue	3.991	3.107	0.902
Percentage of Variance (%)	49.883	38.843	11.273
Cumulative Percentage (%)	49.883	88.727	100

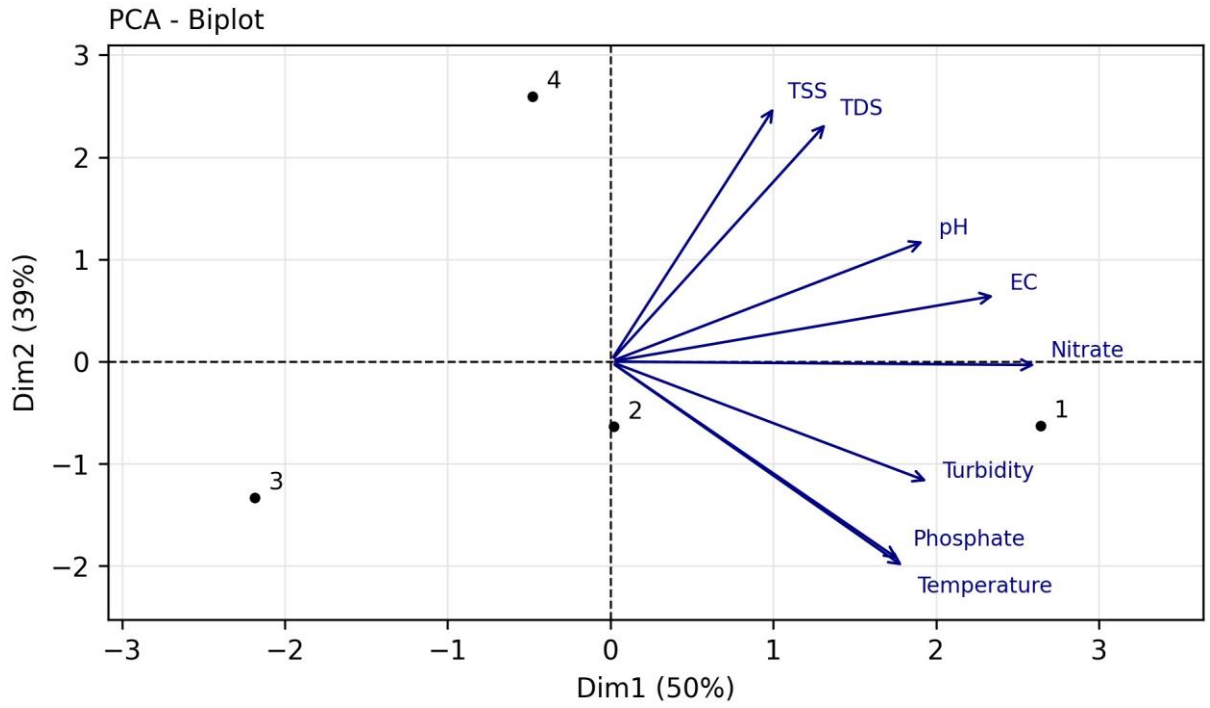


Fig. 3: Principal Component Loadings and Dominant Gradients

3.2 THB and THF obtained from borehole samples across various distances away from the Egbelu dumpsite

Total heterotrophic fungi (THF) decreased markedly with increasing distance away from the Egbelu dumpsite, with the highest mean count recorded at 100 m (60,000.00 ± 43,588.99 CFU/mL) and progressively lower values at 300 m (13,333.30 ± 15,275.25 CFU/mL), 500 m (16,666.70 ± 11,547.01 CFU/mL), and the control at 800 m (3,333.33 ± 5,773.50 CFU/mL). Similarly, total

heterotrophic bacteria (THB) showed elevated counts close to the dumpsite, peaking at 100 m (706,667.00 ± 271,538.80 CFU/mL) and remaining relatively high at 300 m (313,333.00 ± 40,414.52 CFU/mL) and the control (433,333.00 ± 208,166.60 CFU/mL), before declining at 500 m (146,667.00 ± 25,166.11 CFU/mL) as seen in Table 3.

Table 3: Profile of THB and THF obtained from borehole samples across various distances away from the Egbelu dumpsite

	100m	300m	500m	800m(control)
THF	60000.00±43588.99[a]	13333.30±15275.25[a]	16666.70±11547.01[a]	3333.33.00±5773.50[a]
THB	706667.00±271538.80[b]	313333.00±40414.52[b]	146667.00±25166.11[b]	433333.00±208166.60[b]

Note: The averages of different distances that have same subscript letters are not statistically significantly different from each other while the others that have different letters are statistically significantly different at 95% confident level.

