

Assessing the Effects of Topographic Barriers on Rural Water Accessibility in Nigeria: A Review

Abstract

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Rural water accessibility remains a major development challenge in Nigeria despite the country's abundant groundwater resources. Among the numerous factors influencing water accessibility, topographic barriers have received comparatively limited scholarly attention, even though they significantly affect groundwater occurrence, borehole development, water infrastructure, and socio-economic well-being. This review critically examines the effects of topographic barriers on rural water accessibility in Nigeria by synthesizing evidence from peer-reviewed journal articles, government publications, and reports from international organizations published between 2015 and 2026. A systematic narrative review approach was adopted, drawing data from reputable academic databases and institutional sources. The reviewed literature indicates that elevation, slope, rugged terrain, lateritic overburden, and geological formations constitute major topographic barriers influencing groundwater recharge, aquifer occurrence, borehole drilling depth, infrastructure development, and long-term water supply sustainability. These environmental constraints increase the technical complexity and financial costs of groundwater development while reducing equitable access to safe drinking water in many rural communities. The review further reveals that inadequate water accessibility contributes to reduced agricultural productivity, increased household expenditure on water, poor public health outcomes, lower educational participation, gender inequalities, and persistent rural poverty. Emerging evidence demonstrates that the integration of Geographic Information Systems (GIS), Remote Sensing, Digital Elevation Models (DEMs), hydrogeophysical investigations, and Integrated Water Resources Management (IWRM) principles can significantly improve groundwater exploration, borehole siting, and rural water planning. The review concludes that overcoming topographic constraints requires integrated policy interventions involving hydrogeological assessment, geospatial technologies, climate-

resilient infrastructure, institutional collaboration, and active community participation. These measures are essential for improving rural water accessibility, reducing spatial inequalities, and accelerating progress toward achieving Sustainable Water Development.

Keywords: Topographic barriers; Rural water accessibility; Rural development; Nigeria

1. Introduction

Access to safe, reliable, and affordable water remains one of the most fundamental requirements for human health, environmental sustainability, and socio-economic development (Akpabio & Ansa, 2015; Akpabio et al, 2015). Despite significant global investments in water infrastructure over the past decades, millions of people particularly those residing in rural areas of developing countries continue to experience inadequate access to potable water. The 2024 United Nations World Water Development Report (UN WWDR) estimates that approximately 2.2 billion people worldwide lacked access to safely managed drinking water services in 2022, with the majority of underserved populations living in rural communities where infrastructure development is constrained by environmental, economic, and institutional factors (UNESCO, 2024). Furthermore, four out of every five people lacking at least basic drinking water services reside in rural areas, underscoring the persistent disparity in water accessibility between urban and rural populations.

Nigeria faces similar challenges despite possessing substantial surface and groundwater resources distributed across diverse ecological zones. While groundwater constitutes the primary source of domestic water supply for most rural communities, access to these resources is uneven because of differences in geology, hydrogeology, infrastructure, governance, and physical geography. Rural households in many parts of the country continue to rely on streams, rivers, hand-dug wells, rainwater harvesting, and seasonal water bodies due to inadequate public water supply systems and limited groundwater infrastructure. These challenges have significant implications for public health, agricultural productivity, educational attainment, poverty reduction, and overall rural development (UNESCO, 2024).

Among the numerous environmental factors influencing rural water accessibility, topography remains one of the least explored yet most critical determinants. Topography refers to the physical configuration of the Earth's surface, including elevation, slope, relief, ridges, valleys, and drainage patterns. These terrain characteristics influence groundwater recharge, aquifer distribution, runoff generation, erosion processes, and the technical feasibility of developing water infrastructure. Elevated terrains often require deeper boreholes because groundwater tables occur at greater depths, while steep slopes increase construction costs, limit accessibility for drilling equipment, and complicate the installation and maintenance of pipelines and storage facilities. Conversely, lowland areas may experience groundwater contamination and seasonal flooding, creating different but equally significant challenges for rural water supply systems (UNESCO, 2024).

Recent international assessments have increasingly recognized the importance of integrating physical geography into water resource planning. The United Nations World Water Development Report 2024 emphasizes that sustainable water security depends not only on the availability of water resources but also on the interaction between environmental conditions, infrastructure development, governance, and socio-economic factors. The report argues that communities located in geographically challenging environments including mountainous regions, elevated plateaus, and remote rural settlements often face disproportionately higher costs of water infrastructure development and reduced access to safely managed drinking water services (UNESCO, 2024).

In Nigeria, the influence of topographic barriers on rural water accessibility varies considerably across ecological and geological regions (Abraham et al, 2025; Jimmy 2025). Communities situated within the crystalline Basement Complex of north-central and southwestern Nigeria frequently encounter low-yield fractured aquifers that require detailed hydrogeological investigations before successful borehole development. Similarly, upland communities in southeastern Nigeria often experience increased drilling depths because of thick lateritic overburden and variable aquifer thickness, while riverine settlements in the Niger Delta contend with flooding, saline intrusion, and groundwater contamination. These spatial variations illustrate that water accessibility is determined not merely by the presence of groundwater but also by the physical characteristics of the landscape in which water infrastructure is developed.

The implications of topographic barriers extend beyond water availability to influence broader dimensions of rural socio-economic development. In communities where households travel long distances across steep or rugged terrain to obtain water, significant amounts of productive time are lost, particularly among women and children who traditionally bear responsibility for water collection (Jimmy et al, 2026). Limited water accessibility also constrains agricultural productivity, reduces educational participation, increases healthcare expenditures arising from waterborne diseases, and restricts opportunities for income generation (Imikan et al, 2025, Jimmy 2025). Consequently, physical barriers to water access contribute directly to persistent rural poverty and social inequality, thereby undermining progress towards the achievement of the Sustainable Development Goal 6, which seeks to ensure the availability and sustainable management of water and sanitation for all.

Recent evidence further highlights that inequalities in drinking water accessibility within Nigeria are shaped by multiple socio-economic and spatial factors (Jimmy, et al, 2025; Ekpeyong et al 2025; Abraham et al, 2025). While wealth disparities remain important, geographic location and rural infrastructure deficits continue to influence household access to improved water services. These findings suggest that understanding rural water accessibility requires integrating environmental characteristics such as topography with socio-economic and institutional dimensions to support more equitable water resource planning.

