Integrated Hydrochemical Assessment and GIS-Based Mapping of Total Coliform Contamination in Hand-Dug Wells of Yakurr, Cross River State, Nigeria

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Abstract: Groundwater from hand-dug wells is the primary source of domestic water for many households in Yakurr Local Government Area (LGA), Cross River State, Nigeria. However, increasing human activities and inadequate sanitation practices have raised concerns about the safety of these water sources. This study evaluated the physicochemical and bacteriological quality of groundwater and mapped the spatial distribution of total coliform contamination using Geographic Information System (GIS) techniques. Water samples were collected from fifteen hand-dug wells during the dry season (January 2025) and wet season (July 2025). Physicochemical and bacteriological analyses were carried out at the Cross-River State Water Board Authority Laboratory following standard procedures recommended by the American Public Health Association (APHA) and the World Health Organization (WHO). Total coliform bacteria were determined using the membrane filtration technique, while Inverse Distance Weighting (IDW) interpolation was applied to visualize the spatial distribution of contamination. The results showed that total coliform counts ranged from 15 to 155 CFU/100 mL during the wet season and from 27 to 173 CFU/100 mL during the dry season. Persistent contamination hotspots were identified around sampling locations PT5, PT11, PT12, PT14, and PT15. Although most physicochemical parameters complied with WHO guideline values, acidic pH and elevated iron concentrations were recorded in a few locations. Importantly, all groundwater samples contained total coliform levels above the WHO guideline of zero CFU/100 mL for drinking water, indicating widespread microbial contamination and potential public health risks. The study demonstrates the effectiveness of GIS-based spatial analysis in identifying contamination hotspots and supporting groundwater quality management. Regular groundwater monitoring, improved sanitation infrastructure, protection of wellheads, and household water treatment are recommended to safeguard public health and ensure the sustainable use of groundwater resources in the study area.

Keywords: *Groundwater Quality; Hand-Dug Wells; Total Coliform; GIS; IDW Interpolation; Spatial Analysis; Yakurr LGA; Nigeria.*

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I. INTRODUCTION

Groundwater is one of the world's most valuable freshwater resources and serves as a major source of water for domestic, agricultural, and industrial purposes. In many developing countries, particularly in rural communities, groundwater obtained from hand-dug wells and boreholes provides a reliable and affordable source of drinking water. Despite its importance, groundwater quality is increasingly threatened by rapid urbanization, poor sanitation, indiscriminate waste disposal, agricultural activities, and population growth. These pressures have significantly increased the risk of groundwater contamination, particularly in areas where water sources are poorly protected.

Microbial contamination remains one of the most serious threats to drinking water safety because contaminated groundwater can transmit waterborne diseases such as cholera, typhoid fever, dysentery, and gastroenteritis. Total coliform bacteria are widely recognized as important indicator organisms for assessing the sanitary quality of drinking water. Their presence does not necessarily confirm the existence of pathogenic microorganisms but indicates that the water may have been contaminated by human or animal

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waste, thereby increasing the likelihood of disease-causing organisms being present.

Groundwater quality assessment has attracted increasing research attention in Nigeria owing to growing concerns about environmental pollution, rapid urbanization, climate variability, and the deterioration of drinking water resources. Omeka et al. (2024) highlighted the increasing challenges associated with groundwater quality assessment in Nigeria and emphasized the need for integrated approaches that combine hydrochemical analysis, microbiological evaluation, and geospatial techniques to support effective groundwater resource management. Such multidisciplinary approaches provide a more comprehensive understanding of groundwater systems and facilitate the identification of areas vulnerable to contamination.

Microbial contamination of groundwater is largely associated with human activities and poor environmental management practices. Septic tank leakage, inadequate sanitation infrastructure, indiscriminate waste disposal, agricultural activities, and inappropriate land-use practices are recognized as major drivers of groundwater pollution. In a recent study conducted in Yakurr Local Government Area, Ogar et al. (2026) reported that groundwater quality is strongly influenced by well construction characteristics, seasonal variations, surrounding land-use activities, and the proximity of wells to potential contamination sources. These factors significantly increase the vulnerability of shallow hand-dug wells to microbial contamination and pose serious public health concerns for communities that depend on untreated groundwater for domestic use.

In Yakurr Local Government Area of Cross River State, Nigeria, hand-dug wells constitute the primary source of domestic water for many households. However, rapid population growth, inadequate waste management practices, poorly constructed sanitation facilities, and increasing human activities have heightened concerns regarding the microbiological safety of groundwater within the area. Although several studies have investigated groundwater quality in different regions of Nigeria, information on the spatial distribution of microbial contamination in hand-dug wells within Yakurr Local Government Area remains limited. This knowledge gap underscores the need for detailed investigations that integrate hydrochemical assessment with spatial analysis to identify contamination hotspots and support informed groundwater management decisions.

