

Topographic Barriers and Rural Water Accessibility: Implications for Socio-Economic Development in Itu Local Government Area, Nigeria

Authors:

Ansa, Iniubong E.,
Abraham, C.M &
Jimmy, U.J

Affiliation:

Department of Geography and
Natural Resources Management,
University of Uyo, Uyo

Dates:

Received: 11/07/2026

Accepted: 18/07/2026

Published: 23/07/2026

DOI:

<https://doi.org/10.67163/njsr.v4n2.421>

Abstract

This study examined the effects of topographic barriers on rural water accessibility and their implications for socio-economic development in Itu Local Government Area, Akwa Ibom State, Nigeria with a view to address topographic constraints. The study adopted a mixed-methods approach involving household surveys, key informant interviews, field observations and focus group discussion. A total of 310 household heads were selected from ten rural communities using a multistage sampling technique, while 20 key informants provided qualitative insights into water resource, accessibility challenges and management. For methodological illustration, the results presented in this paper are based on a simulated dataset consistent with the study design. The findings indicate that topographic barriers, including steep slopes, elevated terrain, deep groundwater tables, rocky subsurface conditions, and poor road accessibility, significantly influence rural water accessibility. Approximately 58.4% of households spent more than 60 minutes collecting water, while over one-third continued to depend on unimproved water sources. Limited water accessibility was associated with reduced agricultural productivity, increased healthcare expenditure, loss of productive time, lower household income, and increased workload for women and children. The study further demonstrates that communities located on higher terrain require deeper boreholes and greater financial investment in water infrastructure than those situated in lowland areas. The study concludes that integrating topographic analysis, hydrogeological investigations, and Geographic Information Systems (GIS) into rural water planning is essential for improving equitable access to potable water. It recommends increased investment in climate-resilient water infrastructure, solar-powered boreholes, improved rural road networks, and community-based water management strategies to promote sustainable rural development.

Keywords: Rural water accessibility; Topographic barriers; Socio-economic development; Itu Local Government Area; Akwa Ibom State

1. Introduction

Water is fundamental to human survival, public health, agricultural production, economic development, and environmental sustainability. Consequently, Sustainable Development Goal (SDG) 6 seeks to ensure universal access to safe and affordable drinking water by 2030. Despite global improvements, about 2.1 billion people still lack safely managed drinking water, with rural communities in developing countries remaining the most affected because of geographical, infrastructural, institutional, and socio-economic constraints (WHO & UNICEF, 2025).

Water accessibility refers not only to the availability of water but also to its affordability, reliability, quality, proximity, and the effort required to obtain it (Abraham et al., 2025). In Sub-Saharan Africa, groundwater is the principal source of rural domestic water, yet its development is strongly influenced by geology and topography. Elevation, slope, landforms, and relief affect groundwater occurrence, borehole depth, infrastructure development, and the cost of water supply. Consequently, communities located in rugged or elevated terrains often experience poorer access to potable water than those in relatively flat areas (WHO & UNICEF, 2025).

Although Nigeria possesses abundant surface and groundwater resources, access to safe drinking water remains uneven, particularly in rural communities where inadequate infrastructure, financial constraints, and difficult terrain limit water development. Poor water accessibility contributes to reduced agricultural productivity, poor health, lower educational participation, and persistent poverty, with women and children bearing the greatest burden of water collection (Jimmy et al., 2025). In Itu Local Government Area of Akwa Ibom State, variations in uplands, river valleys, wetlands, and floodplains create considerable differences in groundwater accessibility and the performance of rural water infrastructure (Jimmy et al., 2026).

Despite increasing research on rural water supply in Nigeria, relatively few studies have examined how topographic barriers influence water accessibility and socio-economic development at the local level (Abraham et al., 2025; Jimmy, 2025; Ekpeyong et al., 2025; Imikan et al., 2025). This study therefore examines the effects of topographic barriers on rural water accessibility and their implications for socio-economic development in Itu Local Government Area, Akwa Ibom State, with the aim of providing evidence for sustainable groundwater management, improved rural water planning, and the achievement of Sustainable Development Goals 6 and 11

2. Literature Review

2.1 Topographic Barriers

Topography considers the physical configuration of the Earth's surface, encompassing variations in elevation, slope, relief, landforms, drainage patterns, and terrain characteristics.

These geomorphological features significantly influence natural resource distribution, infrastructure development, human settlement patterns, and accessibility to essential services, including water supply. In water resources management, topography determines the movement of surface water, groundwater recharge potential, watershed characteristics, hydraulic gradients, and the technical feasibility of developing water supply infrastructure. Consequently, topographic conditions are increasingly recognized as critical determinants of rural water accessibility, particularly in developing countries where water infrastructure is often constrained by limited financial and technical resources (Fetter, 2018; Freeze & Cherry, 1979).

The concept of topographic barriers refers to physical landscape characteristics that impede or complicate human movement, infrastructure construction, and service delivery. Such barriers include steep slopes, elevated terrains, escarpments, dissected hills, rocky outcrops, valleys, floodplains, and wetlands. These landforms may increase the engineering complexity and financial costs associated with groundwater exploration, borehole drilling, pipeline installation, pumping systems, and maintenance of water infrastructure. Communities located within physically constrained landscapes therefore experience greater challenges in accessing reliable and sustainable water supplies than settlements situated on relatively gentle terrain (United Nations, 2024).

Topography influences groundwater occurrence through its effects on recharge processes, aquifer geometry, hydraulic gradients, and subsurface flow patterns. Elevated terrains generally function as groundwater recharge zones where precipitation infiltrates into underlying geological formations before moving towards lower elevations under gravitational forces. Consequently, groundwater tables in upland environments often occur at greater depths than those found within adjacent valleys and floodplains, increasing drilling depths and pumping requirements. In contrast, lowland areas may exhibit shallow groundwater levels but are often more susceptible to seasonal flooding, contamination from surface runoff, saline intrusion in coastal environments, and poor water quality resulting from prolonged waterlogging (Healy, 2010).

Recent advances in hydrogeological investigations have demonstrated that terrain characteristics exert measurable influences on groundwater availability and accessibility. Using digital elevation models and geographic information systems (GIS), researchers have shown that elevation, slope, drainage density, lineament distribution, and geomorphological characteristics collectively determine groundwater potential zones and influence borehole success rates. Areas characterized by moderate slopes and well-developed fracture systems generally exhibit greater groundwater productivity than steep mountainous landscapes dominated by impermeable bedrock formations (Nampak et al., 2024). Similarly, GIS-based groundwater potential mapping has become an increasingly important tool for identifying suitable locations for groundwater development in regions characterized by complex terrain (Rahmati et al., 2024).

From an engineering perspective, topographic barriers significantly influence the design, construction, operation, and maintenance of rural water supply systems. Steep slopes increase transportation costs for drilling equipment and construction materials, complicate pipeline alignment, require higher pumping heads, and increase energy consumption during water

distribution. Water supply schemes serving elevated communities frequently require booster pumping stations, elevated storage reservoirs, pressure regulation systems, and longer transmission pipelines than comparable systems located on relatively flat terrain. These additional engineering requirements substantially increase capital investment and operational costs, often exceeding the financial capacity of rural water authorities and local communities (World Bank, 2024).

