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Groundwater Development for Potable Water Supply in Sokoto State, Nigeria: Hydrogeological Potential, Water Quality Assessment, and Sustainability Challenges

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Abstract
Groundwater constitutes the primary source of domestic water supply in semi-arid northern Nigeria, yet its suitability for potable use remains insufficiently documented in many rapidly growing urban centres. This study assessed groundwater development for potable water supply in selected neighbourhoods of Sokoto metropolis, Nigeria, including Dambua Area, Arkilla, Gidan Dare, Mana, Runjin Sambo, and Tudun Wada. The study adopted a field-based hydrogeological and water quality assessment design in which groundwater potential was investigated using Vertical Electrical Sounding and borehole data analysis, while water quality was evaluated through physicochemical and microbiological laboratory testing of groundwater samples. Water Quality Index (WQI), statistical analysis, and GIS mapping were applied to determine spatial suitability for drinking purposes. The findings revealed that aquifer systems within the Gwandu Formation show moderate productivity, with borehole yields ranging from 1.2–3.8 L/s and aquifer depths of 18–52 m, indicating adequate groundwater availability for domestic supply. Groundwater quality analysis indicated neutral to slightly alkaline pH but elevated electrical conductivity and total dissolved solids in some locations, reflecting increased mineralisation, while groundwater hardness was widespread with calcium and magnesium concentrations exceeding recommended limits in several samples. Fluoride concentrations exceeded WHO guidelines in parts of Tudun Wada and Dambua, indicating potential long-term public health risks, and iron concentrations surpassed permissible limits in some locations, affecting aesthetic water quality. Microbial contamination, including total coliform and *E. coli*, was detected in shallow groundwater

sources, particularly in Gidan Dare and Mana. Water Quality Index results further revealed that only about one-third of groundwater sources are suitable for direct consumption, while the majority require treatment before use. In addition, increasing borehole drilling, poor sanitation practices, and the absence of groundwater monitoring were identified as major sustainability concerns. The study concludes that although groundwater resources in Sokoto metropolis are adequate to support potable water supply, water quality challenges and sustainability risks require urgent management interventions, and it recommends strengthening groundwater monitoring, regulation, treatment, and protection strategies to ensure safe and sustainable drinking water supply in semi-arid urban environments.

Keywords: Groundwater development; potable water; hydrogeology; water quality; Sokoto; Nigeria.

Introduction

Access to safe drinking water remains a major development challenge across Sub-Saharan Africa, particularly in semi-arid regions where climate variability, population growth, and weak water infrastructure intensify water scarcity. Groundwater plays a critical role in buffering water supply shocks because of its natural storage capacity and resilience to seasonal drought. Across Sub-Saharan Africa, groundwater supports domestic water supply and livelihoods, with more than 40% of the population relying on it as a primary drinking water source (MacDonald et al., 2021; UNESCO, 2024).

In Nigeria, groundwater has become the backbone of potable water supply. National estimates indicate that approximately 60% of Nigerians depend on groundwater sources for drinking water, rising to over 70% in rural areas where piped infrastructure remains limited (Adelana & MacDonald, 2020; World Bank, 2023). This dependence is particularly pronounced in northern Nigeria, where rainfall is low, evapotranspiration is high, and surface water availability is highly seasonal (Odeyemi et al., 2022). Groundwater recharge in northern Nigeria is generally limited and highly variable due to reduced precipitation and high evaporation rates, reinforcing the strategic importance of groundwater resources in the Sudano-Sahelian belt (MacDonald et al., 2021).

Sokoto State, located in north-western Nigeria, lies within the semi-arid Sudan savannah and depends heavily on groundwater for domestic and municipal water supply. The state is underlain by the Sokoto sedimentary basin, where aquifer systems occur within formations such as the Gwandu, Taloka, and Wurno units. Hydrogeological investigations have shown that groundwater levels and borehole productivity vary widely across the basin, with static water levels ranging from a few metres to over 70 m and borehole yields ranging from 6 to 400 L/min, indicating substantial but spatially heterogeneous groundwater potential (Odeyemi et al., 2022;

Tijani et al., 2021). These findings highlight the importance of site-specific hydrogeological assessment for effective groundwater development.

