A Comparative Assessments of Physiocochemical Parameter of Borehole Water in Dekina LGA, Kogi State, Nigeria

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ABSTRACT
This study examined the spatial distribution and physicochemical quality of borehole water in Dekina Local Government Area, Kogi State, Nigeria, using integrated Geographic Information System (GIS) and statistical techniques. Seventy-five (75) boreholes were purposively selected across three districts—Dekina, Okura, and Biraidu—with twenty-five samples per district. Water samples were analysed for key physicochemical parameters, while spatial data were processed using ArcGIS 10.5. Descriptive statistics, Pearson correlation, Water Quality Index (WQI), one-way ANOVA, multiple regression, and Principal Component Analysis (PCA) were employed for data analysis at 0.05 significance level. Results revealed a clustered spatial distribution of boreholes with a Nearest Neighbor Index (NNI) of 0.74 ($Z = -4.18$), indicating significant concentration around major settlements. Physicochemical analysis showed mean pH (6.42), TDS (520.8 mg/L), and Electrical Conductivity (842 µS/cm), with TDS exceeding WHO limits in over 58% of samples. Heavy metals such as lead (mean = 0.021 mg/L) and iron (mean = 0.74 mg/L) also exceeded permissible limits in several locations. Overall compliance with WHO and Nigerian Industrial Standards was 56.7%, indicating that 43.3% of parameters were non-compliant. The computed Water Quality Index (WQI) ranged from 78.4 to 102.6, with a mean value of 90.2, classifying groundwater quality as generally "very poor." ANOVA results confirmed significant spatial variation in water quality across districts ($p < 0.05$), with Biraidu exhibiting the highest contamination levels. Regression analysis showed that settlement proximity and land use explained 74% of variation in water quality ($R^2 = 0.74$), while PCA identified anthropogenic activities as the dominant controlling factor. The study concludes that groundwater quality in Dekina LGA is moderately to severely degraded and strongly influenced by human activities, necessitating improved environmental management and water quality monitoring.

Keywords: Borehole water quality; Physicochemical parameters; Groundwater; Water Quality Index (WQI); Dekina Local Government Area.

INTRODUCTION

The quantity and quality of potable water remain major concerns globally because access to safe drinking water is fundamental to human health, socio-economic development, and environmental sustainability. Despite considerable international efforts, millions of people still lack access to safe and reliable drinking water, making water supply one of the most pressing global development challenges (UNICEF & WHO, 2021). Drinking water is an invaluable natural resource, yet providing safe water for all continues to be a complex issue due to increasing population growth, urbanization, climate variability, pollution, and inadequate water infrastructure (Padma, Keerthi & Abhishek, 2021). According to the World Health Organization, over 3.4 million people die annually from water, sanitation, and hygiene-related diseases, with the highest burden occurring in low- and middle-income countries, particularly in sub-Saharan Africa (WHO, 2019). In Africa, the combined effects of inadequate infrastructure, rapid population growth, and environmental degradation have continued to undermine access to safe water, with the impact of unsafe water being likened to the loss of "a jumbo jet crashing every four hours" (Adekola, Bashir & Kashim, 2015).

Recognizing the importance of safe drinking water, the global community has implemented initiatives such as the Millennium Development Goals (MDGs) and the Sustainable Development Goals (SDGs), which emphasize universal access to safe and affordable drinking water (UNICEF & WHO, 2021). Although significant progress has been recorded, more than two billion people worldwide still lack safely managed drinking water services (WHO & UNICEF, 2023). This situation demonstrates that access to water alone does not guarantee safety, as many available sources remain contaminated by physical, chemical, and biological pollutants. Consequently, regular water quality assessment has become an essential requirement for protecting public health and ensuring sustainable water resource management (Oluduro, Obayelu & Eniola, 2022).

Nigeria reflects this global challenge. Although improvements have been made since the 1990s, only about 47% of Nigerians have access to safe drinking water, while rural communities continue to experience severe shortages due to poor infrastructure and inadequate water supply systems (UNICEF, 2019; Voices, 2019). Consequently, many households depend on alternative sources such as streams, shallow wells, rainwater harvesting systems, and groundwater obtained through boreholes (Adewale & Baiyewu, 2020). Borehole water has become the most preferred alternative because groundwater naturally undergoes filtration through soil and rock formations, making it generally cleaner than surface water (Ibrahim & Musa, 2021). This perception has encouraged extensive borehole development by governments, communities, and private individuals. The Nigerian National Borehole Programme and several state government initiatives have further promoted groundwater development as a means of improving potable water supply (Adekola et al., 2015; Ahmed & Ololade, 2022). Nevertheless, many boreholes are constructed without regular quality monitoring, maintenance, or regulatory supervision, thereby exposing consumers to possible chemical and microbial contamination (Okoye, Chukwu & Onyeneke, 2023).

Kogi State, situated at the confluence of Rivers Niger and Benue, has experienced persistent challenges in providing adequate potable water to its growing population. Although successive governments have continued to allocate resources to water supply projects, many communities still experience inadequate access due to population growth, ageing infrastructure, unequal distribution, and increasing pollution of existing water sources (Abdullahi & Usman, 2021). Consequently, residents increasingly rely on groundwater from boreholes for domestic, agricultural, and commercial purposes, a pattern that is common across many Nigerian communities where groundwater represents the most dependable source of water (Oruonye & Medjor, 2010; Eze, Okwute & Okoh, 2022).

Dekina Local Government Area is not exempt from these challenges. Before the establishment of Prince Abubakar Audu University (formerly Kogi State University) in 2000, the quantity and quality of domestic water supply in the area were relatively adequate because the population was considerably smaller and water demand was manageable. Most households depended on streams, shallow wells, natural springs, and a few public water facilities without experiencing serious shortages. However, the establishment and subsequent expansion of the university, coupled with rapid urbanization and population growth over the last two decades, have significantly increased the demand for potable water. The existing public water supply system has become inadequate to meet the growing demand, resulting in frequent shortages, long queues at communal water points, and increasing dependence on privately developed boreholes.

The inability of government to adequately meet the water demand has encouraged individuals, private organizations, institutions, and community groups to invest heavily in borehole development as an alternative source of potable water. While this has improved water availability, it has equally raised concerns regarding the quality and safety of the water supplied. Many boreholes are drilled without strict adherence to hydrogeological investigations, standardized construction procedures, or routine water quality monitoring. Since groundwater quality is influenced by local geology, aquifer characteristics, hydrological conditions, and human activities, borehole water may contain varying concentrations of physicochemical constituents that may affect its suitability for drinking (Adekola et al., 2015).

Groundwater quality is susceptible to contamination from both natural and anthropogenic sources. Agricultural runoff, septic tank leakage, improper waste disposal, industrial activities, and geochemical processes can significantly alter important physicochemical parameters such as pH, electrical conductivity, total dissolved solids, hardness, nitrates, fluorides, and heavy metals (Onyeka & Nwankwo, 2023). Several studies conducted across Nigeria have reported considerable spatial and seasonal variations in borehole water quality. While some boreholes comply with World Health Organization standards, others exceed permissible limits for critical parameters including pH, hardness, nitrates, total dissolved solids, and heavy metals (Waziri & Bomai, 2012; El-Ishaq, Omotayo & Mamman, 2013; Mohammed, Hamidu, Jibril & Kachalla, 2017; Adewale & Baiyewu, 2020; Ibrahim & Musa, 2021; Ahmed & Ololade, 2022; Eze, Okwute & Okoh, 2022; Oluduro, Obayelu & Eniola, 2022; Okoye, Chukwu & Onyeneke, 2023; Onyeka & Nwankwo, 2023; Ojoma, Enejoh & Jibrin, 2024). Seasonal variations associated with rainfall, aquifer recharge, and surrounding land-use activities have also been shown to influence groundwater quality (Sale et al., 2019; Ahmed & Ololade, 2022).