The integration of Geographic Information System (GIS) techniques into groundwater quality studies has significantly improved the understanding of contamination patterns. GIS provides an effective platform for visualizing spatial variations in water quality, identifying contamination hotspots, and supporting evidence-based environmental management. Among the available spatial interpolation techniques, Inverse Distance Weighting (IDW) is widely applied because of its ability to estimate contaminant concentrations at unsampled locations using measured field data, thereby enhancing the interpretation of groundwater quality data and supporting environmental planning.

Therefore, this study aimed to evaluate the hydrochemical and bacteriological characteristics of groundwater obtained from hand-dug wells in Yakurr Local Government Area and to assess the spatial distribution of total coliform contamination using GIS-based IDW interpolation. The findings are expected to provide valuable information for groundwater quality management, public health protection, and the sustainable development of groundwater resources in the study area.

II. MATERIALS AND METHODS

- *Study Area*

This study was conducted in Yakurr Local Government Area (LGA), Cross River State, Nigeria. Yakurr covers an estimated land area of approximately 670 km² and had a projected population of about 298,900 in 2022. The LGA is bordered by Obubra to the north, Biase to the south, Abi to the west, and Akamkpa to the east. It is located around latitude 5°48′3″N and longitude 8°4′5″E.

The area experiences a humid tropical climate characterized by two distinct seasons: a wet season extending from April to October and a dry season from November to March. Annual rainfall is relatively high, while temperatures generally range between 21°C and 37°C. Groundwater, particularly from hand-dug wells, serves as the principal source of domestic water for many communities within the study area. However, increasing urban development, poor sanitation practices, and indiscriminate waste disposal pose significant threats to groundwater quality.

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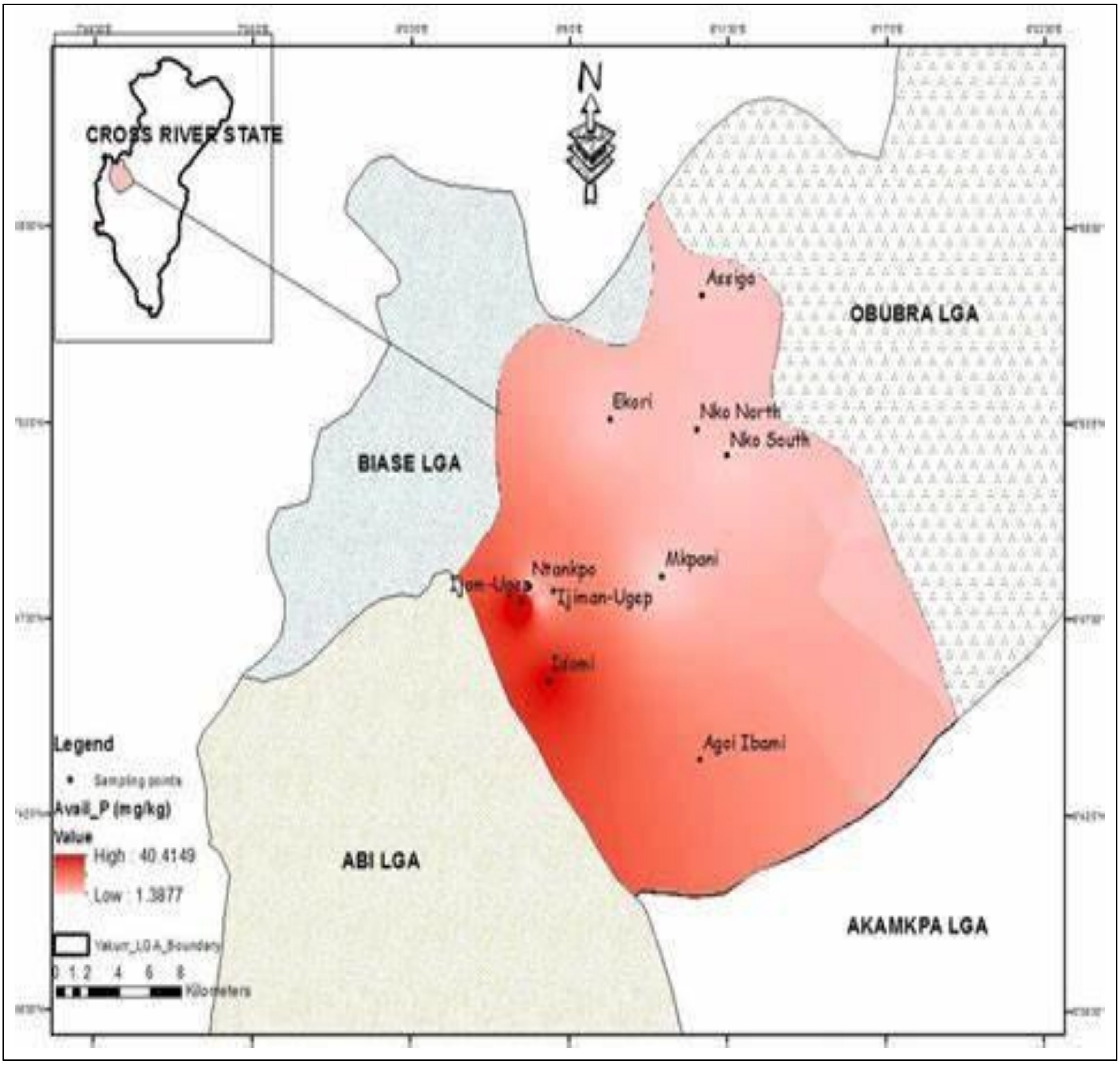

