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A Review of the Hydrogeological Framework and Groundwater Resources Management in Nigeria: Current Status and Future Trend

Mu'awiya Baba Aminu*, Sangodiji Enoch Ezekiel, Rebecca Juliet Ayanwunmi , Anako Shefawu Onize[5], Daniel Chukwunonso Chukwudi[6], Changde Andrew Nanfa.

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Abstract: *This paper aims to review the limited groundwater data that is available, despite Nigeria's substantial surface and groundwater resources. It does this by highlighting recent findings and highlighting the impact of geological formations on the distribution and classification of groundwater across hydrogeological zones. The findings highlight how crucial it is to understand the hydrogeological features of each groundwater basin in order to manage and safeguard Nigeria's groundwater, which is more plentiful than its surface water resources and vital to its sustainability in the future.The groundwater resources is controlled by the local geological conditions, aquifers recharge, which influence well yields and amount of rainfall over the area. Major aquifers are dominantly in the sedimentary platform of Nigeria (above 50%).However, to meet up MDGs objectives,subsurface component must be inclusively in other make subsurface groundwater available for all Nigeria. The review also revealed poor hydrology and hydrogeology data are major problems in management of groundwater resources and sustainability in Nigeria.For essential sustainability, an extensive knowledge of resource management is required. Understanding the availability of groundwater and the mechanisms that recharge and renew it, reflects key sustainable exploitation of the resource. Hence this study tends to evaluates Nigeria groundwater resources potential and provides a framework of the hydrogeology.*

Keywords*: Groundwater resources, hydrogeology, aquifer recharge, water management, development goals.*

Mu'awiya Baba Aminu
School of Materials and Mineral Resources Engineering, Universiti Sains Malaysia, Nibong Tebal, Malaysia
Department of Geology, Federal University Lokoja, Kogi State, Nigeria
Email: **babaaminum@student.usm.my**, **Muawiya.babaaminu@fulokoja.edu.ng**
Orcid id: **https://orcid.org/0000-0001-5278-153X**

Sangodiji Enoch Ezekiel
Applied Geophysics, School of Earth and Mineral Sciences, Nigeria
Email: **enochezekiel@gmail.com**
Orcid id: **https://orcid.org/0009-0006-1879-7080**

Rebecca Juliet Ayanwunmi
Department of Earth and Environmental Science, Temple University, USA
Email: **rebeccaayanwunmi@gmail.com**
Orcid id: **https://orcid.org/0009-0000-2783-7853**

Anako Shefawu Onize
Department of Geology, Federal University Lokoja, Kogi State, Nigeria
Email: **shefawu.anako@fulokoja.edu.ng**
Orcid id: **https://orcid.org/0009-0005-2267-1731**

Daniel Chukwunonso Chukwudi
Department of Geography, Geology, and the Environment, College of Art and Sciences, Illinois State University, Hydrogeology, Illinois, Normal, United States of America
Email: **danielchukwudi2622@gmail.com**

Orcid id: https://orcid.org/0009-0006-0790-5891
Changde Andrew Nanfa
Department of Geology, Federal University Lokoja, Kogi State, Nigeria
Email: nanfa.changde@fulokoja.edu.ng
Orcid id: https://orcid.org/0009-0000-3729-9497

1.0 Introduction

Groundwater is a vital natural resource that plays a significant role in ensuring water security across both urban and rural regions. It accounts for a substantial portion of global freshwater supply—estimated to be nearly 100 times more abundant than surface water (Nwankwoala, 2011)—and is increasingly relied upon due to its relative reliability, resilience to seasonal variability, and cost-effectiveness (Akanni, 2024). In Nigeria, groundwater serves as a primary source of domestic and agricultural water, especially in areas where surface water is either unavailable or heavily polluted. Its importance is further amplified during the dry season when rivers and streams become ephemeral, and groundwater becomes the only dependable source of supply (Agboola & Hashemi, 2024).
Despite its critical role, groundwater resources in Nigeria remain poorly understood and under-managed. The country faces several challenges, including inadequate hydrogeological data, limited monitoring infrastructure, and uncoordinated resource management strategies (Adelana et al., 2008; Nwankwoala, 2015). Furthermore, the occurrence and productivity of groundwater in Nigeria are highly influenced by geological settings, aquifer types, rainfall patterns, and weathering processes, which vary significantly across the country's hydrogeological zones (Adelana & MacDonald, 2008; Zektser & Everett, 2004). While several studies have characterized individual aquifer systems or sedimentary basins, there is a lack of a synthesized, up-to-date national-scale review that integrates geological, hydrogeological, and management perspectives to guide sustainable development.

