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Seasonal and Spatial Variability of Nitrate Concentration in Aquifers of Makurdi Metropolis and Its Environs, North Central Nigeria

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Abstract*:* *This study examined seasonal and spatial variation of nitrate concentrations in aquifers of Makurdi metropolis and environs, with implications for drinking water quality. Twenty-five boreholes were purposively selected to represent major settlements and aquifer types, and samples were collected in the wet (September 2024) and dry (April 2025) seasons using the grab method. Coordinates at each sampling point were recorded with GPS, potential pollution sources documented, and samples analysed for nitrate using spectrometric method in line with APHA (2017) and WHO standards. Spatial variability was mapped with ArcGIS 10.8.2 using Inverse Distance Weighted (IDW) interpolation. Results showed seasonal variation, with mean nitrate levels of 24.26 mg/L in the wet season and 22.27 mg/L in the dry season. While most boreholes complied with the Nigerian Standard for Drinking Water Quality (50 mg/L), exceedances were observed in BH5 (54.4 mg/L) and BH11 (52.1 mg/L) constituting 8% during the wet season, and in BH11 (51.1 mg/L) constituting 4% during the dry season. Elevated concentrations clustered in urban and peri-urban zones such as Akpehe, BSU, Logo, and Agan, largely due to agriculture, sanitation lapses, and waste disposal, whereas deeper aquifers (>100 m) generally showed lower levels. The findings highlight localised nitrate risks, underscoring the need for groundwater protection, improved sanitation, controlled fertilizer use, and safe alternative water sources.*
Keywords: nitrate, seasonal variation, spatiatil variation,water quality, groundwater, aquifers

INTRODUCTION

Groundwater serves as an essential water source for drinking and domestic use in numerous urban and peri-urban areas of sub-Saharan Africa, where centralized piped water systems frequently fail to reach all inhabitants. In Nigeria, many people rely on hand-dug wells and boreholes for their domestic water supply, but the quality of these groundwater resources is increasingly compromised by human activities such as poor sanitation practices, careless waste disposal, and intensive use of agricultural chemicals (Ocheri et al., 2010). Among the various chemical pollutants, nitrate is particularly significant due to its mobility in soil, persistence, and well-established health risks, including infant methemoglobinemia, along with the fact that high concentrations often signal recent contamination from sewage or agricultural sources (WHO, 2022). Given the numerous contaminants being introduced into our environment daily through anthropogenic activities, nitrate is a critical pollutant that cannot be overlooked (Darvishmotevallia et al., 2019). The contamination of groundwater by nitrate has become widespread, diminishing both the viability and quality of groundwater resources globally (Adimalla et al., 2018b). Nitrate is viewed as a contaminant resulting from livestock excrement and the use of inorganic fertilizers in agricultural practices. Additionally, sources such as wastewater treatment, emissions from motor vehicles, and industrial wastewater discharges have been identified as contributors to nitrate pollution in the environment (Asghari et al., 2018; Khosravi et al., 2018). Research on groundwater nitrate contamination and its associated health risks has been thoroughly examined in various studies worldwide (Chen et al., 2017; Adimalla et al., 2018b).

Previous studies in Makurdi Metropolis have recorded high nitrate levels in shallow wells as well as significant seasonal variations. One study focusing on hand-dug wells in Makurdi indicated that a substantial portion of the wells tested exceeded the WHO guideline for nitrate in drinking water (50 mg/L as NO_3^-), with 80% of the wells exceeding this level during the wet season and 67% during the dry season (Ocheri et al., 2010). The research also found that nitrate levels were generally higher during the wet season, suggesting that increased rainfall and water recharge mobilise nitrogen sources from the surface. Other local evaluations of groundwater quality in Makurdi and the Wadata area have similarly reported high nitrate concentrations in certain wells while noting associations with sanitation and surface water inputs (Asen et al., 2019). Despite these earlier findings, there is a scarcity of studies that specifically compare the spatial distribution of nitrate across a diverse network of wells, particularly boreholes, within the study area. A targeted seasonal spatial evaluation can help quantify the extent and distribution of nitrate contamination in relation to the Nigerian Standard for drinking water quality (NSDWQ, 2015) and identify hotspots of contamination along with potential source pathways. Thus, this study aims to quantify and map nitrate levels in groundwater across the Makurdi metropolis during both wet and dry seasons, evaluate compliance Nigerian Standard for Drinking Water Quality (NSDWQ, 2015), and discuss possible sources of contamination and implications for management.

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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.