3.2.1 Correlation between Microbial Load, Physicochemical Parameters, and Distance from the Dumpsite

Distance from the dumpsite showed moderate to strong negative correlations with total heterotrophic fungi (THF; r = −0.83) and total heterotrophic bacteria (THB; r = −0.451), as well as with key physicochemical variables including temperature (r = −0.999), phosphate (r = −0.992), turbidity (r = −0.751), and nitrate (r = −0.685), indicating that microbial abundance and pollution-related parameters declined with increasing distance away from the dumpsite. Both THF and THB were positively correlated (strong to moderate) with temperature (r = 0.842 and 0.45, respectively), electrical conductivity (r = 0.76 and 0.972), turbidity (r = 0.986 and 0.697), nitrate (r = 0.682 and 0.866), and phosphate (r = 0.761 and 0.414), demonstrating that microbial proliferation was closely linked to nutrient enrichment, particulate matter, and ionic content associated with dumpsite leachate. In contrast, weak to moderate correlations were observed between microbes and pH (THF: r = 0.164; THB: r = 0.671), TSS (THF: r = −0.086; THB: r = 0.584), and TDS (THF: r = 0.043; THB: r = 0.687), suggesting that while these parameters contributed to microbial dynamics, they were weaker and less consistent than the relationships with turbidity, electrical conductivity, and nitrate in explaining microbial contamination of groundwater around the dumpsite as summarized in Fig 4.

