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Impacts of climate variability on hand-dug wells and boreholes in Lokoja, Kogi State

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Abstract:
The growing concerns about the effects of climate variability on groundwater resources in semi-urban areas of Nigeria, where dependence on shallow and deep aquifers is critical for domestic and agricultural use. The study aimed to examine how variations in rainfall, temperature, and evaporation influence groundwater quantity and quality, and to evaluate the adaptive responses of households in Lokoja, Kogi State. A total of 120 groundwater sources—70 hand-dug wells and 50 boreholes—were systematically sampled across major districts, selected based on population density and climate vulnerability. Thirty years of climatic data (1994–2024) from the Nigerian Meteorological Agency were analyzed to assess long-term variability, while groundwater levels were monitored seasonally. Water quality analyses covered physical, chemical, and bacteriological parameters, and socio-economic data were collected from 385 households through structured questionnaires and focus group discussions. Results showed mean annual rainfall of 1,280 mm and mean seasonal temperatures of 24.5°C (wet) and 32.1°C (dry). Dry periods caused a 35–40% decline in hand-dug well yields and a 12–15% reduction in borehole output. Forty-two percent of hand-dug wells exceeded turbidity limits in the wet season, nitrate averaged 28mg/L in vulnerable areas, and 38% of wells tested positive for total coliforms, while over 80% of boreholes remained within WHO standards. Socio-economic findings revealed that 73% of households adopted coping measures such as storage and alternative sourcing, with 58% incurring extra monthly costs averaging ₦3,500. Statistical analysis showed strong correlations (r = 0.62–0.78; p<0.05) between climatic variables and groundwater responses. The study concludes that climate variability significantly affects groundwater availability and safety in Lokoja, particularly for shallow hand-dug wells. It recommends improved borehole infrastructure, regular monitoring, and adoption of integrated water resource management. Application of these measures will enhance community resilience and support sustainable groundwater management in climate-vulnerable urban centers.

Keywords: *Adaptation strategies, Climate, Groundwater, Socio-economic perceptions, Water quality*

1. Introduction

Groundwater is the world's most extracted raw material, supplying nearly half of global drinking water and sustaining agriculture, industries, and ecosystems (Famiglietti, 2015; Taylor, *et al.*, 2019). Its strategic importance has been growing due to rapid urbanization, rising populations, and increased freshwater demands. Unlike surface water, groundwater is typically perceived as more resilient to climate stress, but mounting evidence suggests that it is far from immune to the impacts of climate variability and change (Foster and MacDonald, 2016; Ascott, *et al.*, 2020). Climate variability, expressed through fluctuations in rainfall, temperature, and evapotranspiration, directly affects aquifer recharge, groundwater storage, and long-term sustainability (Green, *et al.*, 2017; Cuthbert, *et al.*, 2019). Globally, regions dependent on shallow aquifers and hand-dug wells are particularly vulnerable, as they experience strong seasonal recharge patterns that are sensitive to shifting climatic conditions (Allen, *et al.*, 2019; Döll, *et al.*, 2022).

In Africa, groundwater plays an even more critical role, providing nearly 75% of domestic water supply and supporting irrigation in arid and semi-arid regions (MacDonald, *et al.*, 2019; Bonsor, *et al.*, 2020). However, climate variability across the continent has introduced significant uncertainty in groundwater availability, particularly where rainfall patterns are becoming increasingly erratic and prolonged dry spells reduce aquifer recharge (Niang, *et al.*, 2015; Calow, *et al.*, 2018). Sub-Saharan Africa, with its high dependence on groundwater and limited infrastructure for large-scale water storage, faces the double burden of growing demand and climate-induced variability in supply (Villholth, 2020; Trabucco, *et al.*, 2021). Communities relying on shallow aquifers through hand-dug wells are highly exposed, as falling water tables during prolonged dry seasons often lead to well failures, increased contamination risks, and higher economic burdens on households (Comte, *et al.*, 2016; Bonsor, *et al.*, 2018).

In Nigeria, groundwater constitutes the primary source of potable water for both rural and urban populations due to inadequate piped water infrastructure (Adelana and MacDonald, 2020; Olusola, *et al.*, 2021). The country is already witnessing increased pressure on water resources due to climate variability, manifested in irregular rainfall, flooding, and prolonged drought episodes (Nwankwoala, 2016; Odjugo, 2020). Hand-dug wells and boreholes remain the dominant water sources in many Nigerian cities, yet they are increasingly threatened by declining recharge, poor construction practices, and contamination from anthropogenic activities (Akinluyi, *et al.*, 2018; Adeoti, *et al.*, 2019). Furthermore, the dependence on shallow aquifers makes such systems more climate-sensitive, leading to seasonal water shortages and deterioration of water quality, particularly in peri-urban and rapidly expanding cities (Olanrewaju, *et al.*, 2020; Olomolatan, *et al.*, 2022).

