DEPARTMENT OF STATISTICS
AHMADU BELLO UNIVERSITY, ZARIA
2nd International Conference on Statistical Sciences and Data Analytics (ICSSDA 2026) Proceedings Paper

Comparative Analysis of Groundwater Quality Parameters in Niger State.

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Abstract

Groundwater is the primary source of water for households in Niger State. However, poor sanitation and limited monitoring have raised concerns regarding its quality and safety. This paper evaluated the effects of Total Dissolved Solids (TDS) and pH on microbial contamination and compared groundwater quality (GWQ) parameters between Boreholes (BH) and Hand-Dug Wells (HDW). Data were collected from twenty sampled locations of five BH and fifteen HDW. The results revealed that, in BH, microbial contamination exhibited a moderate positive, insignificant association with TDS ($r = 0.65–0.71$, $p > 0.05$) and a moderate-strong negative, insignificant association with pH ($r = −0.41$ to $−0.74$, $p > 0.05$). Indicated that high TDS and low pH were associated with increased microbial contamination. However, their insignificant correlations suggested that other environmental factors influenced microbial contamination. In contrast, microbial indicators in HDW exhibited strong positive, significant associations with TDS ($r = 0.80–0.86$, $p < 0.05$) and strong negative, significant associations with pH ($r = −0.84$ to $−0.91$, $p < 0.05$), revealing that high dissolved solids and low pH were associated with increased microbial contamination. This study identified pH as the most influential auxiliary variable in modelling microbial contamination, recommended BH as a safe drinking-water source, and showed that HDW require routine monitoring and appropriate treatment before consumption to ensure water safety and compliance with WHO drinking-water standards.

Keywords: Groundwater Quality Parameters, Correlation Analysis, Microbial Contamination, Boreholes and Hand-Dug Wells.

1. Introduction

Groundwater (GW) is the water found underground in the cracks and spaces in soil, sand and rock. It is stored in and moves slowly through geologic formations of soil, sand and rocks called aquifers. It is used for drinking water by more than 50 per cent of the people in the United

States, including almost everyone who lives in rural areas. The largest use for groundwater is to irrigate crops. It can be polluted by landfills, septic tanks, leaky underground gas tanks and over-use of fertilisers and pesticides. If GW becomes polluted, it will no longer be safe to drink. It's also referred to as subsurface water located beneath the water table in saturated soil and rock formations and plays a crucial role in supplying safe drinking water. It accounts for approximately 88% of potable water in rural areas where population is dispersed, and water infrastructure is limited (Yussuff, 2007). Groundwater quality (GWQ) parameters have several qualities that make it suitable for public supply: it is typically free from pathogens, has acceptable turbidity and colour, and can often be consumed without prior treatment (Nafees, 2015). GWQ is a critical source of water globally and is stored within underground aquifers. United Nations Children's Fund (UNICEF, 2019). In many developing countries, boreholes (BH) and hand-dug wells (HDW) provide the primary supply of domestic drinking water. A clean water supply is one of the key indicators for development in any country; however, the situation of most African countries is not encouraging because more than 300 million people in Africa live in water scarce environments WHO (2017). In Nigeria, GW provide the bulk of drinking water for both rural and urban communities. The increasing dependence on GW resources, coupled with rapid urbanisation, inadequate sanitation facilities and poor waste management practices, has heightened concerns regarding GWQ and its implications for human health. Water quality is a critical determinant of human and environmental well-being. Contaminated drinking water has been linked to outbreaks of waterborne diseases, reduced agricultural productivity and ecosystem degradation. GWQ is affected by both natural processes and anthropogenic activities such as indiscriminate waste disposal. Once contaminated, GW become unsafe for human consumption and costly to remediate (WHO, 2017).