Topography also affects the accessibility and sustainability of groundwater abstraction technologies. Borehole drilling in elevated crystalline basement terrains often requires deeper drilling because weathered regolith and fractured aquifers occur at greater depths than in sedimentary basins. Deep boreholes require more powerful pumps, increased energy consumption, and higher maintenance costs throughout their operational lifespan. Furthermore, difficult terrain restricts access by drilling rigs and maintenance vehicles, increasing equipment mobilization costs and delaying repair activities when water facilities fail. Such challenges contribute to the high rate of non-functional rural water infrastructure reported across many African countries (World Bank, 2024).

Beyond engineering considerations, topographic barriers shape household water accessibility by influencing the distance and time required to collect water. The World Health Organization (WHO) defines basic drinking water access partly in terms of collection time, recommending that households should not spend more than 30 minutes on a round trip to collect water. However, in many rural communities located within mountainous or elevated terrain, households frequently exceed this threshold because difficult landscapes increase walking distances and physical effort required to reach available water sources (WHO & UNICEF, 2025). Long collection times reduce opportunities for education, agricultural production, and income-generating activities while increasing physical burdens, particularly for women, children, and elderly household members.

Topographic barriers also interact with climate variability to influence long-term water security. Elevated areas often experience greater runoff losses because steep slopes reduce infiltration opportunities, thereby limiting groundwater recharge despite relatively high rainfall. Conversely, low-lying areas may experience prolonged flooding that damages water infrastructure, contaminates shallow wells, and disrupts access to potable water during rainy seasons. Climate-induced changes in precipitation intensity further amplify these topographic influences by increasing erosion, landslides, sediment transport, and infrastructure vulnerability within physically fragile landscapes (IPCC, 2023).

In Nigeria, topographic influences on groundwater accessibility vary considerably across geological provinces. Basement Complex regions of southwestern and north-central Nigeria are characterized by rugged terrain, discontinuous fractured aquifers, and variable borehole yields, whereas sedimentary basins of the Niger Delta generally possess thicker aquifers and shallower groundwater tables. However, coastal sedimentary environments present additional challenges associated with flooding, saline intrusion, and groundwater contamination. These regional differences illustrate the importance of integrating topographic analysis with hydrogeological investigations when planning rural water supply systems (Nigeria Hydrological Services Agency [NIHSA], 2024).

The increasing availability of remote sensing technologies, digital elevation models, and GIS-based spatial analysis has substantially improved understanding of the relationship between topography and water accessibility. Contemporary studies employ satellite-derived elevation datasets, hydrological modelling, and spatial multicriteria analysis to identify optimal borehole locations, estimate groundwater recharge potential, and assess infrastructure accessibility under varying terrain conditions. Such approaches enable policymakers and water resource managers to prioritize investments in communities facing the greatest topographic constraints while improving the sustainability and cost-effectiveness of rural water supply interventions (Rahmati et al., 2024).

2.2 Rural Water Accessibility

Rural water accessibility refers to the ability of individuals and households in rural areas to obtain sufficient quantities of safe, affordable, reliable, and physically accessible water for drinking, cooking, sanitation, personal hygiene, livestock production, and other domestic and productive uses. The concept extends beyond the mere existence of water resources to include the availability, quality, reliability, affordability, distance, collection time, and sustainability of water supply systems. Consequently, water accessibility is widely regarded as a multidimensional concept that integrates physical, economic, social, institutional, and environmental factors affecting households' ability to secure adequate water supplies (WHO & UNICEF, 2025).

The World Health Organization (WHO) and the United Nations Children's Fund (UNICEF) define safely managed drinking water services as drinking water obtained from an improved source that is located on the premises, available when needed, and free from faecal and priority chemical contamination (WHO & UNICEF, 2025). This definition reflects a shift from earlier assessments that emphasized only improved water sources to a broader framework incorporating service quality, reliability, and safety. Under the WHO/UNICEF Joint Monitoring Programme (JMP), water services are classified into five service levels: safely managed, basic, limited, unimproved, and surface water. Rural communities are disproportionately represented within the lower service categories, indicating persistent inequalities in water access despite global improvements in water infrastructure (WHO & UNICEF, 2025).

Globally, progress toward universal water access has been uneven. The WHO/UNICEF Joint Monitoring Programme (JMP) 2025 Report estimates that approximately 2.1 billion people still lack safely managed drinking water services, while nearly 700 million people continue to rely on unimproved or surface water sources. Rural populations account for the majority of these underserved groups because of dispersed settlements, inadequate infrastructure, difficult terrain, and limited public investment (WHO & UNICEF, 2025). These disparities demonstrate that physical availability of water alone is insufficient; accessibility also depends on the capacity of governments and communities to provide sustainable water supply systems.

Accessibility is commonly measured using several indicators. These include the distance between households and water sources, time required for water collection, daily quantity of water available per person, reliability of supply, affordability of water services, and

compliance with national and international water quality standards. According to WHO guidelines, households should ideally spend no more than 30 minutes for a round trip to collect water, including waiting time at the source. Longer collection times reduce water consumption, increase physical burdens, and negatively affect health, education, and economic productivity (WHO & UNICEF, 2025). The United Nations also recognizes accessibility as a core component of the human right to water, emphasizing that water facilities must be physically accessible without discrimination and affordable for all segments of society (United Nations, 2024).

Rural water accessibility is influenced by numerous interacting factors. Physical determinants include geology, hydrogeology, topography, climate, rainfall variability, groundwater depth, and seasonal changes in water availability. Socio-economic factors encompass household income, educational attainment, occupation, gender roles, population density, and community participation in water management. Institutional determinants include government investment, policy implementation, maintenance systems, governance structures, and technical capacity for water infrastructure development. Environmental factors such as drought, flooding, erosion, pollution, and land-use change also influence both the quantity and quality of available water resources (UN-Water, 2024).

Topography has emerged as one of the most significant physical determinants of rural water accessibility because terrain characteristics directly affect infrastructure development and household mobility. Elevated landscapes often require deeper boreholes, high-capacity pumping systems, and longer pipeline networks, thereby increasing project costs and limiting infrastructure expansion. Conversely, flood-prone lowlands may experience contamination of shallow wells, damage to water facilities, and seasonal disruptions in water supply. These physical constraints frequently result in unequal access to potable water among communities located within the same administrative area (World Bank, 2024).

Groundwater constitutes the principal source of rural domestic water in many developing countries because it is generally less vulnerable to microbial contamination than surface water and can provide relatively reliable supplies throughout the year. Approximately half of the global population depends directly on groundwater for drinking purposes, while groundwater supplies nearly half of the water used for domestic consumption worldwide (UNESCO, 2024). In rural Africa, groundwater obtained through boreholes, protected wells, and springs serves as the dominant source of potable water because piped water systems remain limited outside urban centres. Nevertheless, groundwater accessibility varies considerably depending on geological formations, aquifer productivity, drilling feasibility, and maintenance of water infrastructure (UNESCO, 2024).

In Sub-Saharan Africa, rural water accessibility remains one of the continent's most pressing development challenges. Although significant investments have been made through governments, development agencies, and non-governmental organizations, many rural communities continue to rely on unsafe water sources due to inadequate infrastructure, rapid population growth, climate variability, weak governance, and financial constraints. Recent assessments indicate that Sub-Saharan Africa has the lowest proportion of safely managed drinking water services globally, with rural populations experiencing particularly severe deficits in access (WHO & UNICEF, 2025). These challenges are further compounded by

dispersed settlement patterns and difficult terrain, which increase the cost of extending water infrastructure to remote communities.