Fig 1 The Map of the Study Area of Yakurr Local Government:
Source (www.crossriverhub.ng/yakurr).

➢ *Sample Collection*

A total of fifteen (15) hand-dug wells were selected across three communities within Yakurr LGA Mkpani (PT1-PT5), Ekori (PT6-PT10) and Ugep (PT11-PT15) to represent the spatial distribution of groundwater sources. Water samples were collected during both the dry season (January 2025) and the wet season (July 2025) to evaluate seasonal variations in groundwater quality. The geographic coordinates of each sampling location were recorded using a handheld Global Positioning System (GPS) receiver to facilitate spatial analysis.

Water samples were collected in clean, sterilized one-liter polyethylene bottles. Before sampling, each bottle was rinsed two to three times with water from the respective well to minimize contamination. Following collection, the samples were properly labelled, stored in an ice-filled cooler at approximately 4°C, and transported to the Cross-River State Water Board Authority Laboratory for analysis. All laboratory analyses were completed within 48 hours of sample collection in accordance with internationally accepted water sampling and preservation protocols.

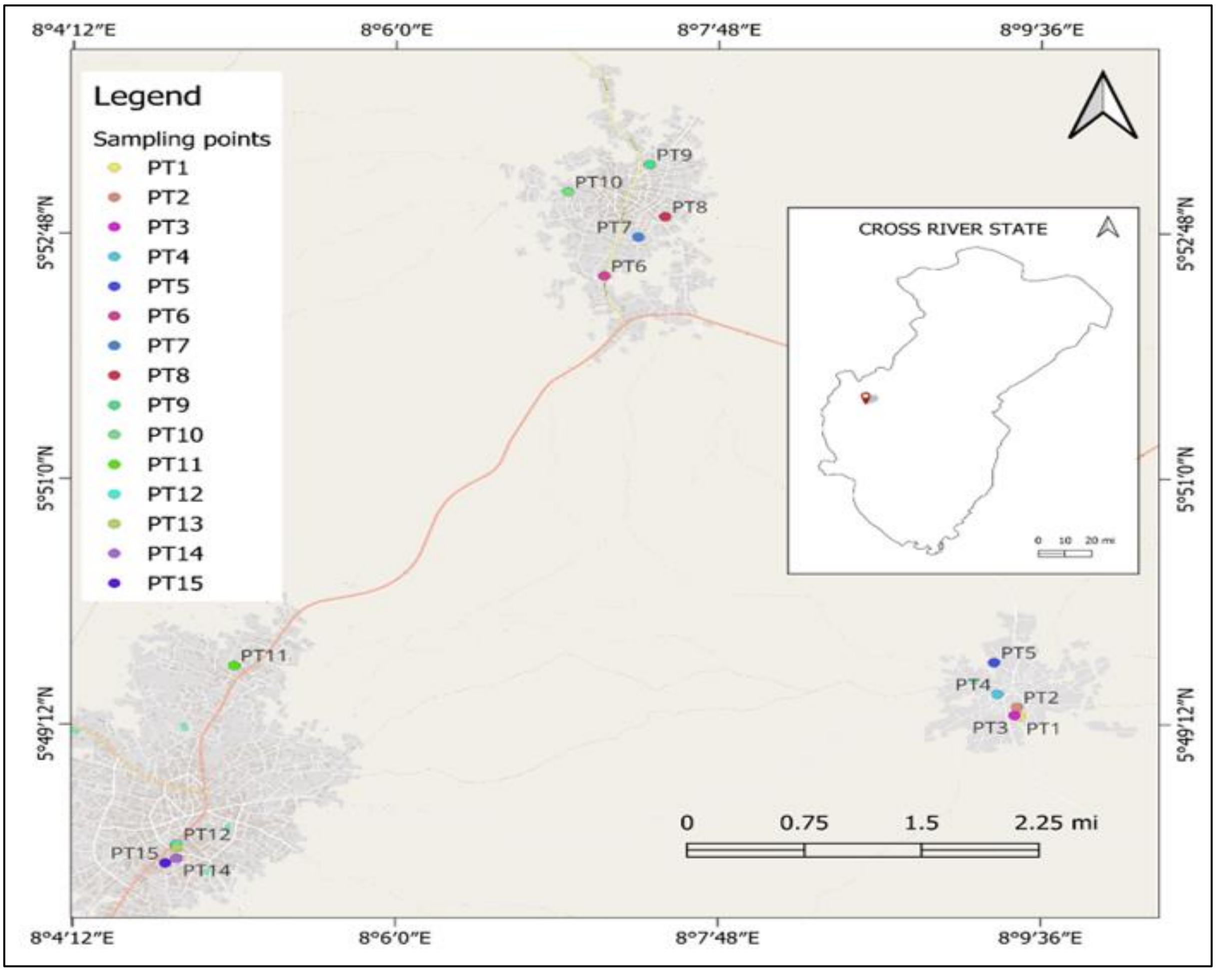

Fig 2 Map Showing the Distribution of Sampling Points (Wells) in the Study Area.

Table 1 The Coordinates of the Sampling Well Points

WELL LOCATION	WELL POINT	LATITUDE	LONGTITUDE
MKPANI	PT1	5.8210475	8.1580233
,,	PT2	5.8221818	8.157785
,,	PT3	5.8211606	8.1575586
,,	PT4	5.823743333	8.155963333
,,	PT5	5.82761	8.1556617
EKORI	PT6	5.8748081	8.1193491
,,	PT7	5.879573333	8.1225
,,	PT8	5.88204	8.124996667
,,	PT9	5.888425	8.123583333
,,	PT10	5.8850672	8.115972
UGEP	PT11	5.827158333	8.084998333
,,	PT12	5.805315	8.079701667
,,	PT13	5.804926667	8.079688333
,,	PT14	5.8036089	8.0796808
,,	PT15	5.8030304	8.0786303

➢ *Laboratory Analysis*

Laboratory analyses were carried out following the Standard Methods for the Examination of Water and Wastewater recommended by the American Public Health Association (APHA, 2023) and the World Health Organization (WHO, 2011 & 2017). Both physicochemical and bacteriological parameters were determined to assess groundwater quality comprehensively.

The physicochemical parameters analyzed included temperature, pH, electrical conductivity (EC), total dissolved solids (TDS), turbidity, total suspended solids (TSS), dissolved oxygen (DO), biochemical oxygen demand (BOD_5), chloride, nitrate, phosphate, total hardness, sodium, calcium, magnesium, bicarbonate, iron, and fluoride.

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Temperature, pH, and electrical conductivity were measured in situ using a calibrated portable water quality meter pH-2603 (a pH meter), while the remaining parameters were analyzed in the laboratory using standard analytical procedures. Total coliform bacteria were determined using the membrane filtration technique, and the results were expressed as colony-forming units per 100 mL (CFU/100 mL).

➢ *Spatial Analysis*

Spatial analysis of total coliform contamination was performed using QGIS version 3.40.4. Geographic coordinates obtained during field sampling were integrated with laboratory results to develop spatial distribution maps.

The Inverse Distance Weighting (IDW) interpolation technique was employed to estimate total coliform concentrations at sampled locations based on the measured values from the sampling points. This approach enabled the identification of contamination hotspots and provided a clear visualization of the spatial variability of microbial contamination across the study area during both the wet and dry seasons.