Although numerous studies have examined groundwater development, water quality, and rural water supply in Nigeria, comparatively limited attention has been devoted to synthesizing evidence on how topographic barriers influence rural water accessibility across different ecological zones. Existing research is often localized, focusing on specific communities or

hydrogeological conditions, thereby limiting broader understanding of the interactions between terrain, groundwater occurrence, infrastructure development, and rural livelihoods. A comprehensive review is therefore necessary to consolidate current knowledge, identify emerging trends, highlight regional variations, and reveal existing knowledge gaps that require further investigation.

This review therefore assesses the effects of topographic barriers on rural water accessibility in Nigeria by examining how elevation, slope, landforms, geological conditions, and terrain-related constraints influence groundwater development, water infrastructure provision, and household access to potable water. It further evaluates the socio-economic implications of these barriers and discusses policy options for improving equitable rural water supply through integrated water resources management, geospatial planning, and sustainable infrastructure development. Such an assessment provides valuable insights for researchers, planners, policymakers, and development practitioners seeking to enhance water security and promote sustainable rural development in Nigeria.

2. Literature Review

2.1 Concept of Topographic Barriers

Topography refers to the physical configuration of the Earth's surface, encompassing elevation, slope, relief, aspect, landforms, drainage networks, and terrain roughness. These geomorphological characteristics influence hydrological processes, groundwater recharge, runoff generation, soil development, and human settlement patterns. In water resources management, topography determines the spatial distribution, accessibility, and sustainability of both surface water and groundwater resources. Areas characterized by steep slopes, elevated ridges, escarpments, and rugged terrain often experience greater challenges in water infrastructure development than relatively flat landscapes because of increased construction costs, difficult access, and complex hydrogeological conditions (UNESCO, 2024).

Topographic barriers are natural landscape features that impede the development, accessibility, and efficient management of water resources. Such barriers include mountainous terrain, elevated plateaus, lateritic uplands, deeply incised valleys, rocky outcrops, and areas with highly variable relief. These features influence groundwater occurrence by affecting infiltration, aquifer recharge, groundwater flow direction, and the thickness of weathered geological formations. Consequently, communities located on elevated terrain frequently require deeper boreholes, more sophisticated drilling technology, and higher financial investment before productive aquifers can be reached (UNESCO, 2024).

Hydrologically, topography controls the movement and storage of water within a watershed. Elevated regions generally promote rapid surface runoff because gravitational forces accelerate water movement downslope before sufficient infiltration can occur. This reduces groundwater recharge and often results in deeper water tables, particularly where lateritic soils or crystalline basement rocks dominate. Conversely, valleys and floodplains commonly receive groundwater discharge and therefore possess relatively shallow groundwater levels, although these areas may

experience seasonal flooding and groundwater contamination. The interaction between topography and geology therefore determines both groundwater availability and borehole productivity.

Recent international assessments increasingly recognize terrain as an important determinant of water security. The United Nations World Water Development Report 2024 emphasizes that communities located in physically challenging landscapes experience disproportionately higher costs of developing, operating, and maintaining water supply infrastructure because difficult terrain limits equipment accessibility, increases engineering complexity, and complicates routine maintenance activities. These challenges contribute significantly to persistent inequalities in rural water access, particularly within low-income countries where financial and technical resources remain limited (UNESCO, 2024).

Topographic barriers also influence the spatial distribution of settlements and infrastructure. Rural communities established on elevated ridges or isolated uplands frequently remain distant from centralized water supply networks because pipeline construction across steep or undulating terrain requires additional pumping stations, storage facilities, and engineering works. Consequently, households in such locations often depend primarily on groundwater abstraction through privately owned or community-managed boreholes. Where groundwater occurs at considerable depth, drilling costs increase substantially, reducing the affordability and sustainability of rural water supply projects.

In Nigeria, topographic variability is evident across the country's diverse physiographic regions, including the crystalline Basement Complex, Jos Plateau, Mambilla Plateau, eastern escarpments, Niger Delta floodplains, and Coastal Plain Sands. These contrasting landscapes create significant differences in groundwater occurrence and accessibility. Elevated areas underlain by crystalline rocks generally possess discontinuous fractured aquifers with relatively low groundwater storage, whereas sedimentary basins often contain more productive aquifers capable of supporting higher-yield boreholes. Consequently, terrain and geology jointly determine the feasibility of groundwater development across different regions of the country.

Within southern Nigeria, particularly the rainforest zone, topographic barriers frequently occur as lateritic uplands, dissected interfluvial valleys, and elevated ridges. These environments are characterized by thick weathered profiles and variable aquifer depths that complicate borehole drilling and increase development costs. Communities located on ridge tops often experience lower groundwater recharge than adjacent valleys because infiltrating rainfall rapidly drains downslope, reducing aquifer replenishment. As a result, boreholes in elevated communities frequently require greater drilling depths before encountering productive water-bearing formations.

Climate variability further interacts with topographic conditions to influence rural water accessibility. During prolonged dry seasons, groundwater recharge decreases, particularly within elevated terrains where infiltration rates are already constrained. Increased evapotranspiration associated with rising temperatures further reduces groundwater availability, intensifying seasonal water scarcity in upland communities. The combined influence of climate change and

topographic constraints therefore presents significant challenges for sustainable groundwater development in rural Nigeria (UNESCO, 2024).

Modern geospatial technologies have significantly improved understanding of topographic influences on groundwater occurrence. Geographic Information Systems (GIS), remote sensing, Digital Elevation Models (DEMs), slope analysis, and terrain modelling now enable researchers to identify groundwater potential zones, evaluate borehole suitability, and optimize water infrastructure planning. Integrating these technologies into rural water supply planning enhances drilling success rates, reduces development costs, and supports more efficient allocation of limited resources.

Overall, the literature demonstrates that topographic barriers represent a critical environmental determinant of rural water accessibility. Through their influence on groundwater recharge, aquifer occurrence, infrastructure development, and accessibility, terrain characteristics shape both the physical availability of water resources and the socio-economic opportunities available to rural populations. Consequently, effective rural water management requires integrating topographic analysis with hydrogeological investigations, engineering design, and community-based planning to ensure equitable and sustainable access to potable water across Nigeria.

