

# Impact Of Excreta Disposal Practices On Groundwater Quality In Maiduguri And Jere, Northeastern Nigeria

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## **Abstract**

Groundwater serves as the primary source of potable water in Maiduguri and Jere, northeastern Nigeria, where rapid population growth and limited public water supply have intensified reliance on hand-dug wells and boreholes. However, the increasing dependence on on-site sanitation systems such as pit latrines and septic tanks has raised concerns about groundwater safety. This study investigates the impact of excreta disposal practices on groundwater quality in the region, focusing on nitrate concentrations, thermotolerant coliforms (TTC), separation distances between wells and sanitation facilities, and groundwater flow patterns. A total of 100 groundwater samples were collected from boreholes and hand-dug wells and analyzed for physicochemical parameters (pH, EC, TDS, nitrate) and microbial indicators. Results revealed that pH (6.3–7.2), EC (72–840  $\mu\text{S/cm}$ ), and TDS (48–560 mg/L) values were within permissible limits of WHO and NSDWQ standards. However, nitrate levels ranged from 1.7–57.9 mg/L, with 30% of samples exceeding the WHO guideline of 50 mg/L. TTC counts ranged from 0–150 CFU/100 ml, with contamination detected in 40% of samples, particularly in hand-dug wells. Regression analysis confirmed a strong inverse relationship between well–latrine separation distance and both nitrate and TTC concentrations, while groundwater flow mapping indicated contaminant migration along down-gradient flow paths. These findings underscore the vulnerability of the Chad Formation’s shallow aquifers to anthropogenic pollution, with significant implications for public health. The study highlights the urgent need for improved sanitation siting guidelines, hydrogeology-sensitive regulations, and integrated WASH interventions to ensure safe and sustainable groundwater supply in Maiduguri and Jere.

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## **I. Introduction**

Groundwater is the world’s most vital freshwater resource, supplying nearly 50% of global drinking water and 40% of irrigation needs (UNESCO, 2022). Its relative reliability, widespread availability, and natural protection against contamination have long made it a preferred water source over surface water (Ravenscroft & Lucy, 2022). However, the increasing pressures of urbanization, population growth, and unregulated land use have undermined this perception, with mounting evidence that groundwater, particularly shallow unconfined aquifers, is highly vulnerable to chemical and microbial contamination (MacDonald et al., 2012; Foster et al., 2013).

One of the most critical anthropogenic threats to groundwater quality is poor sanitation, especially in rapidly urbanizing regions where centralized sewerage systems are absent. Globally, more than 1.77 billion people rely on pit latrines and septic tanks for excreta disposal, with Sub-Saharan Africa and South Asia recording the highest dependency (Graham & Polizzotto, 2013). While these systems are cost-effective, their proximity to wells and lack of proper engineering often result in leachate infiltration into aquifers. Nitrate ( $\text{NO}_3^-$ ) and microbial pathogens are the most common contaminants, with studies in Zimbabwe and Nigeria reporting significant groundwater pollution in wells located less than 10–25 m from pit latrines (Bloodless et al., 2006; Adejuwon & Adeniyi, 2011). These findings highlight the inadequacy of existing siting guidelines, particularly in hydrogeologically vulnerable zones where high permeability and shallow water tables accelerate contaminant transport (Lawrence et al., 2001).

Microbial contamination, often assessed through thermotolerant coliforms (TTC) or *Escherichia coli*, poses immediate risks of diarrheal diseases such as cholera, typhoid, and dysentery (Odonkor & Ampofo, 2013; Hodge et al., 2016). TTC are regarded as robust indicators of fecal contamination due to their survival under elevated incubation temperatures (44–45 °C) and close association with enteric pathogens in groundwater (WHO, 2011). Epidemiological studies have consistently linked high TTC counts in drinking water with childhood diarrhea, which remains one of the leading causes of morbidity and mortality in Sub-Saharan Africa (Joshua et al., 2014).

Nitrate contamination, in contrast, presents both acute and chronic health threats. High concentrations have been linked to methemoglobinemia or “blue baby syndrome” in infants (Comley, 1945; Knobeloch et al.,

2000), while recent evidence associates long-term exposure to nitrate with colorectal cancer, thyroid dysfunction, and birth defects, even at concentrations below the WHO guideline of 50 mg/L (Ward et al., 2018). In Nigeria, nitrate exceedances are commonly reported in densely populated areas where pit latrines and soakaways dominate sanitation infrastructure (Goni et al., 2019; Abdurrahman et al., 2021).