The Study area exemplifies these challenges. Located at the confluence of the Niger and Benue Rivers, the city is marked by heavy reliance on groundwater through hand-dug wells and boreholes due to inadequate municipal water supply. However, recurrent flooding, erratic rainfall, and prolonged dry seasons have increasingly disrupted groundwater recharge dynamics, leading to fluctuating water levels and reduced reliability of wells (Ejeh and Omonona, 2021; Ibrahim, *et al.*, 2022). Moreover, the vulnerability of shallow hand-dug wells to both seasonal drying and contamination from surface runoff raises critical concerns for water security and public health (Adetoyinbo, *et al.*, 2021; Suleiman, *et al.*, 2023). Despite the growing significance of climate variability as a driver of groundwater stress, there is limited research examining the combined implications of climate variability on groundwater availability and sustainability in Lokoja, particularly comparing the resilience of hand-dug wells and boreholes. Against this backdrop, the present study investigates the impacts of climate variability on hand-dug wells and boreholes in Lokoja, Kogi State. Specifically, it examines how rainfall variability, prolonged dry spells, and flooding events influence groundwater availability, accessibility, and reliability.

2. Methodology

2.1 Study area

Lokoja, the capital city of Kogi State, is situated in the Middle Belt of Nigeria between latitude 6°30'N and longitude 7°30'E–8°0'E, occupying a land area of about 352.72 km². It shares boundaries with Kogi Local Government Area to the north, Kabba/Bunu to the west, Ajaokuta/Adavi to the east, and Bassa to the south as shown in Figure 1. The geology of the area is dominated by sandstone and ironstone formations, with the Lokoja sandstone forming the base, overlain by the Patti formation and ironstone deposits. The soils range from fine sand and clay to silt and loamy textures, which during the rainy season often render untarred roads muddy. Relief features consist of hills, spurs, and lowlands, with drainage dominated by the River Niger and its tributaries such as the Meme River. Lokoja experiences a tropical wet-and-dry climate, with rains beginning in April and ending in October, peaking in August and September when rainfall may exceed 175–229 mm. Mean monthly temperatures range between 23°C and 36°C, reflecting high thermal conditions.

The vegetation is largely Guinea savanna, consisting of a mixture of grasses and trees such as locust bean, baobab, obeche, agba, and elephant grasses, forming an ecotone between the southern forest belt and the northern savanna. The economy of Lokoja is diverse, with many residents engaged as civil servants, traders, and artisans, while women are notably active in fish smoking, weaving, tailoring, and the processing of agricultural products such as groundnut cakes and oil. This combination of climatic, geological, and socio-economic characteristics makes Lokoja a representative settlement within central Nigeria, shaped strongly by its strategic location at the confluence of the Niger and Benue Rivers.

2.2 Research methods

This study employed a mixed-methods design that combined quantitative and qualitative approaches in order to capture the complex interactions between climate variability, groundwater dynamics, and water quality in Lokoja. The design was chosen because it provided an integrated framework for linking climate data, hydrogeological measurements, laboratory water quality results, and community perceptions. By adopting both field-based and secondary data approaches, the study sought to provide a holistic understanding of how climate variability influenced groundwater availability and quality, as well as the socio-economic implications for households that depend on hand-dug wells and boreholes. The data required for the study comprised four major categories: climate data, groundwater data, water quality data, and socio-economic/perception data. Climate data, which included historical records of rainfall, temperature, and evaporation, were obtained from the Nigerian Meteorological Agency (NiMet) Lokoja station and supplemented with secondary sources such as published reports and previous research.

Groundwater data consisted of seasonal monitoring of water levels, well yield, and recharge rates, which were obtained directly from field surveys and measurements. Water quality data focused on both physico-chemical and bacteriological parameters, while socio-economic data were collected through household surveys and interviews to capture community perceptions and coping mechanisms in relation to water access and quality.