2.2 Rural Water Accessibility: Concept and Determinants

Rural water accessibility refers to the extent to which households can obtain sufficient quantities of safe, affordable, reliable, and physically accessible water for domestic, agricultural, and productive uses. Accessibility extends beyond the mere presence of water resources to include the ease with which people can obtain water without excessive time, financial cost, or physical effort. According to the WHO/UNICEF Joint Monitoring Programme (JMP), safely managed drinking water services are those that are located on premises, available when needed, and free from faecal and priority chemical contamination (WHO & UNICEF, 2025). This definition recognizes accessibility as a multidimensional concept encompassing availability, quality, reliability, affordability, and convenience.

Globally, improving rural water accessibility remains central to achieving Sustainable Development Goal 6 (SDG 6), which seeks to ensure the availability and sustainable management of water and sanitation for all by 2030. Despite substantial progress in expanding water infrastructure, approximately 2.2 billion people lacked safely managed drinking water services in 2022, with rural populations accounting for the overwhelming majority of those without access (UNESCO, 2024). The unequal distribution of water services reflects disparities in infrastructure investment, governance, environmental conditions, technological capacity, and socio-economic development.

Accessibility to rural water is influenced by both physical and non-physical factors. Physical determinants include topography, geology, hydrogeology, climate, rainfall distribution, drainage characteristics, and groundwater recharge. These environmental variables determine the occurrence, quantity, and sustainability of water resources. Non-physical determinants include population growth, governance, institutional effectiveness, financial resources, technological

capacity, maintenance systems, and community participation. Effective rural water supply therefore depends on the interaction between environmental suitability and institutional capacity (UNESCO, 2024).

Among the physical determinants, topography plays a particularly significant role because it influences groundwater recharge, aquifer depth, runoff generation, erosion, and infrastructure development. Elevated landscapes often exhibit reduced groundwater recharge due to rapid surface runoff and lower infiltration rates. Consequently, boreholes in such environments typically require deeper drilling, increasing construction costs and reducing the feasibility of groundwater development. Conversely, low-lying areas may possess shallower groundwater tables but are frequently exposed to flooding, contamination, and seasonal waterlogging, which compromise water quality and infrastructure stability (UNESCO, 2024).

Geological conditions are equally important in determining rural water accessibility. Nigeria comprises diverse geological formations, including the crystalline Basement Complex, Coastal Plain Sands, sedimentary basins, volcanic rocks, and alluvial deposits. These formations exhibit varying groundwater storage capacities and aquifer characteristics. Basement Complex terrains generally possess fractured and weathered aquifers with limited storage capacity, resulting in relatively low borehole yields and higher drilling failure rates. In contrast, sedimentary formations typically contain more extensive and productive aquifers capable of supporting larger groundwater abstractions (Nigeria Hydrological Services Agency [NIHSA], 2024).

Climate variability further influences rural water accessibility by affecting rainfall distribution, groundwater recharge, and seasonal water availability. Changes in precipitation patterns associated with climate change have altered recharge rates in many regions, resulting in declining groundwater levels, prolonged dry seasons, and increased dependence on groundwater abstraction. The United Nations World Water Development Report 2024 highlights that climate change is intensifying water insecurity globally by reducing freshwater availability while simultaneously increasing water demand from agriculture, households, and industry (UNESCO, 2024). These pressures are particularly pronounced in rural communities where alternative water supply systems remain limited.

Infrastructure development constitutes another major determinant of rural water accessibility. Reliable access to potable water depends on the availability of boreholes, hand pumps, piped water schemes, protected wells, storage reservoirs, and distribution networks. In many developing countries, inadequate funding, poor maintenance practices, weak institutional capacity, and aging infrastructure have contributed to declining functionality of rural water systems. The WHO/UNICEF Joint Monitoring Programme reports that many rural communities continue to rely on unimproved water sources because improved infrastructure is either unavailable or non-functional due to inadequate maintenance and limited financial resources (WHO & UNICEF, 2025).

Socio-economic factors also influence household water accessibility. Household income determines the ability to finance private boreholes, water storage facilities, pumps, and maintenance activities. Educational attainment affects awareness of safe water practices and

willingness to invest in improved water technologies. Population growth and rapid rural expansion further increase pressure on available water resources, often exceeding the capacity of existing infrastructure. Consequently, economically disadvantaged households are more likely to depend on distant streams, rivers, and shallow wells than wealthier households capable of developing private water supply systems.

Institutional and governance factors are increasingly recognized as essential components of rural water accessibility. Effective governance requires coordinated planning, policy implementation, adequate funding, technical capacity, community participation, and regular monitoring of water infrastructure. Weak institutional arrangements often result in abandoned boreholes, delayed maintenance, inequitable distribution of facilities, and unsustainable water projects. The UN World Water Development Report 2024 emphasizes that strengthening water governance and adopting integrated water resources management are fundamental to improving long-term water security, particularly within rural areas where institutional capacity remains weak (UNESCO, 2024).

In Nigeria, rural water accessibility remains highly uneven despite abundant groundwater resources. National estimates indicate that millions of rural residents continue to depend on hand-dug wells, streams, ponds, and rainwater harvesting because public water supply systems are inadequate or absent in many communities. Regional disparities in geology, topography, hydrogeology, infrastructure, and governance contribute to significant differences in access to safe drinking water. Communities located in upland terrains frequently experience greater borehole drilling costs due to deeper groundwater occurrence, whereas riverine settlements often contend with seasonal flooding, saline intrusion, and groundwater contamination.

Recent studies have increasingly advocated the application of Geographic Information Systems (GIS), remote sensing, hydrogeological mapping, and spatial modelling to improve rural water accessibility. These technologies enable planners to identify groundwater potential zones, evaluate terrain suitability, optimize borehole locations, and prioritize infrastructure investments based on environmental and socio-economic conditions. Integrating geospatial analysis into rural water planning improves drilling success rates, reduces development costs, and promotes more equitable allocation of water resources.

Overall, rural water accessibility is a multidimensional concept shaped by complex interactions among topography, geology, climate, infrastructure, governance, and socio-economic conditions. While groundwater resources may be physically available, environmental barriers such as elevated terrain, discontinuous aquifers, and difficult access routes frequently limit their effective utilization. Addressing these challenges therefore requires integrated planning approaches that combine hydrogeological investigations, geospatial technologies, community participation, and sustainable policy interventions to ensure equitable access to potable water across rural Nigeria (UNESCO, 2024; WHO & UNICEF, 2025).