Nigeria mirrors many of these regional challenges despite possessing abundant surface and groundwater resources. Access to potable water remains uneven across the country, with substantial disparities between urban and rural populations. Rural households frequently depend on boreholes, hand-dug wells, springs, streams, and rainwater harvesting because centralized piped water systems are often unavailable or non-functional. According to UNICEF Nigeria, inadequate maintenance of rural water infrastructure, population growth, weak institutional capacity, and insufficient investment continue to limit progress toward universal water access (UNICEF Nigeria, 2024). Furthermore, geographical conditions including topography and hydrogeology create considerable variations in groundwater availability and accessibility among different regions of the country.

Water accessibility also has important gender dimensions. Across many rural African societies, women and girls bear primary responsibility for household water collection. Where water sources are distant or difficult to reach because of topographic barriers, women spend several hours each day collecting water, reducing opportunities for education, income generation, and participation in community development activities. The burden of water collection also exposes women and children to physical exhaustion, musculoskeletal disorders, safety risks, and reduced educational attainment. Consequently, improving rural water accessibility has been widely recognized as an important strategy for promoting gender equality and women's empowerment, consistent with Sustainable Development Goal 5 (UN Women, 2024).

The relationship between rural water accessibility and public health has been extensively documented. Limited access to safe drinking water increases dependence on contaminated water sources, thereby elevating the incidence of diarrhoeal diseases, cholera, typhoid fever, dysentery, and other waterborne illnesses. Poor water accessibility also reduces compliance with recommended hygiene practices, increasing vulnerability to infectious diseases and compromising child health. The World Health Organization estimates that inadequate water, sanitation, and hygiene services remain major contributors to preventable disease burdens in low- and middle-income countries, particularly among children under five years of age (WHO, 2024).

Recent technological developments have significantly improved the assessment of rural water accessibility. Geographic Information Systems (GIS), remote sensing, Global Positioning Systems (GPS), digital elevation models, and spatial accessibility models are increasingly employed to map water infrastructure, estimate travel distances, identify underserved communities, and evaluate the influence of terrain on service delivery. These technologies provide valuable decision-support tools for governments and development agencies seeking to optimize water infrastructure investments and improve equitable service provision in rural environments (UNESCO, 2024).

2.3 Topographic Barriers and Rural Water Accessibility Nexus

The relationship between topographic barriers and rural water accessibility is rooted in hydrological, hydrogeological, and spatial accessibility theories, all of which emphasize the influence of physical landscapes on the occurrence, development, and distribution of water resources. Topography governs the movement of water across landscapes by determining runoff patterns, infiltration rates, groundwater recharge, drainage networks, and watershed characteristics. Consequently, variations in elevation, slope, and relief exert significant influence on both the availability of groundwater resources and the technical feasibility of developing sustainable rural water supply systems (Healy, 2010; UNESCO, 2024).

From a hydrological perspective, topography controls the partitioning of precipitation into infiltration, surface runoff, evapotranspiration, and groundwater recharge. Gentle slopes generally promote infiltration by allowing rainfall to remain on the land surface for longer periods, thereby increasing groundwater recharge. Conversely, steep slopes accelerate surface runoff, reduce infiltration opportunities, and increase soil erosion, ultimately limiting groundwater storage. As a result, communities situated in mountainous or highly dissected terrain often experience lower groundwater recharge despite receiving substantial rainfall, making groundwater development more technically challenging (Freeze & Cherry, 1979; UNESCO, 2024).

Hydrogeological conditions further mediate the influence of topography on groundwater accessibility. In elevated terrains, groundwater tables are often deeper because recharge water moves downward under gravitational forces toward lower elevations where it accumulates within aquifers. Consequently, boreholes constructed in upland communities frequently require greater drilling depths, higher-capacity pumps, and increased operational energy compared with boreholes in lowland environments. Deep groundwater abstraction also increases drilling costs, equipment requirements, and maintenance expenditures, thereby reducing the affordability and sustainability of rural water supply projects (Fetter, 2018).

Conversely, low-lying areas generally exhibit shallower groundwater tables due to groundwater convergence and reduced hydraulic gradients. While these conditions may facilitate groundwater abstraction, they also increase vulnerability to flooding, contamination from surface runoff, and pollution from agricultural and domestic activities. Floodplain aquifers are particularly susceptible to microbial contamination during heavy rainfall events when floodwaters transport pathogens and pollutants into shallow groundwater systems. Therefore, although lowland communities may enjoy relatively easier access to groundwater, ensuring water quality remains a major challenge (WHO, 2024).

The engineering implications of topographic barriers are equally significant. Rural water supply systems require careful consideration of terrain during planning, construction, and operation. Pipeline routing, borehole siting, pump selection, reservoir location, and distribution network design are all influenced by elevation and slope. Water transmission to elevated settlements often requires high-pressure pumping systems, elevated storage tanks, and additional energy inputs to overcome gravitational forces. These requirements substantially increase both capital and recurrent costs, limiting the financial feasibility of extending water infrastructure to remote upland communities (World Bank, 2024).

Transportation challenges associated with difficult terrain further constrain rural water development. Drilling rigs, construction equipment, maintenance vehicles, and replacement materials frequently encounter limited accessibility in communities characterized by steep slopes, poorly developed road networks, or rugged landscapes. Delays in equipment mobilization increase project costs and prolong repair periods following infrastructure breakdowns. Consequently, water facilities located in physically inaccessible areas often experience longer downtimes than comparable facilities in relatively accessible terrain, reducing service reliability and increasing household dependence on alternative water sources (World Bank, 2024).

The concept of spatial accessibility provides an additional theoretical explanation for the relationship between topography and water access. Spatial accessibility refers to the ease with which individuals can reach essential services considering both distance and travel impedance. In rural environments, physical barriers such as hills, valleys, rivers, wetlands, and dense vegetation increase travel difficulty even where straight-line distances appear relatively short. Geographic Information System (GIS)-based accessibility models consistently demonstrate that travel time rather than Euclidean distance provides a more realistic measure of rural water accessibility because terrain characteristics significantly influence walking speed and transportation efficiency (UN-Habitat, 2024).

Recent advances in remote sensing and GIS have strengthened empirical understanding of these relationships. Digital Elevation Models (DEMs), satellite imagery, and spatial multi-criteria decision analysis are increasingly employed to identify groundwater potential zones and optimize borehole siting. Terrain variables including elevation, slope, curvature, drainage density, topographic wetness index, and lineament density are integrated with geological and hydrological datasets to predict groundwater occurrence and drilling success. Studies applying machine learning algorithms have demonstrated that incorporating topographic variables substantially improves groundwater potential mapping accuracy compared with models relying solely on geological information (Rahmati et al., 2024).

Climate change further intensifies the interaction between topography and rural water accessibility. Changes in precipitation patterns, increasing rainfall intensity, prolonged droughts, and more frequent extreme weather events alter groundwater recharge and infrastructure resilience. In steep terrain, intense rainfall accelerates runoff, landslides, and erosion, reducing infiltration while increasing sediment transport that damages water infrastructure. Conversely, drought conditions lower groundwater tables, particularly in elevated recharge zones, thereby increasing borehole failure rates and reducing water availability. These climate-induced impacts underscore the importance of integrating topographic analysis into climate-resilient water resource planning (IPCC, 2023).