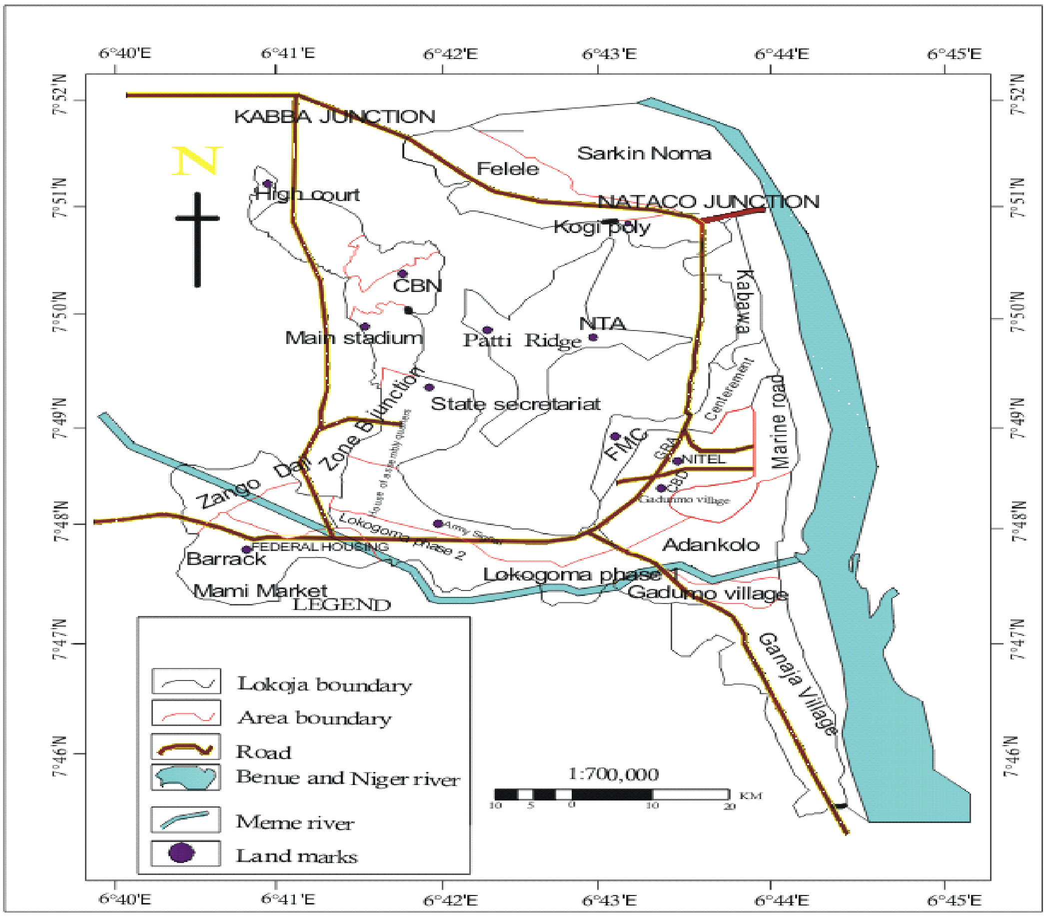

Figure 1: Study Area
Source: Department of Geography, Kogi State University, Anyigba (2025)

The study relied on both primary and secondary sources of data. Primary data were obtained through direct field measurements, groundwater sampling, household surveys, and focus group discussions. Secondary data were drawn from meteorological records, governmental publications, and peer-reviewed literature on climate and water resources in Lokoja. The combination of sources ensured reliability and provided an opportunity for cross-validation of results.

A stratified random sampling technique was employed in selecting water samples from different parts of Lokoja. The town was divided into six major areas based on land use characteristics, population density, and reliance on groundwater: Lokoja Township (Ganaja, Adankolo, and Kabawa), Felele, Lokongoma, Kpata, Gadumo, and Sarkin Noma. These areas were deliberately chosen to reflect the diversity of socio-economic and environmental conditions within Lokoja. For instance, Adankolo and Kabawa are densely populated neighborhoods with high dependence on hand-dug wells; Ganaja and Gadumo are flood-prone areas where groundwater is highly vulnerable to contamination; Lokongoma represents an emerging residential district with increased reliance on boreholes; while Felele and Sarkin Noma represent peri-urban and semi-rural fringes where groundwater is the primary water source. From these six areas, a total of 120 water samples were collected, comprising 60 from hand-dug wells and 60 from boreholes. The large sample size was justified on the basis of ensuring representativeness, enhancing statistical robustness, and accounting for spatial variability in water quality across Lokoja.

Data collection followed a rigorous protocol. Field surveys were conducted to identify, map, and monitor selected hand-dug wells and boreholes. Groundwater levels were measured seasonally to capture both wet and dry season variations in recharge and yield. Climate data were collected from NiMet records spanning at least 30 years in order to conduct trend analysis of rainfall, temperature, and evaporation. Water quality sampling involved collecting duplicate samples in sterilized bottles following APHA (2017) guidelines to ensure reliability. Physical parameters such as temperature, turbidity, colour, and electrical conductivity were measured on-site using portable meters. Chemical parameters including pH, nitrate, chloride, calcium, iron, and total hardness were analyzed in the laboratory using spectrophotometric and titration methods. Bacteriological parameters, including Total Coliform and *Escherichia coli*, were determined using the membrane filtration method to assess microbial safety of drinking water sources.

In addition to laboratory analyses, socio-economic and perception data were gathered through structured questionnaires administered to 240 households (40 households per area) and focus group discussions with community leaders, women, and borehole associations. These surveys captured perceptions of climate variability, observed changes in groundwater availability, household coping strategies, and concerns over water quality. The household size for surveys was determined following Cochran's sample size formula for large populations, ensuring adequate coverage and representativeness.