Despite this potential, groundwater development in Sokoto State faces significant challenges related to water quality and sustainability. Hydrogeochemical studies in the Sokoto Basin indicate widespread groundwater hardness and elevated concentrations of dissolved minerals, particularly calcium, magnesium, and bicarbonate, resulting from intense water–rock interaction in sedimentary aquifers (Abubakar et al., 2023; Tijani et al., 2021). Several groundwater samples have been found to exceed national and World Health Organization (WHO) drinking water limits for certain parameters, raising concerns about long-term public health risks (Abubakar et al., 2023).

More broadly, groundwater quality challenges are well documented across northern Nigeria. Fluoride contamination represents a major public health concern, with national surveys indicating that about 30% of groundwater sources exceed the WHO fluoride guideline value, contributing to fluorosis in affected communities (Edmunds & Smedley, 2019; UNESCO, 2024; Gbadebo et al., 2022). In addition to geogenic contaminants, shallow aquifers are increasingly vulnerable to anthropogenic pollution from agriculture, sanitation systems, and domestic waste disposal (Adelana & MacDonald, 2020; World Bank, 2023). These risks underscore the need for integrated groundwater quality monitoring and protection strategies.

The sustainability of groundwater resources in semi-arid environments is also under increasing pressure. Climate variability, rapid population growth, urban expansion, and uncontrolled borehole drilling are driving increased abstraction rates, while recharge remains limited and uncertain (MacDonald et al., 2021; UNESCO, 2024). Although the Sokoto Basin contains aquifers capable of supporting water supply programmes, previous studies emphasize the need for broader and more integrated assessments that combine hydrogeological characteristics with long-term groundwater management considerations (Odeyemi et al., 2022).

Despite the growing reliance on groundwater in Sokoto State, comprehensive studies integrating aquifer potential, potable water suitability, and sustainability remain limited. Many existing investigations focus either on hydrogeological analysis or water quality assessment in isolation, leaving a gap in the integrated evidence required for policy and planning. Addressing this gap is essential for achieving sustainable access to safe drinking water in line with Sustainable Development Goal 6.

This study therefore evaluates groundwater development for potable water supply in Sokoto State by integrating hydrogeological investigation with physicochemical and microbiological water quality assessment. By assessing aquifer productivity, determining groundwater suitability for drinking based on national and international standards, and identifying key sustainability challenges, the study provides evidence-based recommendations for improving groundwater-based water supply systems in semi-arid northern Nigeria.

Hydrogeological Framework of Groundwater Development

Groundwater development depends fundamentally on the geological and hydrogeological characteristics of aquifer systems. Aquifers are broadly classified into confined, unconfined,

and fractured systems, each with different recharge mechanisms, storage capacities, and vulnerability to contamination (Fetter, 2018). In semi-arid environments, groundwater recharge is typically episodic and strongly controlled by rainfall intensity, soil permeability, and surface infiltration processes (MacDonald et al., 2021).

Northern Nigeria lies within the Sudano-Sahelian belt, where groundwater recharge occurs mainly through seasonal rainfall infiltration and river channel losses (Adelana & MacDonald, 2020). The Sokoto Basin represents one of Nigeria's major sedimentary basins, characterized by porous and permeable sand formations capable of storing significant groundwater reserves (Odeyemi et al., 2022). Aquifers in the basin are primarily associated with the Gwandu, Taloka, and Wurno formations, which contain sandstones, siltstones, and clay layers that influence groundwater occurrence and movement (Tijani et al., 2021). Borehole productivity within these formations varies significantly due to heterogeneity in lithology and aquifer thickness, highlighting the need for detailed hydrogeophysical investigations before groundwater development (Odeyemi et al., 2022).

Groundwater Dependence in Northern Nigeria

Groundwater has become the dominant source of potable water across northern Nigeria due to limited surface water availability and rapid population growth. Rural water supply programmes have increasingly relied on boreholes and hand-dug wells to meet domestic demand (World Bank, 2023). In many communities, groundwater provides the only reliable year-round water supply (Adelana & MacDonald, 2020). Urbanisation in cities such as Sokoto has intensified groundwater abstraction, with private boreholes now serving households, institutions, and small industries (Odeyemi et al., 2022). However, the rapid expansion of borehole drilling has often occurred without adequate hydrogeological planning or regulatory oversight, leading to borehole failure and unsustainable abstraction in some areas (UNESCO, 2024).

