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Physicochemical Assessment of Groundwater in Makurdi Metropolis and Environs Using Water Quality Index (WQI), North-Central Nigeria

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Abstract: *This study assessed physicochemical properties of groundwater in Makurdi metroplis and its environs using index (WQI). A total of twenty five (25) borehole water samples were collected during the wet (September 2024) and dry (April 2025) seasons and analysed using standard laboratory techniques, including atomic absorption spectrometry, photometric, titrimetric, thermometric, and volumetric methods. Results showed that most physicochemical parameters fell within the limits set by the Nigerian Standard for Drinking Water Quality (NSDWQ, 2015), although notable seasonal differences were observed. Water Quality Index (WQI) results indicated a decline in "Good" water quality zones from 72.67% in the wet season to 60.94% in the dry season, with "Very Poor" (2.84%) and "Unsuitable" (0.03%) water quality zones appearing in the dry season. Seasonal trends underscore the positive effect of rainfall recharge, while the dry season showed higher levels of TDS, EC and ions due to evaporation and reduced dilution. While most groundwater remains suitable for domestic purposes, pollution hotspots require focused management through regular monitoring, better sanitation practices, protection of high quality zones, and community awareness programs to ensure sustainable water use.*
Keywords: physicochemical, groundwater, water quality, water quality index

INTRODUCTION

Groundwater is a vital source of freshwater, supporting domestic, agricultural, and industrial needs, particularly in areas where surface water is scarce or seasonal. Its quality is influenced by both natural factors, such as the geology of aquifers, and human activities, including urban growth, industrial effluents, and agricultural runoff. Assessing the physicochemical characteristics of groundwater is essential to determine its suitability for drinking, irrigation, and other uses, as well as to identify potential environmental and health risks from contamination. Evaluating groundwater quality can be challenging because it involves numerous physical, chemical, and biological parameters. To simplify this process, the Water Quality Index (WQI) has been widely adopted. WQI combines multiple water quality parameters into a single value, making it easier to interpret, compare across locations and seasons, and communicate the overall water status effectively (Sajib et al., 2025).

Recent studies have highlighted the use of WQI in groundwater assessment. Sajib et al. (2025) developed a Groundwater Quality Index (GWQI) that reliably evaluates water quality, while Sarker et al. (2025) integrated machine learning with WQI to enhance assessment accuracy. Similarly, Liu et al. (2025) proposed a data driven approach to construct WQI, improving its precision and applicability. These advancements underscore the evolving methodologies in groundwater quality assessment and the importance of comprehensive and standardised evaluation tools. Monitoring water quality is particularly critical in urban areas where groundwater is highly susceptible to contamination.

In Makurdi Metropolis and its surroundings in Benue State, Nigeria, groundwater is heavily relied upon due to its accessibility and affordability. However, rapid urbanisation, population growth, and diverse land use activities may compromise water quality. Key parameters such as pH, electrical conductivity, total dissolved solids, hardness, and major ions are essential for evaluating water quality, informing management strategies, and protecting public health. While previous studies (Ocheri et al., 2010; Ali et al., 2022; Tsor, 2022; Ohiaba et al., 2023; Gyanggyang et al., 2024) have investigated water quality in the area, most focused on surface water or shallow wells, with limited attention given to deep boreholes and seasonal variations in physicochemical characteristics. Available research has highlighted potential contamination from industrial activities, automotive workshops, and naturally occurring substances such as fluoride. Despite this, a comprehensive understanding of the hydrochemical status of groundwater across Makurdi and its environs remains lacking, constraining effective resource management and public health protection.

This study therefore aims to evaluate the physicochemical properties of groundwater in Makurdi Metropolis and surrounding areas, providing a detailed assessment of current water quality and identifying potential challenges to sustainable water resource management in the region.

Study Area

Location

The study area is situated within the geographic coordinates of Latitude 7°38’20” and 7°50’40 North of the equator and between Longitude 8°28’20” and 8°36’40” East of the Greenwich Meridian having a perimeter of 70.4 Kilometres and an area of 335 Square Kilometres. It is located within the central area of Makurdi local government (See Figure 1), the capital city of Benue State which is part of the Middle Benue Trough.