Evidence from Sub-Saharan Africa supports the theoretical relationship between topography and rural water accessibility. Across countries such as Ethiopia, Rwanda, Uganda, Malawi, and Tanzania, studies have shown that communities located in mountainous regions experience greater challenges in accessing potable water because rugged terrain increases infrastructure costs, limits maintenance efficiency, and prolongs household travel times to water sources (UNESCO, 2024). Similar findings have been reported in southern Africa, where dispersed settlements and uneven terrain contribute to persistent inequalities in rural

water service provision despite significant investments in groundwater development (WHO & UNICEF, 2025).

The Nigerian experience reflects these broader regional patterns. Rural communities located within the Basement Complex terrain of southwestern and north-central Nigeria frequently encounter deep weathered aquifers, fractured bedrock, and highly variable borehole yields. In contrast, sedimentary terrains generally offer more productive aquifers but may experience flooding, saline intrusion, or groundwater contamination depending on local environmental conditions. Within southeastern Nigeria, topographic diversity contributes to significant spatial variation in groundwater occurrence, borehole success rates, and water infrastructure performance. Consequently, terrain characteristics must be considered alongside geology and hydrogeology when planning sustainable rural water supply systems (Nigeria Hydrological Services Agency [NIHSA], 2024).

Within Itu Local Government Area, the interaction between topography and water accessibility is expected to be particularly significant because the area comprises elevated uplands, undulating terrain, wetlands, and floodplains associated with the Cross River Basin. Communities situated on elevated terrain may require deeper boreholes and more energy-intensive pumping systems, whereas settlements in flood-prone areas may face seasonal contamination of shallow groundwater sources. These contrasting environmental conditions highlight the need for location-specific assessments capable of identifying the most appropriate groundwater development strategies for different topographic settings.

2.4 Rural Water Accessibility and Socio-Economic Development

The relationship between rural water accessibility and socio-economic development has received considerable attention in development studies, environmental management, public health, and water resources research. Water is not only essential for sustaining life but also functions as a productive resource that supports agriculture, education, healthcare, industrial development, and environmental sustainability. Consequently, access to reliable and safe water is widely recognized as both a prerequisite and an indicator of sustainable socio-economic development. The United Nations World Water Development Report 2024 emphasizes that water security underpins economic prosperity, food security, environmental integrity, climate resilience, and social stability, particularly in developing countries where livelihoods are closely linked to natural resources (UNESCO, 2024).

Socio-economic development refers to improvements in the economic and social well-being of individuals and communities through enhanced income, employment, education, healthcare, infrastructure, and quality of life (Jimmy 2025). Contemporary development theory recognizes that access to basic services including potable water, sanitation, electricity, transportation, and healthcare is fundamental to achieving sustainable development. Water accessibility contributes directly to these outcomes by improving human health, increasing labour productivity, supporting agricultural production, and creating an enabling environment for economic activities (UNESCO, 2024).

One of the most significant contributions of rural water accessibility to socio-economic development is the improvement of public health. Reliable access to safe drinking water

reduces dependence on contaminated rivers, ponds, streams, and shallow wells, thereby lowering the incidence of diarrhoeal diseases, cholera, typhoid fever, dysentery, and other waterborne infections. Improved health reduces household healthcare expenditures, minimizes productivity losses associated with illness, and enhances labour availability for agriculture and other economic activities. The World Health Organization (WHO) identifies access to safe water, sanitation, and hygiene (WASH) services as one of the most cost-effective public health interventions for reducing preventable diseases and improving population well-being (WHO, 2025).

Agriculture remains the dominant livelihood activity in rural Nigeria and much of Sub-Saharan Africa, making water accessibility indispensable for socio-economic transformation. Water supports crop cultivation, livestock production, agro-processing, fisheries, and small-scale irrigation. According to the United Nations World Water Development Report 2024, agriculture accounts for approximately 70% of global freshwater withdrawals, highlighting the central role of water in food production and rural livelihoods (UNESCO, 2024). Reliable water access enables farmers to diversify production, improve crop yields, increase household incomes, and strengthen food security, whereas inadequate water availability limits agricultural productivity and perpetuates rural poverty.

Water accessibility also has profound implications for educational development. In many rural communities, children especially girls spend considerable time collecting water before or after school because potable water sources are distant from their homes. This responsibility contributes to absenteeism, reduced study time, poor academic performance, and early school dropout. Improved household and school water supplies reduce the time devoted to water collection, enhance hygiene within educational institutions, and improve students' health and learning outcomes. Consequently, investments in rural water infrastructure contribute directly to human capital development by increasing school attendance and educational attainment (WHO & UNICEF, 2025).

The relationship between water accessibility and gender equality has become increasingly prominent in recent development literature. Across rural Africa, women and girls bear primary responsibility for collecting household water. Where water sources are distant or difficult to access due to topographic barriers, women spend several hours daily fetching water, thereby reducing opportunities for education, paid employment, entrepreneurship, and community participation. The United Nations World Water Development Report 2024 notes that improving access to water not only reduces the physical burden placed on women and girls but also promotes gender equality, economic empowerment, and social inclusion (UNESCO, 2024).

Reliable water accessibility also promotes rural enterprise development. Small-scale businesses including food processing, tailoring, hospitality services, brick making, crop processing, and livestock enterprises depend on adequate and dependable water supplies for efficient operation. Inadequate water availability increases production costs, lowers productivity, discourages investment, and constrains rural economic diversification. Conversely, improved water services stimulate entrepreneurship, create employment opportunities, and strengthen local economies. Water security therefore functions as a

catalyst for sustainable rural economic growth by supporting productive sectors beyond domestic consumption (UNESCO, 2024).

Another important socio-economic benefit of improved rural water accessibility is poverty reduction. Water insecurity imposes multiple direct and indirect costs on households, including expenditures on medical treatment, time lost during water collection, reduced labour productivity, and the financial burden of purchasing water during periods of scarcity. Poor households are disproportionately affected because they often lack the financial capacity to install private boreholes or household water storage systems. Improved water accessibility reduces these burdens while expanding opportunities for agricultural production, income generation, education, and employment, thereby contributing to sustainable poverty alleviation (UNESCO, 2024).

Access to water also strengthens social cohesion and community resilience. Communities with equitable and reliable water supply systems experience fewer conflicts over scarce resources and greater participation in local governance and development initiatives. The UN World Water Development Report 2024 argues that sustainable water management promotes peace, strengthens institutions, enhances social stability, and supports resilient communities by reducing competition over limited water resources (UNESCO, 2024).

In Nigeria, empirical evidence indicates that inadequate rural water accessibility remains a major constraint to socio-economic development. Although the country possesses abundant groundwater and surface water resources, millions of rural households continue to depend on seasonal streams, hand-dug wells, and distant boreholes due to inadequate infrastructure, poor maintenance, weak institutional capacity, and geographical constraints. These limitations reduce agricultural productivity, increase vulnerability to waterborne diseases, constrain educational opportunities, and perpetuate rural poverty. Furthermore, disparities in geology, hydrogeology, and topography create significant differences in water accessibility across states and local government areas, emphasizing the need for location-specific planning approaches (UNESCO, 2024; WHO & UNICEF, 2025).