Groundwater Quality and Potability Standards

The suitability of groundwater for drinking depends on its physicochemical and microbiological characteristics. The World Health Organization (WHO) and the Nigerian Standard for Drinking Water Quality provide guideline values for acceptable drinking water parameters (WHO, 2022; SON, 2015). Key indicators of potable water quality include pH, total dissolved solids (TDS), hardness, major ions, heavy metals, and microbial contamination (WHO, 2022). Water Quality Index (WQI) methods are widely used to evaluate overall groundwater suitability for drinking by integrating multiple water quality parameters into a single composite indicator (Tyagi et al., 2020). This approach has become common in groundwater assessment studies across developing countries due to its ability to simplify complex hydrochemical data (Abubakar et al., 2023).

Groundwater Contamination in Semi-Arid Environments

Groundwater contamination in semi-arid regions arises from both geogenic and anthropogenic sources. Geogenic contaminants result from natural water–rock interactions and commonly

include fluoride, iron, manganese, and salinity (Edmunds & Smedley, 2019). In northern Nigeria, elevated fluoride levels have been widely reported and linked to geological formations containing fluoride-bearing minerals (Gbadebo et al., 2022). Long-term exposure to fluoride-rich drinking water has been associated with dental and skeletal fluorosis in affected communities (Edmunds & Smedley, 2019). Anthropogenic contamination is increasingly significant due to rapid population growth, poor sanitation, and agricultural activities. Shallow aquifers are particularly vulnerable to contamination from pit latrines, septic systems, fertilizers, and waste disposal sites (Adelana & MacDonald, 2020). Microbial contamination of groundwater has been reported in many Nigerian communities, posing serious public health risks (World Bank, 2023).

Sustainable Groundwater Management

Sustainable groundwater development requires balancing abstraction with recharge while protecting aquifers from contamination. Integrated Water Resources Management (IWRM) promotes coordinated development and management of water resources to maximize social and economic benefits without compromising environmental sustainability (UNESCO, 2024). Managed Aquifer Recharge (MAR), groundwater monitoring networks, borehole regulation, and water demand management are widely recommended strategies for sustainable groundwater use in semi-arid regions (MacDonald et al., 2021). Achieving Sustainable Development Goal 6—ensuring universal access to safe drinking water—requires strengthening groundwater governance and improving data availability in developing countries (UNESCO, 2024).

Conceptual Framework

This study is anchored on the Integrated Water Resources Management framework, which emphasizes the integration of hydrogeological assessment, water quality monitoring, and sustainability planning in groundwater development (UNESCO, 2024). The framework links aquifer productivity, water quality, and resource sustainability to potable water supply outcomes in semi-arid environments.

Research Design

This study adopted a field-based hydrogeological and water quality assessment approach to evaluate groundwater development for potable water supply in selected communities of Sokoto metropolis. The research design integrated hydrogeophysical investigation, borehole productivity analysis, physicochemical water quality assessment, and microbiological analysis to determine the suitability of groundwater for drinking purposes. The approach combined field data collection and laboratory analysis, which is widely used in groundwater resource assessment studies (Fetter, 2018; Adelana & MacDonald, 2020).

Sampling Strategy and Selection of Study Locations

Six communities within Sokoto metropolis were purposively selected for the study: Dambua Area, Arkilla, Gidan Dare, Mana, Runjin Sambo, and Tudun Wada. These communities were

selected because: They are densely populated residential areas; groundwater is the primary source of domestic water supply; boreholes and hand-dug wells are widely used; they represent different hydrogeological conditions within Sokoto metropolis, and groundwater samples were collected from boreholes and hand-dug wells across the selected communities.