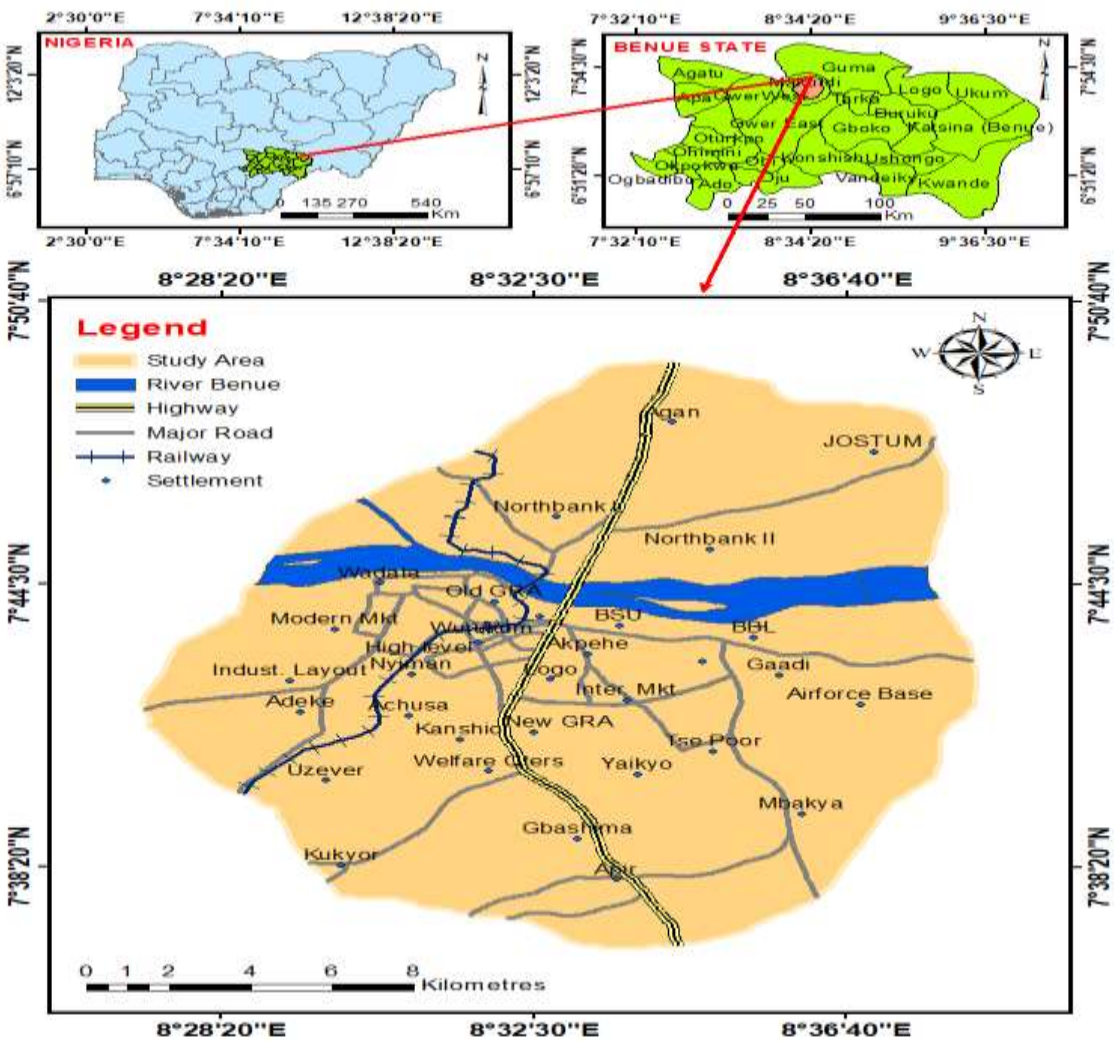

Figure 1: Map of Makurdi Metropolis and its Environs

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Geology and Hydrogeology

Makurdi lies within the Middle Benue Sub-basin of the Benue Trough, a major Cretaceous rift formed during the breakup of Gondwana. The area features thick sequences of fluvial to shallow marine sediments, with the Turonian Makurdi Formation composed of sandstones interbedded with shales and limestones in some places (Nwajide, 1987).

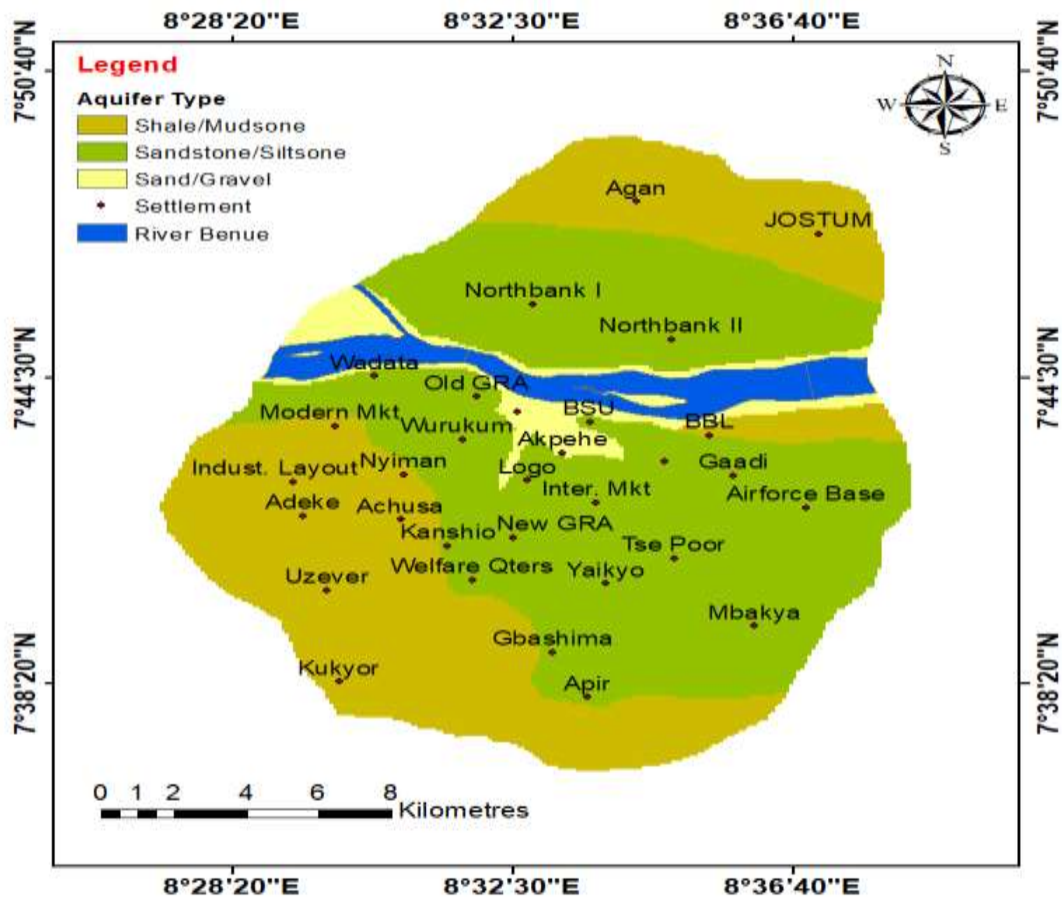

Figure 2.: Simplified Geological Map of Makurdi Metropolis and its Environs

These sediments, derived from nearby Precambrian rocks, were deposited in high energy fluvial to deltaic environments (Nwajide, 1987; Obiora et al., 2015). Beneath them lie older Albian shales and limestones, while minor Maastrichtian Awgu Shale occurs only locally. The region has remained tectonically stable since the end of the Cretaceous, resulting in gently dipping strata, though the original rift structure still influences groundwater flow (Obiora et al., 2015).