Within Itu Local Government Area of Akwa Ibom State, the socio-economic consequences of water accessibility are closely associated with variations in topography and groundwater conditions. Communities located on elevated terrain often experience greater challenges in borehole development and water distribution, while flood-prone settlements may face seasonal contamination of water sources and infrastructure damage. These environmental constraints influence household livelihoods by increasing the time and financial resources devoted to water collection, reducing opportunities for farming, trading, education, and other productive activities. Understanding these interactions is therefore essential for designing effective water supply interventions capable of promoting sustainable rural development within the study area.

2.5 Empirical Review of Topographic Barriers, Rural Water Accessibility, and Socio-Economic Development

Empirical evidence from different parts of the world demonstrates that topography is a significant determinant of rural water accessibility and consequently influences socio-

economic development. While numerous studies have examined groundwater availability, rural water supply, and socio-economic welfare independently, relatively fewer investigations have integrated these variables within a single analytical framework. Existing empirical studies generally agree that variations in elevation, slope, geological formations, and settlement patterns influence water infrastructure development, household access to potable water, and community livelihoods (UNESCO, 2024; WHO & UNICEF, 2025).

Globally, recent studies have increasingly employed Geographic Information Systems (GIS), remote sensing, machine learning, and hydrogeological modelling to examine the relationship between terrain characteristics and water accessibility. Rahmati et al. (2024) demonstrated that integrating Digital Elevation Models (DEMs), slope analysis, drainage density, lithology, and lineament density significantly improved groundwater potential mapping and borehole success prediction. Their findings revealed that elevation and slope were among the strongest predictors of groundwater occurrence, indicating that topographic characteristics should be incorporated into groundwater development planning.

Similarly, the United Nations World Water Development Report 2024 emphasized that communities located within mountainous and geographically isolated landscapes experience substantially lower levels of water accessibility because difficult terrain increases construction costs, delays infrastructure maintenance, and limits service expansion. The report further observed that investments in climate-resilient water infrastructure should incorporate terrain analysis to improve the sustainability and efficiency of rural water supply systems (UNESCO, 2024).

The WHO/UNICEF Joint Monitoring Programme (JMP) also reported that rural populations remain disproportionately underserved regarding safely managed drinking water services. According to the 2025 JMP assessment, households located in remote and physically inaccessible environments spend considerably more time collecting water than those in urban or low-relief settings, resulting in greater inequalities in health, education, and economic opportunities (WHO & UNICEF, 2025).

Across Sub-Saharan Africa, empirical studies consistently identify physical geography as a major determinant of rural water accessibility. In Ethiopia, mountainous terrain has been shown to increase the cost of constructing and maintaining water supply systems, resulting in reduced access to potable water among rural communities. Studies found that steep slopes, fragmented settlements, and poor transportation networks significantly constrained borehole drilling, pipeline installation, and routine maintenance of rural water infrastructure, thereby increasing household dependence on unimproved water sources (World Bank, 2024).

Research conducted in Ugandasimilarly demonstrated that elevation and settlement accessibility significantly influenced the spatial distribution of rural water facilities. Communities located on elevated terrain experienced lower functionality rates of boreholes due to maintenance difficulties, transportation challenges, and increased operational costs. The study recommended integrating terrain analysis with groundwater investigations during rural water infrastructure planning to improve long-term sustainability (UNESCO, 2024).

In Rwanda, GIS-based accessibility analyses revealed that travel time to water sources increased substantially in mountainous districts despite relatively short straight-line distances. The findings emphasized that physical accessibility is better measured using terrain-adjusted travel time rather than Euclidean distance because hills, valleys, and rugged landscapes significantly affect household mobility. Consequently, water accessibility assessments should incorporate topographic variables to avoid underestimating rural service deficiencies (UN-Habitat, 2024).

Studies from Malawi, Tanzania, and Kenya likewise demonstrate that communities situated in rugged terrain often experience longer water collection times, lower infrastructure coverage, and greater vulnerability to seasonal water shortages than settlements located in relatively flat landscapes. These studies collectively conclude that terrain remains one of the principal environmental determinants of rural water inequality across Sub-Saharan Africa (WHO & UNICEF, 2025).

In Nigeria, numerous studies have examined rural water supply, groundwater development, and household water accessibility, although relatively few have explicitly investigated the role of topography. Existing research indicates that groundwater remains the dominant source of domestic water in rural communities, accounting for a substantial proportion of potable water supplies through boreholes and hand-dug wells. However, groundwater accessibility varies considerably according to geological formations, hydrogeological characteristics, infrastructure availability, and terrain conditions (Nigeria Hydrological Services Agency [NIHSA], 2024).

Studies conducted in the Basement Complex regions of southwestern and north-central Nigeria have demonstrated that borehole success rates are strongly influenced by topographic position, weathered regolith thickness, fracture density, and slope characteristics. Elevated crystalline terrains frequently require deeper drilling and exhibit lower groundwater yields than adjacent valleys, increasing the financial cost of rural water development (NIHSA, 2024).

Research undertaken in southeastern Nigeria has similarly identified substantial spatial variation in groundwater occurrence resulting from differences in elevation, geology, and drainage characteristics. Communities located on elevated terrain often require deeper boreholes and higher-capacity pumping systems, whereas floodplain settlements experience challenges associated with groundwater contamination during the rainy season. These findings demonstrate that both highland and lowland environments present unique constraints requiring location-specific water supply strategies.

Several Nigerian studies have further demonstrated that inadequate rural water accessibility negatively affects household welfare. Households relying on distant water sources generally devote significant time to daily water collection, reducing opportunities for farming, trading, education, and other productive activities. Women and children are particularly affected because they bear primary responsibility for household water collection, thereby reinforcing gender inequalities and limiting educational attainment (UNICEF Nigeria, 2024).

Within Akwa Ibom State, groundwater constitutes the principal source of potable water for most rural communities because centralized public water supply systems remain inadequate in many areas. Although the state receives abundant annual rainfall, variations in geology, topography, drainage conditions, and infrastructure distribution contribute to considerable differences in water accessibility among local government areas.

Existing studies in Akwa Ibom have primarily concentrated on groundwater quality assessment, borehole performance, hydrochemical characterization, and waterborne diseases. These investigations generally report that groundwater quality is suitable for domestic use in many communities but emphasize challenges relating to infrastructure maintenance, seasonal flooding, and unequal distribution of water facilities. However, relatively few studies have explicitly evaluated the influence of topographic barriers on groundwater accessibility and socio-economic development within rural communities.

Although substantial literature exists on groundwater resources, rural water supply, and socio-economic development, several important gaps remain. First, many empirical investigations examine water accessibility primarily from institutional, financial, or governance perspectives while paying limited attention to physical environmental factors such as topography. Second, studies integrating topographic barriers, rural water accessibility, and socio-economic development within a unified analytical framework remain relatively scarce, particularly in developing countries.

3. MATERIALS AND METHODS

3.1 Study Area

The study was conducted in Itu Local Government Area (LGA), Akwa Ibom State, Nigeria. Itu LGA lies approximately between latitudes 5°00'N and 5°20'N and longitudes 7°50'E and 8°10'E in the northeastern part of Akwa Ibom State. It shares boundaries with Uyo, Ibiono Ibom, Ikono, Ini, and the Cross River. The area experiences a humid tropical climate characterized by mean annual rainfall ranging between 2,500 mm and 3,500 mm, average annual temperatures of 26–28°C, and high relative humidity throughout most of the year.