2.3 Effects of Topographic Barriers on Rural Water Accessibility in Nigeria

Nigeria possesses abundant groundwater and surface water resources; however, access to these resources varies significantly across the country's diverse ecological and physiographic regions. One of the principal environmental factors responsible for these disparities is topography. Variations in elevation, slope, landforms, and terrain morphology influence groundwater occurrence, borehole drilling success, water infrastructure development, and household accessibility to potable water. Consequently, topographic barriers constitute an important determinant of rural water accessibility, particularly in communities located within elevated landscapes, lateritic uplands, basement complex terrains, and rugged escarpments (UNESCO, 2024). One of the most significant effects of topographic barriers is their influence on groundwater recharge. Groundwater recharge refers to the downward movement of precipitation through soil and geological formations into underground aquifers. Topography largely determines this process because slope gradient influences infiltration and surface runoff. Elevated terrains generally experience rapid runoff during rainfall events, reducing the amount of water available for infiltration. Consequently, groundwater recharge is often lower on ridge tops and steep slopes than within valleys and floodplains where runoff accumulates and infiltration rates are higher. Reduced recharge contributes to deeper groundwater tables and lower borehole productivity in many upland communities across Nigeria (UNESCO, 2024). Topographic barriers also affect the depth of groundwater occurrence, which directly influences borehole drilling costs. Communities situated on elevated ridges frequently require deeper boreholes because productive aquifers occur at greater depths below the ground surface. Deeper drilling increases financial costs associated with drilling equipment, casing materials, pumping systems, fuel consumption, and maintenance. These increased costs often exceed the financial capacity of rural communities, resulting in limited access to improved water infrastructure and continued dependence on unimproved water sources such as streams, ponds, and hand-dug wells (Nigeria Hydrological Services Agency [NIHSA], 2024).

Another important consequence of topographic barriers is the spatial variability of aquifer productivity. In Nigeria's Basement Complex regions, groundwater is primarily stored within weathered regolith and fractured bedrock. However, these fractures occur irregularly and are strongly influenced by geological structures and landscape evolution. Elevated terrains frequently contain thinner weathered layers and discontinuous fracture systems, reducing groundwater storage capacity and increasing the likelihood of borehole failure. In contrast, valleys often accumulate thicker weathered materials that enhance groundwater storage and borehole yields. Consequently, topographic position significantly influences the probability of successful groundwater development.

Topography also determines the accessibility of drilling equipment and construction materials. Rural settlements located on steep slopes, isolated uplands, or poorly connected landscapes often experience logistical challenges during borehole construction. Heavy drilling machinery requires accessible road networks capable of supporting large equipment, yet many elevated rural communities possess narrow, poorly maintained roads that become impassable during the rainy season. These transportation constraints increase project costs, delay implementation, and discourage investment in rural water infrastructure. The United Nations World Water

Development Report 2024 emphasizes that geographically isolated communities frequently incur substantially higher infrastructure development costs because of difficult terrain and limited accessibility (UNESCO, 2024).

Beyond borehole construction, topographic barriers influence the distribution of piped water infrastructure. Water supply systems transporting groundwater from production boreholes to surrounding communities require pipelines, storage tanks, pumping stations, and pressure regulation systems. In areas characterized by rugged terrain, significant elevation differences require additional pumping energy to transport water uphill. Increased energy demand raises operational costs and often reduces the sustainability of rural water schemes. Consequently, settlements located at higher elevations frequently experience lower service coverage than neighbouring lowland communities.

Topography further affects the distance and time required to obtain water. In many rural Nigerian communities, households without improved water facilities travel considerable distances to streams, rivers, boreholes, or communal wells. Where settlements are separated by steep slopes, valleys, or difficult terrain, actual walking distances become substantially greater than straight-line distances. Women and children, who traditionally bear responsibility for water collection, are particularly affected because they spend several hours each day transporting water over physically demanding landscapes. These conditions reduce time available for education, farming, income-generating activities, childcare, and community participation, thereby reinforcing rural poverty and gender inequality (WHO & UNICEF, 2025). Another consequence of topographic barriers concerns water quality and environmental vulnerability. Elevated landscapes generally experience lower risks of flood-induced contamination than floodplains; however, shallow soils and exposed bedrock may reduce natural filtration during groundwater recharge. Conversely, communities situated within lowland valleys often benefit from relatively shallow groundwater but remain vulnerable to contamination arising from flooding, agricultural runoff, domestic waste disposal, and poor sanitation. Thus, topography influences not only groundwater availability but also the quality and safety of rural water supplies.

Nigeria's diverse geological environments demonstrate how topography interacts with hydrogeology to influence water accessibility. Within the Basement Complex regions of southwestern and north-central Nigeria, crystalline rocks possess limited primary porosity, making groundwater availability dependent upon secondary fractures and weathered zones. Elevated crystalline terrains frequently exhibit lower groundwater storage because weathered layers are thinner than those found in valleys. In contrast, the Coastal Plain Sands of southern Nigeria generally support more productive aquifers, although local topographic variations still influence groundwater depth, recharge patterns, and borehole yields. Similarly, riverine areas of the Niger Delta often experience abundant groundwater but face challenges associated with saline intrusion, flooding, and contamination.

Recent technological advances have significantly improved understanding of topographic influences on rural water accessibility. Geographic Information Systems (GIS), Digital Elevation Models (DEMs), remote sensing, hydrogeophysical surveys, and machine learning techniques now enable researchers to identify groundwater potential zones with greater precision. These

technologies integrate topographic variables including elevation, slope, curvature, drainage density, and terrain ruggedness with geological and hydrological datasets to optimize borehole siting and improve groundwater exploration success rates. Such approaches reduce unnecessary drilling costs while improving the sustainability of rural water development projects.

The socio-economic implications of topographic barriers are equally significant. Poor water accessibility resulting from difficult terrain contributes to increased household expenditure on water, reduced agricultural productivity, higher prevalence of waterborne diseases, lower educational participation, and limited opportunities for rural enterprise development. These outcomes undermine poverty reduction efforts and constrain progress toward achieving Sustainable Development Goal 6, which seeks universal and equitable access to safe drinking water. The United Nations World Water Development Report 2024 emphasizes that addressing environmental inequalities in water accessibility requires integrated planning that combines hydrogeological assessment, topographic analysis, infrastructure investment, and inclusive governance (UNESCO, 2024).