Groundwater in Makurdi is primarily hosted in the Makurdi Sandstone, forming a multi-layered aquifer system (Obrike et al., 2022). The shallow Upper Weathered Zone (3–15 m) supports hand-dug wells but is vulnerable to contamination, while the deeper Lower Coarse Sandstone (20–50 m) acts as a semi-confined aquifer with higher yields suitable for mechanized boreholes (Akuh, 2014; Obiora et al., 2015. These aquifers have moderate storage and widely varying transmissivity, and most boreholes provide low yield water for local supply (Ocheri and Vangeryina, 2020).

Relief and Drainage

The landscape of Makurdi is shaped by the underlying Cretaceous Makurdi Sandstone, a soft rock, prone to weathering and erosion. This has given rise to gently rolling plains and low hills. In soelevated areas, lateritic caps are present, while low-lying zones near the river Benue and seasonal streams are dominated by floodplains (Nwajide, 2013). The city is drained by several seasonal streams, such as the Rivers Idye, Amua, and Guma, which feed into the Benue River, forming a dendritic drainage pattern. These streams often dry up during the dry season but can rise quickly during heavy rainfall, causing flash floods in poorly drained parts of the urban area (Ocheri et al., 2010). Drainage density is influenced by both land use and terrain, with more extensive networks found in natural, less developed floodplain regions.

Climate and Vegetation

The study area experiences a tropical wet-and-dry climate, with average temperatures near 28 °C. December is usually the coolest month at about 26 °C, while March is the hottest, reaching around 31 °C (Tyubee, 2008). Humidity levels shift with the seasons, peaking at about 92% during the rains (Onah et al., 2021). Annual rainfall, largely driven by the southwest monsoon, averages 1,190 mm but can range widely from 775 mm to 1,792 mm. The natural vegetation reflects a savannah setting of grasses and scattered trees, though urban growth has reduced this cover. Even so, remnants of the original vegetation remain in parts of the city and its outskirts (Onah et al., 2021).

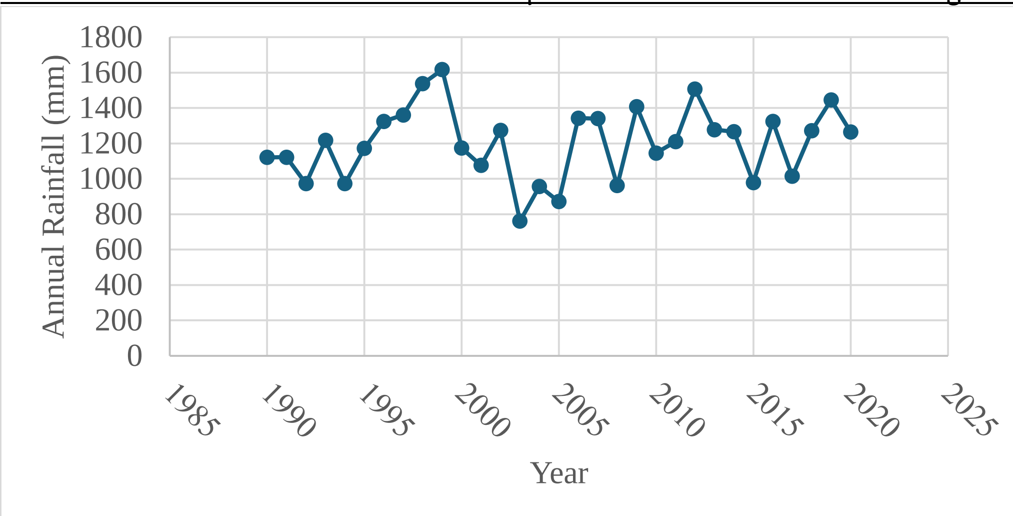

Figure 3: Mean Annual rainfall in Makurdi Metropolis and Environs (1990-2020)
Source: Computed from NIMET rainfall data for Makurdi Station

MATERIALS AND METHODS

Selection of Water Quality Parameters

In this study, twenty five(25) groundwater samples were collected for hydrochemical and geochemical analysis. The number of samples required in such investigations is not fixed and usually depends on study objectives, but previous research suggests that sampling between 16 and 40 sites is sufficient to capture spatial variation and contamination risks in urban settings (Wood, 2013; Guerin et al., 2014; Ojo et al., 2024). Fourteen key physicochemical parameters were analysed: temperature, electrical conductivity, total dissolved solids, pH, nitrate, sulfate, sodium, chloride, calcium, magnesium, fluoride, arsenic, manganese, and iron. Microbiological indicators such as coliforms were excluded, since the focus was on geochemical contaminants and their relevance to water quality index calculations their importance to public health .

Instruments for Data Collection

A Global Positioning System (GPS) device was employed to accurately record the coordinates of all sampling points. Water samples were collected in sterilized bottles to prevent contamination, and a field notebook was used to document relevant information on-site. A high-definition camera was also used to capture images of potential pollution sources and other land use activities near the sampling locations.

In the laboratory, various instruments were utilised to analyse the water quality parameters. Temperature was measured using a digital thermometer, while pH was determined with a pH meter. Electrical conductivity (EC) and total dissolved solids (TDS) were measured using a conductivity meter. Concentrations of nitrate (NO_3), sulphate (SO_4), manganese (Mn), iron (Fe), and fluoride (F) were analyzed using a spectrophotometer. Calcium (Ca), magnesium (Mg), and chloride (Cl) were measured with Atomic Absorption Spectroscopy (AAS), sodium (Na) with a flame photometer, and arsenic (As) was determined using AAS with a hydride generation technique.

Groundwater Sampling Strategy

To ensure balanced coverage of the entire area, twenty five (25) boreholes were purposively selected, representing the main aquifer types and key settlements across Makurdi metropolis and its surroundings (Figure 4). Water samples were collected in both the wet season (September 2024) and the dry season (April 2025) to capture possible seasonal changes in water quality status.

Sampling followed the grab method, which involves collecting a single sample from each source at a given time, an approach considered reliable for assessing physical, chemical, and microbiological properties of drinking water (APHA, 2017). Clean 75cl plastic bottles were used for collection. At every site, bottles were rinsed three times before sampling, and water was allowed to flow for 2–3 minutes before collection. Each bottle was clearly labelled and placed in an ice-filled cooler, and promptly transported to the laboratory for detailed chemical analysis.