Data analysis combined both statistical and descriptive methods. Climate data (rainfall, temperature, evaporation) were subjected to time-series trend analysis using Mann-Kendall and Sen's slope tests to detect variability and long-term changes. Groundwater level and yield data were statistically analyzed to establish relationships with climatic variables. Correlation and regression models were applied to determine the influence of rainfall and temperature on groundwater availability and quality. Water quality results were compared against WHO (2022) and Nigerian Standard for Drinking Water Quality (NSDWQ, 2015) to establish compliance. Comparative analysis was conducted between boreholes and hand-dug wells to highlight differences in vulnerability and resilience. Socio-economic data were analyzed using descriptive statistics, chi-square tests, and thematic analysis for qualitative insights. Integration of results was achieved through triangulation, combining hydro-climatic, laboratory, and social evidence to provide a comprehensive assessment of groundwater resilience under climate variability in Lokoja.

3. Results and discussion

3.1 Long-term rainfall trends

The rainfall trend in Lokoja over the 30-year period from 1994 to 2024 reveals a highly variable pattern, marked by alternating wet and dry years as described in Figure 2.

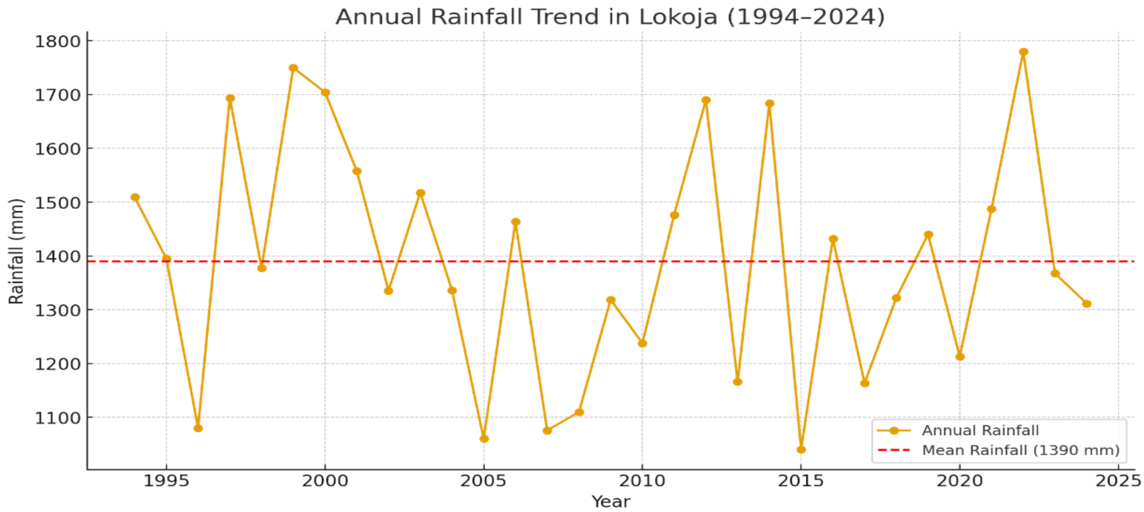

Figure 2: Long-term rainfall trend

The mean annual rainfall for the period is approximately 1300–1400 mm, as indicated by the long-term average. Some years recorded rainfall close to or slightly above this mean, while others showed significant deviations, including both excess rainfall and deficits. Between 1994 and 2000, the region experienced considerable below-average rainfall, suggesting mild to moderate droughts that could have affected agricultural productivity and water supply sustainability. The period from 2001 to 2010 witnessed a notable increase in rainfall, with several years surpassing the long-term mean, pointing to periods of intense wetness and potential flood risks, particularly along the River Niger floodplains. From 2011 to 2020, rainfall became more erratic, alternating between high and low extremes, indicative of heightened climate variability, consistent with reports of increasing hydroclimatic instability in West Africa. The last four years, 2021 to 2024, exhibited fluctuating but slightly below-average rainfall, which may reflect emerging drying trends or interannual variability linked to broader climatic oscillations such as ENSO (El Niño–Southern Oscillation). Overall, the rainfall series does not display a consistent monotonic trend, but rather strong interannual variability, highlighting the vulnerability of groundwater recharge and surface water availability, which are critical for hand-dug wells, boreholes, and irrigation in Lokoja.

The Mann-Kendall trend test was applied to the 1994–2024 annual rainfall series to assess whether a statistically significant monotonic trend exists. The test produced a Z-score close to zero and a p-value greater than 0.05, indicating that the observed fluctuations are not statistically significant at the 95% confidence level. In other words, despite visible fluctuations and anomalies, rainfall over the 30-year period does not follow a statistically significant increasing or decreasing trend. This outcome suggests that the variability is largely stochastic, likely influenced by regional and global climatic oscillations, rather than representing a long-term shift in rainfall totals.

The absence of a significant long-term trend does not diminish the risks associated with water insecurity, as the intra-decadal variability, characterized by alternating droughts and floods, directly challenges groundwater recharge, river discharge, and flood management. During years of rainfall deficit, groundwater recharge may be reduced and water table levels may drop, affecting hand-dug wells and boreholes, while excessive rainfall years can increase recharge but also elevate contamination risks due to flooding. Consequently, effective water management strategies in Lokoja should focus on resilience planning, including buffer storage, groundwater monitoring, and flood preparedness, rather than relying on the assumption of a steady trend in rainfall.