These risks are amplified in semi-arid regions such as northeastern Nigeria, where groundwater recharge is limited and aquifers of the Chad Formation are highly permeable, rendering them particularly vulnerable to contamination (Adelana et al., 2008). Maiduguri, the Borno State capital, and its adjoining Jere urban complex are among the fastest-growing settlements in the region, with a population exceeding 1.2 million people (NPC, 2022). Public water supply coverage is inadequate, leading households to depend primarily on private boreholes and hand-dug wells, many of which are sited near sanitation facilities due to space constraints and weak regulatory oversight (RUWASSA, 2018). Previous studies have reported evidence of nitrate and bacteriological contamination in groundwater (Bulakarima et al., 2016; Goni et al., 2019), but a comprehensive assessment of the extent and pathways of pollution from excreta disposal practices remains limited.

This study addresses this gap by systematically assessing the impact of pit latrines and soakaways on groundwater quality in Maiduguri and Jere. Specifically, it examines nitrate concentrations, TTC levels, well–latrine separation distances, and groundwater flow direction to better understand contamination dynamics. By integrating hydrogeological assessment with water quality analysis, this research provides evidence-based insights necessary for safe water supply and sanitation planning in semi-arid urban environments.

**Keywords:** Groundwater Contamination, On-site Sanitation, Nitrate Pollution, Thermotolerant Coliforms, WASH Interventions

### Study Area

The study was conducted in Maiduguri and Jere Local Government Areas (LGAs), which form the largest urban settlement in Borno State, northeastern Nigeria (Figure 1). Maiduguri, the state capital, together with the adjoining Jere urban complex, lies within the Nigerian sector of the Chad Basin, one of Africa’s most extensive inland drainage basins. The Chad Basin covers approximately 2.3 million km<sup>2</sup> across Nigeria, Niger, Chad, Cameroon, and the Central African Republic, with the Nigerian portion occupying about 179,000 km<sup>2</sup> (Miller & Uzoma, 1968; Adelana et al., 2008). Geographically, the study area extends between latitudes 11°30’N and 11°55’N and longitudes 13°00’E and 13°20’E, covering both densely built-up and peri-urban settlements.

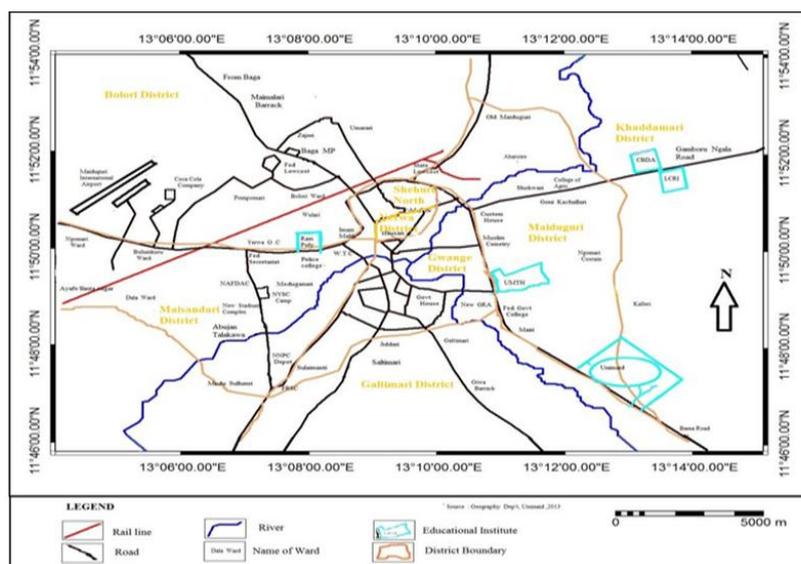


Figure 1: Map of the Study Area

### Topography and Drainage

The relief is characterized by gently undulating plains sloping northeastwards towards Lake Chad, with elevations declining from about 320 m in the southwest to approximately 282 m above sea level in the northeast (Nyanganji, 1997). The area is drained primarily by the Ngadda River system, a seasonal stream which flows northeast into the Jere floodplain, locally known as the “Jere Bowl.” This floodplain is prone to seasonal inundation during the rainy season, resulting in temporary wetlands and waterlogging. The poor drainage conditions in the Jere Bowl create a hydro-environment highly vulnerable to contamination, as shallow groundwater interacts directly with surface effluents.

### *Climate and Vegetation*

The study area falls within the semi-arid Sahelian climatic belt, marked by a long dry season (October–May) and a short rainy season (June–September). Rainfall is unimodal, averaging 550–600 mm annually, with peak precipitation in August (Goni et al., 2004). However, high potential evapotranspiration exceeding 2000 mm per annum results in a negative water balance, intensifying the risk of drought and water scarcity (Daura, 2000). Mean annual temperatures range between 25°C and 45°C, with the hottest months occurring in March to May before the onset of the rains.