Hydrogeophysical Investigation

Hydrogeophysical investigation was conducted using the Vertical Electrical Sounding (VES) technique with the Schlumberger electrode configuration. This method was employed to determine subsurface resistivity variations and identify potential aquifer zones suitable for groundwater development. The VES technique is widely used in groundwater exploration because resistivity differences between geological formations help identify water-bearing layers (Adelana & MacDonald, 2020). Data obtained from the resistivity survey were interpreted using standard curve-matching procedures to estimate: Aquifer depth; aquifer thickness and subsurface geological formations

Borehole Data Collection

Existing boreholes within the study communities were assessed to determine aquifer productivity. Borehole data collected included: Borehole depth; static water level; pumping rate, and drawdown measurements Pumping test data were analysed to estimate aquifer parameters such as transmissivity and storativity, which provide information on groundwater movement and storage capacity (Fetter, 2018).

Groundwater Sampling Procedure

Groundwater samples were collected from selected boreholes and wells using standard sampling techniques. Sampling was conducted during the dry season, when groundwater quality conditions are generally more stable and representative of long-term aquifer characteristics. Sterilised polyethylene bottles were used for water sample collection. Before sampling, the containers were rinsed with the groundwater being sampled to avoid contamination. Samples were properly labelled and transported to the laboratory for analysis.

Laboratory Analysis

Laboratory analysis of groundwater samples was conducted using the Standard Methods for the Examination of Water and Wastewater (APHA, 2017).

Physicochemical Parameters

The following parameters were analysed:

a) pH
b) Electrical Conductivity (EC)
c) Total Dissolved Solids (TDS)
d) Total Hardness

e) Calcium
f) Magnesium
g) Chloride

These parameters help determine the chemical composition and mineralisation level of groundwater.

Trace Metals
Selected trace metals analysed include:

a) Iron (Fe)
b) Fluoride (F^-)
c) Lead (Pb)

These elements are important indicators of groundwater safety for drinking purposes.

Microbiological Analysis
Microbiological quality was evaluated by testing for:

a) Total coliform bacteria
b) *Escherichia coli* (E. coli)

These organisms are widely used as indicators of faecal contamination in drinking water (WHO, 2022).

Water Quality Assessment
The suitability of groundwater for drinking was evaluated using World Health Organization (WHO) drinking water standards and the Nigerian Standard for Drinking Water Quality (WHO, 2022; SON, 2015). Additionally, the Water Quality Index (WQI) method was used to integrate multiple water quality parameters into a single index value representing overall water suitability for drinking (Tyagi et al., 2020).
Water quality was classified as:

a) Excellent
b) Good
c) Poor
d) Unsuitable

Data Analysis
Data collected from field measurements and laboratory analysis were analysed using:

a) Descriptive statistical analysis to summarise water quality parameters.
b) Water Quality Index (WQI) to evaluate overall groundwater suitability.
c) Comparative analysis with WHO standards to determine compliance with potable water guidelines.

The analysis enabled the identification of groundwater contamination patterns and spatial differences in water quality across the study communities.

Table 1: Selected Study Locations

Community	Local Government Area
Dambua Area	Sokoto North LGA
Arkilla	Sokoto South LGA
Gidan Dare	Sokoto North LGA
Mana	Sokoto North LGA
Runjin Sambo	Sokoto South LGA
Tudun Wada	Sokoto South LGA

Source: Author's fieldwork and compilation (2025)

These neighbourhoods were purposively selected because they represent densely populated residential zones within Sokoto metropolis where boreholes and hand-dug wells constitute the primary sources of potable water. The study area lies approximately between latitude 13°03′–13°08′N and longitude 5°12′–5°16′E, within the central part of the Sokoto Basin. The area is underlain predominantly by the Gwandu Formation, which consists of sandstone, clay, and silt deposits that form productive shallow aquifers widely exploited for domestic water supply (Odeyemi et al., 2022; Tijani et al., 2021). Groundwater demand in these neighbourhoods has increased significantly due to rapid urbanisation, population growth, and limited access to municipal piped water systems, leading to widespread reliance on privately constructed boreholes and hand-dug wells (World Bank, 2023).

RESULTS

This section presents the hydrogeological characteristics, groundwater quality results, Water Quality Index (WQI) classification, and spatial patterns of groundwater suitability across the six study communities in Sokoto Metropolis.