GWQ is commonly evaluated using physical, chemical and microbiological parameters. These parameters vary spatially due to hydrogeological conditions, seasonal fluctuations, GW abstraction rates and pollution sources (Appelo and Postma, 2005). In urban and peri-urban environments, anthropogenic inputs are often the dominant factors influencing GWQ, particularly in areas characterised by high population density and inadequate sanitation infrastructure (Francisco *et al*., 2024; Suleiman *et al*., 2020). Regular monitoring is essential for safeguarding public health and ensuring the sustainable management of groundwater resources. However, GWQ can be affected by both natural and anthropogenic factors. Hardness in water arises from contact with mineral-laden geological formations or direct human-induced pollution (Okimiji *et al*., 2024). Urban GWQ in Nigeria is influenced by various factors including underlying geology, geochemical conditions, urbanisation, industrial activities, seasonal variations, and contamination from heavy metals and pathogens (Ocheri *et al*., 2014). Boreholes (BH), which are machine-drilled wells, typically range from 10 to 100 meters in depth and are constructed with 4–8 inch PVC casings and screens. Shallow BH are between 10–30 meters, while deeper ones range from 30–100 meters. Compared to hand-dug wells (HDW), machine-drilled BH are generally regarded as more reliable sources of drinking water, especially in densely populated communities. HDW are constructed manually using shovels or backhoes. They are usually shallow, between 10 and 30 feet deep, since excavation is limited by the groundwater table and the digger's ability to bail out water. These wells are lined with materials such as stones, bricks, or concrete to prevent collapse and are capped for protection. Due to their shallow nature, HDW are more susceptible to contamination. To reduce this risk, proper construction features are required to prevent contaminants from seeping in along or through the casing. To prevent collapse, these wells are usually lined with materials like stones, bricks, tiles, or concrete, and they are often capped with wood, stone, or concrete for added protection (Nadarian *et al*., 2024; Zhang *et al*., 2025).

Correlation analysis has been employed in hydrogeochemical and water quality studies to evaluate the strength and direction of association among water quality parameters (Bisiriyu *et al*., 2020). By quantifying the degree of association between physicochemical parameters, correlation analysis provides a statistical basis for identifying suitable auxiliary variables for geostatistical modelling and spatial prediction of GWQ (Goovaerts, 1997; Isaaks and Srivastava, 1989). Despite the importance of GW, routine monitoring remains constrained in many developing countries by technical, financial and logistical limitations (Goovaerts, 2003; Tijani *et al*., 2005).

This study aimed to evaluate the effect of TDS and pH on microbial GWQ parameters, compare the quality of water from selected machine-drilled BH and HDW in Minna metropolis and identify the parameter (TDS or pH) most strongly associated with microbial indicators using correlation analysis. The findings are expected to identify the auxiliary variable most strongly associated with microbial contamination, strengthen groundwater quality assessment, and facilitate comparison of BH and HDW to identify differences in water quality and contamination level, support public health interventions and sustainable groundwater management in Minna metropolis, Niger State.

2. Materials and Methods

2.1. Study Area

This study was conducted in Minna and its environs, located in Niger State, Nigeria, between latitudes 8°20′N and 11°30′N and longitudes 3°30′E and 7°20′E. The area covers approximately 76,363 km² and had an estimated population of about 513,000 in 2024, increasing to approximately 532,000 in 2025.

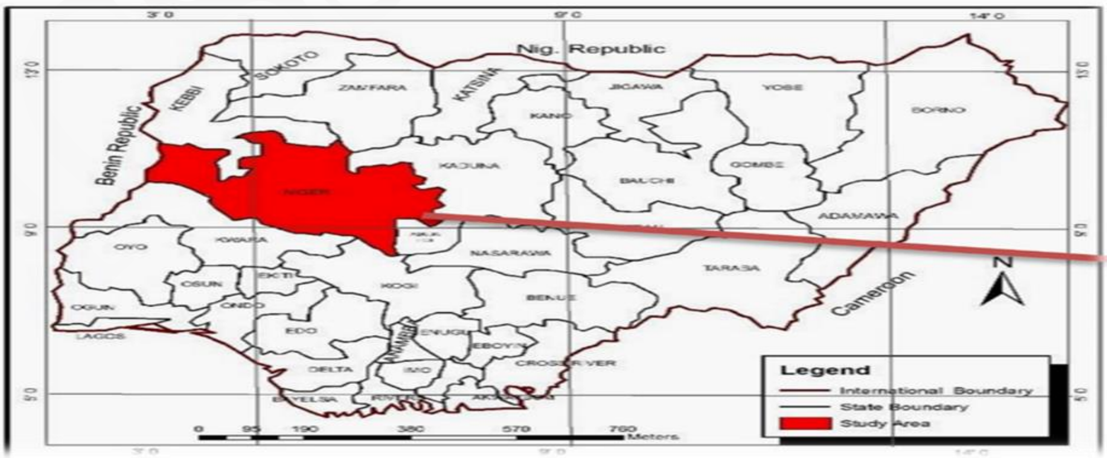

Figure 1. Map of Nigeria.