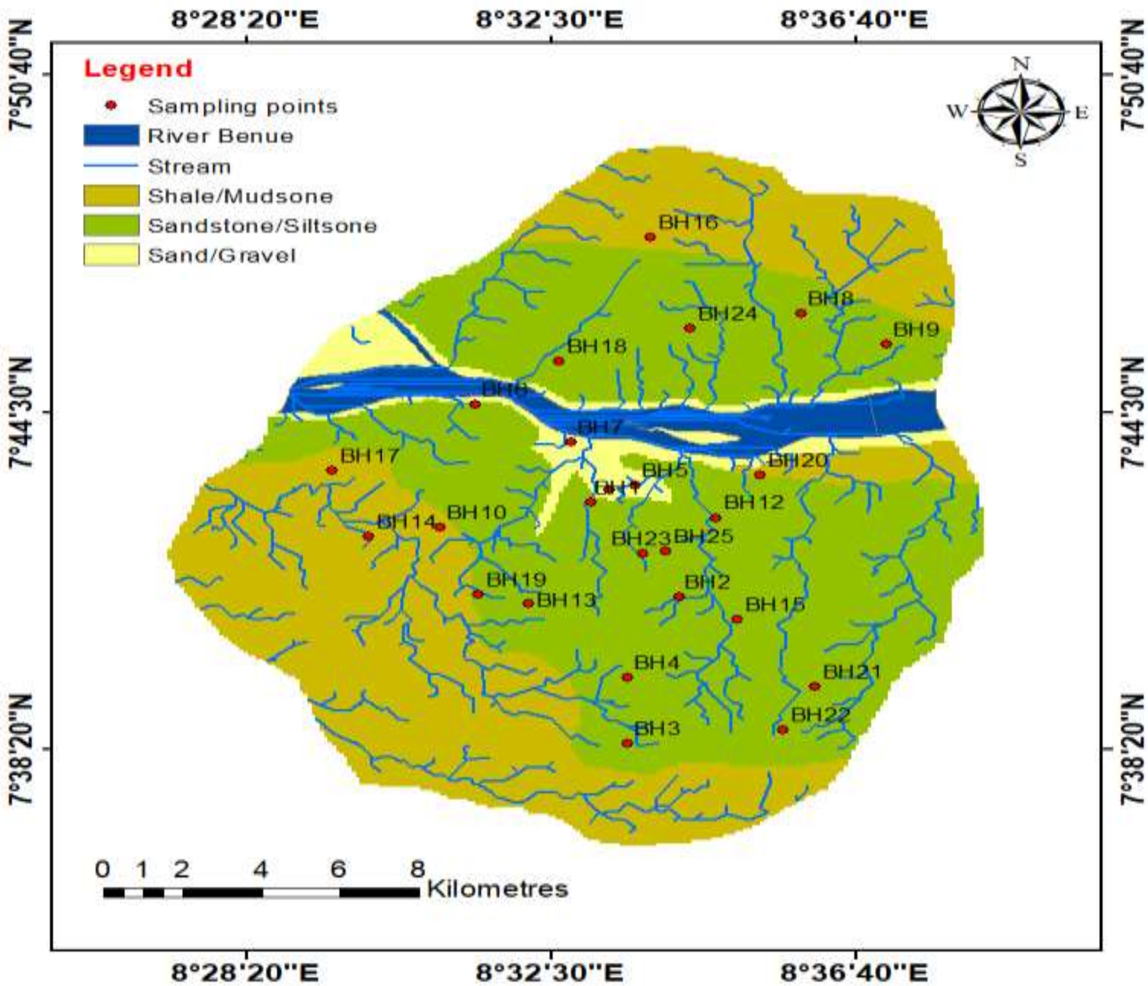

Figure 4: Sampling Points in Makurdi Metropolis and its Environs

Laboratory Instrumentation and Procedure of Water Quality Parameters Analysis

The collected water samples were transported with care to the laboratory for detail analysis. Certain parameters that are highly sensitive to environmental changes, such as temperature and pH, were measured immediately on-site using a digital thermometer and a pH meter, respectively. In the laboratory, the groundwater samples were analysed to assess a range of physicochemical characteristics. A combination of analytical instruments and techniques were employed for this purpos. All procedures followed the Standard Methods for the Examination of Water and Wastewater (23rd edition, APHA, 2017) and the WHO Guidelines for Drinking-Water Quality to ensure accuracy and reliability.

Method of Data Analysis

Descriptive Statistics

At each sampling point, different water quality parameters were recorded and analysed using descriptive statistics. The results were summarised with averages, standard deviations, and visual charts to make the findings easier to interpret. The mean values for each parameter were then compared against the Nigerian Standard for Drinking Water Quality (NSDWQ, 2015) in both wet and dry seasons.

Calculation of Water Quality Index

The Water Quality Index (WQI) is a useful tool that simplifies complex water data by combining several measured parameters into a single score. One of the most common ways of calculating WQI is through the Weighted Average Method (WAM), which considers the relative importance of each parameter. The WAM, first proposed by Horton (1965) and later refined by other researchers, was applied in this study to determine whether the sampled water is safe for drinking.

According to studies by Elemile *et al*. (2021), Okorie and Nweke (2023), and Reddy *et al*. (2021), the calculation process generally follows five key steps:

***Step 1: Assigning Weights (W*):** Each parameter is given a weight based on how strongly it influences water quality and human health. More critical parameters receive higher weights, typically ranging from 1 (least significant) to 5 (most significant) as shown in Table 1.

***Step 2: Normalising the Weights* (*Wi*):** To ensure comparability, the assigned weights are standardised using Equation 1, giving relative weights for each parameter.

The normalization weights of each parameter is done using Equation 1 to obtain relative weights of each parameter.

$$W_i = \frac{W}{\sum W} \qquad 1$$

Where:

W = Assigned weight for a parameter

∑W = Sum of all assigned weights.

Step 3: Computation of Water Quality Rating Scale (Qi)

The quality rating scale was calculated using equation 2

$$Q_i = \left(C_i / S_i \right) * 100 \qquad 2$$

where:

Qi is the quality rating scale; *Ci* is the concentration of each chemical parameter in each sample measured in (mg/l) and *Si* is the drinking water quality standards specified by NSDWQ (2015) for each chemical parameter (mg/l).