This knowledge gap is particularly critical given Nigeria's rising population, urban expansion, and the increasing pressures on freshwater availability. The absence of reliable and accessible groundwater data hinders policy formulation, resource allocation, and long-term planning to meet national development and sustainability goals, including those outlined in the Sustainable Development Goals (SDGs). Without an integrated framework, efforts toward effective groundwater utilization and protection are likely to be fragmented and unsustainable.

This review aims to evaluate the hydrogeological framework of Nigeria, examine the distribution and characteristics of its major aquifers, and assess the current status of groundwater resource management. By synthesizing existing data and identifying key gaps, the study provides a comprehensive baseline for improved groundwater governance. The significance of this study lies in its potential to inform decision-makers, researchers, and water managers on strategies for groundwater development, monitoring, and protection in the context of growing environmental and socioeconomic challenges. Ultimately, the review offers insight into how Nigeria can transition toward a more sustainable and scientifically guided groundwater management regime.

2.0 Study Location and Geological Description

2.1 Study Area and Climate Description

Nigeria is situated on the western coast of Africa, south of the Sahara Desert, between latitudes 4°N and 15°N and longitudes 3°E and 14°E. It is bordered to the north by the Republic of Niger, to the east by Cameroon, to the west by the Republic of Benin, and to the south by the Atlantic Ocean. Covering a total land area of approximately 923,768 square kilometers, Nigeria features diverse physiographic and climatic zones that influence hydrological and hydrogeological conditions across its territory (Nwankwoala, 2015).

The country experiences a wide variation in rainfall, both spatially and temporally. The southern coastal region receives year-round rainfall, while the northern regions are marked by a distinct wet and dry season. In the far northwest near the Niger Republic border, annual rainfall may be as low as 350 mm (Goni et al., 2001; Adelana et al., 2003). Rainfall distribution is a critical determinant of groundwater recharge, influencing both the quality and quantity of groundwater resources available.

2.1.1 Geological and Hydrogeological Framework

Nigeria is geologically located within the West African Craton and the Pan-African Mobile Belt. Its geology is broadly categorized into three major units: the Basement Complex, the Sedimentary Basins, and Volcanic and Alluvial formations. These formations play a crucial role in the occurrence, recharge, and distribution of groundwater resources across the country (Obaje, 2009; Mu'awiya et al., 2022a).

(a) Basement Complex

The Nigerian Basement Complex is composed mainly of Precambrian crystalline rocks, including schists, gneisses, granites, quartzites, and dioritic intrusions. These rocks are widespread in northern and southwestern Nigeria. Groundwater in this terrain is largely confined to secondary porosity formed by weathering and fracturing. Two main aquifer types are recognized: the weathered aquifer with a mean yield of about 1 L/s and the weathered/fractured aquifer with a mean yield of 2.8 L/s. Optimal drilling depths range from 60 to 70 meters (Nwankwoala, 2015). These aquifers are typically unconfined to semi-confined and vary significantly in productivity due to local lithological and structural conditions (Nanfa et al., 2022).

(b) Sedimentary Basins

Nigeria has seven major sedimentary basins: the Sokoto Basin, Chad Basin (Bornu), Benue Trough, Niger Delta Basin, Dahomey Basin, Calabar Flank, and the Mid-Niger (Nupe) Basin (Obaje, 2009; Nwajide, 2013; Aigbadon et al., 2023). These basins consist of formations such as shales, sandstones, siltstones, limestones, and gravels, deposited under varying marine, fluvial, and deltaic conditions.

The Sokoto Basin (northwest Nigeria) features sedimentary rocks of Cretaceous to Tertiary age, gently dipping northwestward.

The Bornu-Chad Basin (northeast) includes the Albian-age Bima Sandstone, which hosts fluviatile and deltaic aquifers.

The Benue Trough is a linear NE-SW trending basin with well-developed Cretaceous sediments, including the Bima, Yolde, and Gombe formations (Offodile, 1989).

The Niger Delta and Lagos-Osse Basins contain Tertiary formations with high-yielding aquifers, important for urban water supply in the southern regions.

Aquifers in these basins are generally more productive than those in the basement complex and exhibit better recharge characteristics due to higher porosity and permeability.