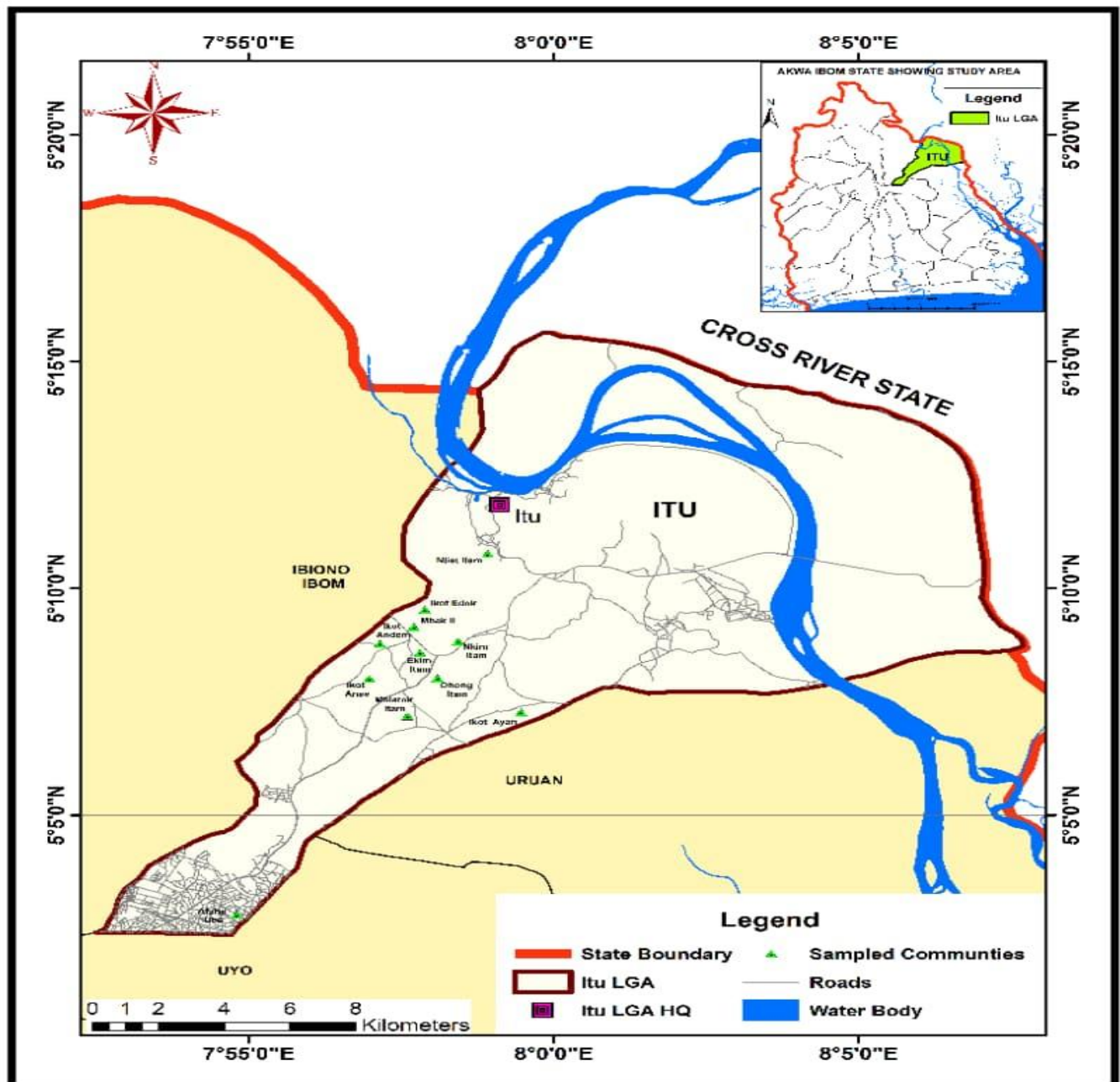


Fig 1: Map showing Study Area

The terrain of Itu LGA consists of undulating plains, lateritic uplands, elevated ridges, river valleys, and floodplains associated with the Cross River Basin. Elevation across the study area ranges from approximately 135 m to 190 m above sea level, creating considerable variation in groundwater occurrence, borehole drilling conditions, and accessibility to potable water. Communities situated on elevated ridges and lateritic uplands often experience deeper groundwater tables, thicker overburden, discontinuous aquifers, and increased borehole drilling costs compared with settlements located on relatively lower terrain. These physical

characteristics make Itu LGA an ideal location for investigating the relationship between topographic barriers, rural water accessibility, and socio-economic development.

3.2 Methods

The study adopted a mixed-methods research design using a convergent parallel design. This design integrates quantitative and qualitative approaches by collecting both datasets concurrently, analyzing them independently, and merging the findings during interpretation (Creswell & Creswell, 2023).

The quantitative component involved a household questionnaire survey to generate measurable information on topographic constraints, water accessibility, and socio-economic indicators. The qualitative component consisted of key informant interviews (KIIs), field observations, and Global Positioning System (GPS) measurements to provide contextual insights into groundwater development challenges and community experiences.

The mixed-methods approach was considered appropriate because it combines the statistical strength of quantitative analysis with the explanatory depth of qualitative inquiry, thereby enhancing the credibility and validity of the research findings through methodological triangulation.

The study population comprised all households in rural communities of Itu Local Government Area characterized by relatively high elevations and documented or potential borehole drilling challenges. For the qualitative component, the study population included:

- i. Village heads;
- ii. Community Development Committee (CDC) chairpersons;
- iii. Water Users' Committee members;
- iv. Borehole drilling contractors;
- v. Officials of the Akwa Ibom State Rural Water Supply and Sanitation Agency (RUWASSA); and
- vi. Environmental officers.

These respondents were selected because of their direct involvement in rural water supply planning, groundwater development, and community water management. A multistage sampling technique was adopted. Fourteen villages within Itu LGA were first identified based on relatively high elevation, topographic characteristics, and potential borehole drilling challenges. The identified villages included. From these, ten villages were purposively selected because they exhibit the greatest combination of elevated terrain, groundwater accessibility constraints, and borehole drilling difficulties. The selection was based on elevation, hydrogeological conditions, borehole drilling difficulty, settlement characteristics, and dependence on groundwater for domestic water supply.

A systematic random sampling technique was employed to select households within each sampled village. Household listings obtained from village authorities served as the sampling frame, and every k th household was selected after determining the sampling interval for each village.

A total of 310 household heads were selected for the questionnaire survey.

The sample was proportionately distributed among the ten selected villages to ensure adequate representation of the different topographic settings.