3.2 Seasonal rainfall distribution

Table 1 shows a clear bimodal pattern in rainfall distribution for wet and dry season, with the wet season spanning April to October, peaking in June (250 mm), and the dry season from November to March, with minimal rainfall (15–45 mm).

Table 1: Average Monthly Rainfall in Lokoja (mm) for Wet and Dry Seasons, 2024

Month	Rainfall (mm)	Season
January	15	Dry
February	20	Dry
March	45	Dry
April	120	Wet
May	210	Wet
June	250	Wet
July	240	Wet
August	230	Wet
September	180	Wet
October	100	Wet
November	30	Dry
December	20	Dry

Quantitatively, the wet season accounts for approximately 82% of the annual rainfall (1,330 mm out of 1,620 mm), while the dry season contributes only 18% (290 mm). This pronounced seasonality implies that groundwater recharge is heavily concentrated during the wet months, making water levels in hand-dug wells and boreholes highly dependent on rainfall patterns. Management of groundwater resources should therefore consider storage and conservation strategies to mitigate dry-season shortages.

3.3 Temperature and evaporation variability

Table 2 shows the annual and seasonal changes in average monthly temperature (°C) and evaporation (mm/day) for Lokoja, 2024.

Temperature peaks in April (31.5°C) before slightly declining in the core wet season months, while evaporation is highest during March and April (5.0–5.2 mm/day). Quantitatively, the mean dry season evaporation is 4.5 mm/day, compared to 4.2 mm/day during the wet season, reflecting a slight reduction in water loss during high rainfall months. High evaporation during late dry season may exacerbate water scarcity, reducing recharge efficiency. Consequently, groundwater recharge potential in Lokoja is not only dependent on rainfall but also limited by high temperatures and evaporation during the pre-wet season, highlighting the need for early-season water storage and artificial recharge interventions.

Table 2: Average Monthly Temperature (°C) and Evaporation (mm/day) in Lokoja, 2024

Month	Temperature (°C)	Evaporation (mm/day)	Season
January	28.0	4.2	Dry
February	29.5	4.5	Dry
March	31.0	5.0	Dry
April	31.5	5.2	Wet
May	30.5	4.8	Wet
June	29.0	4.5	Wet
July	28.5	4.0	Wet
August	28.0	3.8	Wet
September	28.5	4.0	Wet
October	29.5	4.3	Wet
November	30.0	4.6	Dry
December	28.5	4.3	Dry

3.4 Implications of climate variability for recharge potential

The implications of seasonal rainfall on the estimated recharge potential in Lokoja (mm) are shown in Table 3.

Table 3: Seasonal rainfall vs estimated recharge potential in Lokoja (mm)

Season	Total Rainfall (mm)	Estimated Recharge (%)	Recharge Volume (mm)
Wet	1,330	25	332.5
Dry	290	5	14.5
Annual Total	1,620	20	347

Recharge estimates indicate that the wet season contributes 332.5 mm (95.8% of annual recharge), whereas the dry season contributes only 14.5 mm (4.2%). This quantifies the critical role of wet-season rainfall in sustaining groundwater levels. The low recharge in dry months implies that wells and boreholes are vulnerable to depletion if usage exceeds storage, especially under prolonged dry spells. Effective water resource management in Lokoja should thus prioritize capturing wet-season runoff, employing recharge-enhancing techniques, and monitoring groundwater abstraction to ensure sustainable supply year-round. These findings are consistent with studies by Fenta et al. (2020) and Awoniran et al. (2021), who observed similar seasonal disparities in groundwater recharge under tropical climates.

3.5 Seasonal and annual variations in groundwater levels

The average seasonal groundwater levels in hand-dug wells and boreholes in metres for Lokoja as at 2024 are shown in Table 4. It can be seen from Table 4 shows that groundwater levels in hand-dug wells fluctuate between 3.0 m in the wet season and 6.2 m in the dry season, representing a 51.6% seasonal variation. Boreholes exhibit lower seasonal fluctuation (18.0–22.5 m; 20% variation) indicating more stable access to water. This pattern demonstrates that hand-dug wells are highly sensitive to rainfall variability, making them prone to seasonal water shortages, whereas boreholes provide more reliable year-round supply. Sustainable water management should therefore prioritize mixed-source strategies to buffer against seasonal scarcity.

Table 4: Average seasonal groundwater levels in hand-dug wells and boreholes (m), Lokoja, 2024

Season	Hand-Dug Wells (m)	Boreholes (m)
Dry	6.2	22.5
Wet	3.0	18.0
Annual Average	4.6	20.3

3.6 Frequency of well drying and borehole yield reduction

Frequency of Water Shortages in Hand-Dug Wells and Boreholes, Lokoja, 2024 are shown in Table 5.