Step 4: Computation of Sub-Index (SI)

In the fourth step, the subindex value is calculated for each chemical parameter by multiplying the water quality rating by the normalized weight as shown in Equation 3

$$SI_i = W_i \times Q_i \qquad 3$$

Where:

SIi represents the subindex of the *ith* parameter; *Qi* denotes the quality rating scale based on the concentration of the *ith* parameter, and *Wi* signifies the relative weight of the *ith* parameter.

Step 5: Calculation of the final Water Quality Index (WQI)

In the fifth step, WQI is calculated in accordance with the above calculations. The sum of subindices of each of the water samples defines the WQI value.

$$WQI = \sum SI_i \qquad 4$$

The final index is compared with ratings in Table 2 to classify the status of water quality at each sampling point and consequently the general status of water quality in the study area is then spatially represented using ArcGIS version 10.8..

Table 1: Weight and relative weights of physicochemical parameters used for WQI calculation

Parameters	Unit	Symbol	NSDWQ limits (2015)	Weight (*wi*)	Relative Weight (*wi*)
Acidity and Alkalinity		pH	8.5	4	0.07
Electrical Conductivity	(µS/cm)	EC	1000	4	0.07
Total Dissolved Solids	(mg/l)	TDS	500	5	0.09
Nitrates	(mg/l)	NO_3^-	50	5	0.09
Sulphate	(mg/l)	SO_4^-	100	5	0.09
Magnesium	(mg/l)	Mg^+	20	2	0.04
Calcium	(mg/l)	Ca	100	2	0.04
Sodium	(mg/l)	Na	200	4	0.07
Chloride	(mg/l)	Cl	250	5	0.09
Fluoride	(mg/l)	F^-	1.5	5	0.09
Arsenic	(mg/l)	As^-	0.01	5	0.09
Iron	(mg/l)	Fe	0.3	4	0.07
Manganese	(mg/l)	Mn+	0.2	4	0.07
				$\sum wi$ =54	$\sum wi$ =1

Source: Adopted from Imneisi & Aydin, 2016 and Elemile *et al.* (2021).

Table 2: Water Quality Rating

Water Quality Index	Water Quality Status	Grade
0-25	Excellent water quality	A
26-50	Good water quality	B
51-75	Poor water quality	C
76-100	Very poor water quality	D
More Than 100	Unsuitable for drinking	E

Source: Adapted from Imneisi & Aydin, 2016 and Elemile *et al.* (2021).

RESULTS AND DISCUSSION OF FINDINGS

Compliance with Nigerian Standard for Drinking Water Quality

The average concentrations of physicochemical paramters for both wet and dry seasons in the study area is shown in Table 3. These seasonal averages were then compared with the benchmark values specified in the Nigerian Standard for Drinking Water Quality (NSDWQ, 2015), as outlined in Table 3.

pH: The average pH values ranged from 7.05 during the wet season to 6.58 in the dry season, both falling comfortably within the NSDWQ's recommended range of 6.5–8.5 (NSDWQ, 2015). The slightly lower pH in the dry season may be a result of increased concentration of acidic compounds as water levels decline (EPA, 2012).Total Dissolved Solids (TDS): TDS showed a seasonal increase, rising from 297.24 mg/L in the wet season to 335.76 mg/L in the dry season, yet remaining well below the permissible limit of 500 mg/L (NSDWQ, 2015).Electrical Conductivity (EC): EC also increased slightly from 476.80 µS/cm to 498.60 µS/cm, staying within the safe threshold of 1000 µS/cm (WHO, 2017). These increases in TDS and EC during the dry season are likely linked to evaporation and limited dilution, a pattern reported by Nwankwoala and Eludoyin (2021).

Table 3: Summary Statistics for Water Quality Parameters for Wet and Dry Season in Makurdi Metropolis and its Environs

Wet Season						Dry Season				
Parameter	No	Min	Max	Mean	SD	Min	Max	Mean	SD	NSDWQ Limit
pH	25	5.80	7.80	7.05	7.05	5.60	7.10	6.58	0.34	8.50
TDS	25	87.00	810.00	297.24	297.24	122.00	979.00	335.76	172.78	1000
EC	25	125.00	1233.00	476.80	476.80	139.00	1300.00	498.60	278.61	500
NO_3	25	0.00	54.40	24.26	24.26	0.00	51.10	22.27	13.26	50
SO_4	25	10.00	147.00	78.13	78.13	19.30	143.20	91.92	42.09	100
Mg	25	2.90	29.20	11.10	11.10	8.90	33.10	16.32	6.38	20
Ca	25	14.60	255.00	88.58	88.58	33.40	255.00	97.83	73.43	100
Na	25	10.20	160.00	59.34	59.34	22.00	191.10	77.26	45.56	200
Cl	25	9.80	248.80	67.57	67.57	18.00	248.80	82.11	63.07	250
F	25	0.00	1.32	0.36	0.36	0.01	1.58	0.58	0.50	1.50
As	25	0.00	0.01	0.00	0.00	0.00	0.01	0.00	0.00	0.01
Fe	25	0.00	1.20	0.14	0.14	0.00	1.20	0.14	0.24	0.30
Mn	25	0.00	0.21	0.02	0.02	0.00	0.22	0.03	0.05	0.20

Source: Authors computation 2025

Nitrate (NO_3): Nitrate levels averaged 24.26 mg/L in the wet season and decreased slightly to 22.27 mg/L in the dry season, remaining within NSDWQ guidelines (2015). The minor drop could reflect reduced agricultural runoff, which is typically higher during rainfall.

Sulphate (SO_4): Sulphate concentrations rose from 78.13 mg/L in the wet season to 91.92 mg/L in the dry season, still below the NSDWQ limit of 100 mg/L (2015). This increase may be due to evaporative concentration and potential industrial or agricultural inputs, as noted by Olobaniyi and Owoyemi (2006).