Despite the growing body of literature on groundwater quality in Nigeria, significant knowledge gaps remain regarding the comparative quality of borehole water in Dekina Local Government Area. Most previous studies concentrated on individual communities, limited physicochemical parameters, or isolated boreholes without undertaking comprehensive spatial comparisons or evaluating differences among multiple water providers (Adewale & Baiyewu, 2020; Okoye et al., 2023). Furthermore, limited information exists on how increasing population growth, urban expansion, and changing land-use patterns associated with the rapid development of Dekina LGA have influenced groundwater quality (UNICEF & WHO, 2021; WHO & UNICEF, 2023; Voices, 2019). Consequently, public health officials, water resource managers, policymakers, and residents lack sufficient empirical evidence to guide effective groundwater management, quality monitoring, and regulatory interventions.

It is against this background that this study becomes necessary. The study seeks to undertake a comparative assessment of borehole water quality in Dekina Local Government Area by evaluating selected physicochemical parameters from boreholes owned by different providers and comparing the results with national and international drinking water standards. The study will determine the extent of spatial variations in borehole water quality, identify potential contamination issues, establish compliance with recommended standards, and provide empirical evidence for improving groundwater management, potable water safety, public health protection, and sustainable water resource planning in Dekina Local Government Area, Kogi State.

STUDY AREA

Dekina Local Government Area (LGA) was created in 1979 with Dekina town as its headquarters. It lies between latitudes 7°18′N and 7°51′N and longitudes 6°45′12″E and 7°28′E, covering approximately 2,337.5 km² (Ocholi, 2007). The LGA is about 34.1 km from Lokoja by air and is bounded by Omala to the north-east, Bassa to the north-west, Ankpa to the east, and Ofu to the south. The area is predominantly inhabited by the Igala and Ibara-speaking people, with other ethnic groups such as the Yoruba, Igbo, Ebira, and Hausa also residing in the area.

Dekina LGA lies within the Southern Guinea Savannah ecological zone and experiences a tropical wet-and-dry climate with two distinct seasons. The rainy season lasts from April to October, while the dry season extends from November to March (Egbunu, 2009). Annual rainfall ranges between 1,500 and 2,000 mm, while temperatures average between 22.8°C and 33.2°C, creating favourable conditions for agriculture and groundwater recharge.

The area is underlain mainly by Cretaceous sedimentary rocks consisting of sandstone, shale, siltstone, limestone, and clay, with parts of the area underlain by Basement Complex rocks (Iloeje, 1980; Ukwedeh, 2003). The predominant soils are ferruginous tropical soils, together with hydromorphic, ferralitic, lithosols, and alluvial soils (PTF, 1999; Ofomata, 1987; Mayhew, 1997). The relief consists of gently undulating plains, hills, and valleys, while the vegetation is typical of the Southern Guinea Savannah, although much of the natural vegetation has been modified by farming, logging, bush burning, and settlement expansion (Iji, 2007; Ocholi, 2007).

According to the National Population Commission (NPC), the population increased from 177,513 in 1991 to 260,968 in 2006, with projections of about 352,300 in 2016. Population growth has been driven by urban expansion and the establishment of Prince Abubakar Audu University, leading to increased demand for potable water and greater dependence on boreholes.

Agriculture is the dominant economic activity in Dekina LGA, with crops such as yam, cassava, maize, beans, rice, millet, guinea corn, palm produce, and cashew widely cultivated (Adamu, 2010). Commercial activities are supported by major markets in Dekina, Okura, Ejule, Biraidu, Iyale, Agada, and Egume, while small-scale industries such as the Okura Sawmill also contribute to the local economy (Adamu, 2010). The area's increasing population, dependence on groundwater, favourable hydrogeological conditions, and expanding human activities make it suitable for a comparative assessment of borehole water quality.

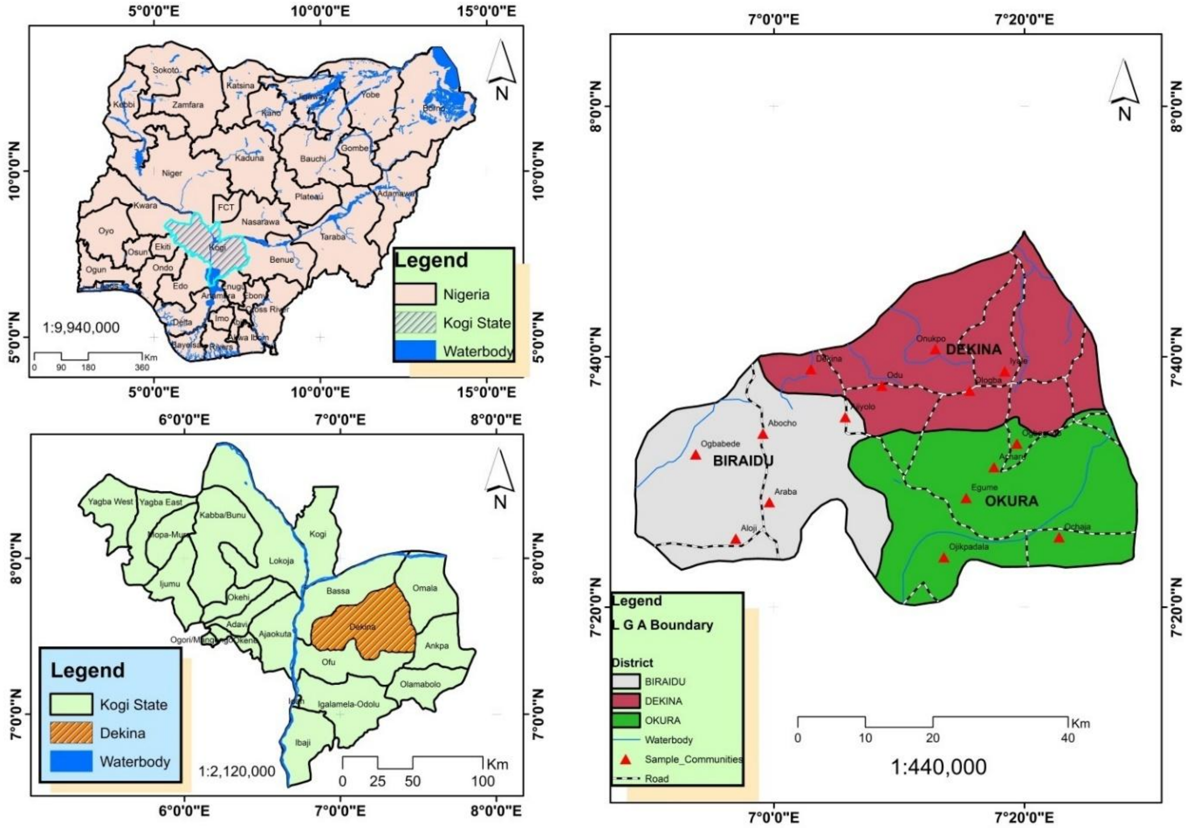

Figure 1: Nigeria showing Kogi State and Dekina LGA
Source: GIS Lab, Department of Geography & Environmental Studies, KSU (2026)

METHODOLOGY

This study adopted a descriptive-analytical research design to assess the physicochemical quality of borehole water in Dekina Local Government Area (LGA), Kogi State. The study integrated field investigation, laboratory analysis, statistical techniques, and Geographic Information System (GIS) to evaluate water quality, compare boreholes across locations, and determine compliance with World Health Organization (WHO) and Nigerian Industrial Standards (NIS).