Figure 1 shows the international boundary, state boundary networks and the study area in red colour as reference layers.

Figure 2. Borehole and Hand-dug well

2.2. Sampling Techniques

Purposive Sampling (PS) techniques were adopted in this study. The PS select samples based on specific study objectives. It does not use a formula to select individual samples. The study area was divided into zones (Residential, Agricultural and Industrial zones), from which samples were randomly selected, while key sites with contamination risk were deliberately included. This approach improves representativeness and reduces sampling bias (Creswell and Creswell, 2018).

2.3. Data Sources

The data utilised in this study were obtained from twenty (20) locations of five (5) BH and fifteen (15) HDW through field sampling and laboratory analysis by the Department of Geology, Federal University of Technology (FUT) Minna (2024) and datasets from Isah and Abdullahi (2015). The analysed GWQ parameters included E. coli, F. col, T. col, TDS and pH, with their map using the sampled points' coordinates, Build-up areas, roads, and drainage networks as reference layers. BH and HDW were symbolised by colours according to sample type and water quality parameters across the study area for assessing groundwater quality patterns and contamination hotspots.

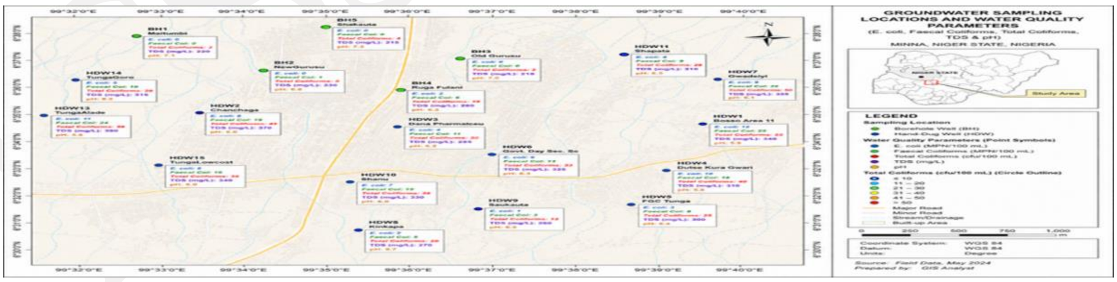

Figure 3. Map of the sampled Locations of BH and HDWs

Figure 3 presents the map, indicating that microbial contamination is higher in HDW than BH. Where most BH are represented by dark blue and light blue colours, corresponding to low microbial concentrations (≤2.00 cfu/100 mL). While HDW are represented by green, yellow, orange and red colours, indicating moderate (21–30 cfu/100 mL), high (31–40 cfu/100 mL), very high (41–50 cfu/100 mL) and extremely high (>50 cfu/100 mL) contamination concentrations and health risks, suggested water obtained from HDW should be treated before consumption to minimise health risks associated with microbial contamination.

2.4. Method of Data Analysis

Pearson's Correlation Coefficient (PCC) was used to examine the strength and direction of the linear relationships among the GWQ parameters, namely E. coli, F. col, T. col, TDS, and pH. PCC values range from 0 to ± 1*, where 0 indicates no linear correlation, −1 represents a perfect negative correlation, and +1 represents a perfect positive correlation (Igibah & Tanko, 2019). The observed GWQ parameters at each sampled location are denoted by* w_i*, where* w_1*= E. coli,* w_2*= F. col,* w_3*= T. col,* w_4*= TDS, and* w_5*= pH. The computed PCCs were then arranged into a correlation matrix following Johnson and Wichern (2007).*