(c) Volcanic Plateau

The Jos Plateau and surrounding uplands in central Nigeria are underlain by volcanic rocks, including basalt, tuff, rhyolite, and trachyte. These rocks, formed from extensive lava flows, are often interbedded with coarse alluvial deposits. The volcanic terrains, such as the Sugu Plateau, may contain perched aquifers within weathered and fractured lava flows, but their hydraulic properties vary significantly. According to Akujieze et al. (2003), these areas comprise the Fluvio-Volcanic Series, with variable groundwater potential depending on local stratigraphy and structure.

(d) River Alluvium

Alluvial deposits along river valleys—especially the Niger, Benue, and their tributaries—consist of unconsolidated sand, silt, clay, and gravel. These deposits form highly permeable aquifers, particularly in low-gradient river sections where thick layers of coarse sediments occur. The thickness and extent of these alluvial formations vary with the nature of the river system. For example, in many northern rivers, thick coarse sand beds underlie floodplains, forming important shallow aquifers with high recharge potential (Du Preez and Barber, 1965; Mu'awiya et al., 2022).

Each of these geological settings plays a distinct role in groundwater occurrence and management in Nigeria. The sedimentary basins offer the most productive and reliable aquifers, while the basement complex terrains are more heterogeneous and yield variable water quantities. Understanding the spatial distribution of aquifer types, their recharge mechanisms, lithological controls, and groundwater yield is crucial for sustainable exploitation and planning. This geological diversity underscores the need for region-specific groundwater development and management policies to meet the increasing water demands across the country.

2.1.2 Hydrogeological Significance

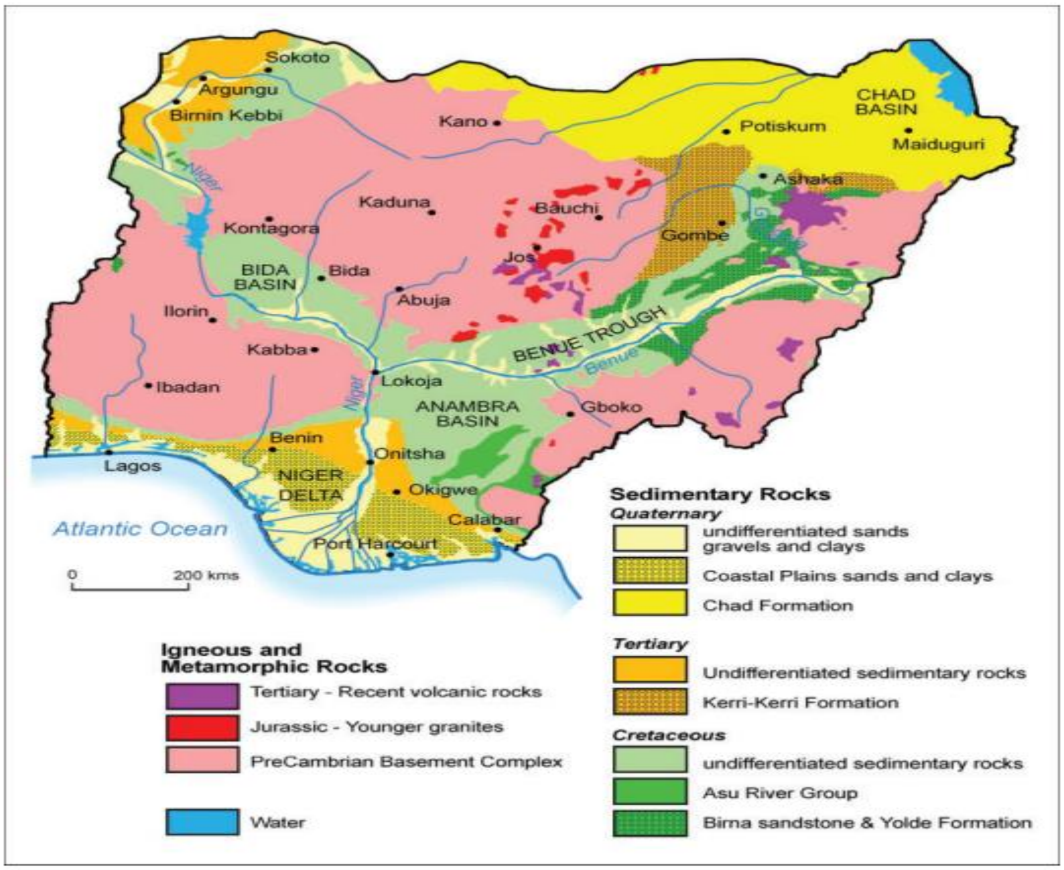

Fig. 1: Geological map with groundwater Provinces (adapted from Adelana et al., 2008)