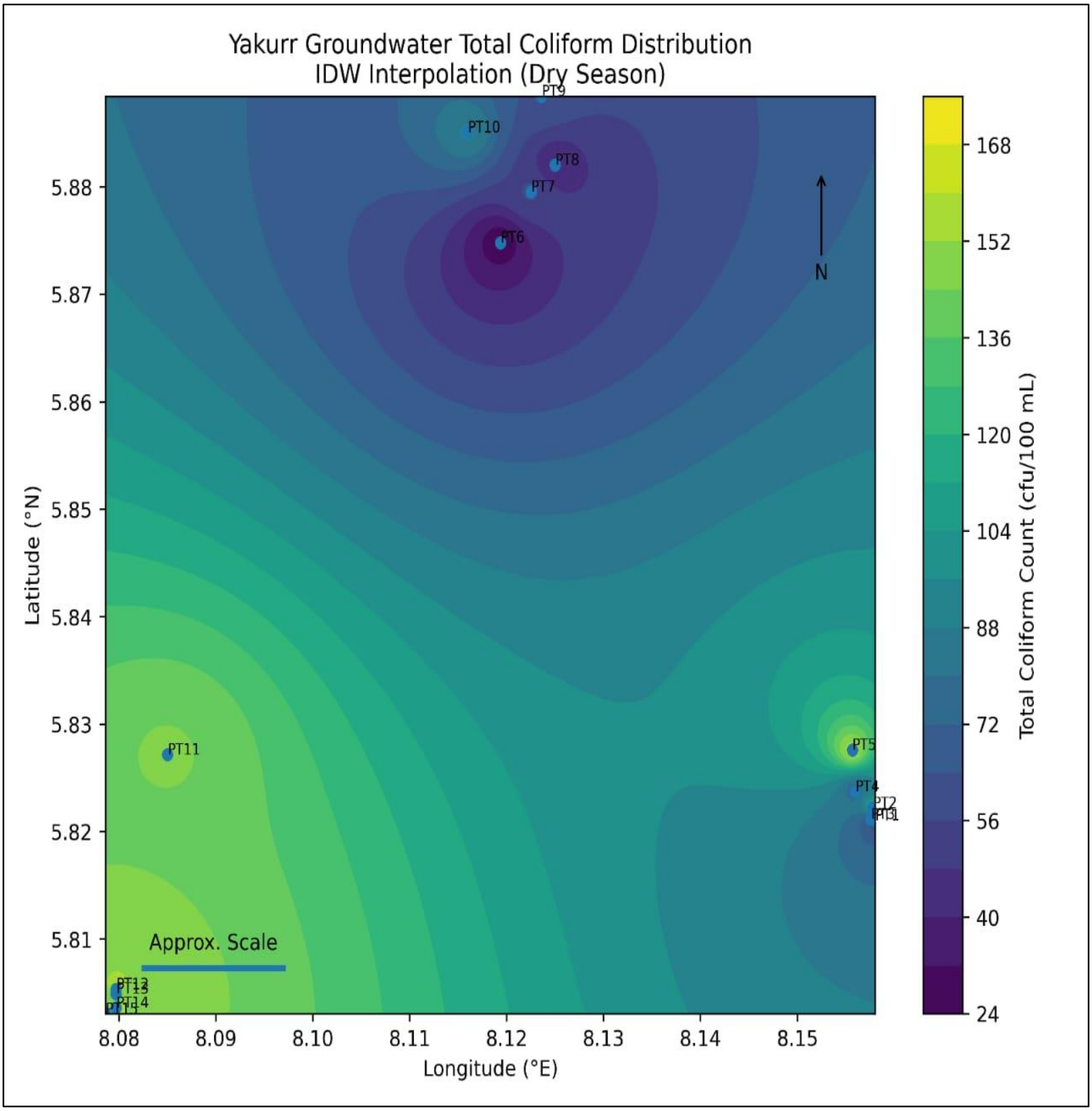

Fig 3 Yakurr Groundwater (Well) Total Coliform Distribution IDW Interpolation