Magnesium, Calcium, and Sodium: Levels of these cations increased in the dry season: magnesium from 11.10 to 16.32 mg/L, calcium from 88.58 to 97.83 mg/L, and sodium from 59.34 to 77.26 mg/L. Sodium remained well under the 200 mg/L safety limit, posing no health concerns (NSDWQ, 2015; WHO, 2017). These seasonal changes reflect the typical concentration effect during periods of low water flow.

Chloride: Chloride rose from 67.57 mg/L in the wet season to 82.11 mg/L in the dry season, remaining well below the 250 mg/L guideline. This increase may be linked to evaporation or inputs from sewage and fertilizers.

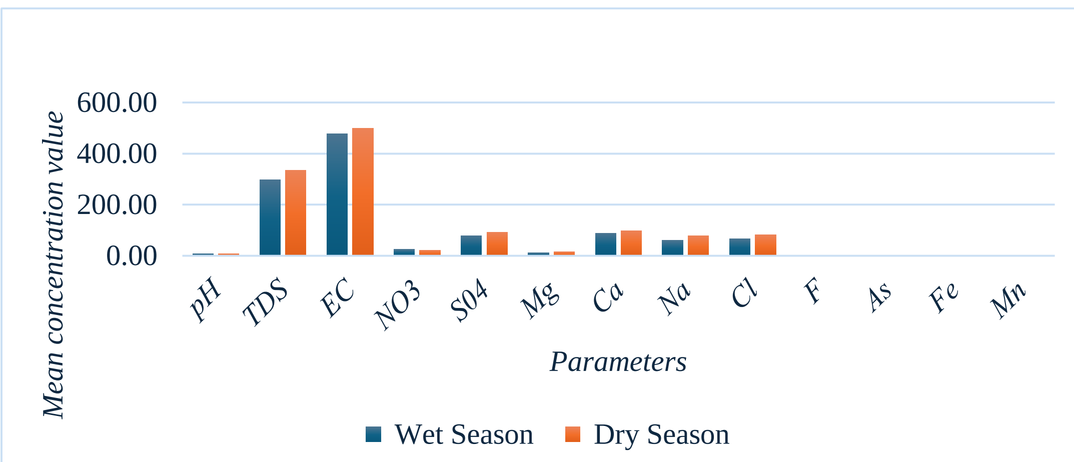

Figure 5: Bar chart showing Seasonal Variation in Mean values of Water Quality Parameters in Makurdi Metropolis and its Environs

Fluoride: Fluoride values ranged from 0.36 mg/L in the wet season to 0.58 mg/L in the dry season, safely within the NSDWQ limit of 1.5 mg/L. The slight seasonal increase could be explained by natural leaching intensified by reduced water recharge.Iron and Manganese: Iron remained steady at 0.14 mg/L, well below the NSDWQ limit of 0.3 mg/L, while manganese increased slightly from 0.02 to 0.03 mg/L, far below the 0.2 mg/L threshold. These values indicate minimal seasonal variation and no immediate health or aesthetic concerns.

Arsenic: Arsenic was not detected in either season (0.00 mg/L), consistent with NSDWQ's zero-tolerance policy due to its high toxicity.

Groundwater Water Quality Index in Makurdi Metropolis and its Environs

The sub-index values from each sampling site were combined to calculate the final Water Quality Index (WQI) for every location. The results for both wet and dry seasons are presented in Table 5

Table 4: Calculated Ground Water Quality Index for Wet and Dry Seasons in Makurdi Metropolis and its Environs

Code	Latitude	Longitude	WQI (Wet Season)	WQI (Dry Season)
BH1	7.71416	8.55065	47.17	53.77
BH2	7.68539	8.57072	47.63	54.28
BH3	7.64052	8.55923	45.78	50.27
BH4	7.66061	8.55924	64.10	56.72
BH5	7.71939	8.561	54.54	59.08
BH6	7.74402	8.52463	31.73	33.91
BH7	7.73255	8.54615	41.13	44.52
BH8	7.77159	8.59867	33.84	36.45
BH9	7.76231	8.61812	32.62	38.66
BH10	7.7064	8.51637	58.66	61.82
BH11	7.71778	8.55481	44.48	53.77
BH12	7.70941	8.57926	27.26	33.95
BH13	7.68336	8.53665	97.41	101.16
BH14	7.70365	8.50032	61.31	64.42
BH15	7.67852	8.58413	48.85	47.31
BH16	7.79479	8.56445	27.74	33.95
BH17	7.72388	8.49203	37.68	42.32
BH18	7.75707	8.54361	28.87	36.89
BH19	7.68613	8.52522	65.91	88.30
BH20	7.72252	8.58941	50.40	68.19
BH21	7.65788	8.60187	19.16	22.10
BH22	7.64469	8.59456	38.49	42.09
BH23	7.69846	8.56241	26.04	32.98
BH24	7.76705	8.57347	31.07	36.16
BH25	7.69914	8.56781	27.11	33.31
Average WQI			43.56	49.05

Source:Authors computation 2025

The overall Water Quality Index (WQI) values for Makurdi and its surrounding areas suggest that groundwater in the region is generally of good quality in both seasons, recording 43.56 during the wet season and 49.05 in the dry season. These findings align with the work of Ekwule *et al*. (2023), who reported that about 93% of groundwater samples in Makurdi fell within the excellent to good quality range based on hydrochemical analysis using WQI.

During the wet season, WQI values in at different sampling points the study area ranged from 19 to 97, showing clear differences in water quality across locations. The northern and southeastern parts, including Agan, Northbank I and II, and Mbakya, recorded WQI scores between 19 and 58, placing them in the excellent to good category. These areas are less densely populated and face lower land-use pressure, which helps keep groundwater cleaner. On the other hand, the central and southwestern parts such as Welfare Quarters, Kanshio, Uzever, Gbashima, and Achusa had WQI values between 59 and 97, reflecting poor to very poor water quality. The poorer conditions here are linked to high population density, unregulated waste disposal, and farming activities, which add pollutants like nitrates, chlorides, and dissolved solids into the groundwater.

In the dry season, WQI values ranged from 22 to 100, with many parts of the metropolis experiencing a decline in quality. The most severe cases were found in Welfare Quarters and Kanshio, where WQI scores above 85 made the water unfit for drinking. Other areas, including Uzever, Kukyor, and BBL, also saw a shift from very poor to almost unsuitable conditions.