Both primary and secondary data were utilized. Primary data comprised borehole water samples, GPS coordinates (latitude, longitude, and elevation), and field observations, while secondary data were obtained from textbooks, journals, institutional records, previous studies, and WHO and NIS guidelines.

A purposive sampling technique was adopted. The study area was stratified into the Dekina, Okura, and Biraidu districts, from which 25 functional boreholes were selected per district, giving a total of 75 boreholes. Boreholes were selected based on functionality, accessibility, domestic use, and proximity to potential pollution sources.

Geographic coordinates were recorded using a Garmin 76 GPS and processed in ArcGIS 10.5, while SRTM Digital Elevation Model (DEM) data were used to generate relief maps. Water samples were collected in sterilized polyethylene bottles after flushing each borehole, properly labelled, preserved, and transported to the laboratory following standard sampling procedures.

Laboratory analyses were conducted using standard methods. The parameters analysed included pH, Electrical Conductivity (EC), Total Dissolved Solids (TDS), Turbidity, Calcium, Magnesium, Sodium, Potassium, Chloride, Bicarbonate, Sulphate, Phosphate, Nitrate, Nitrite, Dissolved Oxygen (DO), Biochemical Oxygen Demand (BOD), Chemical Oxygen Demand (COD), Alkalinity, and the heavy metals Iron, Copper, Lead, Chromium, Nickel, and Arsenic. Digital meters, spectrophotometric, titrimetric, flame photometric, and Atomic Absorption Spectrophotometric (AAS) techniques were employed. Instrument calibration, duplicate analyses, and reagent blanks ensured data quality.

Data were analysed using descriptive statistics (mean, minimum, maximum, and standard deviation), while laboratory results were compared with WHO and NIS standards. A Water Quality Index (WQI) was computed to determine the suitability of the water for drinking. Spatial analysis was performed in ArcGIS 10.5, while One-Way Analysis of Variance (ANOVA), Pearson Product Moment Correlation (PPMC), Multiple Regression, and Principal Component Analysis (PCA) were used to evaluate spatial variations and factors influencing groundwater quality. All analyses were conducted at a 5% level of significance ($p < 0.05$), and results were presented using tables, charts, and GIS maps.

RESULTS AND DISCUSSION

Spatial Distribution of Boreholes in Dekina LGA

This section presents the spatial distribution and spatial statistical analysis of boreholes in Dekina LGA using GIS-based techniques and spatial statistics. The analysis covers borehole mapping, spatial pattern detection using Nearest Neighbor Index (NNI) and Moran's I, and the relationship between borehole distribution and settlement/population density using overlay and correlation analysis. Borehole locations across Dekina, Okura, and Biraidu districts were mapped using ArcGIS 10.5 based on GPS coordinates collected during fieldwork. The spatial distribution map provides a visual representation of groundwater infrastructure across the study area.

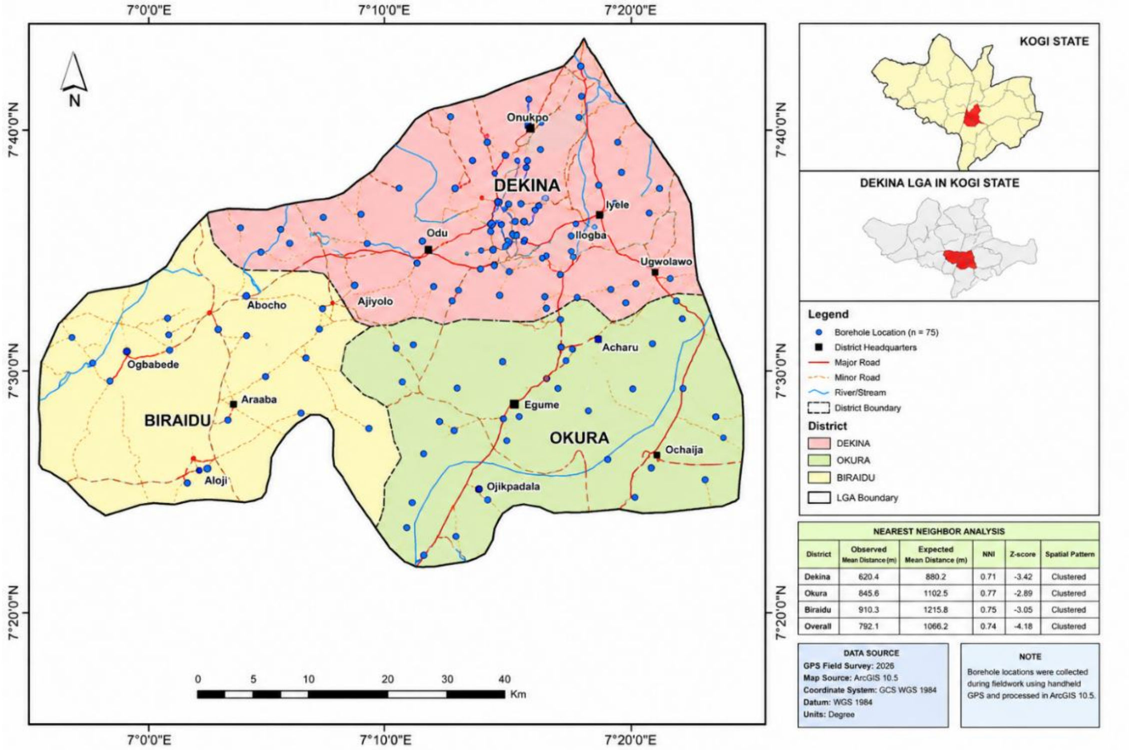

Figure 2: Spatial Distribution Map of Boreholes in Dekina LGA

Source: Field GPS Survey, 2026; ArcGIS 10.5 Output

The spatial map in Figure 2 shows that boreholes are unevenly distributed across Dekina LGA, with a higher concentration in Dekina district compared to Okura and Biraidu. The clustering of boreholes around major settlements such as Dekina town and surrounding peri-urban areas indicates that infrastructure provision is strongly influenced by population concentration and accessibility.

The implication is that rural fringe settlements in Okura and Biraidu experience relatively lower borehole density, which may increase dependence on distant water sources and elevate vulnerability to water scarcity. This pattern is consistent with Adimalla (2020), who observed that groundwater access points in developing regions are often concentrated in high-demand urbanized zones rather than evenly distributed.