for Dry Season.

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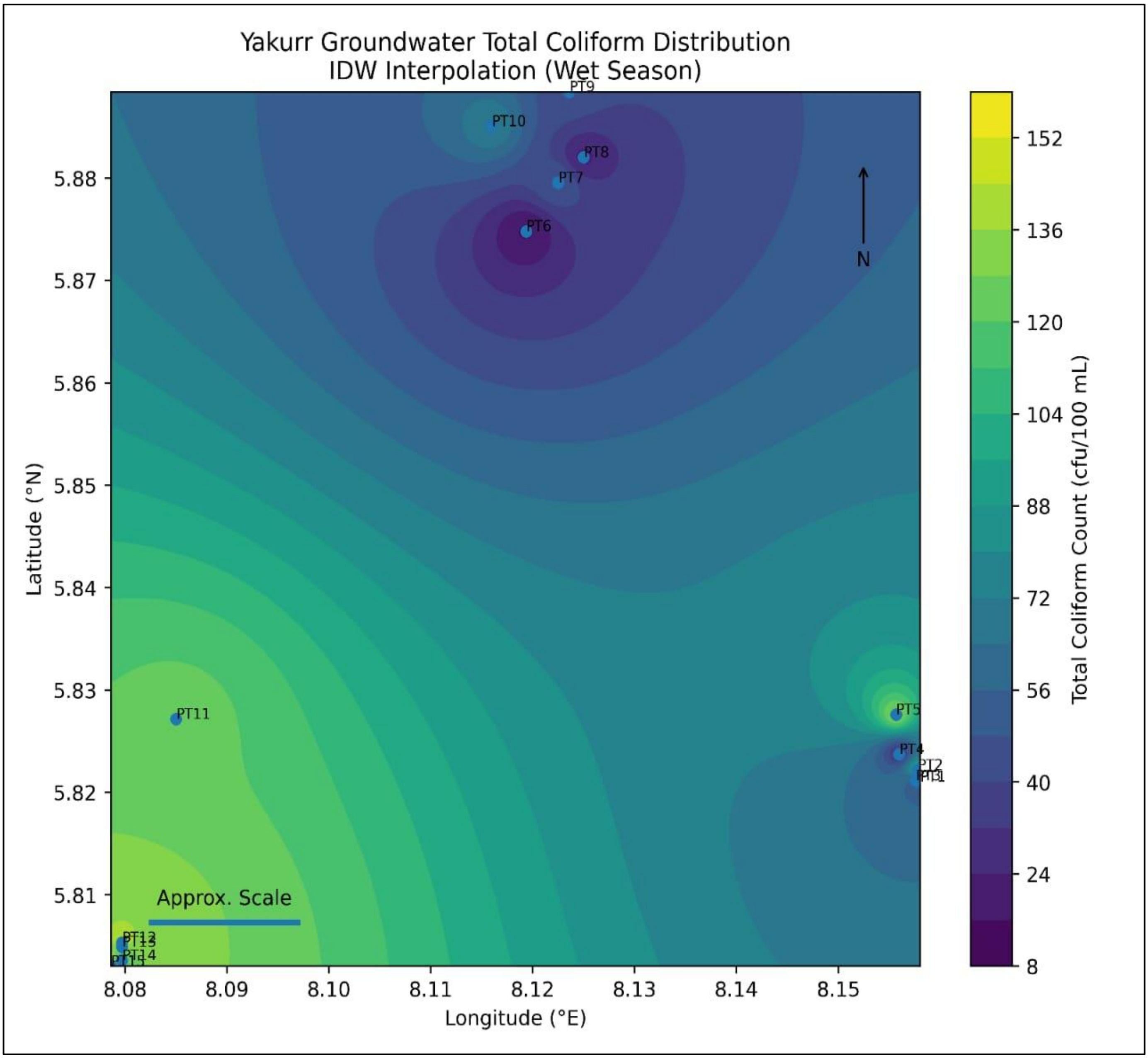