$$R = \begin{pmatrix} 1 & w_{1,2} & w_{1,3} & w_{1,4} & w_{1,5} \\ w_{2,1} & 1 & w_{2,3} & w_{2,4} & w_{2,5} \\ w_{3,1} & w_{3,2} & 1 & w_{3,4} & w_{3,5} \\ w_{4,1} & w_{4,2} & w_{4,3} & 1 & w_{4,5} \\ w_{5,1} & w_{5,2} & w_{5,3} & w_{5,4} & 1 \end{pmatrix} \quad (1)$$

where R is the correlation matrix, w_{ij} denotes the PCC between the i^{th} and j^{th}, GWQ parameters (i, j=1, 2,…, 5), elements (w_{11},…, w_{55}) are equal to 1, represent the perfect correlation of each parameter with itself, while the off-diagonal elements (w_{12},…, w_{15},…, w_{54}) are the strength and direction of the linear association between pairs of GWQ parameters. The R Packages Used (psych, Hmisc, corrplot and stats) are by Revelle (2024).

3. Results and Discussions

The correlation results presented in Tables 3 and 4 and Figures 4, 5 and 6 showed the association between GWQ parameters. Pearson correlation analysis, which assessed the strength and direction of association between microbial indicators, TDS, and pH, highlighted the influence of TDS and pH on microbial contamination and identified appropriate auxiliary variables for geostatistical modelling. The values with asterisks (*) denoted significant correlations ($p < 0.05$), while non-asterisk values denoted insignificant correlations ($p > 0.05$) and diagonal values (1.00) denoted self-correlations.

Table 1. The Correlation Analysis Results of Boreholes

Source/Parameters	E. coli	F. Col	T. Col	TDS	pH
BH1	1.00				
BH2	0.99*	1.00			
BH3	0.99*	0.99*	1.00		
BH4	0.97*	0.99*	0.99*	1.00	
BH5	−0.91*	−0.96*	−0.92*	−0.95*	1.00

Table 1 presented the correlation result of BH which showed strong positive association among microbial indicators ($r = 0.99$–1.00, $p < 0.05$), strong positive association between microbial indicators and TDS ($r = 0.97$–0.99, $p < 0.05$) and Strong negative association with pH ($r = -0.91$ to -0.96, $p < 0.05$) suggested that TDS does not affect microbial contermination but low pH influence microbial contamination, which highlighted the need for regular monitoring to maintain GWQ and ensure safe drinking water.

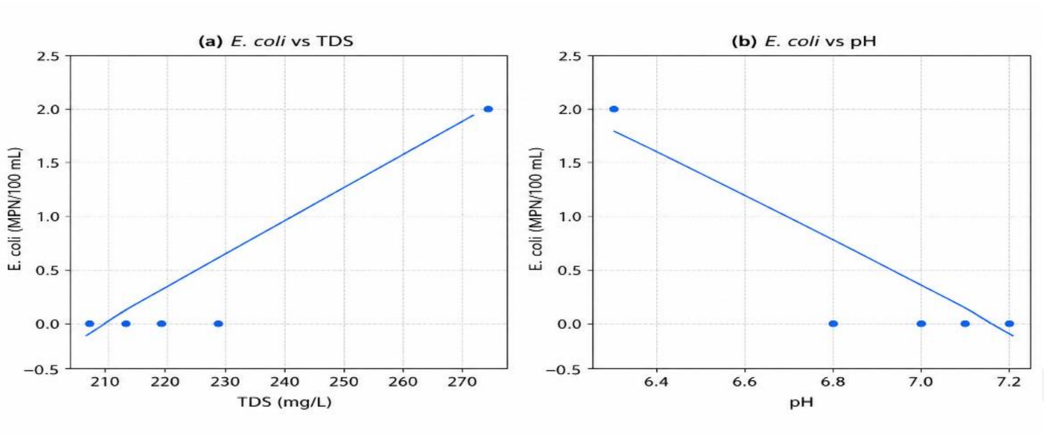

Figure 4 (a-b). Scatter plots of E. coli against TDS and pH for BH

Figures 4(a-b) showed that TDS and E. coli concentrations in BH are moving togerther. The hight TDS (280 mg/L) at BH4 coincided with the only detectable E. coli (2 CFU/100 mL) concentration, while BH with low TDS (210–230 mg/L) recorded no detectable E. coli concentration, indicated better groundwater quality. Figure 4.3b showed that when pH concentration is low concided with high E. coli concentration, suggested that low pH (acidic water) was associated with high microbial contamination. These indicated that GWQ deteriorated with decreased pH and increased E.coli contermination, while low TDS and near-neutral pH are associated with good GWQ and safe drinking water.