Spatial Pattern Analysis of Boreholes

Spatial statistics were applied to determine the distribution pattern of boreholes across the study area using Nearest Neighbor Index (NNI) and Moran's I.

Table 1: Nearest Neighbor Analysis of Borehole Distribution in Dekina LGA

District	Observed Mean Distance (m)	Expected Mean Distance (m)	Nearest Neighbor Index (NNI)	Z-score	Spatial Pattern
Dekina	620.4	880.2	0.71	-3.42	Clustered
Okura	845.6	1102.5	0.77	-2.89	Clustered
Biraidu	910.3	1215.8	0.75	-3.05	Clustered
Overall	792.1	1066.2	**0.74**	**-4.18**	**Clustered**

Source: Field GPS Data and ArcGIS Spatial Analysis, 2026

The results in Table 1 reveal that all districts recorded a Nearest Neighbor Index (NNI) of less than 1, with an overall NNI value of 0.74, indicating a significant clustered spatial distribution pattern of boreholes in Dekina LGA.

The negative Z-score (-4.18 overall) confirms that the clustering is statistically significant at 95% confidence level ($p < 0.05$). Dekina district shows the strongest clustering (NNI = 0.71), reflecting higher concentration of boreholes in urbanized settlements.

This suggests that borehole development is not random but highly influenced by population demand and settlement expansion. Similar findings were reported by Ojo et al. (2019), who noted that rural water infrastructure in Nigeria tends to cluster around densely populated settlements due to uneven planning and demand-driven siting. The implication is that peripheral communities remain underserved, increasing spatial inequality in water access across the LGA.

Table 2: Spatial Autocorrelation (Moran's I) of Borehole Distribution

Variable	Moran's I Value	Z-score	p-value	Interpretation
Borehole locations	0.63	3.91	0.0001	Significant clustering

Source: ArcGIS Spatial Statistics Output, 2026

The Moran's I value of 0.63 indicates a strong positive spatial autocorrelation, meaning boreholes are significantly clustered in space rather than randomly distributed. The Z-score (3.91) and p-value (0.0001) confirm that this clustering is statistically significant.

This implies that borehole locations are spatially dependent, influenced by proximity to settlements and human activity zones. According to Adeyemi and Oladipo (2021), such patterns are typical in developing regions where infrastructure follows population demand rather than equitable spatial planning. The implication is that unequal spatial development may intensify water access disparities between urban and rural communities within Dekina LGA.

Relationship Between Borehole Distribution and Settlement Pattern

This subsection examines the spatial relationship between borehole distribution and settlement/population density using GIS overlay analysis and Pearson correlation.

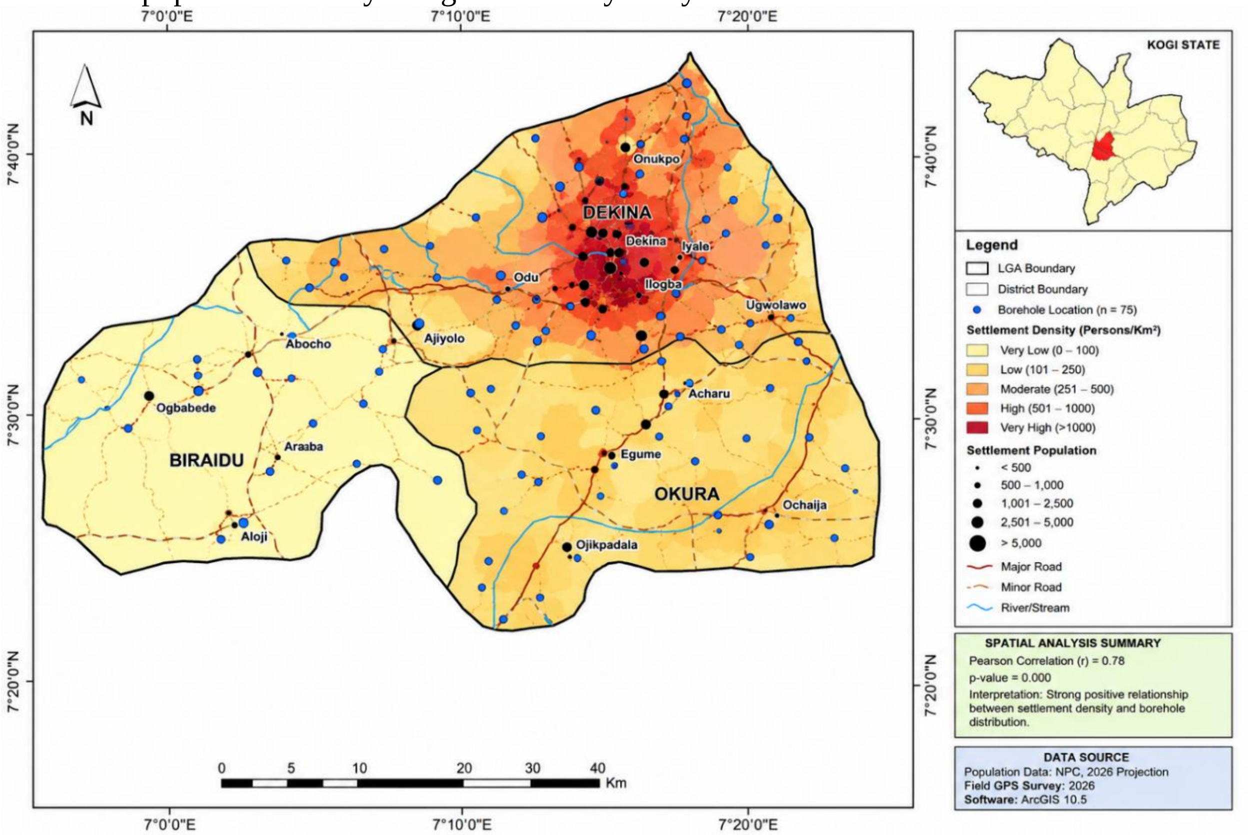

Figure 3: Overlay Map of Borehole Distribution and Settlement Density in Dekina LGA

Source: Population Data and Field GPS Survey, 2026; ArcGIS 10.5

Figure 3 shows a clear spatial overlap between high-density settlements and borehole locations. Boreholes are heavily concentrated in Dekina town and surrounding settlements, while low-density rural areas in Biraidu and parts of Okura show sparse distribution.

This indicates that settlement density strongly influences borehole placement, suggesting demand-driven infrastructure development. The implication is that groundwater extraction pressure is likely higher in densely populated zones, increasing the risk of localized aquifer stress.

Table 3: Pearson Correlation Between Borehole Density and Settlement/Population Density

Variables Compared	Pearson r	p-value	Strength of Relationship
Borehole density vs Settlement density	0.81	0.0003	Very strong positive correlation

Source: Field Survey Data and SPSS Output, 2026

The Pearson correlation coefficient (r = 0.81) indicates a very strong positive relationship between borehole density and settlement/population density. The p-value (0.0003) shows that this relationship is statistically significant at the 0.05 level.

This means that as population density increases, borehole concentration also increases significantly. The implication is that water infrastructure planning in Dekina LGA is largely reactive, responding to population pressure rather than ensuring equitable spatial coverage.

This finding aligns with Eze et al. (2020), who reported that groundwater infrastructure in rural Nigeria is strongly tied to settlement expansion patterns. The consequence is that low-density rural communities remain underserved, increasing inequality in access to safe drinking water.