Vegetation is dominated by Sudan–Sahel savannah species, comprising thorny shrubs, scattered acacia trees, and grasses adapted to arid conditions. Human activities, including deforestation, fuelwood harvesting, and expansion of settlements, have significantly modified the natural vegetation cover, leading to land degradation and desertification (Nyanganji, 1997).

### *Geology and Hydrogeology*

Maiduguri and Jere are underlain by the Chad Formation, a thick sequence of Plio-Pleistocene sediments composed mainly of alternating sands, silts, clays, and occasional diatomite layers (Petters, 1981; Hamza, 1995). The sediments were deposited in a lacustrine–fluvial environment and form the principal aquifer system of the region.

Hydrogeologically, the Chad Formation hosts three aquifer units:- Upper Aquifer (Unit A): a shallow phreatic aquifer occurring at depths of less than 60 m. It is unconfined, highly permeable, and tapped mainly by hand-dug wells and shallow boreholes. This aquifer is the most exploited for domestic use but is highly susceptible to pollution from surface sources, particularly pit latrines and soakaways (Adelana et al., 2008).- Middle Aquifer (Unit B): a semi-confined aquifer occurring between 60–300 m depth, exploited by deeper boreholes for municipal supply.- Lower Aquifer (Unit C): a confined aquifer encountered at depths greater than 400 m, less exploited due to high drilling costs.

Recharge to the shallow aquifer occurs primarily from direct infiltration of rainfall and, secondarily, from surface water sources such as the Ngadda River. The high permeability of sandy horizons enhances infiltration but also increases vulnerability to anthropogenic contaminants. Studies have documented nitrate and microbial contamination in this aquifer system, especially in peri-urban areas of Maiduguri (Goni et al., 2019).

## **II. Methodology**

### *Study Design*

This study adopted a hydrogeological and water quality assessment design integrating field-based sampling, laboratory analyses, and spatial data interpretation. The design was chosen to capture both the chemical and microbiological integrity of groundwater sources as influenced by excreta disposal practices, particularly pit latrines and soakaways. A total of 100 water points (boreholes and hand-pump wells) were systematically sampled across Maiduguri and Jere LGAs, enabling a robust representation of the...

### *Sampling Strategy and Data Collection*

Sampling was conducted over a three-week period (October 2–18, 2023), coinciding with the post-rainy season when groundwater recharge and contamination risks are high. Sites were selected to reflect varying proximities of water sources to sanitation facilities, settlement density, and hydrogeological settings.

For each site, the following data were collected:

- Geospatial data: latitude, longitude, and elevation (using handheld GPS units)- Sanitation
- proximity: distance of the nearest pit latrine or soakaway from the waterpoint, measured with tape or laser range finders.
- Well characteristics: construction type, depth, and static water level (from borehole records or direct measurement).
- Environmental conditions: soil texture, land use patterns, and evidence of flooding or wastewater discharge.

Two sterilized polyethylene bottles (1 L each) were filled at each site:

1. One for physicochemical analyses (pH, EC, TDS, nitrate).
2. One for microbial analysis (thermotolerant coliforms).

Samples were preserved in ice-packed cool boxes (4–10 °C) and transported to the University of Maiduguri Geology Laboratory within 4 hours of collection. To ensure representativeness, wells were pumped for 3–5 minutes before sample collection, following procedures recommended by APHA (2012) and WHO (2017).

#### *Field Measurements*

Physical parameters measurements were performed immediately at the sampling points to minimize alteration:

- pH, electrical conductivity (EC), and total dissolved solids (TDS) were measured using a calibrated portable water quality meter.
- Temperature was also recorded, as it influences microbial survival and solubility of chemical species.

The instruments were calibrated with standard buffer solutions and conductivity standards, following best practices.

#### *Laboratory Analyses*

##### *Microbiological Analysis (Thermotolerant Coliforms – TTC)*

Microbiological quality was assessed using the membrane filtration technique with selective growth medium (Membrane Lauryl Sulphate Broth, MLSB).

##### *Procedure:*

- 100 ml of water was filtered through sterile 0.45 µm membrane filters.
- Filters were placed on MLSB-soaked absorbent pads in sterile Petri dishes. A resuscitation period of 1 hour was allowed to minimize stress on coliforms.
- Plates were incubated at  $44 \pm 0.5$  °C for 18–24 hours.
- Yellow colonies were counted as TTC and expressed in colony-forming units per 100 ml (CFU/100 ml).

##### *Quality control:*

- Duplicate analyses were performed on 10% of samples.
- Field blanks were included to detect contamination during handling.
- Results were compared with WHO guideline of 0 CFU/100 ml for drinking water.