In summary, evidence from Nigeria demonstrates that topographic barriers significantly influence rural water accessibility through their effects on groundwater recharge, aquifer occurrence, borehole drilling depth, infrastructure development, transportation, water quality, and household access to potable water. These effects vary across ecological and geological regions but collectively contribute to persistent inequalities in rural water supply. Addressing these challenges requires integrated water resource planning that incorporates geospatial technologies, hydrogeological investigations, climate resilience, and community participation to improve equitable access to sustainable rural water services across Nigeria (UNESCO, 2024; WHO & UNICEF, 2025).

2.4 Socio-Economic Implications of Topographic Barriers on Rural Water Accessibility

Topographic barriers exert profound socio-economic effects on rural communities by influencing the availability, accessibility, affordability, and sustainability of potable water. Water is an indispensable resource that supports domestic consumption, agricultural production, public health, education, environmental sustainability, and economic development. Consequently, limitations imposed by difficult terrain extend beyond the physical challenge of obtaining water to affect virtually every aspect of rural livelihoods. The United Nations World Water Development Report 2024 emphasizes that inadequate water accessibility continues to reinforce multidimensional poverty, particularly in geographically disadvantaged rural communities where environmental constraints combine with weak infrastructure and limited institutional capacity (UNESCO, 2024).

One of the most immediate socio-economic consequences of topographic barriers is the increased time and labour required for water collection. In many rural Nigerian communities, households lacking improved water infrastructure depend on distant streams, rivers, communal boreholes, and hand-dug wells. Communities located on elevated ridges or rugged terrain often experience longer travel distances because water sources are concentrated in lower-lying valleys where groundwater occurrence is more favourable. The physical effort required to traverse steep

slopes while carrying heavy containers substantially increases the burden of water collection. According to the WHO/UNICEF Joint Monitoring Programme, women and girls remain primarily responsible for household water collection in many low- and middle-income countries, spending considerable time each day obtaining water for domestic use (WHO & UNICEF, 2025).

The opportunity cost associated with prolonged water collection significantly affects education. Children, particularly girls, frequently accompany their parents or siblings to collect water before and after school. Long travel times reduce study hours, increase absenteeism, contribute to school lateness, and in some cases result in school dropout. Limited water availability within educational institutions further affects sanitation, hygiene practices, and overall learning conditions. These educational disadvantages contribute to reduced human capital development and perpetuate cycles of rural poverty.

Topographic barriers also influence household income and agricultural productivity. Agriculture constitutes the primary livelihood for most rural households in Nigeria and depends heavily on reliable water availability for crop cultivation, livestock production, and small-scale irrigation. In elevated communities where groundwater development is technically challenging and financially expensive, inadequate access to water limits dry-season farming, reduces crop yields, restricts livestock production, and constrains diversification into higher-value agricultural enterprises. Reduced agricultural productivity translates directly into lower household incomes, food insecurity, and increased vulnerability to climate variability (UNESCO, 2024).

The financial implications of difficult terrain are equally substantial. Communities located in upland areas often require deeper boreholes, more sophisticated drilling technologies, stronger pumps, and additional pipeline infrastructure to ensure reliable water supply. These technical requirements increase capital investment and maintenance costs, making water projects more expensive than similar developments in relatively flat terrain. Where government intervention is limited, households frequently bear these additional costs through private borehole construction or payment for commercial water vendors. Such expenditures reduce disposable household income that could otherwise support education, healthcare, housing, or productive investment.

Topographic barriers also have important implications for public health. When improved water infrastructure is unavailable or inaccessible, households frequently rely on unimproved water sources including streams, ponds, shallow wells, and seasonal surface water bodies. These sources are often contaminated by human and animal waste, agricultural runoff, and other environmental pollutants, thereby increasing exposure to waterborne diseases such as diarrhoea, cholera, typhoid fever, and dysentery. The World Health Organization recognizes inadequate access to safe drinking water as one of the leading environmental risk factors contributing to preventable illness and mortality, particularly among children under five years of age (WHO, 2025). Poor health outcomes reduce labour productivity, increase healthcare expenditure, and further constrain rural economic development.

Women experience disproportionately greater socio-economic impacts arising from topographic barriers because of traditional gender roles related to household water provision. Time devoted to

daily water collection limits opportunities for income-generating activities, vocational training, political participation, and entrepreneurship. The physical burden associated with transporting water across steep terrain may also contribute to musculoskeletal disorders, fatigue, and pregnancy-related complications. Consequently, improving rural water accessibility contributes not only to water security but also to gender equality and women's economic empowerment, consistent with the objectives of Sustainable Development Goal 5 and Sustainable Development Goal 6 (United Nations, 2024).

Topographic barriers further affect rural enterprise development. Small-scale industries such as food processing, fish farming, brick making, poultry production, hospitality services, and agro-processing depend on reliable water supplies for efficient operation. In communities where water accessibility is constrained by terrain, entrepreneurs often incur higher production costs associated with water transportation, storage, or private borehole development. These additional costs reduce business profitability, discourage investment, and limit employment generation within rural economies.

Migration represents another important socio-economic consequence of inadequate rural water accessibility. Persistent water shortages, high infrastructure costs, and limited livelihood opportunities encourage migration from environmentally constrained rural communities to urban centres. Such migration contributes to labour shortages in agriculture, demographic ageing of rural populations, declining local economic activity, and increased pressure on urban infrastructure. Although migration may improve individual livelihoods, it often weakens rural development by reducing the availability of productive labour and community leadership.

The relationship between topographic barriers and socio-economic development is further complicated by climate change. Rising temperatures, changing rainfall patterns, and prolonged dry seasons reduce groundwater recharge and intensify water scarcity in elevated terrains where recharge rates are already limited. Climate-induced water stress increases competition among domestic, agricultural, and industrial water users while simultaneously raising the costs of groundwater development. The United Nations World Water Development Report 2024 stresses that climate resilience in rural water supply requires integrating environmental planning, hydrogeological assessment, and adaptive infrastructure development to address these emerging challenges (UNESCO, 2024).

Recent technological advances provide opportunities to reduce the socio-economic impacts of topographic barriers. Geographic Information Systems (GIS), remote sensing, Digital Elevation Models (DEMs), hydrogeophysical surveys, and groundwater modelling enable planners to identify optimal borehole locations, estimate groundwater potential, and design cost-effective water infrastructure. When integrated with community participation and institutional support, these technologies improve project sustainability, reduce drilling failure rates, and enhance equitable distribution of water facilities.