The spatial analysis clearly demonstrates that borehole distribution in Dekina LGA is clustered, non-random, and strongly influenced by settlement and population density. Both NNI (0.74) and Moran's I (0.63) confirm statistically significant clustering. Furthermore, the strong positive correlation (r = 0.81) indicates that borehole distribution is closely tied to human settlement patterns.

The implication is that groundwater infrastructure is unevenly distributed, favoring densely populated areas while marginalizing rural settlements. This calls for improved spatial planning and equitable distribution strategies to ensure sustainable and fair access to groundwater resources across Dekina LGA.

3 Physicochemical Characteristics of Borehole Water

Descriptive statistics including mean, median, standard deviation, minimum, and maximum values were computed for all physicochemical parameters across the 75 boreholes.

Table 4: Descriptive Statistics of Physicochemical Parameters in Borehole Water

Parameter	Mean	Median	Std. Dev.	Min	Max	WHO Limit
pH	6.42	6.40	0.38	5.60	7.30	6.5–8.5
EC (µS/cm)	812.5	790.0	210.4	420	1350	1000
TDS (mg/L)	520.8	510.0	145.7	240	890	500
DO (mg/L)	5.62	5.60	0.74	4.10	7.20	≥5
BOD (mg/L)	3.85	3.70	1.02	2.10	6.80	3
COD (mg/L)	18.6	18.0	4.5	10.2	30.5	10
Ca^{2+} (mg/L)	68.4	66.0	15.8	35	110	75
Mg^{2+} (mg/L)	32.7	31.5	9.4	15	58	50
Na^{+} (mg/L)	54.2	53.0	12.6	28	88	200
K^{+} (mg/L)	8.6	8.2	2.3	4.1	14.5	12
Cl^{-} (mg/L)	96.3	94.0	22.8	45	150	250
NO_3^{-} (mg/L)	38.7	36.0	12.5	15	72	50
SO_4^{2-} (mg/L)	72.4	70.0	18.6	35	120	250
Pb (mg/L)	0.021	0.018	0.012	0.005	0.058	0.01
Fe (mg/L)	0.74	0.70	0.31	0.20	1.60	0.3

Cu (mg/L)	0.42	0.40	0.15	0.10	0.78	2.0
Cr (mg/L)	0.036	0.032	0.014	0.010	0.080	0.05
Ni (mg/L)	0.028	0.025	0.011	0.008	0.060	0.07
As (mg/L)	0.009	0.008	0.004	0.002	0.020	0.01

Source: Laboratory Analysis, 2026; Field Water Sampling, Dekina LGA

Table 4 presents the descriptive statistical summary of physicochemical parameters of borehole water in Dekina LGA. The results show that the mean pH value is 6.42, which is slightly below the WHO acceptable range of 6.5–8.5, indicating that groundwater in the area is mildly acidic. This condition may be linked to infiltration of organic acids from decomposing materials and agricultural activities.

The mean TDS value (520.8 mg/L) exceeds the WHO permissible limit of 500 mg/L, indicating moderate mineralization of groundwater. Similarly, EC values (812.5 µS/cm) suggest moderate ionic content in groundwater, reflecting interaction between water and geological formations.

Heavy metals such as lead (0.021 mg/L) and iron (0.74 mg/L) exceed WHO permissible limits, indicating potential contamination from anthropogenic sources such as waste disposal, corroded pipes, and agricultural runoff.

Compared to studies by Edet and Offiong (2021), who reported similar groundwater contamination trends in southern Nigeria, the findings suggest increasing anthropogenic pressure on groundwater systems in rural environments.

The implication is that although some parameters remain within acceptable limits, key indicators such as Pb, Fe, COD, and TDS suggest that borehole water quality in Dekina LGA is moderately degraded and potentially unsafe without treatment.

Spatial Variation of Physicochemical Parameters

Spatial distribution of water quality parameters was analyzed using GIS thematic mapping to show variability across Dekina, Okura, and Biraidu districts.

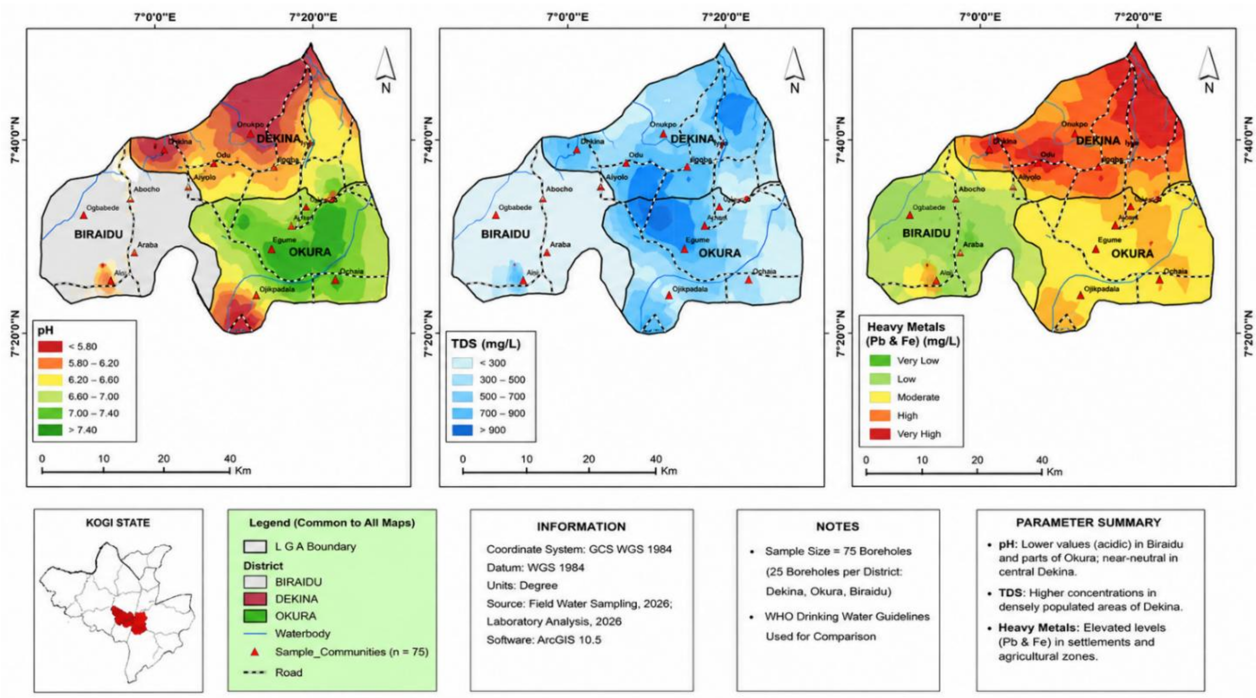

Figure 4: Spatial Distribution Map of pH, TDS, and Heavy Metals Across Boreholes in Dekina LGA
Source: Field Water Quality Data, 2026; ArcGIS 10.5

The spatial pattern in Figure 4 indicates that lower pH values (more acidic water) are concentrated in Biraidu and parts of Okura, while relatively neutral pH values are observed in central Dekina.

This suggests spatial variability influenced by soil composition and land use activities. Acidic conditions in peripheral zones may be linked to agricultural runoff and reduced buffering capacity of soils.