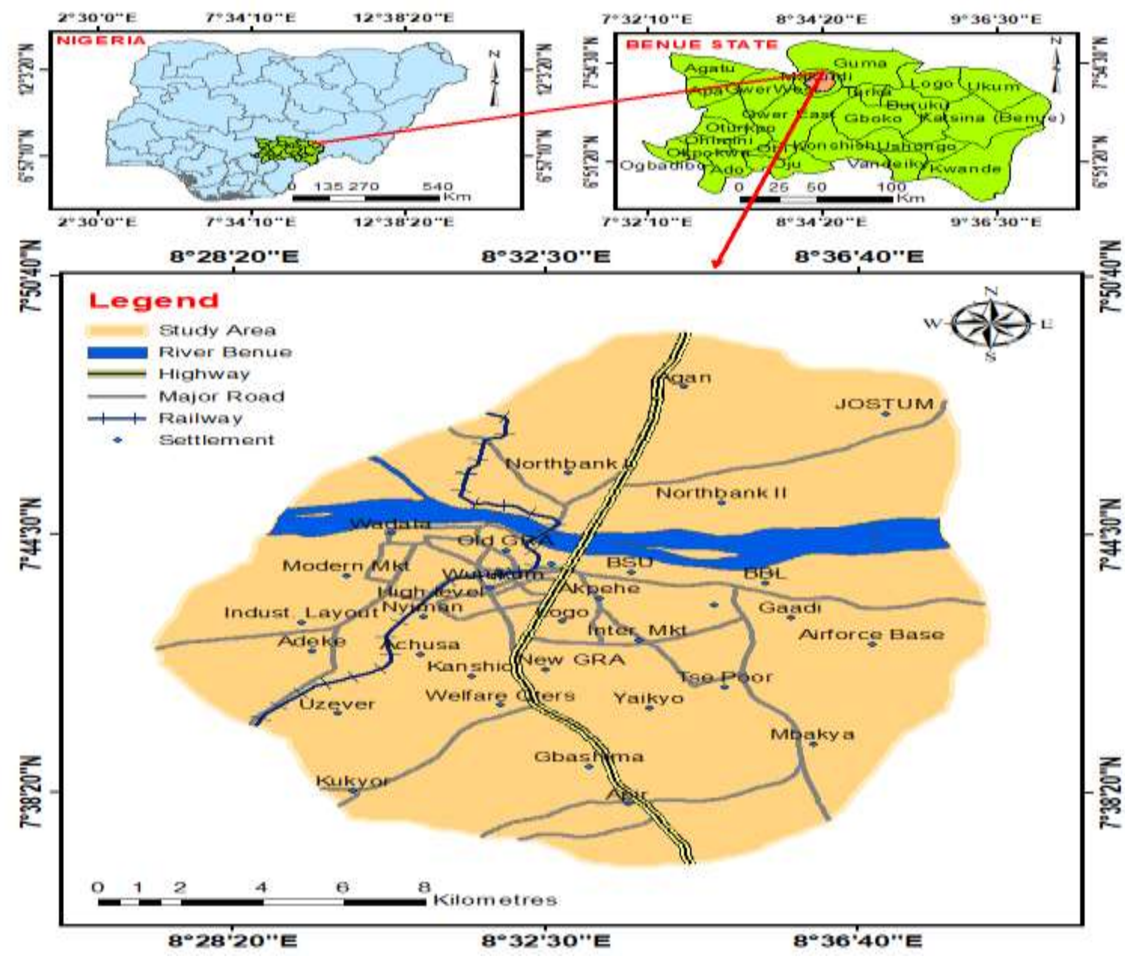

Figure 1: Map of Makurdi Metropolis and its Environs

Geology and Hydrogeology

Makurdi is situated within the Middle Benue Sub-basin of the Benue Trough, a significant Cretaceous rift that emerged during the fragmentation of Gondwana. The region is characterized by substantial deposits of fluvial to shallow marine sediments, with the Turonian Makurdi Formation consisting of sandstones intermixed with shales and limestones in certain areas (Nwajide, 1987).