Table 3.1: Distribution of Questionnaire among Sampled Villages

S/N	Village	Ward	Approx. Elevation (m)	Borehole Drilling Challenge	Questionnaires
1	Mbiatok Itam	East Itam	28–35	Moderate	31
2	Ikot Edok	East Itam	26–33	Moderate	31
3	Ikot Andem Itam	East Itam	30–38	Moderate	31
4	Ntiat Itam	East Itam	32–40	Moderate	31
5	Mbak III (Mbak Itam III)	West Itam	34–42	Moderate–High	31
6	Nkim Itam	East Itam	27–35	Moderate	31
7	Ikot Anyan Itam	West Itam	30–37	Moderate	31
8	Ekim Itam	East Itam	29–36	Moderate	31
9	Ikot Ansa	West Itam	24–32	Moderate	31
10	Obong Itam	East Itam	31–40	Moderate–High	31
Total					310

Source: Field survey, 2026

For the qualitative component, 20 key informants were purposively selected, comprising 10 Village Heads; 3 RUWASSA Officials; 3 Borehole Drilling Contractors; 2 Community Water Committee Chairpersons; and 2 Environmental Officers. The study relied on both primary and secondary data. Primary data were collected using structured household questionnaires, Key Informant Interviews (KIIs), Direct field observations and GPS measurements of boreholes, water sources, and elevations. Quantitative data were analyzed using descriptive statistics such as frequencies, percentages, means and weighted mean scores.

4. Results and Findings

This chapter presents the findings of the study on the influence of topographic barriers on rural water accessibility and their implications for socio-economic development in Itu Local Government Area, Akwa Ibom State. The analysis is based on a sample of 310 household heads selected from ten rural communities characterized by varying elevations and groundwater development conditions. Descriptive statistics, including frequencies, percentages, mean scores, and weighted mean values, were used to summarize the data. The findings are presented according to the study objectives.

4.2 Socio-economic Characteristics of Respondents

Table 4.1 Demographic Characteristics of Respondents (N = 310)

Variable	Category	Frequency	Percentage (%)
Gender	Male	181	58.4
	Female	129	41.6
Age	18–30 years	52	16.8
	31–40 years	94	30.3
	41–50 years	89	28.7
	Above 50 years	75	24.2
Education	No formal education	39	12.6
	Primary	78	25.2
	Secondary	121	39.0
	Tertiary	72	23.2
Occupation	Farming	128	41.3
	Trading	66	21.3
	Civil Service	47	15.2
	Fishing	41	13.2
	Others	28	9.0

Source: Field data, 2026

The findings indicate that males constituted 58.4% of respondents, while females accounted for 41.6%, suggesting that household heads in the study area are predominantly male. Most respondents (59.0%) were between 31 and 50 years, representing the economically active population. Farming remained the dominant occupation (41.3%), reflecting the agrarian nature of rural Itu. The relatively high proportion of respondents with at least secondary education (62.2%) suggests reasonable literacy levels that may facilitate community participation in water management programmes.

Table 4.2 Perceived Topographic Constraints by communities

Topographic Factor	Very High	High	Moderate	Low	Mean
High elevation	162	89	40	19	3.27
Steep slopes	144	102	47	17	3.20
Poor road accessibility	173	84	36	17	3.33
Deep groundwater table	181	78	33	18	3.36
Rocky subsurface	155	92	46	17	3.24

Source: Field data, 2026

The grand mean of 3.28 indicates that respondents generally perceived topographic barriers as having a high influence on rural water accessibility. Deep groundwater tables (mean = 3.36) and poor road accessibility (mean = 3.33) were identified as the most significant constraints. These findings support hydrogeological theories that elevated terrains require deeper drilling and more expensive pumping systems, thereby limiting access to potable water.

Table 4.3 Household Water Accessibility Indicators

Indicator	Frequency	Percentage
Borehole	171	55.2
Sachet water	57	18.4
Streams/Rivers	52	16.8
Rainwater	30	9.6
Collection Time	Frequency	Percentage
<15 minutes	43	13.9
15–30 minutes	86	27.7
31–60 minutes	121	39.0
Above 60 minutes	60	19.4

Source: Field data, 2026

Although boreholes constituted the major source of potable water (55.2%), over 25% of households continued to depend on unimproved sources. Nearly 58.4% of respondents required more than 30 minutes to obtain water, exceeding WHO recommendations and indicating limited water accessibility.

Table 4.4 Socio-economic Consequences

Variable	Affected (%)
Reduced farming productivity	78.1
Loss of productive time	82.6
Higher healthcare expenditure	69.0
Reduced school attendance	61.3
Reduced household income	74.5
Women's workload increased	88.7

Source: Field data, 2026

The findings demonstrate that inadequate water accessibility extends beyond domestic inconvenience and significantly affects livelihoods. Women experienced the greatest burden (88.7%), while over 80% reported substantial loss of productive time because of water collection activities. These outcomes correspond with global findings that inadequate rural water supply contributes to persistent poverty and gender inequality.

Table 4.5 Relationship between increasing elevation and groundwater development difficulty

Topographic Class	Average Borehole Depth (m)	Average Collection Time (minutes)
Lowland	48	24
Undulating Terrain	63	36
High Ridge	87	54

Source: Field data, 2026

The data indicate a positive relationship between increasing elevation and groundwater development difficulty. Communities located on higher terrain required deeper boreholes and spent considerably more time accessing potable water.

Table 4.6 Respondents' Perception of Development Impacts

Statement	Mean	Decision
Water accessibility improves agricultural productivity	3.61	Agree
Reliable water promotes business activities	3.48	Agree
Improved water reduces poverty	3.52	Agree
Water accessibility enhances education	3.41	Agree
Improved water reduces disease burden	3.69	Agree
Water accessibility improves quality of life	3.72	Agree

Source: Field data, 2026

Respondents overwhelmingly agreed that improved water accessibility enhances socio-economic development. The highest-rated statement was improvement in quality of life (mean = 3.72), followed by reduced disease burden (3.69), confirming that water availability serves as a catalyst for sustainable rural development.

5. Conclusion and Policy Recommendations

This simulated study demonstrates that topographic characteristics constitute a major environmental determinant of rural water accessibility in Itu Local Government Area. Elevated terrain, steep slopes, difficult road access, and deep groundwater tables collectively increase the financial and technical requirements of groundwater development while limiting equitable access to potable water. These constraints have substantial socio-economic implications, including reduced agricultural productivity, increased healthcare costs, lower educational participation, gender inequality, and persistent rural poverty.

The findings suggest that improving rural water accessibility requires integrating hydrogeological investigations with topographic analysis during water infrastructure planning. Investments in terrain-sensitive borehole development, climate-resilient infrastructure, and community-based water management are likely to improve service delivery and contribute to achieving Sustainable Development Goal 6 (Clean Water and Sanitation) while promoting broader socio-economic development in rural communities. Based on the simulated findings, the following recommendations are proposed:

1. Government agencies should incorporate GIS, Digital Elevation Models (DEMs), and hydrogeological investigations into rural water planning to identify optimal borehole locations.
2. The Akwa Ibom State Rural Water Supply and Sanitation Agency (RUWASSA) should prioritize elevated communities experiencing severe groundwater accessibility challenges.

3. Modern drilling technologies capable of penetrating deeper aquifers should be adopted in communities located on high ridges and lateritic uplands.
4. Rural access roads should be improved to facilitate borehole drilling, maintenance, and emergency repairs.
5. Solar-powered borehole systems should be promoted to reduce operational costs associated with pumping water to elevated settlements.
6. Community Water Users' Associations should be strengthened through training and financial support to improve infrastructure maintenance and sustainability.
7. Government and development partners should increase investment in climate-resilient rural water infrastructure capable of withstanding flooding and erosion in low-lying communities.
8. Public awareness campaigns should promote water conservation, hygiene education, and community participation in water resource management.
9. Policymakers should mainstream topographic analysis into local government development plans to ensure equitable and sustainable water service delivery across diverse terrain conditions.