HYDROGEOLOGICAL CHARACTERISTICS OF THE STUDY AREA

a. Aquifer Depth and Borehole Characteristics

Geophysical surveys and borehole records across Dambua Area, Arkilla, Gidan Dare, Mana, Runjin Sambo, and Tudun Wada revealed relatively shallow to moderately deep aquifer systems consistent with the Gwandu Formation.

Key observations include:

(a) Depth to aquifer: 18–52 m
(b) Static water level: 6–18 m
(c) Borehole depth: 25–65 m
(d) Aquifer thickness: 10–28 m

The results confirm the presence of productive shallow sandstone aquifers suitable for groundwater abstraction within Sokoto metropolis.

b. Borehole Yield and Aquifer Productivity

Pumping test analysis indicates moderate aquifer productivity across the study locations.

Table 2: Borehole Yield and Aquifer Productivity

Parameter	Range
Borehole yield	1.2 – 3.8 L/s
Transmissivity	$1.5 \times 10^{-3} – 6.2 \times 10^{-3}$ m²/s
Storativity	$2.1 \times 10^{-4} – 8.5 \times 10^{-4}$

Source: Author's fieldwork and compilation (2025)

Highest yields were recorded in Arkilla and Runjin Sambo, while relatively lower yields occurred in Mana and Gidan Dare, reflecting lithological variability within the aquifer. These results confirm that the aquifer system can sustain domestic groundwater supply when properly managed.

PHYSICOCHEMICAL GROUNDWATER QUALITY

Laboratory analysis of groundwater samples revealed noticeable spatial variation in water quality parameters across the six communities.

Table 3: 4.2.1 pH, EC and TDS

Parameter	Range	WHO Limit
pH	6.6 – 7.9	6.5–8.5
Electrical Conductivity	420 – 1320 µS/cm	1000 µS/cm
Total Dissolved Solids	210 – 690 mg/L	500 mg/L

Source: Author's fieldwork and compilation (2025)

Most samples fall within acceptable pH range. Elevated EC and TDS values were observed in Tudun Wada and Dambua, indicating higher mineralisation.

Table 4: Major Ions and Hardness

Parameter	Range	WHO Limit
Total Hardness	120 – 360 mg/L	200 mg/L
Calcium	40 – 110 mg/L	75 mg/L
Magnesium	25 – 85 mg/L	50 mg/L
Chloride	45 – 210 mg/L	250 mg/L

Source: Author's fieldwork and compilation (2025)

Groundwater is predominantly moderately hard to very hard. Elevated hardness was most prominent in Arkilla and Tudun Wada, indicating strong water–rock interaction.

Table 5: Trace Metals

Parameter	Range	WHO Limit
Iron	0.05 – 0.58 mg/L	0.3 mg/L
Fluoride	0.4 – 1.7 mg/L	1.5 mg/L
Lead	<0.01 – 0.02 mg/L	0.01 mg/L

Source: Author's fieldwork and compilation (2025)

Iron exceeded limits in Mana and Runjin Sambo. Fluoride exceeded limits in Tudun Wada and Dambua. Lead exceeded WHO limit in isolated samples from Arkilla.

MICROBIOLOGICAL WATER QUALITY: Microbial analysis revealed contamination in shallow wells.

Table 6: Microbiological Water Quality

Parameter	Range	WHO Standard
Total coliform	0 – 35 CFU/100 mL	0
E. coli	0 – 9 CFU/100 mL	0

Source: Author's fieldwork and compilation (2025)

Microbial contamination was highest in Gidan Dare and Mana, suggesting influence from sanitation practices and shallow groundwater vulnerability.

Water Quality Index (WQI): WQI values ranged from **42 to 168** across the study area.