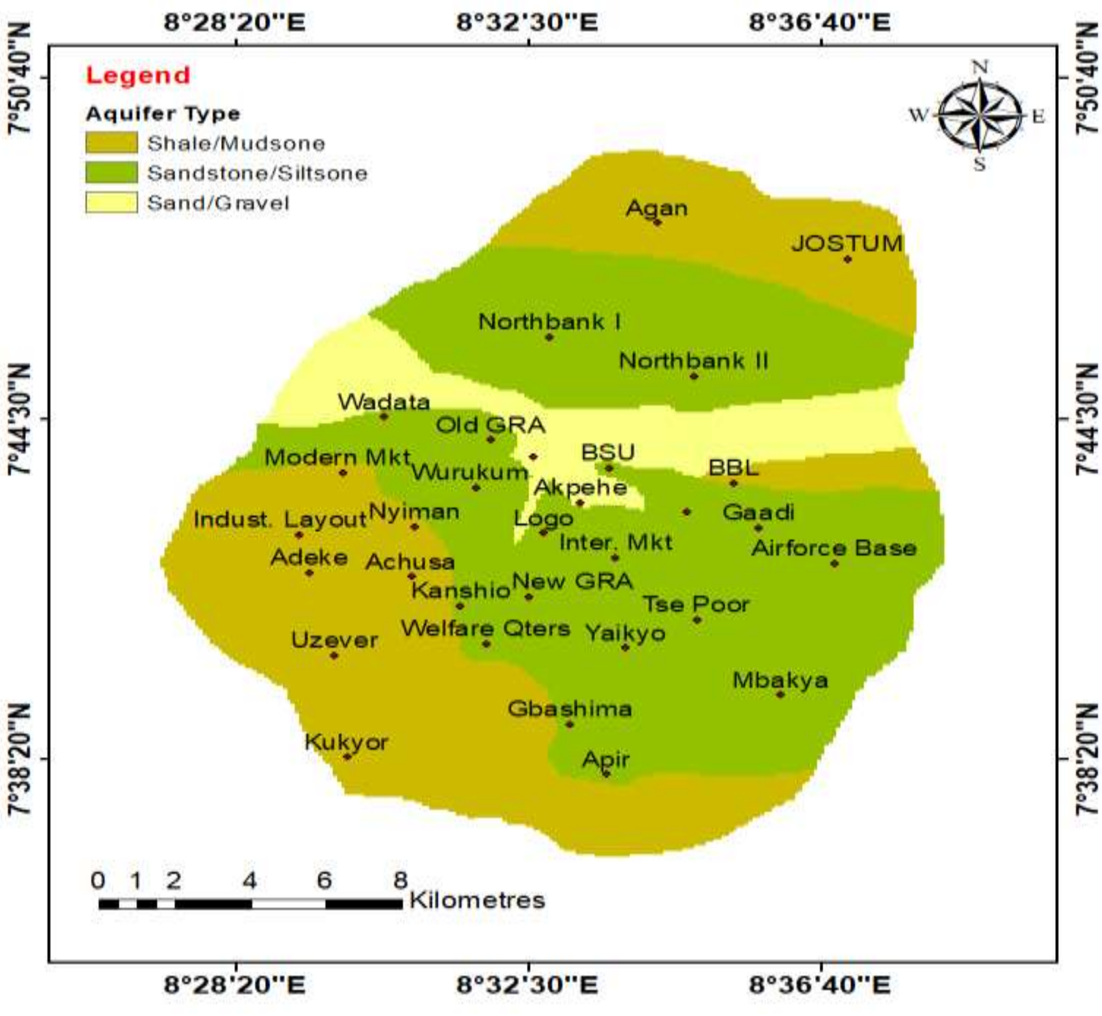

Figure 2.: Simplified Geological Map of Makurdi Metropolis and its Environs

These sediments, originating from adjacent Precambrian rock, were laid down in environments with high-energy fluvial to deltaic conditions (Nwajide, 1987; Obiora et al., 2015). Below these layers are older Albian shales and limestones, while localized Maastrichtian Awgu Shale exists only in certain areas. The tectonic stability of the region since the close of the Cretaceous has resulted in gently sloping strata, though the initial rift characteristics still impact groundwater movement (Obiora et al., 2015). Groundwater resources in Makurdi are mainly found in the Makurdi Sandstone, creating a multi-layered aquifer structure (Obrike et al., 2022). The shallow Upper Weathered Zone (3–15 m) allows for hand-dug wells but is susceptible to contamination, whereas the deeper Lower Coarse Sandstone (20–50 m) serves as a semi-confined aquifer that offers higher yields suitable for mechanized boreholes (Akuh, 2014; Obiora et al., 2015). These aquifers have moderate storage capacities and vary significantly in transmissivity, with most boreholes yielding low quantities of water for local use (Ocheri and Vangeryina, 2020).

Relief and Drainage

The topography of Makurdi is predominantly molded by the underlying Cretaceous Makurdi Sandstone, a relatively soft rock that is vulnerable to weathering and erosion. This has led to the formation of smoothly rolling plains and low hills. In certain elevated regions, lateritic caps can be found, while low-lying areas adjacent to the Benue River and seasonal streams are characterized by floodplains. The city is intersected by several seasonal streams, including the Rivers Idye, Amua, and Guma, which converge into the Benue River, creating a dendritic drainage pattern. These streams frequently dry up during the dry season but can experience swift rises during intense rainfall, resulting in flash floods in inadequately drained sectors of the urban area (Ocheri et al., 2010). The density of drainage is affected by land use and topography, with more intricate networks appearing in natural, less developed floodplain zones.