Table 5: Water Quality Index Rating

Water Quality Index	Water Quality Status	Grade
0-25	Excellent water quality	A
26-50	Good water quality	B
51-75	Poor water quality	C
76-100	Very poor water quality	D
More Than 100	Unsuitable for drinking	E

Source**:** Adopted from Imneisi & Aydin, 2016 and Elemile *et al.* (2021).

WQI maps for both wet and dry seasons were produced from concentration of physicochemical parameter using IDW interpolation methodin ArcGIS as displayed in Figure 6. The produced maps were reclassified using the rating scale in Table 5 to produced maps for both season as shown in Figure 7.

The spatial analysis of WQI as shown in Table 6 show that during the wet season, areas with good water quality dominated much of the region, particularly around settlements stretching from the Northbank area through the central and southeastern zones such as Gaadi, Airforce, Tse Poor, Mbakya, and the central-western axis around Wadata. This category (Table 6) covered about 242.96 km², or 72.67% of the study area. The dominance of good quality water in this season suggests that rainfall recharge helps dilute contaminants, thereby improving groundwater quality. It also highlights relatively favorable aquifer conditions, especially in the northern and northeastern parts and Kuyor covering 87.22 km² (26.09%). Very poor quality accounted for a much smaller portion, about 2.76 km² (0.83%), mainly in urban centers like Welfare Quarters and parts of Kanshio. These conditions are likely tied to urban runoff, poor sanitation, waste disposal, and mineral dissolution. Excellent water quality was rare, occupying only 1.39 km² (0.42%) in isolated spots such as Mbakya, where minimal human activity and protective natural factors help sustain pristine groundwater.

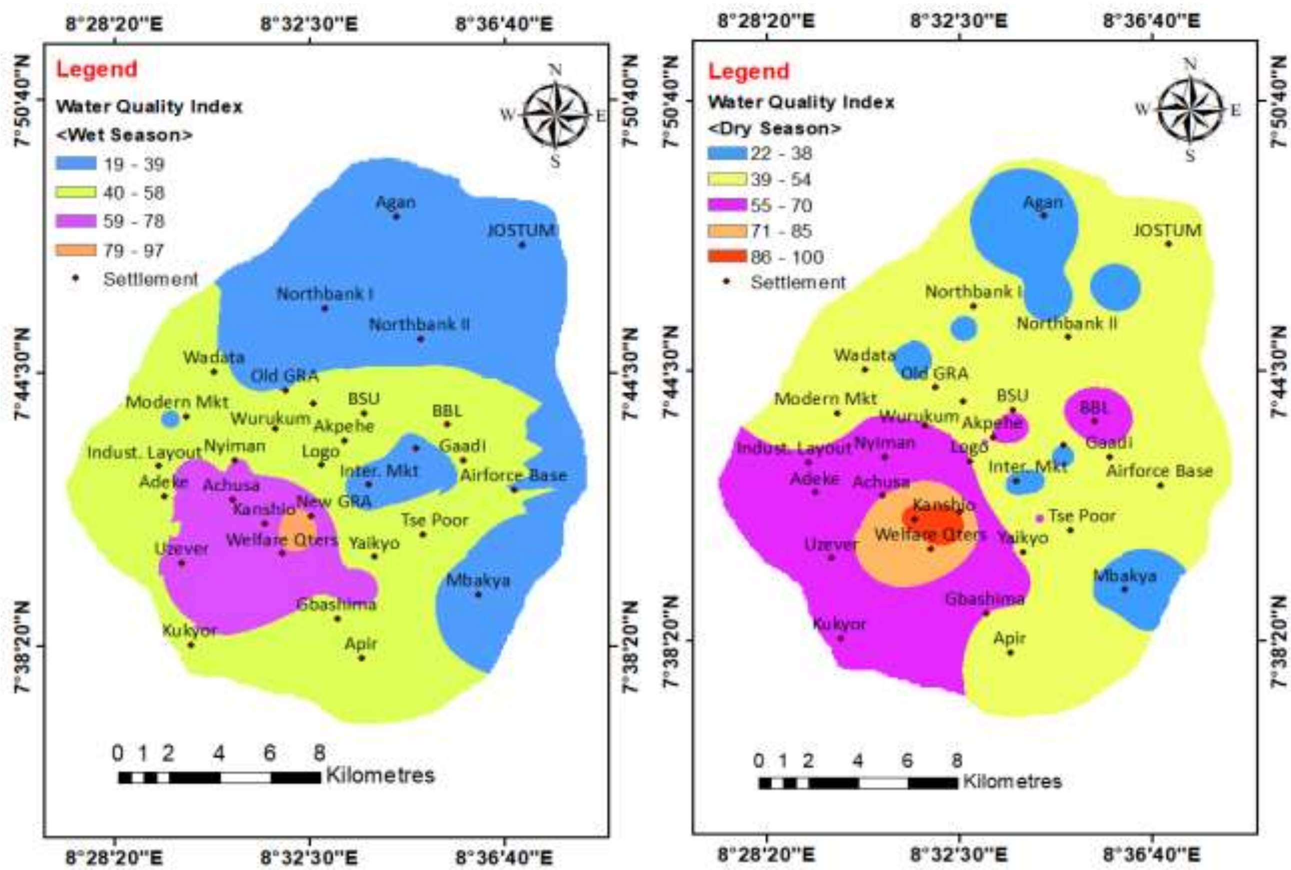

Figure 6: Spatial Distribution of Water Quality Index for Wet and Dry Seasons across Makurdi Metropolis and its Environs
Source: Authors spatial analysis in GIS environment, 2025

Overall, while good water quality dominated the wet season due to recharge effects, the persistence of poor and very poor zones indicates chronic pollution in certain locations. The small extent of excellent water quality further emphasizes the importance of protecting these high value aquifer zones from future contamination.