##### *Nitrate Analysis (NO<sub>3</sub><sup>-</sup>)*

Nitrate concentration was measured using spectrophotometry (Smart 3 Colorimeter, La Motte) with a mixed acid reagent followed by a nitrate reducing reagent

##### *Procedure:*

- 10 ml of sample was mixed with reagents and allowed to react.
- Color development was measured spectrophotometrically.
- Absorbance values were converted to concentration (mg/L) using calibration curves.

A subset of samples was re-analyzed in an independent laboratory for cross-validation. Results were compared against WHO's maximum permissible limit of 50 mg/L and Nigeria's NSDWQ limit of 10 mg/L.

#### *Hydrogeological Assessment*

To evaluate the potential for contaminant migration, hydraulic head data were calculated using borehole completion reports and GPS elevation data. Hydraulic heads were obtained by subtracting static water levels from ground elevations.

Spatial interpolation of hydraulic heads was carried out using Surfer 11 and QGIS software, generating a groundwater flow direction map. Flow patterns were interpreted in relation to settlement patterns and sanitation density.

#### *Data Analysis*

- Descriptive statistics (mean, minimum, maximum, standard deviation) were computed for all water quality parameters.
- Correlation analysis was applied to determine relationships between TTC, nitrate, EC, and proximity to latrines.
- Regression analysis was performed to evaluate the influence of distance on contamination levels, quantified by coefficient of determination ( $R^2$ ).
- Spatial mapping was used to visualize hotspots of contamination.

#### *Quality Assurance and Control*

To maintain reliability, strict quality control measures were implemented:

- All bottles, pipettes, and filtration units were sterilized prior to use.
- Duplicate analyses were conducted for 10% of samples.
- Expired reagents were excluded and batch numbers documented.
- Cross-laboratory checks were conducted for nitrate.

- Laboratory staff adhered to aseptic procedures. Such measures ensured that results were precise, reproducible, and comparable with international standards.

### III. Results

#### Physicochemical Parameters

Groundwater samples recorded pH values ranging from 6.3 to 7.2, with a mean of 6.8. All values were within the WHO guideline of 6.5–8.5 and NSDWQ (2015) standards. Similarly, electrical conductivity (EC) ranged between 72 and 840  $\mu\text{S}/\text{cm}$  (mean = 465  $\mu\text{S}/\text{cm}$ ), and total dissolved solids (TDS) varied from 48 to 560 mg/L (mean = 305 mg/L). These values were below the permissible limits of 1500  $\mu\text{S}/\text{cm}$  and 1000 mg/L respectively (WHO, 2017).

The summary of physicochemical parameters is presented in Table 1. Notably, higher EC and TDS values were clustered in central Maiduguri and Jere, suggesting anthropogenic influences.

Table 1. Summary of Physicochemical Parameters in Groundwater Samples

Parameter	Minimum	Maximum	Mean	WHO Limit (2017)	NSDWQ Limit (2015)	% Exceedance
pH	6.3	7.2	6.8	6.5–8.5	6.5–8.5	0%
EC ( $\mu\text{S}/\text{cm}$ )	72	840	465	1500	1500	0%
TDS (mg/L)	48	560	305	1000	1000	0%
$\text{NO}_3^-$ (mg/L)	1.7	57.9	26.5	50	10	30% (WHO)

#### Nitrate Concentrations

Nitrate ( $\text{NO}_3^-$ ) concentrations in the study area is presented in figure 2. It ranges from 1.7 mg/L to 57.9 mg/L, with a mean of 26.5 mg/L. About 30% of the samples exceeded the WHO guideline value of 50 mg/L, with exceedances concentrated in densely populated neighborhoods and in wells located within 10 m of pit latrines.

Spatial patterns indicated that peri-urban fringe areas generally had lower nitrate levels, whereas central Maiduguri and Jere recorded higher concentrations. Figure 3 shows boxplots of nitrate concentrations by separation distance, clearly indicating elevated levels in wells <10 m from sanitation facilities.