Climate and Vegetation

The region experiences a tropical wet-and-dry climate, with average temperatures hovering around 28 °C. December typically represents the coolest month at approximately 26 °C, while March is the warmest, reaching about 31 °C (Tyubee, 2008). Humidity levels fluctuate throughout the seasons, peaking at approximately 92% during the rainy period (Akpegi et al., 2020). The average annual rainfall, predominantly influenced by the southwest monsoon, totals around 1,190 mm but can vary considerably from 775 mm to 1,792 mm. The indigenous vegetation mirrors a savannah ecosystem of grasses and scattered trees, although urban expansion has diminished this cover. Nonetheless, remnants of the original vegetation persist in certain areas of the city and its peripheries (Akpegi et al., 2020).

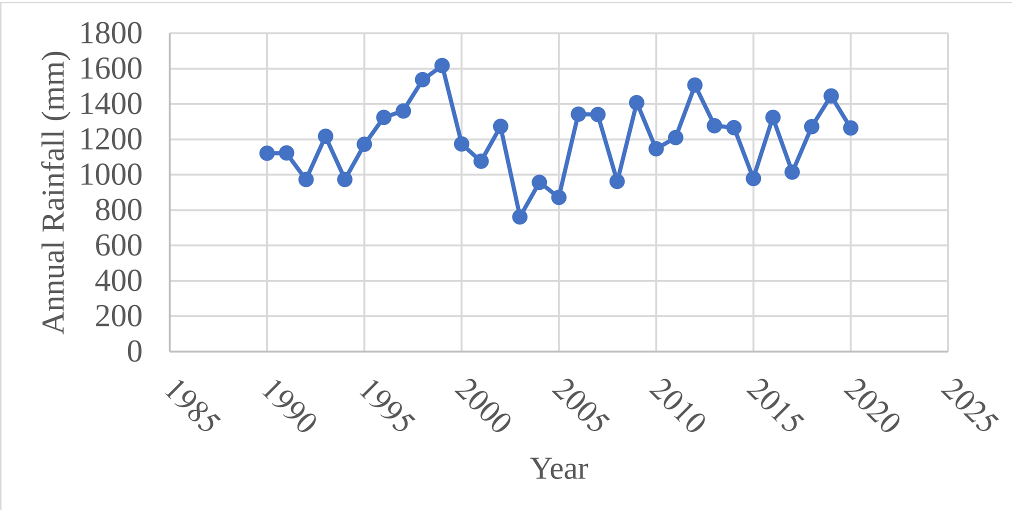

Figure 3: Mean Annual rainfall in Makurdi Metropolis and Environs (1990-2020)

Source: Computed from NIMET rainfall data for Makurdi Station

MATERIALS AND METHODS

Instruments for Data Collection

A Global Positioning System (GPS) device was utilized to precisely document the coordinates of all sampling locations. Water samples were gathered in sterilized containers to avoid contamination, while a field notebook was employed to record pertinent information on-site. A high-resolution camera was also used to photograph potential pollution sources and various land use activities near the sampling sites. Spectrometric method was employed to analyze the concentration of Nitrate in the collected samples. Arc GIS version 10.8.2 was utilized for the spatial analysis of nitrate levels.

Selection of Water Quality Parameters

The number of samples needed in such studies is not predetermined and typically depends on the study's goals; however, prior research indicates that sampling between 16 and 40 locations is adequate to capture spatial variation and contamination risks in urban environments (Wood, 2013; Guerin et al., 2014; Ojo et al., 2024). A total of twenty-five (25) groundwater samples from boreholes were taken during both the wet season (September, 2024) and the dry season (April, 2025).

Groundwater Sampling Strategy

To achieve balanced coverage of the entire region, twenty-five (25) boreholes were purposefully chosen, representing the primary aquifer types and significant settlements within and around Makurdi metropolis. Water samples were obtained during both the wet season (September 2024) and the dry season (April 2025) to assess any potential seasonal variations in water quality. Sampling was conducted using the grab method, which entails taking a single sample from each source at a specific time, a method deemed reliable for evaluating the physical, chemical, and microbiological characteristics of drinking water (APHA, 2017). Clean 75cl plastic bottles were utilized for sample collection. At every collection site, bottles were rinsed three times, and water was allowed to flow for 2–3 minutes before collecting the sample. Each bottle was clearly labeled and stored in an ice-filled cooler, then quickly transported to the laboratory for comprehensive chemical analysis.