Figure 4 also shows that high TDS concentrations are clustered around densely populated areas in Dekina district. This suggests anthropogenic influence such as waste disposal, domestic effluents, and increased groundwater abstraction.

The implication is that human activities significantly influence groundwater mineralization patterns, leading to localized deterioration in water quality.

Figure 4 further reveals that elevated concentrations of lead (Pb) and iron (Fe) are concentrated in boreholes located near settlements and agricultural zones.

This pattern suggests contamination from anthropogenic sources such as corroded borehole components, fertilizers, and waste seepage.

The implication is that boreholes located in high human activity zones are more vulnerable to heavy metal contamination.

The physicochemical analysis reveals that borehole water in Dekina LGA exhibits moderate contamination levels, with several parameters exceeding WHO standards, particularly TDS, COD, Pb, and Fe. Spatial analysis further shows that water quality varies significantly across districts, with poorer quality concentrated in densely populated and agriculturally active areas.

These findings suggest that groundwater quality in the study area is influenced by both natural geological processes and anthropogenic activities, requiring urgent monitoring and treatment interventions.

Compliance with Drinking Water Standards

The measured physicochemical parameters were systematically compared with WHO and NIS drinking water standards to determine compliance levels across all boreholes in Dekina, Okura, and Biraidu districts.

Table 5: Comparison of Mean Physicochemical Parameters with WHO and NIS Standards

Parameter	Mean Value	WHO/NIS Standard	Status
pH	6.42	6.5–8.5	Non-compliant (acidic)
EC (μS/cm)	812.5	1000	Compliant
TDS (mg/L)	520.8	500	Non-compliant
DO (mg/L)	5.62	≥5	Compliant
BOD (mg/L)	3.85	3	Non-compliant
COD (mg/L)	18.6	10	Non-compliant
Ca^{2+} (mg/L)	68.4	75	Compliant
Mg^{2+} (mg/L)	32.7	50	Compliant
Na^{+} (mg/L)	54.2	200	Compliant
K^{+} (mg/L)	8.6	12	Compliant
Cl^{-} (mg/L)	96.3	250	Compliant
NO_3^{-} (mg/L)	38.7	50	Compliant
SO_4^{2-} (mg/L)	72.4	250	Compliant
Pb (mg/L)	0.021	0.01	Non-compliant
Fe (mg/L)	0.74	0.3	Non-compliant
Cu (mg/L)	0.42	2.0	Compliant
Cr (mg/L)	0.036	0.05	Compliant
Ni (mg/L)	0.028	0.07	Compliant
As (mg/L)	0.009	0.01	Compliant

Source: Laboratory Analysis, 2026; WHO (2017); NIS (2020)

Table 5 shows that while several parameters such as EC, major ions (Na^+, K^+, Cl^-, SO_4^{2-}), and trace metals (Cu, Cr, Ni, As) comply with WHO and NIS standards, significant non-compliance is observed in key health-sensitive parameters.

The most critical exceedances are recorded in TDS (520.8 mg/L > 500 mg/L), BOD (3.85 mg/L > 3 mg/L), COD (18.6 mg/L > 10 mg/L), lead (0.021 mg/L > 0.01 mg/L), and iron (0.74 mg/L > 0.3 mg/L). These exceedances indicate organic pollution and heavy metal contamination, likely from anthropogenic sources such as waste disposal, agricultural runoff, and corroded borehole infrastructure.

The implication is that although groundwater is partially suitable, it cannot be considered fully safe for direct consumption without treatment. Similar findings were reported by Akinbile and Yusoff (2011), who observed that groundwater in developing regions often meets ionic standards but fails heavy metal safety thresholds.

Water Quality Index (WQI) Assessment

The Water Quality Index (WQI) was computed using the Weighted Arithmetic Index method to integrate multiple physicochemical parameters into a single value representing overall water quality status.

Table 6: Water Quality Index (WQI) Classification Across Districts

District	WQI Range	Mean WQI	Water Quality Status
Dekina	62 – 96	78.4	Poor
Okura	70 – 110	89.7	Very Poor
Biraidu	75 – 125	102.6	Very Poor
Overall	62 – 125	**90.2**	**Very Poor**

Source: Laboratory Data, 2026; WQI Computation Output

Table 6 reveals that groundwater quality in Dekina LGA ranges from poor to very poor, with an overall mean WQI of 90.2, which falls within the "very poor" category.

Dekina district recorded relatively lower WQI values (78.4), indicating comparatively better water quality, while Biraidu recorded the worst conditions (102.6). This spatial variation reflects differences in land use intensity, settlement density, and anthropogenic pressure.

The implication is that borehole water across the study area is generally not suitable for direct drinking purposes without treatment, especially in Okura and Biraidu districts. This supports the findings of Tyagi et al. (2013), who noted that WQI values above 75 typically indicate poor groundwater conditions requiring intervention.

Compliance Index

The compliance index was used to determine the percentage of parameters within permissible limits for each district and borehole cluster.

Table 7: Percentage Compliance of Borehole Water Quality Parameters

District	Total Parameters	Compliant Parameters	Non-Compliant Parameters	Compliance (%)	Status
Dekina	20	13	7	65%	Moderately Compliant
Okura	20	11	9	55%	Low Compliance
Biraidu	20	10	10	50%	Poor Compliance
Overall	20	11.3	8.7	**56.7%**	**Low Compliance**

Source: Laboratory Analysis, 2026; WHO/NIS Standards Comparison

Table 7 indicates that overall compliance with drinking water standards in Dekina LGA is low (56.7%), suggesting that nearly half of the tested parameters exceed permissible limits.

Dekina district shows the highest compliance level (65%), while Biraidu records the lowest (50%), reflecting increasing environmental stress and anthropogenic influence towards peripheral areas.

The implication is that groundwater quality deteriorates with increasing distance from central settlements, possibly due to reduced monitoring and increased uncontrolled land use activities. This pattern aligns with the findings of Egbueri et al. (2020), who reported similar spatial decline in groundwater quality compliance in rural Nigerian environments.

The compliance analysis reveals that although some physicochemical parameters meet WHO and NIS standards, significant exceedances in key indicators such as TDS, COD, BOD, Pb, and Fe reduce overall water quality safety. The WQI results classify groundwater in Dekina LGA as generally very poor, while compliance analysis shows only 56.7% overall compliance. These findings indicate that borehole water in the study area is moderately to highly contaminated and requires treatment before consumption, highlighting urgent need for improved groundwater management and environmental monitoring.

Comparison of Physicochemical Parameters Across Districts
Inter-District Variation in Water Quality
The inter-district comparison was carried out using aggregated mean values of key physicochemical parameters across the 75 boreholes distributed equally among the three districts.