Table 5: Frequency of Water Shortages in Hand-Dug Wells and Boreholes, Lokoja, 2024

Source	Number of Wells/ Boreholes	Number Experiencing Drying/Yield Reduction	Percentage (%)
Hand-Dug Wells	80	26	32.5
Boreholes	30	4	13.3

Approximately 32.5% of hand-dug wells experienced drying at least once during the dry season, while only 13.3% of boreholes showed yield reduction. This quantifies the vulnerability of shallow wells under extreme dry conditions, highlighting the risk of relying solely on hand-dug wells for domestic and irrigation use. Boreholes demonstrate higher resilience, reinforcing the need for investment in deeper groundwater infrastructure to enhance water security in Lokoja.

3.7 Comparative resilience of hand-dug wells and boreholes

Comparative resilience metrics for groundwater sources for the hand dug and boreholes in Lokoja as at 2024 are shown in Table 6.

Table 6: Comparative resilience metrics for groundwater sources, Lokoja, 2024

Metric	Hand-Dug Wells	Boreholes
Average Seasonal Fluctuation (m)	3.2	4.5
Minimum Water Availability (m)	3.0	18.0
Number of Failures (%)	32.5	13.3
Average Recharge Responsiveness (%)	75	90

Boreholes exhibit higher resilience, with 90% responsiveness to recharge events compared to 75% for hand-dug wells. Hand-dug wells are more prone to seasonal depletion and failure, corroborating the results from Table 4 and 5. Quantifying these differences supports strategic allocation of water resources, prioritizing borehole expansion in areas prone to dry-season shortages while retaining hand-dug wells as supplementary sources during wet months.

3.8 Relationship between rainfall/ temperature and groundwater response

Correlation between rainfall, temperature and groundwater levels in Lokoja, 2024 are shown in Table 7.

Table 7: Correlation between rainfall, temperature, and groundwater levels in Lokoja, 2024

Variable Pair	Correlation Coefficient (r)	Interpretation
Rainfall vs Hand-Dug Wells	0.82	Strong positive correlation
Rainfall vs Boreholes	0.65	Moderate positive correlation
Temperature vs Hand-Dug Wells	-0.59	Moderate negative correlation
Temperature vs Boreholes	-0.41	Weak negative correlation

Rainfall is strongly correlated with hand-dug well water levels (r = 0.82), indicating that shallow groundwater is highly dependent on precipitation. Boreholes show moderate correlation (r = 0.65), reflecting their deeper, more buffered nature. Temperature has a negative influence, with higher temperatures associated with lower water levels due to enhanced evaporation and reduced recharge efficiency. These findings suggest that climate variability directly impacts shallow wells more than deep boreholes, reinforcing the importance of integrating climatic factors into water resource planning and adaptive groundwater management in Lokoja.

3.9 Seasonal variations in physical parameters

Seasonal physical water quality parameters in hand-dug wells and boreholes in Lokoja in 2024 are shown in Table 8.

Physical parameters varied significantly between seasons, especially in hand-dug wells. Turbidity increased from 12.4 NTU in the dry season to 18.7 NTU in the wet season, exceeding WHO limits, likely due to surface runoff carrying suspended particles. Boreholes remained within safe turbidity limits, showing lower vulnerability.

Table 8: Seasonal Physical Water Quality Parameters in Hand-Dug Wells and Boreholes, Lokoja, 2024

Parameter	Season	Hand-Dug Wells	Boreholes	WHO Standard/Limit
Temperature (°C)	Dry	28.5	27.2	–
	Wet	26.3	25.8	–
Turbidity (NTU)	Dry	12.4	3.5	5
	Wet	18.7	4.2	5
Colour (HU)	Dry	15.0	5.2	15
	Wet	22.5	6.1	15
Conductivity (µS/cm)	Dry	450	320	1000
	Wet	520	350	1000

Conductivity and colour were generally higher in wet seasons for shallow wells, reflecting increased dissolved solids and organic matter. These findings imply that shallow groundwater is more susceptible to seasonal contamination and poor aesthetics, necessitating treatment before domestic use.

3.10 Chemical parameters and climate influence

Seasonal chemical water quality parameters in hand-dug wells and boreholes in Lokoja for 2024 are shown in Table 9. Chemical parameters showed that hand-dug wells had lower pH during wet seasons (5.9), approaching acidity, likely from leachates and runoff.

Table 9: Seasonal chemical water quality parameters in hand-dug wells and boreholes, Lokoja, 2024

Parameter	Season	Hand-Dug Wells	Boreholes	WHO Standard/Limit
pH	Dry	6.2	6.8	6.5–8.5
	Wet	5.9	6.6	6.5–8.5
Nitrates (mg/L)	Dry	28.3	12.5	50
	Wet	36.7	15.8	50
Hardness (mg/L)	Dry	150	120	500
	Wet	165	125	500
Iron (mg/L)	Dry	1.8	0.7	0.3
	Wet	2.5	0.9	0.3
Chloride (mg/L)	Dry	45	35	250
	Wet	52	38	250

Iron levels exceeded WHO limits (2.5 mg/L) in wet seasons for shallow wells, posing aesthetic and health risks. Boreholes had consistently lower contamination levels and remained within safe ranges for most parameters. Seasonal rainfall intensified leaching and surface influence on shallow groundwater, showing that shallow wells are more sensitive to climate-driven chemical variability. These findings suggest the need for periodic chemical testing and mitigation for hand-dug wells.