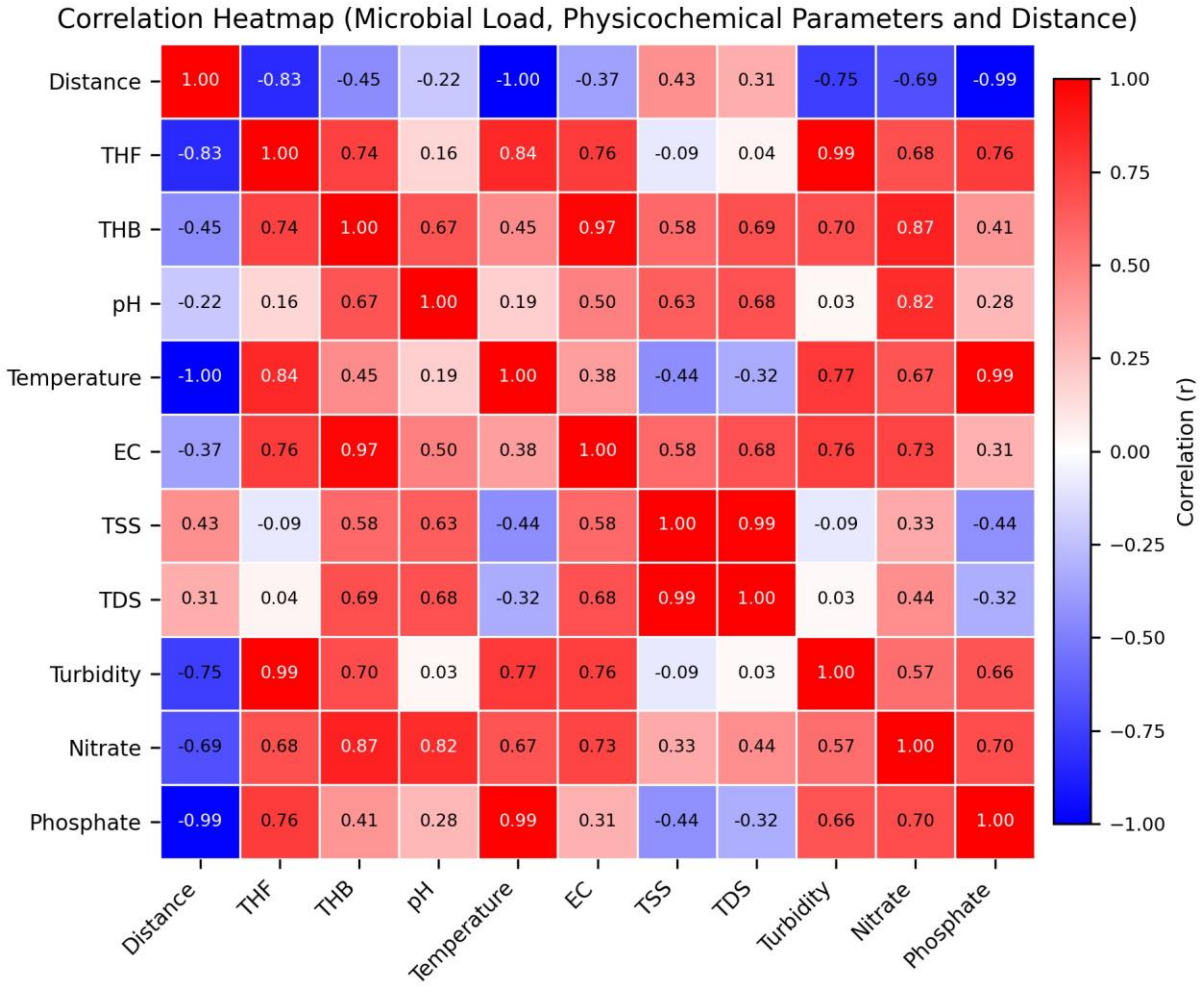


Fig. 4: Correlation between Microbial Load, Physicochemical Parameters, and Distance from the Dumpsite

4.0 Discussion

The present study revealed a distance-related trend in groundwater quality, characterized by elevated physicochemical parameters near the dumpsite and progressive attenuation with increasing distance. pH values ranged from 6.35 at 500 m to 6.69 at 300 m, remaining within WHO and NSDWQ limits, while temperature declined from 29.60 °C at 100 m to 28.20 °C at 800 m. Electrical conductivity decreased from 98.33 µS/cm at 100 m to 70.80 µS/cm at 500 m. Nutrient enrichment was most pronounced close to the dumpsite, with nitrate reaching 5.31 mg/L and phosphate 2.61 mg/L before decreasing outward. These spatial patterns were supported by strong negative correlations between distance and temperature ($r = -0.999$) and phosphate ($r = -0.992$), as well as strong to moderate negative correlations with turbidity ($r = -0.751$), nitrate ($r = -0.685$), and electrical conductivity ($r = -0.370$). Principal component analysis further identified a dominant gradient on PC1 (49.88% of the variance), driven mainly by nitrate (0.967), electrical conductivity (0.874), turbidity (0.723), pH (0.715), temperature (0.667), and phosphate (0.657), consistent with leachate-derived influence, although pH, which did not vary significantly with distance, also loaded on this axis. PC2 (38.84% of the variance) was instead controlled by TSS

(0.924) and TDS (0.865), which showed only weak positive correlations with distance, indicating that suspended and dissolved solids varied independently of the dumpsite gradient. It should be noted, however, that ANOVA did not show statistically significant differences across distances overall (p 0.05). The distance-related pattern is therefore best interpreted as a trend supported by the strong correlations and the multivariate structure, rather than as a statistically confirmed gradient. This caution is reinforced by the small number of boreholes per distance (n = 3), the use of distance means in the correlation and PCA analyses, and the single sampling event.

These findings closely align with the work of Ndoma et al. (2025) in Calabar, Nigeria, who reported higher pH, TDS, electrical conductivity, hardness, and metal concentrations in boreholes closest to the Lemna dumpsite, with concentrations decreasing as distance increased. Their factor analysis showed that a single dominant factor explained over 99 % of the total variance, whereas PC1 in the present study explained a smaller share (49.88 %), with the largest loadings from nitrate, EC, turbidity, and temperature. Although absolute EC values reported by Ndoma et al. (2025) were higher than the present maximum of 98.33 µS/cm, both studies point to distance from the dumpsite as an important influence on groundwater quality variation.

Similarly, studies by Omofunmi et al. (2019) and Omofunmi et al. (2020) in Ado-Ekiti, Nigeria, recorded electrical conductivity values as high as 385 µS/cm, total dissolved solids of 168 mg/L, turbidity of 4.6 NTU, and nitrate concentrations of 6 mg/L in wells closest to the dumpsite, with statistically significant reductions at greater distances ($p \leq 0.05$). While the present study recorded lower EC (98.33 µS/cm) and nitrate (5.31 mg/L), the spatial trend is identical, with higher EC, turbidity, and nitrate occurring near the dumpsite and declining with distance.