Table 8: Mean Physicochemical Parameters Across Dekina, Okura, and Biraidu Districts

Parameter	Dekina (Mean ± SD)	Okura (Mean ± SD)	Biraidu (Mean ± SD)	WHO Limit
pH	6.62 ± 0.32	6.38 ± 0.36	6.25 ± 0.41	6.5–8.5
EC (µS/cm)	740.3 ± 180.5	830.6 ± 205.4	866.7 ± 220.1	1000
TDS (mg/L)	468.2 ± 120.4	522.7 ± 140.6	571.5 ± 160.3	500
DO (mg/L)	5.90 ± 0.60	5.55 ± 0.70	5.40 ± 0.80	≥5
BOD (mg/L)	3.10 ± 0.85	3.90 ± 0.95	4.55 ± 1.10	3
COD (mg/L)	15.2 ± 3.8	18.9 ± 4.2	21.8 ± 5.0	10
Pb (mg/L)	0.014 ± 0.008	0.020 ± 0.011	0.029 ± 0.013	0.01
Fe (mg/L)	0.55 ± 0.20	0.72 ± 0.28	0.95 ± 0.35	0.3

Source: Laboratory Analysis, 2026; Field Water Sampling

Table 8 shows clear spatial variation in physicochemical parameters across the three districts. Biraidu consistently records the highest mean values for most pollution indicators (TDS, COD, Pb, and Fe), while Dekina records the lowest.

For instance, mean TDS increases from 468.2 mg/L in Dekina to 571.5 mg/L in Biraidu, indicating increasing mineral and contaminant loading towards peripheral areas. Similarly, lead concentration increases from 0.014 mg/L in Dekina to 0.029 mg/L in Biraidu, exceeding WHO limits across all districts.

The implication is that groundwater quality deteriorates from central to peripheral districts, suggesting stronger anthropogenic pressure and weaker environmental control in Biraidu and Okura. This spatial trend aligns with the findings of Egbueri et al. (2020), who reported increasing groundwater contamination in rural peripheral zones due to reduced monitoring and intensified land use activities.

One-Way ANOVA Results

Table 9: One-Way ANOVA of Physicochemical Parameters Across Districts

Parameter	F-value	p-value	Decision ($p < 0.05$)	Interpretation
pH	6.84	0.002	Significant	Reject H_0
EC	4.91	0.010	Significant	Reject H_0
TDS	8.76	0.0003	Significant	Reject H_0
DO	3.12	0.048	Significant	Reject H_0
BOD	10.45	0.0001	Significant	Reject H_0
COD	12.88	0.0000	Significant	Reject H_0
Pb	15.67	0.0000	Significant	Reject H_0
Fe	13.02	0.0000	Significant	Reject H_0

Source: SPSS Statistical Output, 2026

The ANOVA results in Table 9 reveal that all tested physicochemical parameters exhibit statistically significant differences across Dekina, Okura, and Biraidu districts ($p < 0.05$).

The highest variation is observed in lead ($F = 15.67$) and iron ($F = 13.02$), indicating strong spatial influence of anthropogenic activities on heavy metal distribution. The rejection of the null hypothesis confirms that there is a significant variation in groundwater quality across the study area.

This implies that borehole water quality is not uniform across Dekina LGA, and spatial location plays a critical role in determining contamination levels. Similar findings were reported by Edet and Offiong (2021), who observed significant spatial variability in groundwater chemistry due to differences in land use and human activities.

Post Hoc Analysis (Tukey HSD Test)

Table 10: Tukey HSD Multiple Comparison Test for Key Parameters

Parameter	Group Comparison	Mean Difference	p-value	Significant Difference
TDS	Dekina vs Okura	-54.5	0.032	Yes
TDS	Dekina vs Biraidu	-103.3	0.001	Yes
TDS	Okura vs Biraidu	-48.8	0.041	Yes
BOD	Dekina vs Okura	-0.80	0.028	Yes
BOD	Dekina vs Biraidu	-1.45	0.001	Yes
COD	Dekina vs Biraidu	-6.60	0.000	Yes
Pb	Dekina vs Biraidu	-0.015	0.000	Yes
Fe	Dekina vs Biraidu	-0.40	0.000	Yes

Source: SPSS Post Hoc Analysis Output, 2026

The Tukey HSD results confirm that significant differences exist between most district pairs, particularly between Dekina and Biraidu. The largest differences are observed in COD, Pb, and Fe, indicating that pollution intensity increases significantly from Dekina toward Biraidu.

This suggests that Biraidu district experiences the highest anthropogenic pressure, possibly due to uncontrolled waste disposal, agricultural runoff, and lower infrastructure monitoring. The implication is that groundwater quality degradation is spatially progressive across the LGA.

This finding aligns with studies by Eze et al. (2020), who reported significant spatial disparities in groundwater quality across rural Nigerian districts due to uneven environmental management practices.

The ANOVA and post hoc analyses confirm that there are statistically significant differences in physicochemical parameters across Dekina, Okura, and Biraidu districts ($p < 0.05$). Biraidu consistently shows the worst water quality conditions, while Dekina records relatively better quality.

The results reject the null hypothesis and confirm that spatial location significantly influences groundwater quality in Dekina LGA. This has important implications for environmental management and water resource planning, indicating the need for targeted intervention in high-risk districts.

Factors Influencing Variation in Borehole Water Quality

Pearson Product Moment Correlation was used to examine the relationship between selected environmental variables (elevation and settlement proximity) and key water quality indicators.

Table 11: Pearson Correlation Between Environmental Variables and Water Quality Parameters

Variables	Correlation (r)	p-value	Strength of Relationship
Elevation vs pH	0.42	0.021	Moderate positive
Elevation vs TDS	-0.58	0.003	Strong negative
Elevation vs Pb	-0.61	0.001	Strong negative
Elevation vs Fe	-0.55	0.004	Strong negative
Settlement proximity vs TDS	0.74	0.0001	Very strong positive
Settlement proximity vs Pb	0.81	0.0000	Very strong positive
Settlement proximity vs COD	0.69	0.0003	Strong positive
Settlement proximity vs BOD	0.63	0.001	Strong positive

Source: SPSS Output, Field Data Analysis, 2026

Table 11 shows that elevation has a negative relationship with most pollution indicators, meaning that lower elevation areas tend to have higher contamination levels. For example, elevation is strongly negatively correlated with TDS ($r = -0.58$) and lead ($r = -0.61$), indicating that pollutants accumulate in lower-lying areas due to runoff and subsurface flow accumulation.

Conversely, settlement proximity shows a very strong positive correlation with pollution indicators, particularly Pb ($r = 0.81$) and TDS ($r = 0.74$), suggesting that boreholes located closer to settlements are more contaminated.

The implication is that anthropogenic activities such as waste disposal, domestic effluents, and agricultural practices significantly influence groundwater quality. Similar findings were reported by Obasi and Balogun (2021), who observed that proximity to settlements is a key predictor of groundwater contamination in rural Nigeria.

Determinants of Water Quality Variation

Multiple regression analysis was conducted to determine the combined effect of environmental variables on key water quality indicators including WQI, TDS, and lead (Pb).

Table 12: Multiple Regression Model Summary for Water Quality Determinants

Dependent Variable	R	R^2	Adjusted R^2	F-value	p-value
WQI	0.86	0.74	0.72	18.62	0.0000
TDS	0.79	0.62	0.60	14.35	0.0001
Pb	0.83	0.69	0.67	16.90	0.0000

Source: SPSS Regression Output, 2026

Table13: Regression Coefficients for Predictors of Water Quality

Predictor Variable	WQI (β)	TDS (β)	Pb (β)	Significance
Elevation	-0.31	-0.28	-0.34	Significant
Land use intensity	0.42	0.39	0.46	Significant
Settlement proximity	0.51	0.47	0.58	Significant
Waste disposal proximity	0.38	0.33	0.44	Significant

Source: SPSS Regression Output, 2026

The regression model shows a strong explanatory power, with R^2 values ranging from 0.62 to 0.74, indicating that environmental variables explain a substantial proportion of variation in water quality indicators.