Laboratory Instrumentation and Procedure of Water Quality Parameters Analysis

The collected water samples were handled carefully during transport to the laboratory for thorough analysis. The Standard Methods for the Examination of Water and Wastewater (23rd edition, APHA, 2017) and the WHO Guidelines for Drinking Water Quality served as the benchmarks for laboratory analysis of nitrate to guarantee accuracy and dependability.

Spatial Analysis and Mapping of Nitrate in Aquifers of Makurdi Metropolis and its Environs

The analysis of groundwater quality distribution was conducted using Geographic Information System (GIS) techniques. Nitate concentraion value at each sampling point was taken into account for spatial interpolation and mapping to evaluate the extent and variability of groundwater contamination within the study area.

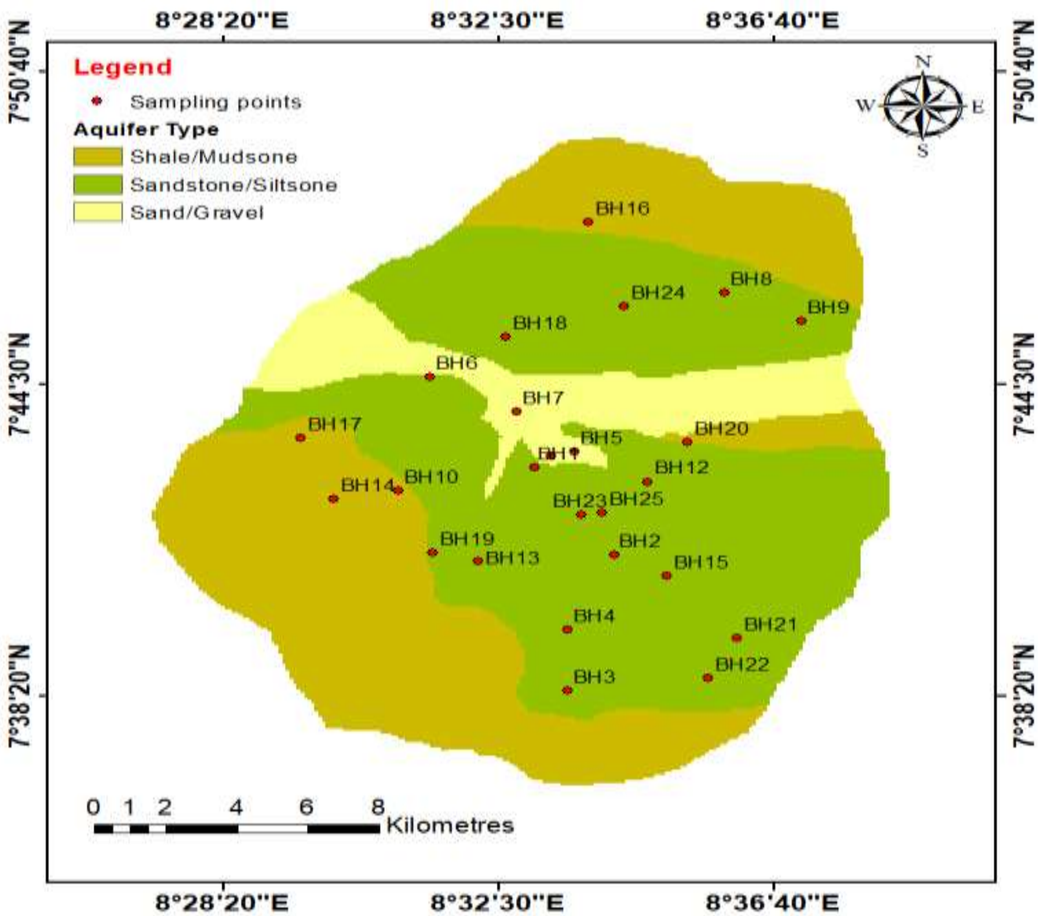

Figure 4: Map Showing Sampling Points in Makurdi Metropolis and its Environs
Source: Produced by the Author

The results from the water quality analysis for the 25 sampled locations were compiled into a spreadsheet containing the following fields: Sample ID, Latitude, Longitude, and the measured values for each sampling point. The final dataset was saved in a Microsoft Excel.csv format for easy import into ArcGIS version 10.8.2 software. The csv file was imported into ArcGIS, and point features were created to represent the sampling locations through the "Display XY Data" tool. Longitude and Latitude were used as the X and Y coordinates, respectively. The spatial reference system was established as WGS 1984. The created point layer was subsequently exported as a shape file and saved as the foundational layer for interpolation. To generate continuous spatial distribution surfaces for nitrate, the Inverse Distance Weighted (IDW) interpolation method was utilised. IDW is commonly employed in groundwater quality mapping because of its straightforwardness and efficiency in interpolating environmental variables with spatially correlated data (Childs, 2004), resulting in an interpolated raster map that illustrates the spatial variability of nitrate in the study area.