In Amassoma, Bayelsa State, Chokor and Roberts (2022) reported alkalinity values ranging from 46.7 to 273.3 mg/L and iron concentrations between 0.99 and 5.07 mg/L within 0–100 m of a dumpsite, with concentrations decreasing as distance increased. Although alkalinity and iron were not central parameters in the present study, the inverse distance–concentration relationship observed by Chokor and Roberts is consistent with the strong negative correlations recorded for nutrients and temperature in the present investigation.

Groundwater studies in Port Harcourt by Abiye and Raimi (2025) further support these findings, showing that Water Quality Index values increased significantly in areas influenced by dumpsites, with some locations classified as “dangerously high,” particularly during periods of enhanced leachate migration. This supports the present study’s observation that although most parameters remain within guideline limits, their spatial structuring reflects anthropogenic influence rather than pristine background conditions.

In Onne, Rivers State, Olagbemiro et al. (2025) reported groundwater electrical conductivity ranging from 152 to 380 µS/cm, sulfate concentrations of 1.19–5.93 mg/L, phosphate levels of 3.04–9.32 mg/L, and nitrate concentrations of 0.44–2.19 mg/L, with significant spatial differences for EC, sulfate, phosphate, and nitrate ($p < 0.05$). The present study aligns closely with these findings, particularly in identifying EC, nitrate, and phosphate as parameters showing statistically significant spatial variation, although absolute concentrations were lower.

Studies at Solous dumpsite, Lagos, by Ojo-Awo et al. (2018) recorded mean pH of 6.31, electrical conductivity of 1224.9 µS/cm, nitrate of 0.01 mg/L, and phosphate of 0.30 mg/L, with most parameters declining away from the dumpsite. Despite the much higher EC reported by Ojo-Awo et al., both studies demonstrate similar behavior in pH stability and distance-dependent attenuation of ionic and nutrient parameters.

Beyond Nigeria, Naeem and Asam (2024) in Islamabad and Rawalpindi, Pakistan, reported groundwater EC values of 103–3460 µS/cm, TDS of 436–4425 mg/L, and nitrate concentrations

of 7.8–19.9 mg/L, all of which decreased progressively with increasing distance from dumpsites. Although concentrations were considerably higher than those observed in the present study, the monotonic decline of EC, TDS, and nitrate mirrors the strong negative correlations observed here. Comparable trends were reported by Farzaneh et al. (2021) in Tehran, Iran, where groundwater near landfills exhibited EC of 1177.9 µS/cm, sulfate of 254 mg/L, and elevated phosphate, with statistically significant differences across distances ($p < 0.05$) and PCA dominated by nutrient and ionic variables, analogous to the present PC1 structure.

The present study demonstrated a pronounced spatial pattern in groundwater microbial quality around the Egbelu dumpsite, with both total heterotrophic fungi (THF) and total heterotrophic bacteria (THB) strongly influenced by proximity to the waste source. THF declined with distance, decreasing from 60,000.00 ± 43,588.99 CFU/mL at 100 m to 13,333.30 ± 15,275.25 CFU/mL at 300 m, 16,666.70 ± 11,547.01 CFU/mL at 500 m, and 3,333.33 ± 5,773.50 CFU/mL at the 800 m control. THB followed a similar enrichment near the dumpsite, peaking at 706,667.00 ± 271,538.80 CFU/mL at 100 m and remaining elevated at 300 m (313,333.00 ± 40,414.52 CFU/mL), before declining at 500 m (146,667.00 ± 25,166.11 CFU/mL). These patterns were supported by strong to moderate negative correlations between distance and THF ($r = -0.83$) and THB ($r = -0.451$), suggesting that microbial contamination attenuated with increasing separation from the dumpsite, although the differences among distances were not statistically significant (Table 3). Comparable distance-controlled declines in microbial load have been widely reported in Nigeria. At the Igwuruta dumpsite in Rivers State, Ugbebor and Ntesat (2019) recorded THB values of 6.0×10^3 CFU/mL at 10 m, 4.8×10^3 CFU/mL at 630 m, and only 42 CFU/mL at 1500 m from the dumpsite, accompanied by total coliform counts declining from 140 to 0 CFU/100 mL. This sharp gradient mirrors the present study's strong negative microbial–distance relationships, although absolute counts at Egbelu were substantially higher, indicating a more intense or persistent organic load. Similarly, groundwater studies at Epe and Laje dumpsites in Ondo State by Simon-Oke et al. (2023) reported extremely high microbial counts close to active dumpsites, with THB values of 42×10^6 and 27×10^6 CFU/mL and THF values of 14×10^6 and 10.5×10^6 sfu/mL, respectively. The authors linked these elevated counts to high waste input, temperature, and nutrient availability. While the magnitude of microbial counts in Epe and Laje exceeded those observed at Egbelu, both studies align in showing that waste intensity and physicochemical enrichment near dumpsites strongly promote heterotrophic microbial proliferation.