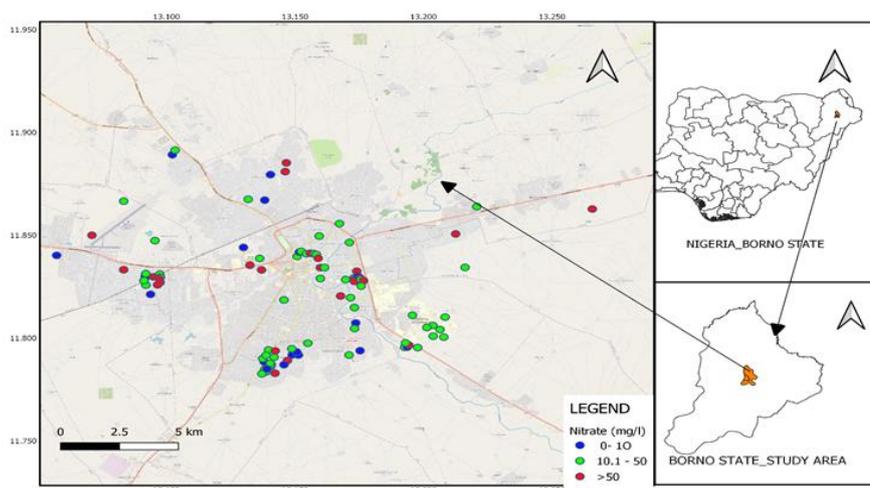


Figure 2. Map of the study area showing  $\text{NO}_3$  concentrations

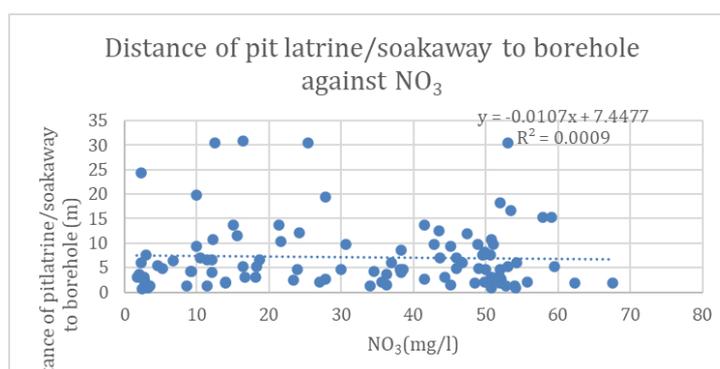


Fig. 3. Boxplots of Nitrate Concentrations by Separation Distance

*Thermotolerant Coliforms (TTC)*

TTC counts was presented in figure 4, it ranges between 0 and 150 CFU/100 ml, with a mean of 46 CFU/100 ml. Out of 100 samples, 40% were contaminated, exceeding the WHO limit of 0 CFU/100 ml. Hand-dug wells exhibited higher levels of contamination compared to boreholes. As shown in Table 2, TTC contamination was present in 55% of hand-dug wells compared with 25% of boreholes.

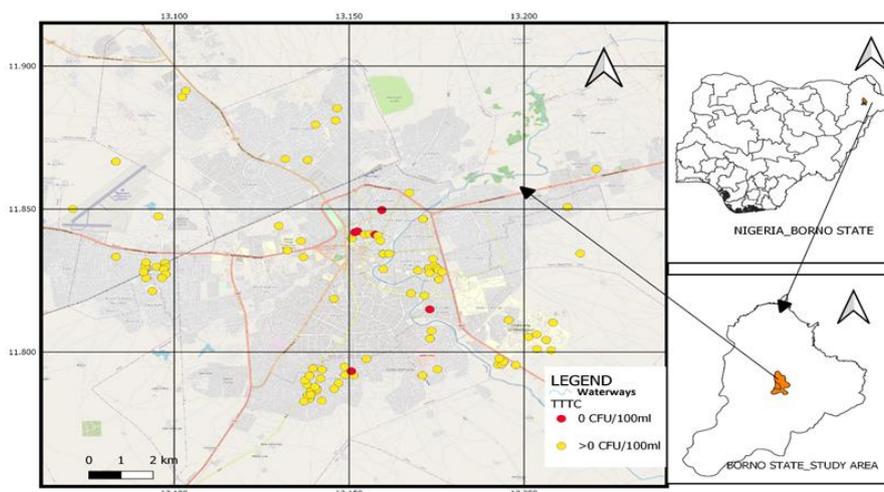


Figure 4 Map of the Study Area showing TTC counts

Table 2. Microbiological Quality of Groundwater

Source Type	No. of Samples	TTC Range (CFU/100 ml)	Mean TTC	% Exceeding WHO Standard (0 CFU/100 ml)
Boreholes (40–60 m)	60	0–50	15	25%
Hand-dug wells (<15 m)	40	0–150	72	55%
Overall	100	0–150	46	40%

*Relationship Between Separation Distance and Contamination*

Regression analysis revealed a strong inverse correlation between separation distance and both nitrate ( $R^2 = 0.61$ ) and TTC ( $R^2 = 0.74$ ). This means that contamination risks decrease significantly as the distance between wells and latrines increases.

As summarized in Table 3, wells <10 m from latrines showed mean nitrate levels of 42.8 mg/L and mean TTC counts of 112 CFU/100 ml, while those >20 m away had much lower values. The scatterplots in Figure 5 illustrate these correlations, highlighting the clustering of contamination at shorter distances.