RESULTS AND DISCUSSION OF FINDINGS

Seasonal Variation of Nitrate Concentration in Aquifers of Makurdi Metropolis and its Environs

The findings of this research, as presented in Table 1 and 2, reveal distinct seasonal fluctuations in nitrate levels across the boreholes in the examined area. The mean nitrate concentrations as seen in Table 2 were 24.26 mg/L during the wet season and 22.27 mg/L in the dry season, suggesting a slight increase during the wet season. At the level of individual boreholes, variations were generally minimal; however, several key trends were identified: Boreholes BH1, BH2, BH4, BH5, BH11, BH12, BH19, and BH22 exhibited higher nitrate levels in the wet season, which aligns with leaching driven by rainfall. Conversely, Boreholes BH3, BH10, BH13, BH14, BH15, BH16, and BH24 displayed consistently stable concentrations across both seasons, indicating effective aquifer protection or deeper recharge areas. Boreholes BH9 and BH20 recorded low levels in both seasons, which may suggest isolated or less contaminated aquifers. Additionally, Borehole BH11 surpassed the allowable limit during both the wet (52.1 mg/L) and dry (51.1 mg/L) seasons, underscoring ongoing contamination and vulnerability due to its shallow depth of 25 meters.

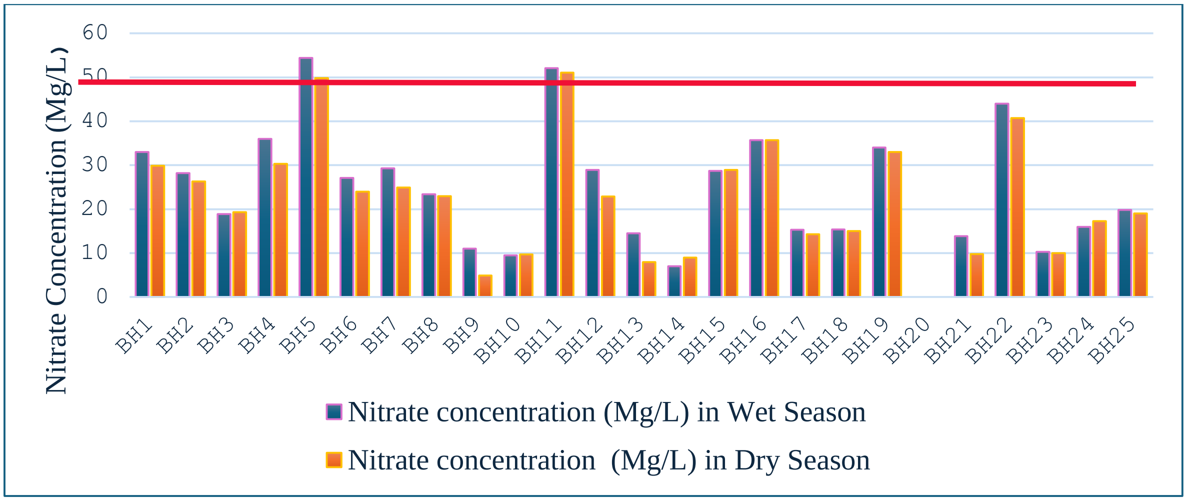

Figure 5: Bar chart showing seasonal variation in Nitrate concentration in Aquifers of Makurdi Metropolis and its Environs

Table 1: Seasonal Variation in Concentration of Nitrate in Aquifers of Makurdi Metropolis and its Environs