3.0 Hydrogeology and Groundwater Occurrence in Nigeria

Nigeria relies heavily on groundwater for domestic and agricultural purposes, and its distribution and flow are controlled by hydrological and meteorological factors, such as rainfall and stream flow, as well as geological factors, such as the lithology, texture, and structure of the rocks. The geology of the region affects the groundwater's occurrence. Groundwater can be found in the fresh crystalline rock fissures and the weathered regolith of the Basement Complex environment. In regions with extensive weathered zones or fractures in fresh rock, wells and boreholes draw water from the earth. Groundwater development in the Basement Complex locations has been completely transformed by the combination of down-the-hole hammer and surface geophysical techniques.

Nowadays, a lot of villages use motorized or hand pumps to draw water from boreholes (Eduvie, 2006). Boreholes and hand-dug wells can be used to harvest groundwater from aquifers, which are permeable geological formations having properties that allow water to be stored and transferred through them. Two types of groundwater were formed by Nigeria's geological structure: pore-type water found in sedimentary cover and fissure-type water found in crystalline rocks (Eduvie, 2006). There are three types of aquifers in Nigeria: i) water with pores found in sedimentary deposits; ii) water with fissures found in Precambrian crystalline rocks; and iii) water with holes found in superficial layers.

Fig. 2: Hydrogeological province highlightingthe relative permeability and runoff potential (BUK, 2024; Tanko et al., 2021).

The distribution of aquifers in Nigeria are well described in Table 1. The Nigeria's groundwater potential is much greater than its surface water resources, with an estimated 224 trillion liters annually (Hanidu, 1990). According to Rijswlk (1981), Nigeria's groundwater resources at a depth of 0–50 meters are 6 x 10km3 (6 x 1018m^3). Akujieze et al. (2003) state that there are eight mega regional aquifers ranging in depth from 0 to 630 meters below ground level, with an average depth of 220 meters, and a viable average thickness range of 360 meters, with thickness ranges of 15 to 3,000 meters.Among the eight regional aquifer the Ajali and Benin sandstone units produces above 8.0 litres/secondAbout 40% of the nation is made up of huge sedimentary basins with significant groundwater reserves. Sedimentary basins make about 67% of the projected 51.93 x109 m^3 of potential yearly groundwater resources (Nwankwoala, 2015). The National Water Resources Master Plan, completed in 1995, estimates that each year there are fifty-two billion cubic meters of replenishable output from groundwater resources and about Two hundred and sixty-seven billion cubic meters of surface water. Sedimentary basins usually contain the most abundant aquifers.

The water table typically ranges from 15 to 75 meters deep in the Sokoto basin's unconfined portions (Adelana and Vrbka, 2005). Artesian conditions can be found in 75-100 m deep limited aquifers around Argungu. For Chad basin, three primary aquifers are being discovered, artesian conditions are also present: (i) an upper aquifer that is between 30 and 100 meters deep; (ii) a middle aquifer in the eastern portion of the basin, which is between 40 and 100 meters thick and 230 meters deep and (iii) a lower aquifer, which is composed of 100 meters of medium to coarse sands and clays and is between 425 and 530 meters deep.; though aquifer i-ii are heavily exploited(Nwankwoala, 2015). Groundwater levels in the aquifers of the Chad basin have recently dropped, making deeper drilling necessary to reach the lower aquifer (Goni, 2008). Coarse Cretaceous sandstones throughout the Anambra and Bida Basin provide an excellent aquifer that is mostly unconfined in the north but develops artesian in the south (UN, 1988). The average depth of groundwater is between 60 and 150 meters. Nigeria's hydro-geological regions and its regional aquifer systems and yields are shown in Tables 1 and 2.

Estimates for Groundwater Recharge and Hydrology It is predicted that 263 km^3 of surface water flow annually from Nigeria to the sea (FAO, 2005). The Niger and Benue are transboundary waterways that are the largest of Nigeria's water bodies. Floods in the Niger River Basin, which includes the Benue, are influenced by external factors and discharges as far to Republic of Guinea's Futa Jalon Mountains' foothills that could wind up in Nigeria's Niger Delta. Eight continuous hydrological basins known as Hydrological Areas are described diagrammatically (Fig. 3).