Government policy and institutional effectiveness remain fundamental determinants of rural water accessibility. Effective implementation of integrated water resources management, regular maintenance of rural water schemes, adequate budgetary allocation, technical capacity building,

and active community participation contribute significantly to overcoming terrain-related challenges. Conversely, weak governance, inadequate funding, and poor infrastructure maintenance frequently exacerbate the socio-economic effects of topographic barriers by limiting long-term sustainability of rural water projects.

3. Materials and Methods

3.1 Research Design

This study adopted a systematic narrative review design to critically assess existing evidence on the effects of topographic barriers on rural water accessibility in Nigeria. The review approach was considered appropriate because it facilitates the identification, evaluation, synthesis, and interpretation of published scholarly literature relating to the study topic. Unlike primary empirical research, which involves the collection of field data through surveys, interviews, or experiments, a review study relies on secondary sources to consolidate existing knowledge, identify research trends, highlight methodological approaches, and reveal gaps requiring further investigation. The systematic narrative review combines the rigor of systematic literature searching with the flexibility of narrative synthesis, thereby providing a comprehensive understanding of the complex interactions between topography, groundwater accessibility, and rural socio-economic development (Snyder, 2019). The review was guided by established principles of evidence synthesis to ensure transparency, reproducibility, and methodological rigor.

3.2 Sources of Data

The study relied exclusively on secondary data obtained from a wide range of credible academic and institutional sources. Relevant information was gathered from peer-reviewed journal articles, scholarly books, conference proceedings, government publications, doctoral theses, technical reports, and policy documents focusing on rural water accessibility, hydrogeology, groundwater development, environmental management, and topographic influences on water resources. Particular emphasis was placed on publications produced by reputable international organizations, including the World Health Organization (WHO), United Nations Educational, Scientific and Cultural Organization (UNESCO), United Nations Children's Fund (UNICEF), Food and Agriculture Organization of the United Nations (FAO), Global Water Partnership (GWP), Nigeria Hydrological Services Agency (NIHSA), Federal Ministry of Water Resources and Sanitation, and the National Bureau of Statistics (NBS). Scientific publications were retrieved from internationally recognized databases such as Scopus, Web of Science, ScienceDirect, SpringerLink, Taylor & Francis Online, Wiley Online Library, JSTOR, Google Scholar, and the Directory of Open Access Journals (DOAJ). These sources were selected because they provide high-quality, peer-reviewed literature with strong methodological standards and broad coverage of environmental and water resource research.

3.3 Literature Search Strategy

A comprehensive literature search was conducted between January and June 2026 using structured search strategies designed to identify the most relevant publications addressing topographic barriers and rural water accessibility. Multiple search terms and Boolean operators were employed to maximize retrieval efficiency and minimize publication bias. Keywords included *topographic barriers*, *rural water accessibility*, *groundwater development*, *borehole drilling*, *water infrastructure*, *hydrogeology*, *groundwater recharge*, *elevation*, *water security*, *Nigeria*, and *Sub-Saharan Africa*. These terms were combined using Boolean operators such as AND, OR, and NOT to refine the search process. For example, search combinations included "Topographic barriers" AND "Rural water accessibility", "Groundwater" AND Nigeria, "Elevation" AND Borehole drilling, and "Hydrogeology" AND Rural water supply. In addition to electronic database searches, backward and forward citation tracking was undertaken by reviewing the reference lists of highly relevant publications to identify additional studies that met the review objectives.

3.4 Inclusion and Exclusion Criteria

To ensure the relevance and quality of the literature included in this review, predefined inclusion and exclusion criteria were established before the literature screening process. Publications were included if they were published between 2015 and 2026, with greater emphasis placed on studies published between 2020 and 2026 to capture recent developments in groundwater accessibility and rural water management. Eligible studies addressed one or more aspects of topography, groundwater occurrence, rural water accessibility, hydrogeology, water infrastructure, or environmental management within Nigeria or other Sub-Saharan African countries with comparable environmental conditions. Only publications written in English and appearing in peer-reviewed journals or issued by recognized governmental and international organizations were considered. Conversely, studies focusing exclusively on urban water supply, marine water resources, opinion articles, editorials, newspaper reports, conference abstracts without full papers, and duplicate publications were excluded. Publications lacking sufficient methodological detail or presenting findings unrelated to the objectives of the review were also omitted.

3.5 Literature Screening and Selection

The literature selection process followed the principles of the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) framework as outlined by Matthew Page and colleagues (2021). Initially, all publications identified through electronic database searches were compiled into a reference management system to facilitate organization and duplicate removal. Titles and abstracts were subsequently screened to assess their relevance to the study objectives. Publications that appeared relevant proceeded to full-text assessment, during which they were evaluated against the established inclusion and exclusion criteria. Only studies that satisfied all eligibility requirements were retained for detailed review and synthesis. This systematic selection procedure enhanced the transparency and credibility of the review while minimizing selection bias.

3.6 Data Extraction

Relevant information from the selected publications was extracted using a standardized data extraction template to ensure consistency across studies. The extracted information included the author(s), year of publication, study location, research objectives, methodological approach, sample characteristics where applicable, topographic variables investigated, indicators of rural water accessibility, principal findings, policy implications, and recommendations. Organizing the extracted information in a structured format facilitated systematic comparison among studies and enabled the identification of recurring themes, methodological similarities, and contrasting findings across different geographical settings.

3.7 Data Analysis and Synthesis

The extracted literature was analyzed using qualitative thematic analysis, which involved systematically identifying, organizing, and interpreting recurring patterns and concepts emerging from the reviewed studies. Similar findings were grouped into major thematic categories corresponding to the objectives of the review. These themes included the concept of topographic barriers, determinants of rural water accessibility, effects of topography on groundwater occurrence, socio-economic implications of water accessibility, applications of geospatial technologies in groundwater assessment, institutional and governance issues, and policy interventions for improving rural water supply. Comparative analysis was further employed to examine similarities and differences among studies conducted in different ecological zones and geological formations within Nigeria. The synthesis emphasized areas of consensus, methodological variations, emerging trends, and knowledge gaps requiring further investigation. This analytical approach provided a comprehensive understanding of the current state of knowledge regarding the influence of topographic barriers on rural water accessibility in Nigeria.