In the dry season (Table 7), good water quality still dominated the study area but reduced to 60.94%, covering about 203.73 km², largely across the Northbank region. Water in this category is generally safe for most purposes, including domestic and agricultural use, though minor treatment may be advisable. Poor water quality expanded to 36.03% of the area, about 120.44 km², mainly affecting locations such as BBL, Akpehe, Yaikor, Apir, and Adeke. In these places, water treatment is necessary before use, reflecting the influence of human activities like agriculture, waste disposal, and urban runoff, as well as possible natural contamination sources.

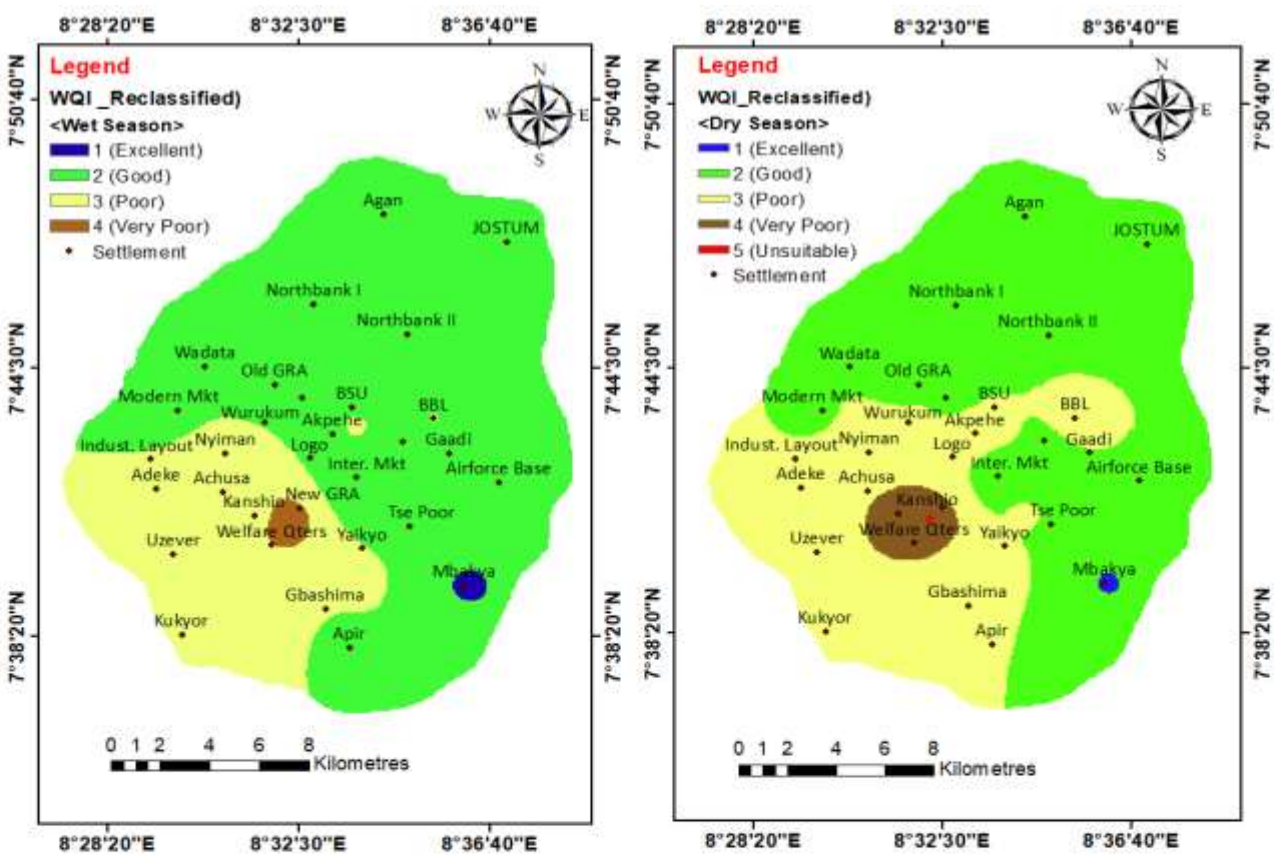

Figure 7: Spatial Distribution of Water Quality Index for Wet and Dry Seasons across Makurdi Metropolis and its Environs
Source: Authors spatial analysis in GIS environment based on field data 2025

Table 6: Area and Percentage coverage of WQI in Wet Season

WQI Wet Season	Water Quality Class	Area (km²)	Percentage (%)
1	Excellent	1.39	0.42
2	Good	242.96	72.67
3	Poor	87.22	26.09
4	Very Poor	2.76	0.83

Source: Authors computation in Arc GIS environment

A smaller portion of the area, 2.87%, showed very poor to unsuitable water quality, totaling 9.59 km² around Welfare Quarters and Kanshio. Groundwater in these zones is unsafe without significant treatment, marking them as pollution hotspots likely linked to sewage discharge, dense settlement, or naturally occurring contaminants.

Table 7: Area and Percentage coverage of WQI in Dry Season

WQI Dry Season	WQI Class	Area (km²)	Percentage (%)
1	Excellent	0.57	0.17
2	Good	203.73	60.94
3	Poor	120.44	36.03
4	Very poor	9.50	2.84
5	Unsuitable	0.09	0.03

Source: Authors computation in Arc GIS environment

CONCLUSION AND RECOMMENDATIONS

Groundwater in Makurdi and its surrounding communities is mostly safe and falls within the "good" category during both wet and dry seasons. In the wet season, rainfall recharge helps dilute pollutants, giving wider coverage of good quality water. By contrast, the dry season shows a drop in water quality, with some areas particularly Welfare Quarters, Kanshio, Adeke, and parts of the southwest recording poor to very poor conditions, and in a few cases water that is unsafe without treatment. These problem spots are linked to population pressure, poor sanitation, waste disposal, farming activities, and in some cases natural geological influences. Overall, while most groundwater is suitable for use, the persistence of degraded zones calls for urgent attention to safeguard public health.

To protect Makurdi's groundwater, regular monitoring should focus on vulnerable areas, while efforts to reduce pollution through better waste management, sanitation, and sustainable farming practices are essential. Households in poorer quality zones should treat their water before use, and the few areas with excellent water quality should be safeguarded. Raising community awareness and investing in sanitation infrastructure will further help maintain safe groundwater in the long term.

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