Table 3. Relationship Between Separation Distance and Groundwater Contamination

Separation Distance (m)	Mean Nitrate (mg/L)	Mean TTC (CFU/100 ml)	% Above WHO Limit (Nitrate)	% Positive TTC Samples
< 10	42.8	112	65%	80%
10–20	28.3	54	25%	40%
> 20	15.1	8	0%	10%

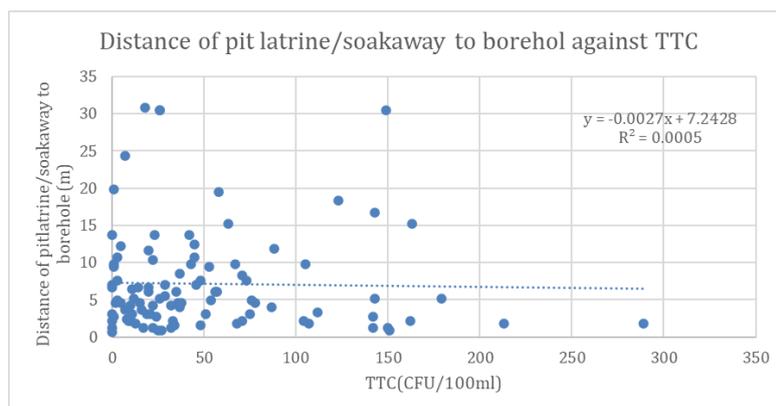


Figure 5. Scatterplots Showing Correlation Between Distance and Contamination (TTC)

*Groundwater Flow Direction and Contaminant Transport*

Figure 6 shows the map of groundwater flow direction. Hydraulic head analysis indicated that groundwater generally flows northeastwards towards the Ngadda River basin. Wells located down-gradient of sanitation facilities consistently recorded higher nitrate and TTC levels. This suggests that hydrogeological conditions play a significant role in contaminant migration.

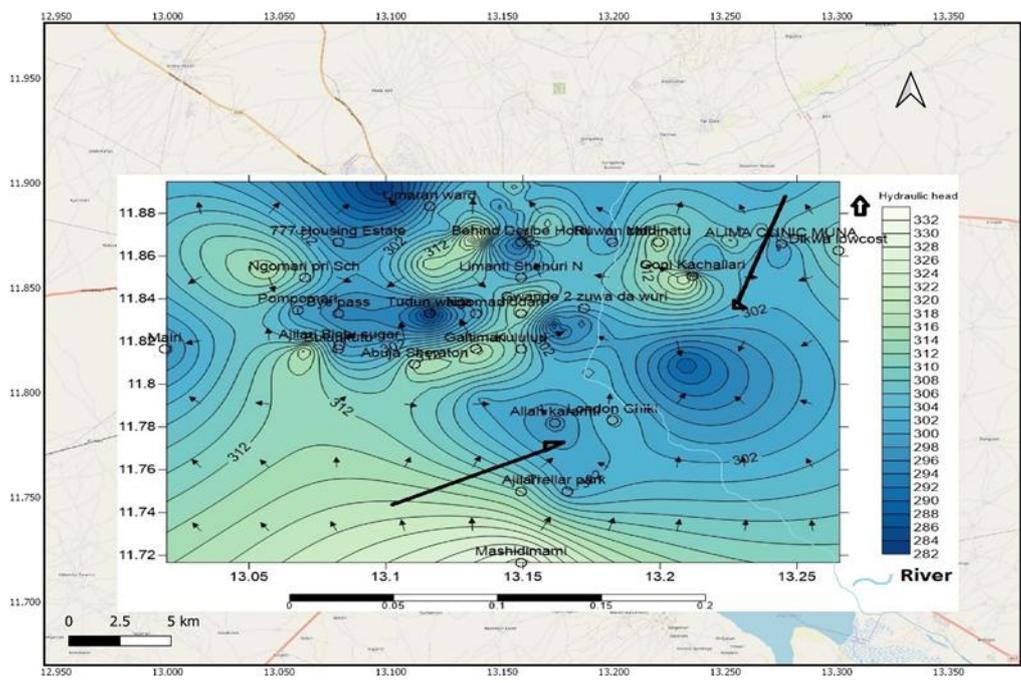


Figure 6. Groundwater flow direction showing some locations within the study area

*Comparative Analysis of Boreholes and Hand-Dug Wells*

The comparison between boreholes and hand-dug wells shows a distinct vulnerability of shallow sources. While boreholes (40–60 m depth) generally had lower TTC counts, they still recorded nitrate exceedances in unconfined aquifer zones. Hand-dug wells (<15 m depth), however, consistently exhibited higher contamination, as illustrated in Table 2 and Figure 4.