Evidence from Bayelsa State further supports these observations. In soils surrounding an oilfield wastewater pond at Igwuruta, Owhonka and Obire (2019) reported THB values ranging from 7.32–7.35 $\log_{10}$ CFU/g at the pond edge compared to 7.38-7.40 $\log_{10}$ CFU/g at 80 m, while Owhonka and Omokaro (2022) observed fungal counts of 4.65-4.85 $\log_{10}$ CFU/g near the pond and 5.03–5.05 $\log_{10}$ CFU/g at 80 m. Although the medium differed (soil rather than groundwater), these studies demonstrate a clear distance effect on microbial abundance, consistent with the strong THF gradient observed in the present groundwater study.

Not all studies show monotonically higher microbial counts near contamination sources, highlighting important contrasts. In the Santa Barbara River, Bayelsa State, Ntongha and Omokaro (2022) reported THB values of 3.8×10^4–9.2×10^4 CFU/mL and fungal counts of 1.2×10^2–3.2×10^2 CFU/mL, with the control station exhibiting higher microbial loads than contaminated points. The authors attributed this pattern to toxicity effects suppressing microbial growth at polluted sites. This contrasts with the Egbelu findings, where nutrients and organic matter appear to dominate over toxicity, enabling microbial enrichment near the dumpsite rather than inhibition.

A weaker spatial signal was also reported in the Soku River by Ntongha and Omokaro (2023), where THB ranged from 0.02–2.4 $\log_{10}$ CFU/mL and fungal counts from 0.05–0.95 $\log_{10}$ CFU/mL, with no significant differences among stations. Compared with these results, the strong negative correlations between distance and THF ($r = -0.83$) and THB ($r = -0.451$) in the present study indicate a more clearly defined contamination plume and stronger physicochemical control.

Studies on dumpsite soils in Port Harcourt by Williams and Hakam (2016) further reinforce the Egbelu pattern. They reported THB values of 2.4×10^7–1.2×10^8 CFU/g and fungal counts of 4.8×10^6–2.3×10^7 CFU/g at dumpsites, compared with only 2.1×10^4 CFU/g (THB) and 1.1×10^3 CFU/g (fungi) at control locations. Although conducted in soil, the extreme contrast between dumpsite and control mirrors the elevated THB and THF observed at 100 m relative to 800 m in the present groundwater study.

International evidence shows similar trends. In Norway, Abiriga et al. (2021) reported groundwater plate counts ranging from 1×10^2 to 3.2×10^5 CFU/mL, with contaminated wells exhibiting substantially higher counts than background wells and distal sites showing marked reductions. Recent Chinese studies also reinforce this linkage. Qi et al. (2023) and Sha et al. (2023) showed that microbial abundance and composition within leachate plumes were strongly structured by EC, organic matter, and nutrient gradients, while Li et al. (2024) and Cai et al. (2024) reported that nitrogen, phosphorus, organic matter, and solids explained a substantial proportion of bacterial and fungal variability near landfills. These findings align closely with the present study, where THF and THB were positively correlated with nutrients, electrical conductivity, and turbidity but showed weaker or less consistent relationships with pH, TDS, and TSS.

5.0 Conclusion

The study indicates that the Egbelu dumpsite influences groundwater quality, with elevated physicochemical parameters and microbial loads observed at boreholes closer to the dumpsite and a general decline with increasing distance. Multivariate and correlation analyses confirmed that nutrients (nitrate and phosphate), electrical conductivity, turbidity, temperature, and microbial indicators are the principal drivers of groundwater contamination associated with dumpsite leachate, whereas suspended and dissolved solids were largely independent of distance. Because overall ANOVA differences across distances were not significant, and sampling was done once with three boreholes per distance, these findings should be treated as indicative trends. Repeated (seasonal) sampling with more boreholes per distance is recommended to confirm them.

6.0 Recommendations

It is recommended that boreholes located within close proximity to the dumpsite be subjected to regular monitoring and appropriate treatment before use to reduce potential health risks. Additionally, improved waste management practices, including engineered landfill systems and leachate control measures, should be implemented to minimize further groundwater contamination in the study area.

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