Table 7: Water Quality Index

Location	WQI	Water Quality
Arkilla	68	Good
Runjin Sambo	72	Good
Dambua	112	Poor
Tudun Wada	138	Poor
Mana	158	Poor
Gidan Dare	168	Poor

Source: Author's fieldwork and compilation (2025)

Overall:

(a) 33% of samples were suitable for drinking without treatment
(b) 67% require treatment before consumption

Spatial Pattern of Groundwater Suitability

Clear spatial trends emerged:

Relatively Safer Zones

(a) Arkilla
(b) Runjin Sambo

High-Risk Zones

(a) Tudun Wada
(b) Mana
(c) Gidan Dare
(d) Dambua Area

Major drivers:

(a) High mineralisation
(b) Fluoride enrichment
(c) Microbial contamination

DISCUSSION

1. **Groundwater Potential for Urban Water Supply**: The hydrogeological results confirm that the Gwandu Formation beneath Sokoto metropolis contains productive shallow sandstone aquifers capable of supporting domestic water supply. Borehole yields ranging from 1.2–3.8 L/s fall within the typical range for sedimentary aquifers in northern Nigeria and are sufficient for household and community water supply systems. The relatively shallow depth to groundwater (6–18 m static water level) indicates favourable drilling conditions and relatively low pumping costs, which explains the widespread proliferation of private boreholes in the study communities. Similar findings have been reported across the Sokoto Basin, where groundwater represents the most reliable and economically viable water source in the absence of functional municipal water infrastructure. However, spatial variability in borehole yield observed across the study area reflects lithological heterogeneity within the aquifer system. Higher productivity in Arkilla and Runjin Sambo suggests thicker and more permeable sandstone layers, while lower yields in Mana and Gidan Dare may indicate increased clay intercalations that reduce permeability. These variations highlight the importance of hydrogeophysical investigations prior to borehole drilling to reduce failure rates and improve groundwater development success.
2. **Suitability of Groundwater for Potable Use:** Although groundwater quantity appears adequate, water quality results indicate that a significant proportion of groundwater sources require treatment before drinking. Elevated electrical conductivity and total dissolved solids observed in Tudun Wada and Dambua suggest increased mineralisation resulting from prolonged water–rock interaction, a common characteristic of groundwater in semi-arid sedimentary basins. The dominance of hardness across most samples reflects high concentrations of calcium and magnesium

derived from carbonate and sandstone formations. While hard water is not typically a direct health risk, long-term consumption may contribute to scaling, taste problems, and household infrastructure damage. Similar hydrochemical characteristics have been reported across northern Nigeria (Adelana & MacDonald, 2020). Fluoride concentrations exceeding WHO limits in Tudun Wada and Dambua are particularly significant. Elevated fluoride in groundwater has been widely documented across the Sudano-Sahelian belt and is associated with fluoride-bearing minerals in sedimentary and crystalline rocks. Chronic exposure to high fluoride levels may lead to dental and skeletal fluorosis, posing long-term public health risks.

3. **Microbial Contamination and Public Health Risks:** Microbiological analysis revealed the presence of coliform bacteria and *E. coli* in several shallow groundwater sources, particularly in Gidan Dare and Mana. The occurrence of faecal indicator bacteria indicates contamination from human or animal waste and suggests vulnerability of shallow aquifers to surface pollution. This contamination is likely linked to the widespread use of pit latrines and septic systems in densely populated urban neighbourhoods. Inadequate sanitation infrastructure has been identified as a major driver of groundwater contamination across developing countries (World Bank, 2023). The findings highlight the need for groundwater protection zones and improved sanitation planning in Sokoto metropolis.
4. **Major Drivers of Groundwater Deterioration:** The study identifies three major drivers of groundwater quality deterioration in the study area:
    1. Geogenic processes: Water–rock interaction leading to high hardness, mineralization, and fluoride enrichment.
    2. Anthropogenic activities: Poor sanitation, waste disposal, and urban expansion contributing to microbial contamination.
    3. Unregulated borehole development: Lack of groundwater monitoring and protection measures.

    These drivers align with broader groundwater challenges documented across Sub-Saharan Africa (UNESCO, 2024; MacDonald et al., 2021).
5. **Sustainability of Groundwater Resources:** The long-term sustainability of groundwater in Sokoto metropolis is increasingly uncertain. Rapid population growth, urbanisation, and rising borehole drilling are increasing abstraction rates, while recharge remains limited due to low rainfall and high evapotranspiration. Without effective groundwater governance, continued abstraction may lead to declining water levels, reduced borehole yields, and increased water quality deterioration. Sustainable groundwater management strategies are therefore essential to ensure long-term potable water supply.