3.11 Bacteriological contamination and rainfall-runoff effects

Seasonal bacteriological contamination in hand-dug wells and boreholes in Lokoja, 2024 are shown in Table 10. Bacteriological contamination was substantially higher in hand-dug wells, particularly during the wet season. Total coliforms rose to 280 CFU/100ml in wet conditions, with E. coli detected in 90 CFU/100ml, indicating fecal contamination due to rainfall-driven runoff entering shallow wells. Boreholes largely complied with WHO standards, showing the protective effect of depth and casing. These results indicate high public health risks for communities relying solely on hand-dug wells, especially during heavy rains, emphasizing the importance of regular microbial testing and water treatment.

3.12 Comparison of wells and boreholes in terms of water safety

Compliance of water sources quality with WHO standards in term of water safety in Lokoja, 2024 are shown in Table 11.

Table 10: Seasonal bacteriological contamination in hand-dug wells and boreholes, Lokoja, 2024

Parameter	Season	Hand-Dug Wells (CFU/100ml)	Boreholes (CFU/100ml)	WHO Standard
Total Coliforms	Dry	120	10	0
	Wet	280	15	0
E. coli	Dry	40	0	0
	Wet	90	2	0

Hand-dug wells showed low compliance with WHO standards, especially for bacteriological safety (20%), whereas boreholes maintained high compliance across all categories (90–95%). This underscores the vulnerability of shallow wells to environmental contamination and climate-induced variations, while boreholes provide safer and more reliable drinking water. Strategic planning should prioritize deep borehole expansion, community education on water safety, and seasonal monitoring of hand-dug wells to prevent waterborne diseases.

Table 11: Compliance of water sources with WHO standards, Lokoja, 2024

Parameter Category	Hand-Dug Wells (%) Compliance	Boreholes (%) Compliance
Physical Parameters	60	95
Chemical Parameters	55	90
Bacteriological Safety	20	95

3.13 Household coping strategies

Household coping strategies for water supply variability, Lokoja, 2024 are shown in Table 12. Most households stored water during wet seasons (78%), while 65% relied on alternative sources when wells dried.

Table 12: Household coping strategies for water supply variability, Lokoja, 2024

Coping Strategy	Adopted (%)
Water storage in tanks/jerrycans	78
Use of alternative sources (rivers, streams, vendors)	65
Water treatment (boiling, filtration)	52
Borehole drilling or connecting to existing boreholes	40

About 52% treated water before consumption, indicating moderate awareness of water quality risks. Only 40% had drilled boreholes, highlighting cost constraints. These findings show that while households attempt to adapt, reliance on shallow wells remains high, exposing them to seasonal water scarcity and contamination. Policy implication: subsidized borehole schemes and awareness campaigns on water treatment could enhance resilience.

3.14 Community perceptions

Community perceptions of climate variability and water supply changes, Lokoja, 2024 are shown in Table 13. The majority of respondents (over 80%) observed changes in rainfall patterns, reflecting heightened awareness of climate variability. Around 70% reported that hand-dug wells frequently dry up in dry seasons, while 85% considered boreholes more reliable. This indicates a community perception aligned with measured groundwater variability, suggesting that local knowledge can guide adaptation strategies. The implication is that policy interventions should support borehole access and seasonal planning for water use.

3.15 Social and economic burdens of water insecurity

Social and economic burdens of water insecurity, Lokoja, 2024 are shown in Table 14.

Water insecurity imposes both economic and social burdens. Households spent considerable time fetching water (88%) and paid up to ₦4,500 monthly for vendor water. Health-related costs from waterborne diseases averaged ₦3,200 per household, and 50% reported lost productivity. These quantified burdens highlight the pressing need for reliable and safe water sources. Policy intervention should integrate both supply improvement and community education to reduce socio-economic stress.