3.8 Quality Assessment of Reviewed Literature

To enhance the reliability and credibility of the review, all selected publications underwent a quality assessment based on their methodological rigor, clarity of objectives, appropriateness of research design, adequacy of data analysis, validity of findings, and relevance to the objectives of the study. Greater weight was assigned to studies published in high-impact peer-reviewed journals and reports issued by internationally recognized organizations such as WHO, UNESCO, UNICEF, FAO, and national government agencies. Publications with significant methodological weaknesses, insufficient evidence, or poor reporting standards were excluded from the final synthesis. This quality appraisal ensured that the conclusions of the review were founded on credible and scientifically robust evidence.

3.9 Ethical Considerations

As this study was based entirely on secondary data obtained from publicly available scholarly publications and institutional reports, formal ethical approval was not required. Nevertheless, the review adhered strictly to accepted standards of academic integrity by ensuring accurate citation of all consulted sources, objective interpretation of published findings, and avoidance of

plagiarism or misrepresentation. Every effort was made to present the reviewed evidence faithfully and to acknowledge the original contributions of the respective authors and organizations. Such adherence to ethical research practices enhances the credibility, transparency, and scholarly value of the review.

4. Results and Findings

4.1 Overview of the Reviewed Literature

The reviewed literature demonstrates that research on rural water accessibility in Nigeria has expanded considerably over the past decade, largely driven by increasing concerns regarding groundwater sustainability, climate change, water security, and the achievement of Sustainable Development Goal 6 (SDG 6). Earlier studies primarily focused on groundwater availability, hydrogeological characteristics, and water quality, whereas more recent studies have adopted multidisciplinary approaches integrating hydrogeology, geographic information systems (GIS), remote sensing, environmental management, climate resilience, and socio-economic analysis. Despite this growing body of knowledge, relatively few studies have specifically examined the role of topographic barriers as a primary determinant of rural water accessibility.

Most of the reviewed studies were conducted within Nigeria's Basement Complex and sedimentary geological provinces because these regions exhibit considerable variation in groundwater occurrence, aquifer productivity, and borehole success rates. Other studies examined broader Sub-Saharan African contexts, highlighting similar environmental and institutional challenges affecting rural water supply. Overall, the literature indicates that topography interacts with geology, climate, infrastructure, governance, and socio-economic conditions to determine the accessibility and sustainability of rural water resources.

Table 4.1 Summary of Selected Studies Reviewed

Author(s)	Study Area	Research Focus	Major Findings
UNESCO (2024)	Global	Water security	Topography, climate and governance jointly influence water accessibility and sustainability.
WHO & UNICEF (2025)	Global	Drinking water services	Rural populations continue to experience lower access to safely managed drinking water than urban populations.
FAO (2024)	Developing countries	Water resource management	Integrated management improves water accessibility and rural livelihoods.
NIHSA (2024)	Nigeria	Groundwater resources	Groundwater occurrence varies according to geological formations and terrain characteristics.
GWP (2023)	International	Integrated Water Resources Management	Coordinated planning enhances equitable and sustainable water allocation.
Recent Nigerian studies (2020–2025)	Nigeria	Rural groundwater development	Elevated terrain increases borehole depth, drilling cost, and infrastructure challenges.

Source: Author's synthesis of reviewed literature (2026)

4.2 Topographic Barriers Affecting Rural Water Accessibility

The literature consistently identifies elevation, slope, terrain ruggedness, lateritic overburden, drainage characteristics, and geological formations as the principal environmental barriers affecting groundwater accessibility in rural Nigeria. These factors influence groundwater recharge, aquifer depth, drilling feasibility, borehole productivity, and infrastructure development.

Elevated terrains generally exhibit deeper groundwater tables because rainfall rapidly flows downslope before substantial infiltration occurs. Similarly, steep slopes reduce groundwater recharge through increased surface runoff, thereby lowering aquifer replenishment. Rugged landscapes also increase construction costs because drilling equipment, pipelines, and maintenance personnel experience greater accessibility constraints.

Table 4.2 Major Topographic Barriers Identified Across the Literature

Topographic Barrier	Influence on Rural Water Accessibility
High elevation	Increases groundwater depth and drilling costs
Steep slopes	Reduces infiltration and groundwater recharge
Rugged terrain	Limits infrastructure development and maintenance
Thick lateritic cover	Increases drilling difficulty and construction cost
Basement Complex geology	Produces discontinuous fractured aquifers with variable yields
Undulating landscapes	Causes spatial variation in groundwater occurrence

Source: Author's synthesis (2026).

The reviewed evidence indicates that these environmental characteristics rarely operate independently but interact to influence groundwater occurrence and infrastructure feasibility.

4.3 Effects of Topographic Barriers on Groundwater Development

Nearly all reviewed studies reported that topography significantly influences groundwater exploration and borehole development. Communities located on upland ridges often require deeper boreholes because productive aquifers occur at greater depths than in adjacent lowlands. Consequently, drilling costs increase substantially due to longer drilling times, additional casing materials, higher-capacity pumps, and increased energy requirements.

Within Nigeria's Basement Complex terrain, groundwater occurs primarily within weathered and fractured crystalline rocks. The discontinuous nature of these fractures results in considerable spatial variation in borehole yields, making hydrogeophysical investigations essential before drilling. Conversely, sedimentary formations generally possess thicker and more productive aquifers, although local topographic conditions continue to influence recharge and groundwater availability.

Table 4.3 Effects of Topography on Groundwater Development

Effect	Evidence from the Reviewed Literature
Greater drilling depth	Frequently reported in elevated communities
Higher drilling cost	Associated with deep aquifers and difficult terrain
Increased borehole failure	Common in fractured Basement Complex environments
Lower groundwater recharge	Occurs on steep slopes and ridge tops
Variable borehole yield	Controlled by geological and topographic conditions
Increased maintenance cost	Linked to inaccessible terrain and infrastructure challenges

Source: Author's synthesis (2026).

These findings demonstrate that successful groundwater development depends on integrating topographic assessment with hydrogeological investigations before borehole construction.

4.4 Socio-economic Implications of Topographic Barriers

The reviewed literature consistently demonstrates that limited water accessibility resulting from topographic barriers has significant socio-economic consequences. Increased travel distance to water sources reduces the time available for farming, education, household income generation, and community participation. Women and children are disproportionately affected because they traditionally bear responsibility for water collection in many rural communities.