The findings of this study are consistent with previous research in the Sokoto Basin and northern Nigeria, which report moderate aquifer productivity, elevated groundwater hardness,

fluoride contamination, and vulnerability to microbial pollution (Odeyemi et al., 2022; Abubakar et al., 2023; Gbadebo et al., 2022; Edmunds & Smedley, 2019; Gbadebo et al., 2022; WHO, 2022; Abubakar et al., 2023; World Bank, 2023). The study contributes to existing knowledge by integrating hydrogeological, physicochemical, and microbiological assessments within a single urban groundwater supply context.

Policy and Groundwater Management Implications

The findings of this study have significant implications for urban water supply planning, groundwater governance, and public health protection in Sokoto metropolis. Although groundwater remains the most reliable source of potable water in the study area, the results demonstrate that both quality deterioration and sustainability risks require urgent policy attention. Effective groundwater management is essential for achieving safe and sustainable water supply in line with Sustainable Development Goal 6

1 Need for Groundwater Monitoring and Regulation

The widespread reliance on privately constructed boreholes in the study communities highlights the absence of a comprehensive groundwater monitoring and regulatory framework. Uncontrolled drilling increases the risk of aquifer over-exploitation, borehole failure, and declining groundwater levels. Similar concerns have been reported across Nigeria, where groundwater abstraction often occurs without licensing, mapping, or monitoring (World Bank, 2023). Establishing a state-wide groundwater monitoring network would allow authorities to track:

a. Groundwater levels and recharge trends
b. Borehole density and abstraction rates
c. Spatial variation in groundwater quality

Such monitoring systems are widely recommended for sustainable groundwater governance in semi-arid regions (MacDonald et al., 2021).

2 Borehole Siting and Construction Guidelines

The observed spatial variability in aquifer productivity and water quality underscores the need for mandatory hydrogeophysical investigations prior to borehole drilling. In many Nigerian cities, boreholes are drilled without professional assessment, leading to poor yields and contamination risks (Adelana & MacDonald, 2020). Policy measures should therefore require:

a. Hydrogeophysical surveys before drilling
b. Licensing of groundwater drilling contractors
c. Registration and mapping of boreholes

These measures would reduce borehole failure rates and improve long-term groundwater sustainability.

3 Water Treatment and Household Safety

The study shows that approximately two-thirds of groundwater sources in the study area require treatment before consumption. Fluoride exceedance, iron contamination, hardness, and microbial pollution pose significant public health risks. Policy interventions should promote:

a. Household water treatment technologies (filtration, chlorination)
b. Community-scale treatment systems
c. Public awareness campaigns on groundwater safety

These approaches are essential in regions where centralized water treatment systems are limited (WHO, 2022).

4 Protection of Groundwater from Sanitation Impacts

Microbial contamination detected in several communities indicates vulnerability of shallow aquifers to sanitation practices. Poorly located pit latrines and septic systems can allow pathogens to infiltrate groundwater, particularly in densely populated urban areas. Groundwater protection policies should include:

a. Minimum safe distances between wells and sanitation facilities
b. Urban sanitation planning integrated with water supply planning
c. Enforcement of environmental health regulations

Protecting aquifer recharge zones is critical for long-term water quality preservation.

5 Sustainable Groundwater Development Strategy

Sustainable groundwater development requires balancing abstraction with recharge while protecting aquifers from contamination. Key strategies recommended for Sokoto include:

a. Development of managed aquifer recharge initiatives
b. Integration of groundwater planning into urban development
c. Strengthening institutional capacity for groundwater governance

Integrated Water Resources Management (IWRM) provides a suitable framework for implementing these strategies.

6 Implications for Urban Water Supply Planning

The results highlight the urgent need to integrate groundwater into formal urban water supply planning in Sokoto metropolis. Groundwater should be treated as a strategic resource requiring:

a. Data-driven planning
b. Long-term sustainability considerations
c. Strong regulatory oversight

Without proactive management, increasing groundwater dependence may lead to long-term water insecurity.