Table 2. The Correlation Analysis Result of HDW

Source	Parameter	E. coli	F. Col	T. Col	TDS	pH
HDW1	E. coli	1				
HDW2	F. Col	0.97*	1			
HDW3	T. Col	0.95*	1.00*	1		
HDW4	TDS	0.55	0.69	0.69	1	
HDW5	pH	-0.92*	-0.85	-0.8	-0.46	1
HDW6	E. coli	1				
HDW7	F. Col	0.99*	1			
HDW8	T. Col	0.99*	0.99*	1		
HDW9	TDS	1.00*	0.99*	0.98*	1	
HDW10	pH	-0.95*	-0.91*	-0.93*	-0.94*	1
HDW11	E. coli	1				
HDW12	F. Col	0.99*	1			
HDW13	T. Col	0.96*	0.98*	1		
HDW14	TDS	0.94*	0.92*	0.95*	1	
HDW15	pH	-0.93*	-0.91*	-0.85	-0.79	1

Table 2 presents the correlation matrix of GWQ parameters of HDW1–HDW15 locations; correlations with an asterisk (*) indicate significant ($p < 0.05$). Correlations without an asterisk are insignificant ($p > 0.05$), and Diagonal values (1.00) represent self-correlations. The Strong positive association among microbial indicators (r = 0.95–1.00, $p < 0.05$) indicated common faecal contamination sources. TDS was also strongly associated with microbial parameters (r = 0.92–1.00, $p < 0.05$), suggesting that high dissolved solids were associated with elevated microbial contamination. While pH showed a strong negative association with microbial indicators at HDW10 (r = −0.91 to −0.95, $p < 0.05$), indicating that low pH was associated with increased microbial contamination and poor GWQ.

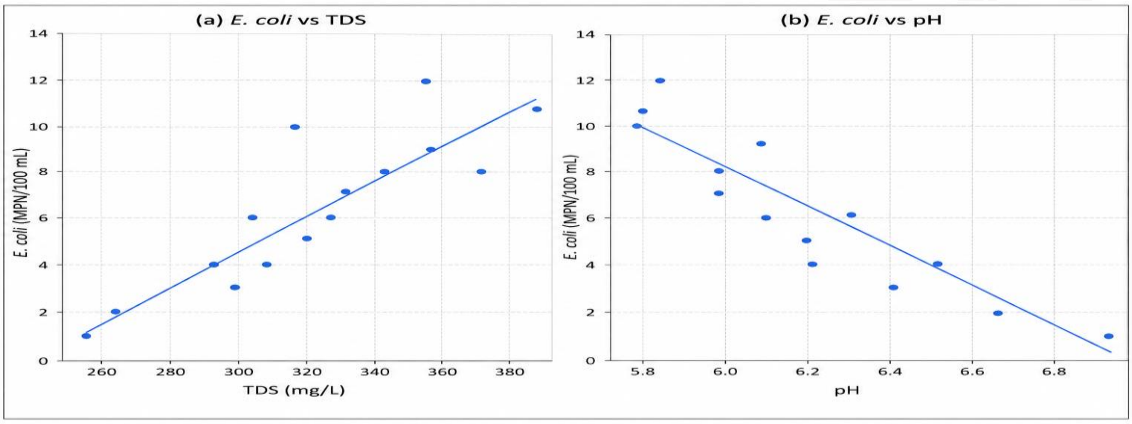

Figure 5 (a-b). Scatter plots of E. coli against TDS and pH for HDW

Figure 5(a-b) showed scatter plots of E. coli against TDS and pH for BH and HDW. E. coli exhibited a positive association with TDS, indicating that increased dissolved solids were associated with high microbial contamination and declined GWQ. Conversely, E. coli showed a strong inverse association with pH, suggesting that low pH (more acidic conditions) corresponded to higher microbial contamination. These associations indicated poor GWQ, particularly in HDW, and highlighted the need for routine monitoring and appropriate treatment before consumption.