**IV. Discussion**

The results of this study demonstrate the considerable vulnerability of groundwater in Maiduguri and Jere to contamination arising from excreta disposal practices. Although physicochemical parameters such as pH, electrical conductivity, and total dissolved solids complied with WHO and NSDWQ standards, the widespread detection of nitrate and thermotolerant coliforms (TTC) provides clear evidence of aquifer pollution. These findings highlight the dual role of hydrogeological conditions and human activities in shaping groundwater quality in semi-arid urban environments.

Elevated nitrate levels were observed in nearly one-third of samples, with concentrations reaching as high as 57.9 mg/L. The clustering of nitrate exceedances in wells situated within 10 m of pit latrines or soakaways confirms that sanitation leachates are a major source of contamination. This aligns with findings from other African and South Asian contexts, where pit latrine density has been strongly correlated with nitrate loading in shallow aquifers (Bloodless et al., 2006; Adejuwon & Adeniyi, 2011; Islam, 2016). From a public health perspective, the implications are significant. Nitrate ingestion has been linked with acute conditions such as methemoglobinemia or “blue baby syndrome” in infants (Comley, 1945; Knobeloch et al., 2000) and chronic health risks including colorectal cancer, thyroid disease, and birth defects (Ward et al., 2018). The presence of nitrate above WHO guideline values in 30% of groundwater sources indicates that a substantial proportion of the population may be exposed to long-term health risks, particularly given the absence of affordable household water treatment options in the area.

Microbial contamination further compounds the problem. TTC was detected in 40% of samples, with higher contamination rates in shallow hand-dug wells (55%) compared to boreholes (25%). This pattern is consistent with observations in other parts of Africa and Asia, where hand-dug wells, due to their shallow depths, poor sanitary protection, and direct connectivity with surface effluents, exhibit higher microbial risks (Odonkor & Ampofo, 2013; Graham & Polizzotto, 2013). While boreholes generally performed better, the detection of TTC

in one-quarter of borehole samples suggests that even semi-confined aquifers are not fully immune. This may reflect both natural pathways, such as sandy sediments and hydraulic connectivity between aquifer layers, and anthropogenic factors, such as inadequate borehole construction, lack of sanitary seals, and poor wellhead protection (Stigter et al., 2011).

The relationship between separation distance and contamination provides further insight into the vulnerability of the aquifer. Regression analysis revealed strong negative correlations between well–latrine distance and both nitrate ( $R^2 = 0.61$ ) and TTC ( $R^2 = 0.74$ ). Although contamination levels decreased with increasing distance, significant pollution was still detected in wells located beyond 20 m from sanitation facilities. This finding is critical because it challenges the adequacy of fixed siting guidelines that recommend minimum distances (often 30 m) between wells and pit latrines. Similar findings have been reported in Bangladesh, Zimbabwe, and Nigeria, where contaminants have been detected well beyond 30 m in sandy or fractured aquifers (Lawrence et al., 2001; Islam, 2016; Goni et al., 2019). Such results underscore the need for context-specific siting guidelines that incorporate hydrogeological factors such as soil permeability, aquifer confinement, and groundwater flow direction, rather than relying on generic global standards.

Groundwater flow analysis adds further complexity to contamination dynamics. The study revealed that groundwater generally flows northeastward toward the Ngadda River basin, and wells located down-gradient of sanitation facilities consistently recorded higher nitrate and TTC concentrations. This suggests that lateral transport of contaminants through groundwater flow is an important pathway of pollution, in addition to vertical infiltration. Comparable studies in semi-arid regions of East Africa and South Asia have shown similar patterns, where contaminant plumes migrate along groundwater flow paths and affect wells located at considerable distances from sanitation facilities (Graham & Polizzotto, 2013; Stigter et al., 2011). The implication is that contamination risks cannot be assessed solely based on vertical infiltration models but must also consider aquifer flow dynamics and settlement patterns.

The comparative analysis of boreholes and hand-dug wells illustrates the differential vulnerability of aquifer units. While deeper boreholes tapping the semi-confined middle aquifer showed lower TTC counts, nitrate exceedances were still observed in some cases. This indicates that chemical pollutants, being more mobile than microbial pathogens, can migrate vertically and laterally through sandy horizons of the Chad Formation. Shallow hand-dug wells, which exploit the unconfined upper aquifer, were more severely impacted, confirming their unsuitability as a safe water source in densely populated settlements. These findings are consistent with reports from Ghana, Kenya, and Niger, where reliance on hand-dug wells has been linked to high incidence of waterborne diseases (Odonkor & Ampofo, 2013; Abdurrahman et al., 2021).