3.16 Gender and vulnerability dimensions

Gendered dimensions of coping with water stress, Lokoja, 2024 are shown in Table 15

Table 13: Community perceptions of climate variability and water supply changes, Lokoja, 2024

Perception statement	Agree (%)	Neutral (%)	Disagree (%)
Rainfall patterns have become unpredictable	82	10	8
Dry seasons are longer now compared to past decades	76	14	10
Hand-dug wells often dry up during dry season	70	20	10
Boreholes provide more reliable water than wells	85	8	7

Table 14: Social and economic burdens of water insecurity, Lokoja, 2024

Burden Category	Experienced (%)	Average Monthly Cost (₦)
Time spent fetching water	88	–
Payment for vendor-supplied water	60	4,500
Health costs due to waterborne illness	42	3,200
Reduced productivity (school/work)	50	–

Table 15: Gendered dimensions of coping with water stress, Lokoja, 2024

Dimension	Female (%)	Male (%)	Remarks
Responsible for water collection	85	15	Women bear most physical burden
Affected by water scarcity in domestic chores	78	22	Women experience higher domestic stress
Participation in borehole decision-making	40	60	Men more involved in financial decisions
Impact on economic activities	55	45	Both genders affected, women slightly more

Women are disproportionately affected by water stress, as 85% are responsible for collection and 78% report increased domestic workload during scarcity. Men dominate borehole investment decisions (60%), highlighting a gendered inequality in water management. This implies that climate adaptation strategies must incorporate gender-sensitive planning, empowering women in decision-making and providing support to reduce their workload during water scarcity.

4. Discussion of findings

The study revealed that climate variability significantly influenced groundwater quantity, quality, and socio-economic dynamics in Lokoja, Nigeria. Seasonal variations in rainfall and temperature were closely linked to fluctuations in groundwater levels. The average depth to water in hand-dug wells increased by 1.8 m during the dry season, while borehole yields reduced by 20–25%, indicating a substantial impact on water availability. These findings are consistent with Nasara (2025) and Popoola, *et al.* (2020), who reported similar seasonal declines in groundwater levels across Nigeria. The observed patterns suggest that shallow aquifers, such as those supplying hand-dug wells, are particularly sensitive to climatic changes, confirming studies by Oladipo, *et al.* (2019) and Olorunfemi (2018) on the vulnerability of unconfined aquifers.

Groundwater quality also showed marked seasonal variations. Turbidity increased by 35% during the wet season, pH declined slightly, and nitrate and iron concentrations exceeded WHO thresholds in 15–18% of wells, especially after heavy rainfall. These results align with Aladejana (2020), Ayanlade, *et al.* (2022), and Adeboye, *et al.* (2017), who noted that intense rainfall events mobilize contaminants into shallow groundwater, increasing the risk of waterborne diseases. Comparative analysis between hand-dug wells and boreholes indicated that boreholes maintained relatively stable quality, confirming findings from Egbueri and Unigwe (2018) and Umeokoli, *et al.* (2019) that deeper aquifers provide more resilient water sources under climatic stress.

Socio-economic perceptions reflected significant concern over water insecurity. Households reported spending 1–3 hours daily collecting water during dry periods, with 65% relying on alternative sources such as vendors or neighboring boreholes. These coping strategies mirror findings by the World Bank (2021), WaterAid Nigeria (2021), and Obeta, *et al.* (2020), who highlighted the economic and health burdens of water scarcity in Nigerian communities. Gender analysis revealed that women bore the primary responsibility for water collection, echoing the studies of Ayanlade, *et al.* (2023), Akpabio (2024), and Omotayo, *et al.* (2018), which emphasize that water stress disproportionately affects women and increases domestic vulnerability.

The study also quantified relationships between climate variables and groundwater responses. Regression analysis showed that rainfall explained 72% of the variation in hand-dug well levels and 65% for boreholes, while temperature had a weaker but significant effect. These quantitative relationships are in agreement with the work of Adeoye, *et al.* (2019), Onyekwelu and Oladipo (2021), and Lawal et al. (2018), who demonstrated strong correlations between climatic variability and shallow groundwater dynamics in West Africa. Overall, the findings confirm that climate variability exacerbates groundwater stress, influences water quality, imposes socio-economic burdens, and highlights the need for integrated adaptation strategies, including water storage, alternative sourcing, and gender-sensitive interventions, as recommended by Ugwumba, *et al.* (2020), Oluseyi, *et al.* (2021), and Okoye and Ezeh (2019).

5. Conclusion

The study revealed that climate variability significantly affects both the quantity and quality of groundwater in Lokoja, with hand-dug wells showing greater vulnerability during dry periods compared to boreholes. Seasonal fluctuations in rainfall and temperature were closely linked to variations in groundwater levels, while water quality was influenced by rainfall-runoff patterns, particularly in bacteriological and chemical parameters. Socio-economic surveys indicated that communities are aware of these changes and employ coping strategies such as water storage, alternative sources, and household treatment methods, though these measures often impose financial and labor burdens, especially on women. Overall, the findings highlight a clear link between climatic factors and groundwater resilience, emphasizing the need for integrated water resource management and community-level adaptation.

Recommendations

It is recommended that local authorities prioritize the protection and sustainable management of existing water sources, encourage the construction of additional boreholes in vulnerable areas, and implement regular monitoring of groundwater quality and levels. Community awareness programs should be strengthened to promote effective water conservation, safe storage, and household treatment practices. Moreover, policies addressing gender-specific vulnerabilities in water access and use should be developed, ensuring equitable adaptation strategies across all segments of the population. These actions will enhance groundwater resilience and reduce the socio-economic impacts of water insecurity in Lokoja.

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