Sample Code	Latitude	Longitude	Borehole Depth	Nitrate concentration (mg/L) in Wet Season	Nitrate concentration (mg/L) in Dry Season
BH1	7.7142	8.55065	45	33	29.9
BH2	7.6854	8.57072	90	28.2	26.3
BH3	7.6405	8.55923	70	18.9	19.3
BH4	7.6606	8.55924	80	36	30.3
BH5	7.7194	8.561	40	54.4	49.8
BH6	7.744	8.52463	110	27.1	24
BH7	7.7326	8.54615	50	29.3	24.9
BH8	7.7716	8.59867	90	23.4	23
BH9	7.7623	8.61812	80	11	4.9
BH10	7.7064	8.51637	110	9.5	9.7
BH11	7.7178	8.55481	25	52.1	51.1
BH12	7.7094	8.57926	60	28.9	22.9
BH13	7.6834	8.53665	120	14.5	8
BH14	7.7037	8.50032	65	7	9
BH15	7.6785	8.58413	75	28.7	28.9
BH16	7.7948	8.56445	120	35.7	35.7
BH17	7.7239	8.49203	130	15.3	14.3
BH18	7.7571	8.54361	76	15.4	15
BH19	7.6861	8.52522	110	34	33
BH20	7.7225	8.58941	80	0	0
BH21	7.6579	8.60187	70	13.9	9.8
BH22	7.6447	8.59456	75	44	40.7
BH23	7.6985	8.56241	70	10.3	10
BH24	7.7671	8.57347	110	16	17.3
BH25	7.6991	8.56781	65	19.8	19

Source: Field and Laboratory Analysis 2025

Table 2: Mean Seasonal values of Nitrate concentration in Aquifers of Makurdi Metropolis and its Environs

Season	Number	Mean	Range	Minimum	Maximum
Wet	25	24.256	54.4	0	54.4
Dry	25	22.272	51.1	0	51.1

Source: Authors compution, 2025

While most boreholes recorded nitrate concentrations below the Nigerian Standard for Drinking Water Quality (50 mg/L), two boreholes constituting 80% surpassed this limit during the wet season (BH5: 54.4 mg/L; BH11: 52.1 mg/L), and one borehole constituting (4%) exceeded it in the dry season (BH11: 51.1 mg/L). The Nigerian Standard for Drinking Water Quality (NSDWQ, 2015) stipulates that the maximum allowable nitrate level is 50 mg/L. Figure 4 illustrates this finding. Similar instances of nitrate exceeding the permissible level have been reported in various regions of Nigeria (Akanbi & Akinseye, 2023; Akinwumi et al., 2024), attributed to extensive agricultural practices and inadequate sanitation methods that lead to nitrate contamination. Two boreholes surpassed this limit during the wet season (BH5: 54.4 mg/L and BH11: 52.1 mg/L), while one borehole (BH11: 51.1 mg/L) exceeded it in the dry season. This trend is consistent with observations by Ocheri et al. (2010) and Amadi et al. (2012), who identified higher nitrate levels during rainy seasons due to increased leaching from agricultural fertilizers and surface contaminant infiltration.

The wet season promotes the movement of nitrates from the soil and surface runoff, whereas in the dry season, limited recharge often restricts nitrate movement. These exceedances indicate localized sources of nitrate contamination, potentially linked to shallow borehole depths, proximity to agricultural areas, or sewage leakage. For instance, BH11, which persistently exceeded the permissible limit in both seasons, has a relatively shallow depth (25 m), rendering it more susceptible to surface contamination.

The spatial distribution of nitrate concentrations further highlights the impact of borehole depth. Boreholes that are deeper (>100 m) typically exhibited lower concentrations (for example, BH13, BH17, BH24), indicating natural attenuation and decreased susceptibility to surface nitrate pollution. Conversely, shallow boreholes (<50 m) were more likely to show elevated levels, corroborating findings from earlier research in similar hydrogeological areas.

Spatial Variation of Nitrate in Aquifers of Makurdi Metropolis

Figure 6 illustrates clear patterns in nitrate distribution throughout the study area during both wet and dry seasons. During the wet season, nitrate concentrations varied from 0.0 to 54.3 mg/L, with high concentrations concentrated around Akpehe, BSU, Logo, and Agan. The spatial clustering of

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elevated nitrate levels in these regions indicates urban and peri-urban pollution sources, particularly arising from domestic wastewater, leaking septic systems, and unregulated waste disposal, as noted by Akanbi et al. (2023). Increased rainfall promotes the leaching of nitrates from surface and near-surface layers into the groundwater, causing a significant rise in concentration during the wet season. In contrast, many settlements, including Northbank II, Adeke, and JOSTUM, displayed lower concentrations, likely reflecting lesser human activity and/or improved natural filtration.

In the dry season, nitrate levels slightly decreased, ranging from 0.0 to 50.8 mg/L. The high concentration zones remained relatively consistent, particularly around BSU, Akpehe, and Mbakya, though the intensity diminished in some areas, presumably due to reduced leaching and dilution effects without rainwater recharge. Nonetheless, the localized persistence of nitrate hotspots in regions such as BSU, Akpehe, and Logo indicates point source pollution, potentially from poor waste disposal practices, in addition to intensive land use within densely populated areas as observed in field visits.