Conclusion

This study evaluated groundwater development for potable water supply in selected communities within Sokoto metropolis, north-western Nigeria, through integrated hydrogeological assessment and physicochemical and microbiological water quality analysis. The findings confirm that groundwater remains the most reliable and accessible source of domestic water supply in the study area, largely due to favourable aquifer conditions within the Gwandu Formation and the limited availability of municipal piped water systems. Hydrogeological results indicate that the aquifer system underlying Dambua Area, Arkilla,

Gidan Dare, Mana, Runjin Sambo, and Tudun Wada possesses moderate productivity capable of sustaining household and community water supply. Borehole yields and transmissivity values demonstrate that the groundwater resource is sufficient for domestic use when properly managed.

However, spatial variability in aquifer productivity highlights the importance of hydrogeophysical investigations prior to borehole drilling to improve success rates and ensure efficient groundwater development. Despite the availability of groundwater resources, water quality analysis revealed significant concerns regarding potable water suitability. Elevated total dissolved solids, hardness, fluoride, iron, and microbial contamination were detected in several locations, indicating that a substantial proportion of groundwater sources require treatment before consumption. The presence of fluoride above recommended limits in some communities raises long-term public health concerns, while microbial contamination in shallow groundwater reflects the influence of sanitation practices and urban environmental conditions. The Water Quality Index results further demonstrate that only a minority of groundwater sources are suitable for direct consumption without treatment. The majority require varying levels of treatment, highlighting the need for improved water safety planning and household water treatment practices in Sokoto metropolis.

The study also identifies increasing groundwater abstraction, poor borehole regulation, and limited monitoring as key sustainability challenges. Continued reliance on unregulated groundwater development may lead to long-term aquifer depletion and further water quality deterioration. These findings underscore the urgent need for integrated groundwater governance, monitoring, and protection strategies. Overall, the study contributes to the growing body of knowledge on groundwater resources in semi-arid regions of Nigeria by providing integrated evidence on aquifer productivity, water quality, and sustainability challenges. The findings provide a scientific basis for improving groundwater management and strengthening potable water supply systems in Sokoto metropolis and similar semi-arid urban environments.

Recommendations

Based on the hydrogeological and water quality findings, the following recommendations are proposed to improve groundwater development and ensure safe potable water supply in Sokoto metropolis.

1 Establish a Groundwater Monitoring Programme

A state-level groundwater monitoring network should be developed to track groundwater levels, abstraction rates, and water quality trends. Regular monitoring will enable early detection of aquifer depletion and contamination risks and support evidence-based water resource planning. Monitoring boreholes should be strategically distributed across urban communities to generate reliable long-term data.

2 Regulate Borehole Drilling and Groundwater Abstraction

The rapid increase in private borehole construction requires formal regulation. Government agencies should introduce borehole licensing and registration systems to control drilling

activities and maintain a comprehensive database of groundwater infrastructure. Mandatory hydrogeophysical surveys should be required before drilling to reduce borehole failure rates and improve aquifer protection.

3 Promote Household and Community Water Treatment

Since a significant proportion of groundwater sources require treatment before consumption, public health authorities should promote affordable water treatment methods such as filtration, chlorination, and defluoridation where necessary. Community-level water treatment facilities should also be considered in areas with persistent groundwater quality challenges.

4 Strengthen Sanitation and Groundwater Protection Measures

To reduce microbial contamination, urban sanitation planning must be integrated with groundwater protection strategies. Policies should enforce minimum safe distances between boreholes and sanitation facilities such as pit latrines and septic tanks. Public awareness campaigns should educate residents on safe waste disposal and groundwater protection practices.

5 Implement Managed Aquifer Recharge and Water Conservation Strategies

Given the semi-arid climate and limited natural recharge, strategies such as rainwater harvesting and managed aquifer recharge should be promoted to enhance groundwater replenishment. Water conservation initiatives should also be encouraged to reduce excessive groundwater abstraction.

6 Integrate Groundwater into Urban Water Supply Planning

Groundwater should be formally incorporated into urban water supply policies and planning frameworks. Long-term water supply strategies for Sokoto metropolis should combine groundwater development, water treatment infrastructure, and sustainable management practices.

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