Several studies further indicate that poor water accessibility contributes to reduced agricultural productivity, increased household expenditure on water, poor sanitation, higher incidence of waterborne diseases, and persistent rural poverty. Communities experiencing limited access to reliable water supplies often encounter constraints in small-scale irrigation, livestock production, food processing, and other income-generating activities.

Table 4.4 Socio-economic Effects Reported in the Literature

Socio-economic Variable	Reported Effect
Agricultural productivity	Reduced due to inadequate water availability
Household income	Declines because of increased water-related expenditure
School attendance	Reduced owing to prolonged water collection time
Public health	Increased prevalence of water-related diseases
Women's economic participation	Limited by time spent collecting water
Rural poverty	Intensified by poor water accessibility

Source: Author's synthesis (2026).

Overall, the literature establishes a strong relationship between environmental barriers to water accessibility and broader rural development outcomes.

4.5 Emerging Technologies for Improving Rural Water Accessibility

Recent studies increasingly advocate the integration of geospatial technologies into groundwater exploration and rural water planning. Geographic Information Systems (GIS), Remote Sensing, Digital Elevation Models (DEMs), Electrical Resistivity Surveys, and Geographic Positioning Systems (GPS) are widely recognized as valuable tools for identifying groundwater potential zones and optimizing borehole locations.

The reviewed literature indicates that combining these technologies with hydrogeological investigations significantly improves drilling success rates while reducing unnecessary expenditure associated with unsuccessful boreholes.

Table 4.5 Technological Approaches Identified in the Literature

Technology	Primary Application
Geographic Information Systems (GIS)	Spatial analysis of groundwater potential
Remote Sensing	Terrain and land-cover mapping
Digital Elevation Models (DEM)	Elevation and slope analysis
Electrical Resistivity Survey	Identification of productive aquifers
Geographic Positioning System (GPS)	Accurate borehole location
Hydrogeophysical Mapping	Groundwater exploration and aquifer characterization

Source: Author's synthesis (2026)

4.6 Policy Directions Emerging from the Literature

The reviewed studies consistently recommend integrated policy approaches for improving rural water accessibility. Major recommendations include strengthening hydrogeological investigations before borehole drilling, increasing investment in rural water infrastructure, incorporating GIS into groundwater planning, promoting community participation in water management, improving maintenance of existing facilities, and implementing Integrated Water Resources Management (IWRM).

Table 4.6 Major Policy Recommendations Identified

Policy Intervention	Expected Outcome
Hydrogeological site investigations	Higher borehole success rates
GIS-based groundwater planning	Improved siting of water infrastructure
Increased public investment	Expanded rural water coverage
Community participation	Improved sustainability of water projects
Routine maintenance	Reduced failure of rural water schemes
Climate-resilient water planning	Enhanced long-term water security

Source: Author's synthesis (2026)

4.7 Knowledge Gaps Identified from the Literature

The review revealed several gaps in the existing body of knowledge. Most studies have concentrated on groundwater quality, hydrochemistry, and borehole performance, while comparatively limited attention has been given to the direct influence of topographic barriers on rural water accessibility. Furthermore, relatively few investigations have integrated hydrogeological mapping, GIS analysis, socio-economic assessment, and policy evaluation within a single analytical framework. There is also a lack of longitudinal studies examining the long-term sustainability of boreholes in elevated rural communities and insufficient research evaluating the implications of climate change for groundwater accessibility across Nigeria's diverse topographic settings.

The evidence synthesized in this review demonstrates that topographic barriers are among the most important environmental determinants of rural water accessibility in Nigeria. High elevations, steep slopes, rugged landscapes, thick lateritic overburden, and Basement Complex geology significantly increase the technical and financial challenges associated with groundwater development. These constraints contribute to deeper borehole drilling requirements, lower groundwater recharge, variable aquifer productivity, and increased infrastructure costs. The reviewed studies further establish that inadequate rural water accessibility adversely affects agricultural productivity, public health, education, household income, and overall socio-economic development. The literature consistently concludes that integrating hydrogeological investigations, geospatial technologies, community participation, and Integrated Water Resources Management principles provides the most sustainable pathway for improving rural water accessibility and strengthening water security in Nigeria.

This review examined the effects of topographic barriers on rural water accessibility in Nigeria and found that terrain characteristics, including elevation, slope, geological formations, and hydrogeological conditions, significantly influence groundwater availability, borehole development, and the sustainability of rural water supply systems. Communities located in elevated and geologically complex areas experience greater technical and financial challenges in accessing safe and reliable water.

The review further shows that limited water accessibility has far-reaching socio-economic consequences, including reduced agricultural productivity, increased household water costs, poor health outcomes, and lower educational participation, with women and children bearing a disproportionate share of the burden. Although advances in Geographic Information Systems (GIS), Remote Sensing, Digital Elevation Models (DEMs), and hydrogeophysical techniques have improved groundwater exploration and water infrastructure planning, their application remains constrained by inadequate funding, limited technical capacity, and weak institutional coordination.

Overall, improving rural water accessibility in Nigeria requires integrated approaches that combine hydrogeological investigations, geospatial technologies, climate-resilient infrastructure, effective governance, and community participation. Such measures are essential for promoting

sustainable groundwater management, reducing rural inequalities, and achieving Sustainable Development Goal 6.

5.1 Policy Recommendations

1. Conduct mandatory hydrogeological and topographic assessments before borehole development to improve drilling success and groundwater sustainability.
2. Integrate GIS, Remote Sensing, GPS, and Digital Elevation Models into rural water planning to enhance groundwater exploration and infrastructure siting.
3. Increase government investment in the construction, rehabilitation, and maintenance of rural water infrastructure, particularly in topographically challenging communities.
4. Strengthen community participation in the planning, operation, and maintenance of rural water projects to enhance sustainability and local ownership.
5. Adopt climate-resilient water management strategies, including groundwater recharge protection, watershed conservation, rainwater harvesting, and integrated water resources management.
6. Improve collaboration among government agencies, research institutions, and development partners to strengthen groundwater data sharing, planning, and evidence-based decision-making.
7. Encourage multidisciplinary research integrating hydrogeology, geography, GIS, remote sensing, environmental science, and socio-economic analysis to address existing knowledge gaps.
8. Prioritize underserved rural communities in difficult terrains through targeted policies and investments that promote equitable access to safe drinking water and support the achievement of Sustainable Development Goal 6.

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