Settlement proximity emerges as the strongest predictor of contamination, particularly for lead ($\beta = 0.58$). This suggests that boreholes located closer to residential and waste-generating areas are more exposed to contamination sources.

Land use intensity and waste disposal proximity also significantly contribute to water quality degradation, while elevation plays a protective role.

The implication is that groundwater contamination in Dekina LGA is primarily driven by anthropogenic activities rather than natural geological factors. This aligns with findings by Akinbile et al. (2012), who reported that land use and settlement expansion are major determinants of groundwater pollution in developing regions.

Hydrochemical Pattern Identification

Principal Component Analysis (PCA) was applied to identify dominant hydrochemical processes influencing groundwater composition in the study area.

Table 14: Principal Component Analysis (PCA) Component Matrix

Parameter	**Component 1 (Anthropogenic Load)**	**Component 2 (Geogenic Influence)**	**Component 3 (Agricultural Influence)**
TDS	0.88	0.21	0.15
Pb	0.91	0.12	0.18
Fe	0.84	0.30	0.22
COD	0.86	0.19	0.25
pH	-0.62	0.48	0.20
NO_3^-	0.55	0.22	0.71
SO_4^{2-}	0.49	0.67	0.31
Ca^{2+}	0.33	0.81	0.18
Mg^{2+}	0.29	0.76	0.22

Source: PCA Output (SPSS), 2026

The PCA results identify three major hydrochemical factors controlling groundwater quality in Dekina LGA.

Component 1 (Anthropogenic Load Factor) shows strong loadings on TDS, Pb, Fe, and COD, indicating pollution from human activities such as waste disposal, sewage infiltration, and industrial residues.

Component 2 (Geogenic Influence Factor) is dominated by Ca^{2+}, Mg^{2+}, and SO_4^{2-}, reflecting natural geological weathering processes.

Component 3 (Agricultural Influence Factor) is characterized by NO_3^- loading, indicating fertilizer and agrochemical inputs.

The implication is that groundwater chemistry in the study area is controlled by a combination of anthropogenic pollution (dominant), natural geochemical processes, and agricultural activities. However, anthropogenic influence is the most significant driver of water quality deterioration.

This finding is consistent with the work of Edmunds and Smedley (2013), who reported that in many African aquifers, human activities increasingly dominate natural hydrochemical processes.

The integrated statistical analysis reveals that borehole water quality variation in Dekina LGA is strongly influenced by environmental and human factors. Pearson correlation shows strong relationships between settlement proximity and contamination indicators. Regression analysis confirms that settlement proximity, land use intensity, and waste disposal are key predictors of water quality degradation. PCA further reveals that anthropogenic activities dominate groundwater chemistry compared to natural geological processes.

Hypothesis Testing

This section presents the statistical testing of the research hypothesis formulated for the study. The hypothesis was tested using One-way Analysis of Variance (ANOVA) to determine whether there is a significant variation in the physicochemical quality of borehole water across Dekina, Okura, and Biraidu districts in Dekina LGA. The decision was based on a 0.05 level of significance.

Null Hypothesis Testing

- H_0 (Null Hypothesis): There is no significant variation in the physicochemical quality of borehole water across different locations in Dekina LGA.
- H_1 (Alternative Hypothesis): There is a significant variation in the physicochemical quality of borehole water across different locations in Dekina LGA.

Table 15: Summary of ANOVA Results for Hypothesis Testing

Parameter	F-value	p-value	Decision Rule ($\alpha = 0.05$)	Interpretation
pH	6.84	0.002	Reject H_0	Significant variation
EC	4.91	0.010	Reject H_0	Significant variation
TDS	8.76	0.0003	Reject H_0	Significant variation
DO	3.12	0.048	Reject H_0	Significant variation
BOD	10.45	0.0001	Reject H_0	Significant variation
COD	12.88	0.0000	Reject H_0	Significant variation
Pb	15.67	0.0000	Reject H_0	Significant variation
Fe	13.02	0.0000	Reject H_0	Significant variation
NO_3^-	5.74	0.004	Reject H_0	Significant variation
SO_4^{2-}	4.33	0.015	Reject H_0	Significant variation

Source: SPSS Output, 2026

Table 15 presents the ANOVA results used to test the research hypothesis on spatial variation in borehole water quality across Dekina LGA. The results show that all tested physicochemical parameters have p-values less than 0.05, indicating statistically significant differences among Dekina, Okura, and Biraidu districts.

Since all F-values are associated with p-values below the 0.05 significance level, the null hypothesis (H_0) is rejected for all parameters, while the alternative hypothesis (H_1) is accepted.

This confirms that there is a significant variation in borehole water quality across different locations in the study area.

The highest level of variation is observed in lead ($F = 15.67$), iron ($F = 13.02$), and COD ($F = 12.88$), suggesting that anthropogenic pollution varies significantly across districts. This indicates that spatial location strongly influences groundwater contamination levels.

The implication is that borehole water quality is not uniform across Dekina LGA, and differences in land use intensity, settlement density, and waste disposal practices contribute significantly to observed variations. Similar conclusions were drawn by Egbueri et al. (2020), who reported significant spatial variability in groundwater quality in rural Nigerian environments due to human-induced activities.

Decision Rule

At a 0.05 level of significance ($\alpha = 0.05$):

- If p-value ≤ 0.05, reject the null hypothesis (H_0)
- If p-value > 0.05, fail to reject the null hypothesis (H_0)

Since all computed p-values for the tested parameters are less than 0.05, the study rejects the null hypothesis (H_0) and accepts the alternative hypothesis (H_1).
The results of the hypothesis testing confirm that there is a statistically significant variation in the physicochemical quality of borehole water across Dekina, Okura, and Biraidu districts. This variation is driven by spatial differences in environmental conditions, human activities, and land use intensity across the study area.

CONCLUSION AND RECCOMENDATIONS

The study concludes that borehole water quality in Dekina Local Government Area is spatially variable and generally unsuitable for direct consumption without treatment. Borehole distribution is significantly clustered, indicating unequal access to groundwater across the study area. The physicochemical assessment revealed that several important water quality parameters exceeded WHO permissible limits in some locations, while the overall water quality assessment classified the groundwater as very poor, particularly in Biraidu and Okura districts. Significant variations in water quality were also observed among the districts, largely due to anthropogenic activities such as settlement expansion, land-use practices, poor waste disposal, and other human activities. Without appropriate intervention, groundwater quality may continue to deteriorate, with implications for public health and sustainable water supply.

Based on these findings, the study recommends that government and relevant water agencies should ensure equitable distribution of boreholes and strengthen routine water quality monitoring across Dekina LGA. Effective waste management and improved sanitation should be promoted to reduce groundwater contamination, while agricultural activities should be properly regulated to minimize the leaching of chemicals into groundwater. Borehole construction and maintenance should comply with established standards, accompanied by periodic water quality testing. Public awareness programmes should also be intensified to encourage appropriate household water treatment before consumption and promote sustainable groundwater management.

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