Fig 4 Yakurr Groundwater (Well) Total Coliform Distribution IDW Interpolation for Wet Season.

➢ *Statistical Analysis*

Descriptive statistical analyses were performed to summarize the groundwater quality data. Minimum, maximum, mean, and standard deviation values were computed for each physicochemical and bacteriological parameter. Seasonal variations between the wet and dry seasons were evaluated through comparative analysis, and the observed values were compared with the permissible limits specified by the Nigerian Standard for Drinking Water Quality (NSDWQ, 2016) and the World Health Organization (WHO, 2011 & 2017).

Table 2 Statistical Analysis of Hand-Dug Well Water Quality Parameters and its Coherence with Nsdwq and who Standards.

S/NO	PARAMETERS /UNIT	DRINKING WATER STANDARDS		STATISTICAL ANALYSIS OF OBSERVED VALUED			
		NSDWQ 2016	WHO (2011), (2017)	MIN	MAX	MEAN	SD
1	TEMPERATURE (ºC)	Ambient	27-29	26.45	27.45	26.95	0.707106781
2	PH	6.5-8.5	7-8.5	5.5	7.4	6.45	1.343502884
3	TURBIDITY (NTU)	5	5	0.362	2.421	1.3915	1.455932862
4	CONDUCTIVITY (us/cm)	500	500	44	331.5	187.75	203.2931996
5	TDS (mg/l)	500	600-1000	26.4	171.9	99.15	102.8840367

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6	TSS (mg/l)	0.1	1	0.006	1.952	0.979	1.376029796
7	CHLORIDE (mg/l)	100	250	**2**	5.95	3.975	2.793071786
8	NITRATE (mg/l)	10	50	2.53	7.8	5.165	3.726452737
9	PHOSPHATE (mg/l)	100	5	4.1	8.8	6.45	3.323401872
10	TOTAL HARDNESS (mg/l)	100	100	9.35	50.35	29.85	28.99137803
11	SODIUM (mg/l)	100	50-200	0.83	3.2	2.015	1.675843071
12	CALCUIM (mg/l)	10	75	4.1	16.5	10.3	8.768124087
13	MAGNESIUM (mg/l)			7.55	34.8	21.175	19.26865979
14	BICARBONATE (mg/l)			1.015	6.25	3.6325	3.701704
15	DISSOLVED OXYGEN (mg/l)	14	5≥14	7	12.5	9.75	3.889087297
16	BOD_5 @ 25 °C			5.5	11	8.25	3.889087297
17	IRON (mg/l)	0.3	0.3	0.03	0.975	0.5025	0.668215908
18	FLOURIDE (mg/l)	1.5	1.5	0.17	0.955	0.5625	0.555078823
19	TOTAL COLIFORM COUNT /100ml (cfu)	0	1	21	164	92.5	101.1162697

III. RESULTS AND DISCUSSION

- *Physicochemical Characteristics of Groundwater:*

The physicochemical characteristics of groundwater obtained from the fifteen hand-dug wells are presented in Table 2. The results revealed noticeable spatial and seasonal variations among the measured parameters, although most values remained within the permissible limits recommended by the Nigerian Standard for Drinking Water Quality (NSDWQ, 2016) and the World Health Organization (WHO, 2011 & 2017).

Groundwater temperature showed only slight variation across the sampling locations, ranging from 26.4°C 5 to 27.45 °C, with a mean value of 26.95 °C. This relatively stable temperature reflects the natural thermal conditions of shallow groundwater in the study area and suggests minimal seasonal influence on groundwater temperature.