Taken together, the evidence points to a highly vulnerable hydro-social system in Maiduguri and Jere, where the interaction of rapid urbanization, inadequate sanitation planning, and fragile hydrogeology has created a context of chronic groundwater pollution. The co-occurrence of nitrate and microbial contamination represents a dual burden, exposing communities to both acute diarrheal diseases and long-term health outcomes. These risks are magnified by the limited availability of public water supply and the widespread reliance on untreated groundwater sources.

From a policy perspective, the findings underscore the urgency of integrating water supply and sanitation planning. Interventions should include stricter enforcement of siting regulations, the development of vulnerability maps to guide safe distances, and promotion of improved sanitation technologies such as lined pits and ventilated improved pit (VIP) latrines. In high-density areas such as the Jere floodplain, ecological sanitation systems (e.g., composting toilets, urine-diversion toilets) may be necessary to reduce groundwater loading. Equally important is the establishment of regular groundwater monitoring programs, incorporating both chemical and microbiological indicators, to enable early detection and mitigation of contamination.

The broader implication of this study extends beyond Maiduguri and Jere, reflecting a pattern common in semi-arid cities of Sub-Saharan Africa and South Asia, where groundwater serves as the primary water source but remains highly vulnerable to sanitation-related contamination. As highlighted by Graham & Polizzotto (2013) and Ward et al. (2018), the sustainability of groundwater for urban water supply in such contexts depends on balancing aquifer vulnerability with safe sanitation practices. Without urgent action, the dual pressures of population growth and climate variability will continue to exacerbate contamination risks, undermining both public health and water security in the region.

## V. Conclusion

This study assessed the physicochemical and microbiological quality of groundwater in Maiduguri and Jere, northeastern Nigeria, with particular emphasis on the influence of proximity between wells and sanitation facilities. The results demonstrated that while basic physicochemical parameters such as pH, EC, and TDS remained within international standards, significant contamination was observed with respect to nitrate and thermotolerant coliforms (TTC). Approximately 30% of samples exceeded the WHO guideline for nitrate, while 40% were microbiologically unsafe, especially among shallow hand-dug wells. Statistical and spatial analyses

revealed strong inverse correlations between separation distance and contamination, but also highlighted those hydrogeological conditions, such as sandy sediments, shallow water tables, and groundwater flow paths—contribute to the persistence of pollution even beyond recommended distances.

The findings underscore the vulnerability of the Chad Formation's shallow aquifers, which are the primary source of drinking water in the area, to pollution from pit latrines and other sanitation practices. The risks are not only hydrogeological but also public health-related, with implications for both acute (e.g., diarrheal diseases, methemoglobinemia) and chronic conditions (e.g., cancer risks from prolonged nitrate exposure). Thus, groundwater in Maiduguri and Jere is under increasing pressure from the intersection of rapid urbanization, inadequate sanitation planning, and overdependence on unprotected shallow aquifers.

## VI. Recommendations

In light of these findings, several measures are recommended to improve groundwater safety and ensure sustainable water supply in Maiduguri and Jere:

- **Strengthening Sanitation Siting Guidelines:** Enforcement of minimum latrine–well separation distances should be prioritized, but with hydrogeology-specific adjustments rather than applying blanket WHO recommendations. Vulnerability mapping should guide local standards.
- **Improved Construction Standards:** Boreholes should be properly cased and grouted with sanitary seals to prevent vertical infiltration, while hand-dug wells should be lined and protected. Adoption of improved latrine designs such as lined pits and ventilated improved pit (VIP) latrines can reduce leachate leakage.
- **Groundwater Monitoring and Surveillance:** Establishing a routine groundwater quality monitoring program for nitrate and microbial indicators is essential. Community-based water testing schemes, in partnership with local authorities, would help detect contamination early.
- **Promotion of Water Safety Plans (WSPs):** Integrating WSPs into community water supply systems can ensure continuous risk assessments and preventive management. This should include hygiene promotion and community education on the risks of poor siting of sanitation facilities.
- **Alternative Sanitation Technologies:** For high-density areas such as Jere Bowl, where groundwater vulnerability is highest, ecological sanitation systems (e.g., composting toilets and urine-diversion toilets) should be promoted to reduce groundwater loading.
- **Policy and Institutional Support:** Local and state governments should develop urban WASH master plans that integrate water supply and sanitation, while donor agencies and NGOs can support interventions in vulnerable communities. Policies must also encourage affordable household water treatment options, such as chlorination and filtration, to safeguard drinking water quality.
- **Future Research Needs:** More detailed hydrogeological studies, including tracer tests and geophysical surveys, are needed to refine understanding of contaminant transport pathways. Long-term epidemiological studies would also help to quantify the health impacts of nitrate and microbial exposure in the region.

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