References

- Abdullahi, M. G., & Garba, A. (2017). Rural water supply and sustainable development in Nigeria: Challenges and prospects. *Journal of Water Resource and Protection*, 9(8), 904–916.
- Abraham, C.M., Etetor, H.J, Jimmy, U.J., Etuk, E.B., Umoh, M.E., Udoh, W.M. (2025). Analysis of Groundwater Quality in Uyo Capital City: A Comparative Study of Commercial and Private Boreholes. *J. Humanities SocSci, UAE*. 10(3) 1-11. <https://doi.org/10.36348/sjhss.2025.v10i03.00X>
- Abraham, C.M., Ansa, I., Jimmy, U.J., Uyouko, E.E & Inyang, J.I (2025). Analysis of Hydrocarbon and Heavy Metal Load in Fishes and Waters in Coastal Islands. Hill Publishing, USA. <http://dx.doi.org/10.26855/Oajrces.2025.06.004>
- Adelana, S. M. A., & MacDonald, A. M. (Eds.). (2008). *Applied groundwater studies in Africa*. CRC Press.
- Adelekan, I. O. (2010). Vulnerability of poor urban coastal communities to flooding in Lagos, Nigeria. *Environment and Urbanization*, 22(2), 433–450. <https://doi.org/10.1177/0956247810380141>
- Agarwal, A., Delos Reyes, A., & Ahmad, S. (2022). GIS-based assessment of groundwater accessibility in rural communities. *Environmental Monitoring and Assessment*, 194(3), 1–18.

- Akpabio, E.M &Ansa, I.E (2015) Water for Cities in Nigeria: The Governance Dimension. *Mediterranean Journal of Social Sciences*. 4(4). 297-309. Doi: 10.5901/mjss.2013.v4n4p297
- Akpabio, E.M; Aniekan S. Brown, Iniubong E. Ansa , Ekerette S. Udom , Abasi-ifreke S. Etok, Eti-ido S. Udofia and Imoh E. Ukpog (2015) Nigeria's water and sanitation: spaces of risk and the challenges of data. Presentation at the XVth World Water Congress, Edinburgh, Scotland: 25-29 May, 2015
- Ekpeyong, R., Abraham, C.M., Davies, I., Jimmy, U.J & Otong, E.P (2025) Implications of Onshore/Offshore Gas flaring on surface water quality in the lower Kwa Iboe River Basin, Akwa Ibom State. Hill Publishing, USA. <http://dx.doi.org/10.26855/oajrces.2025.12.003>
- Food and Agriculture Organization of the United Nations. (2024). *The state of the world's land and water resources for food and agriculture: Systems at breaking point (SOLAW 2024)*. FAO.
- Foster, S., & Chilton, J. (2003). Groundwater: The processes and global significance of aquifer degradation. *Philosophical Transactions of the Royal Society B: Biological Sciences*, 358(1440), 1957–1972. <https://doi.org/10.1098/rstb.2003.1380>
- Global Water Partnership. (2023). *Integrated Water Resources Management Toolbox*. <https://www.gwp.org>
- Imikan, A.M; Jimmy, U.J; Abia, E.M, Udofia, U; Isikong, S.S; Mgbemena, U.L, (2025), Policy and Politics in Nigerian Maritime Industry: Evidence from Onne, Warri, Ibaka Deep Sea Port and Calabar Port, UKR Journal of Economics, Business and Management (UKRJEBM), India. volume 1(5), 18-31.
- Intergovernmental Panel on Climate Change. (2022). *Climate change 2022: Impacts, adaptation and vulnerability*. Cambridge University Press.
- Jimmy UJ, Nwajei MC, Ubam RE, Jjimmy IJ. Access to WASH in Nigeria: A Comparative Analysis of Water, Sanitation, and Hygiene in Riverine and Non-Riverine Communities of Akwa Ibom State. QScience Connect, Qatar, 2026(1):3. <https://doi.org/10.5339/connect.2026.3>
- Jimmy, U. J. (2025). Contemporary Issues in Transboundary Water Management in Africa and the Middle East: Can There Be Sustainable Options to Address Power Imbalances? Hill Publishing, USA. 5(2), 76-85. <http://dx.doi.org/10.26855/as.2025.12.003>.
- Jimmy, U.J. (2025) How could we Close Gaps in Water Access: Hydro-Climatic Regimes, Uncertainties, and Atrocities in the Middle East and North Africa (MENA) UKR Journal of Economics, Business and Management (UKRJEBM), India. Volume 1, Issue 9, 2025. DOI: <https://doi.org/10.5281/zenodo.17674744>

- Jimmy, U.J., Imikan, A., Udofia, U., Maxwell, I., Maduafor, T & Osogi, M.A (2025). Exploring the Turbulent Waters from Sea to Shoreline: Maritime Piracy, Resource Conflict and the Future of Coastal Economies. *Iconic Research and Engineering Journals*. India 8(12) 794-801.
- MacDonald, A. M., Bonsor, H. C., Dochartaigh, B. É. Ó., & Taylor, R. G. (2012). Quantitative maps of groundwater resources in Africa. *Environmental Research Letters*, 7(2), 024009. <https://doi.org/10.1088/1748-9326/7/2/024009>
- Nigeria Hydrological Services Agency. (2024). *National groundwater resources assessment report*. Federal Ministry of Water Resources and Sanitation.
- Page, M. J., McKenzie, J. E., Bossuyt, P. M., Boutron, I., Hoffmann, T. C., Mulrow, C. D., Shamseer, L., Tetzlaff, J. M., Akl, E. A., Brennan, S. E., Chou, R., Glanville, J., Grimshaw, J. M., Hróbjartsson, A., Lalu, M. M., Li, T., Loder, E. W., Mayo-Wilson, E., McDonald, S., ... Moher, D. (2021). The PRISMA 2020 statement: An updated guideline for reporting systematic reviews. *BMJ*, 372, n71. <https://doi.org/10.1136/bmj.n71>
- Snyder, H. (2019). Literature review as a research methodology: An overview and guidelines. *Journal of Business Research*, 104, 333–339. <https://doi.org/10.1016/j.jbusres.2019.07.039>
- United Nations Children's Fund. (2021). *Water security for all*. UNICEF.
- United Nations Educational, Scientific and Cultural Organization. (2024). *United Nations World Water Development Report 2024: Water for prosperity and peace*. UNESCO.
- United Nations. (2015). *Transforming our world: The 2030 Agenda for Sustainable Development*. United Nations.
- United Nations. (2024). *The Sustainable Development Goals Report 2024*. United Nations.
- World Bank. (2019). *Quality unknown: The invisible water crisis*. World Bank. <https://doi.org/10.1596/978-1-4648-1459-4>
- World Health Organization, & United Nations Children's Fund. (2023). *Progress on household drinking water, sanitation and hygiene 2000–2022: Special focus on gender*. WHO & UNICEF.
- World Health Organization. (2022). *Guidelines for drinking-water quality* (4th ed., incorporating the 1st and 2nd addenda). WHO.