The pH values ranged from 5.50 to 7.40, with an average of 6.45, indicating that some groundwater sources were slightly acidic. The acidic nature of groundwater observed in a few locations may be attributed to the dissolution of naturally occurring minerals, decomposition of organic matter, and local geological conditions. Long-term consumption of acidic water may enhance corrosion in water distribution systems and increase the dissolution of certain metals into drinking water.

Electrical conductivity (44.0–331.5 µS/cm) and total dissolved solids (26.4–171.9 mg/L) remained considerably below the recommended guideline limits, indicating low mineralization and relatively low concentrations of dissolved inorganic constituents. Similarly, chloride, nitrate, sodium, calcium, magnesium, bicarbonate, and total hardness were all within acceptable drinking water standards, suggesting limited influence of saline intrusion or excessive agricultural contamination.

Iron concentrations ranged from 0.03 to 0.975 mg/L, with several sampling locations exceeding the WHO guideline value of 0.30 mg/L. Elevated iron levels may be associated with the natural weathering of iron-bearing geological formations and localized hydrogeochemical processes. Although iron is not generally considered a significant public health hazard at these concentrations, excessive levels may impair the aesthetic quality of drinking water by causing unpleasant taste, staining of plumbing fixtures, and discoloration.

Overall, the physicochemical results indicate that groundwater quality in Yakurr LGA is generally satisfactory with respect to most chemical parameters. However, localized acidity and elevated iron concentrations warrant continuous monitoring to ensure long-term water quality and consumer safety.

Table 3 Observe Values of Total Coliform Count of the Study Area

WELL LOCATION	WELL POINT	TCC FOR WET SEASON CFU/100ml	TCC FOR DRY SEASON CFU/100ml
MKPANI	PT1	38	51
MKPANI	PT2	104	121
MKPANI	PT3	52	63
MKPANI	PT4	26	75
MKPANI	PT5	131	156
EKORI	PT6	15	27
EKORI	PT7	49	57
EKORI	PT8	22	40
EKORI	PT9	45	64

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EKORI	PT10	71	89
UGEP	PT11	123	145
UGEP	PT12	155	173
UGEP	PT13	118	121
UGEP	PT14	112	162
UGEP	PT15	145	135
Wet Season Mean: ≈80.5CFU/100ml Dry Season Mean: ≈ 98.6 CFU/100ml			