The bar chart was used to compare the values of GWQ parameters between BH and HDW, providing a clear assessment of differences in microbial and physicochemical water quality between the two sources (Egbeyale *et al*., 2025).

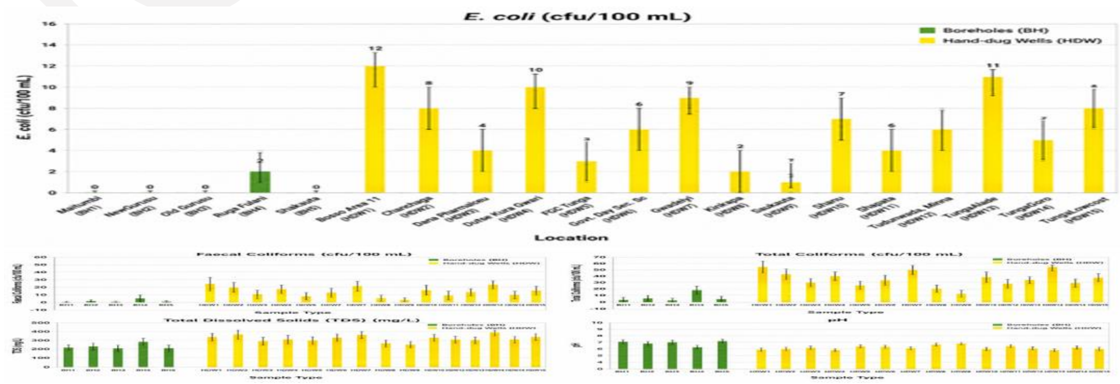

Figure 6. Comparison of GWQ Parameters between BH and HDW

Figure 6 compares GWQ parameters between BH and HDW. The green bars showed that BH recorded negligible E. coli, low F.col, T. col, low TDS and high pH concentration, indicating minimal microbial contamination and good physicochemical quality, safe for drinking. In contrast, the yellow bars showed that HDW exhibited higher microbial loads, higher TDS, and generally more acidic pH, HDW exhibits high microbial loads and acidic pH, reflected greater vulnerability to surface-derived contamination. These indicated that BH water is safer for human consumption than HDW, which compromised water safety and requires appropriate sanitation and treatment measures before human consumption.

4. Discussion of Major Findings

Table 2 revealed significant positive correlations between microbial indicators and TDS but a strong, inverse association with pH, indicating that increased TDS and decreased pH were associated with elevated microbial concentrations and poorer GWQ. Figure 6 showed that the most acidic wells corresponded with the highest E. coli concentrations, indicating that acidic conditions were associated with increased microbial contamination. These findings agreed with Tijani *et al*. (2005), Igibah and Tanko (2019), Suleiman *et al*. (2020), Francisco *et al*. (2024) and Egbeyale et al. (2025), who attributed groundwater contamination to hydrochemical conditions and anthropogenic activities. Figure 6 revealed that BH provided safe drinking water, while HDWs require treatment before consumption to minimise public health risks, consistent with Bisiriyu *et al*. (2020) and Egbeyale *et al*. (2025).

4. Conclusion

This study provided strong evidence that GWQ differs between BH and HDW in terms of TDS and pH. BH exhibited negligible microbial contamination, with a moderate positive association between TDS and microbial indicators and a weak to moderate negative association between pH and microbial indicators, indicating better groundwater. However, the detection of E. coli showed that such water should not be considered microbiologically safe without appropriate treatment. In contrast, HDW showed a strong positive association between TDS and microbial indicators and a strong negative association between pH and microbial indicators. The study concluded that increased TDS and decreased pH were associated with increased microbial contamination, with acidic conditions indicating poor groundwater.

The implications of this study are that TDS and pH should be routinely monitored alongside microbial indicators. High TDS was associated with increased microbial concentrations, while low pH showed a stronger association with microbial contamination, particularly in HDW. Therefore, pH should be prioritised as an auxiliary variable for spatial modelling and risk assessment. However, the correlation indicated an association between parameters but does not provide sufficient evidence to confirm the cause of the association.

Based on the findings of this study, it is recommended that routine GWQ monitoring should be strengthened for both BH and HDW, Prioritise construction of BH to improve safe drinking water, and incorporate pH as an auxiliary variable for GWQ modelling.

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