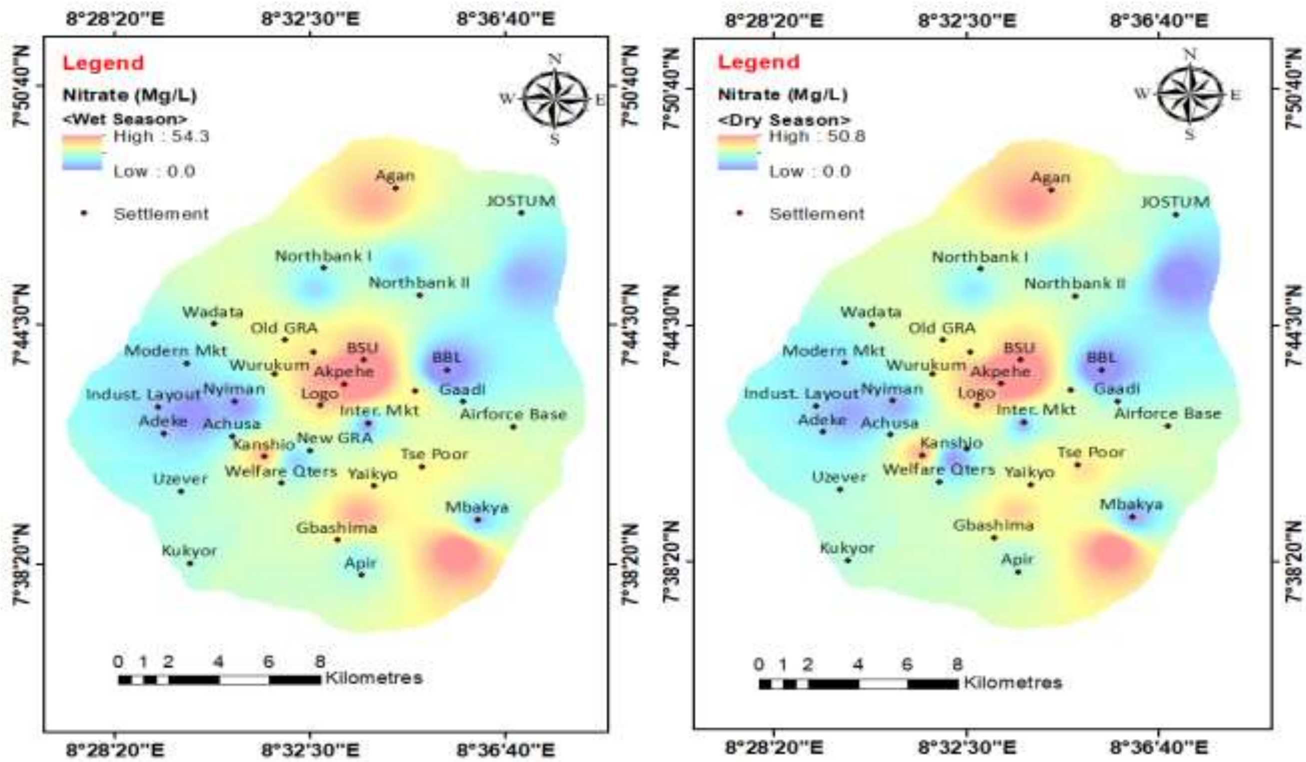

Figure 6: Spatial Distribution and Seasonal Variation of Nitrate in Groundwater of Makurdi Metropolis and its Environs
Source: Authors spatial analysis in GIS environment based on field data 2025.

CONCLUSION AND RECOMMENDATIONS

The results of this research indicate that groundwater in the Makurdi metropolis experiences moderate nitrate contamination, with variability influenced by seasonal changes, rainfall patterns, human activities, and the depth of boreholes. While most boreholes comply with NSDWQ standards, localized instances of contamination present health risks, especially for communities dependent on shallow wells located in areas vulnerable to pollution. The ongoing presence of high nitrate levels in specific boreholes (e.g., BH11) highlights the urgent need for focused groundwater protection strategies. If no action is taken, factors such as rising population, uncontrolled waste disposal, and intensive farming practices could worsen nitrate pollution, jeopardizing the safety of drinking water supplies.

Regular monitoring of groundwater in critical areas should be implemented. Improvements in sanitation and waste management are necessary to decrease nitrate leaching. Whenever feasible, boreholes should be drilled at greater depths, and safe distances from sources of pollution should be established. It is vital to raise public awareness about health risks and promote safe agricultural methods, while also providing alternative safe water sources or simple treatment solutions in areas that consistently experience contamination.

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