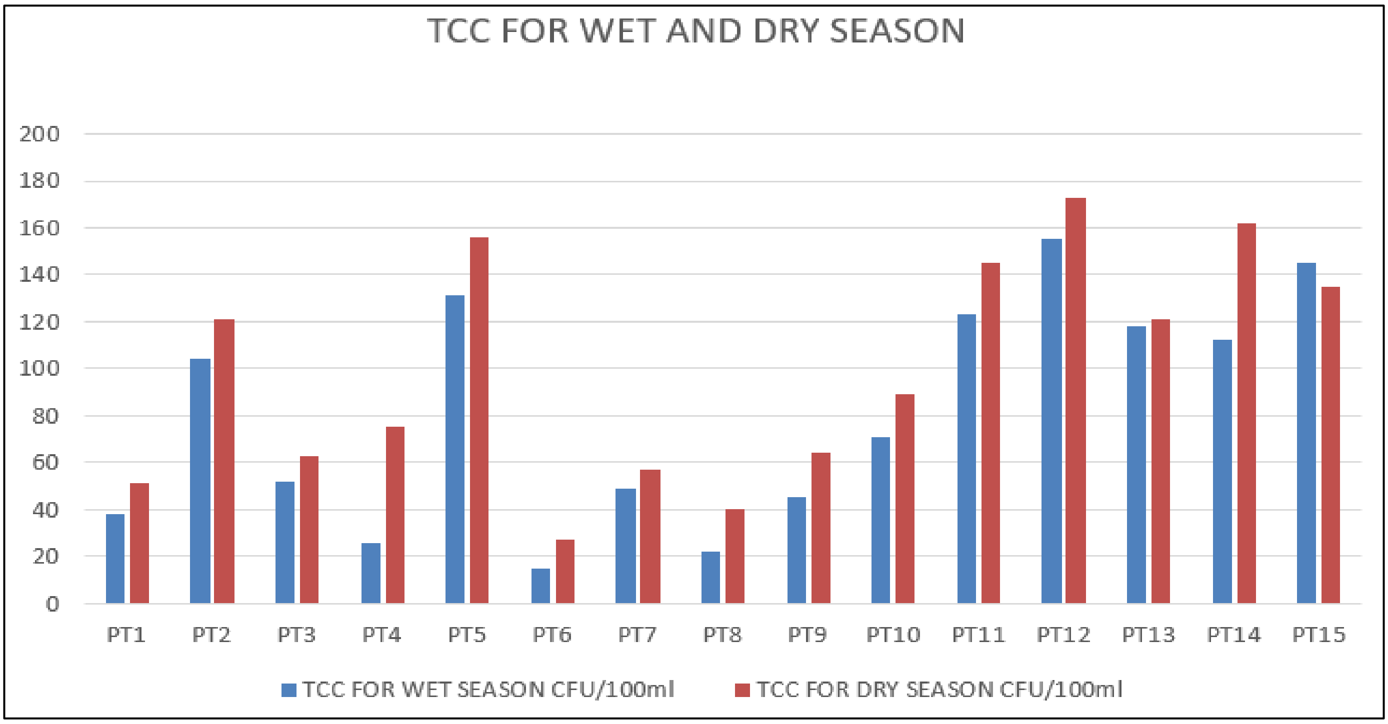

Fig 5 Comparison Analysis for Total Coliform Count (TCC) CFU/100ml for Wet and Dry Season of the 15 Hand-Dug Wells in Yakurr.

➢ *Total Coliform Contamination*

The total coliform counts recorded in groundwater samples are presented in Table 3. Total coliform bacteria were detected in every hand-dug well sampled during both the wet and dry seasons, confirming widespread microbial contamination throughout the study area.

During the wet season, total coliform counts ranged from 15 to 155 CFU/100 mL, with a mean concentration of approximately 80.5 CFU/100 mL. In the dry season, concentrations increased to between 27 and 173 CFU/100 mL, with a corresponding mean of approximately 98.6 CFU/100 mL. The highest contamination levels were consistently observed at sampling locations PT5, PT11, PT12, PT14, and PT15, whereas relatively lower concentrations were recorded at PT6 and PT8.

The presence of total coliform bacteria in all groundwater samples exceeds the WHO guideline value of zero CFU/100 mL for drinking water, indicating that none of the sampled wells is microbiologically safe for direct human consumption without adequate treatment. The generally higher coliform counts observed during the dry season may reflect reduced groundwater recharge, concentration of contaminants, and continuous pollution from nearby anthropogenic sources.

➢ *Spatial Distribution of Contamination*

Spatial interpolation using the Inverse Distance Weighting (IDW) technique clearly demonstrated the distribution pattern of microbial contamination across Yakurr Local Government Area. The generated spatial maps in Figure 3 and 4 identified persistent contamination hotspots around sampling locations PT5, PT11, PT12, PT14, and PT15 during both sampling seasons.

The interpolation maps further revealed increasing contamination intensity towards the southern and western parts of the study area, suggesting that groundwater quality is strongly influenced by localized environmental conditions and human activities. These spatial patterns provide valuable information for identifying vulnerable communities and prioritizing groundwater protection and remediation strategies.

The application of GIS proved highly effective in visualizing contamination trends, thereby providing a practical decision-support tool for groundwater quality management and environmental planning.

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IV. CONCLUSION

The widespread occurrence of total coliform bacteria across all sampled wells indicates significant microbial deterioration of groundwater quality within Yakurr Local Government Area. Although the majority of the physicochemical parameters complied with national and international drinking water standards, the microbiological quality of the groundwater was unsatisfactory, highlighting the importance of including bacteriological assessments in routine groundwater monitoring programmes.

The elevated microbial contamination observed in several locations is likely associated with inadequate sanitation facilities, poor well construction, seepage from septic tanks, indiscriminate refuse disposal, surface runoff, and the close proximity of wells to potential pollution sources. Since most hand-dug wells in the study area are shallow and poorly protected, they remain highly vulnerable to contamination through infiltration of polluted surface water, particularly during rainfall events.

Persistent contamination hotspots identified at PT5, PT11, PT12, PT14, and PT15 suggest that these locations are affected by continuous pollution sources rather than isolated contamination events. The consistency of these hotspots during both wet and dry seasons indicates long-term environmental pressures that require targeted intervention. The slightly acidic pH observed in some groundwater samples may be explained by natural hydrogeochemical processes, including the weathering of surrounding rocks and decomposition of organic materials within the aquifer system. Likewise, elevated iron concentrations may result from the dissolution of iron-rich minerals commonly found in the local geological formations.

The successful integration of laboratory analysis with Geographic Information System (GIS) techniques provided a comprehensive understanding of groundwater quality and contamination patterns within the study area. The use of IDW interpolation enabled the identification of high-risk areas requiring immediate attention and demonstrated the potential of spatial analysis as an effective tool for groundwater monitoring, environmental management, and public health planning.

Overall, the findings emphasize the urgent need to improve sanitation infrastructure, enforce proper siting and protection of hand-dug wells, and promote household water treatment before consumption. Routine groundwater quality monitoring supported by GIS-based spatial analysis should be adopted to ensure sustainable groundwater management and safeguard public health in Yakurr Local Government Area.

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