Finally, Table 1 provides a summary of major aquifer systems within Nigeria's sedimentary basins, along with their respective groundwater yield ranges, expressed in litres per second (L/s). The productivity of these aquifers varies significantly, reflecting differences in geological formation, porosity, and recharge capacity. For instance, the Lower Chad Formation shows relatively high yields (10–35 L/s), indicating its potential for large-scale groundwater exploitation. In contrast, the Kerri Kerri Formation exhibits lower productivity (1.25–9.5 L/s), implying limited yield suitability for intensive use. The Ajali and Benin Formations, widely exploited across southeastern and southwestern Nigeria respectively, demonstrate moderate yields (7–10 L/s and 6–9 L/s). Notably, the crystalline fluvio-volcanic aquifer, likely representing fractured basement rocks mixed with volcanic materials, has a yield of 15 L/s, showcasing the role of secondary porosity in crystalline terrains.

Also, Table 2 outlines the areal distribution of Nigeria's major hydrogeological zones, classified broadly into sedimentary basins and crystalline basement areas. The largest hydrogeological unit is the Crystalline Rock Area, covering approximately 445,100 km^2**,** which spans much of the southern, western, and northern parts of the country. Among the sedimentary areas, the Chad Basin and Benue Basin are the most extensive, covering 120,400 km² and 116,300 km², respectively. These data provide a spatial framework for groundwater resource assessment and planning, as different regions require unique strategies based on the extent and characteristics of the underlying hydrogeological systems. Collectively, the total area covered by these hydrogeological zones is 923,800 km², which approximates the total landmass of Nigeria, indicating nationwide aquifer coverage.

Table 1: Geological aquifer systems and yields in Nigeria (adopted after Akujieze et al., 2003)

Major aquifers in Nigeria sedimentary basin	Productivity/discharge rate (Litres/ seconds)
Ajali Formation (sandstone units)	7 – 10
Benin Formation (sands and sandstone units) aquifer	6 - 9
The Upper Chad Formation	2.5 – 30
The Middle Chad Formation	24 – 32
The Lower Chad Formation	10 – 35
The Gwandu Formation (sandstone aquifer)	8 - 15
The Kerri kerri Formation (sandstone units)	1.25 - 9.5
The crystalline fluvio–volcanic aquifer	15

Table 2: List of hydro-geological Areas of Nigeria (After FMWRRD, 1995)

	Sector	Area (km2)
1	Sokoto Sedimentary Area- Sokoto Basin	63,700
2	Chad Sedimentary Area- Chad Basin	120,400
3	Upper Niger Sedimentary Area-Niger Basin	38,300
4	Benue Sedimentary Area- Benue Basin	116,300
5	Ogun / Osun Sedimentary Area- South Western Zone	110, 200
6	Lower Niger Sedimentary Area- South Central	110,300
7	Cross River Sedimentary Area- South Eastern zone	29,700
8	Crystalline Rock Area- Basement Complex Area in the southern, western and northern parts of Nigeria	445,100`
	TOTAL	923,800

3.1 Nigeria's River Basin Development Agencies (RBDAs)

The operations of the River Basin Development Authorities (RBDAs) are currently guided by the RBDA Act, as outlined in Section 396 of the Laws of the Federation of Nigeria (1990). They are tasked with the responsibility of planning, development, and control of water storage facilities for domestic and industrial use.To keep an eye on and oversee operations in the management units and river catchments, Nigeria has eleven River Basin Development Authorities (RBDAs). The RBDAs lack the scope and coverage of hydro-geological units necessary to enable effective groundwater management.

Nigerian water management is characterized by decentralization, which results in various ministries and organizations operating at various levels and enforcing laws without sufficient coordination (FAO, 2005). The River Basin Development Authorities Act No. 35 of 1986 outlines the RBDAs' irrigation-related responsibilities. Surface water and groundwater have traditionally institutionally separated, which has led to basic communication hurdles between technical experts, policymakers, operational managers, and water consumers. Understanding the mechanisms and effects of groundwater-surface water interactions is hampered by these obstacles (Owen et al., 2008).

An in-depth review of Nigeria's hydrological zones, alongside River Basin Development Authorities (RBDAs), and related groundwater systems shows that the country has struggled to establish a steady and adequate supply of water due to its excessive reliance on surface water alone, without utilizing its groundwater resources.

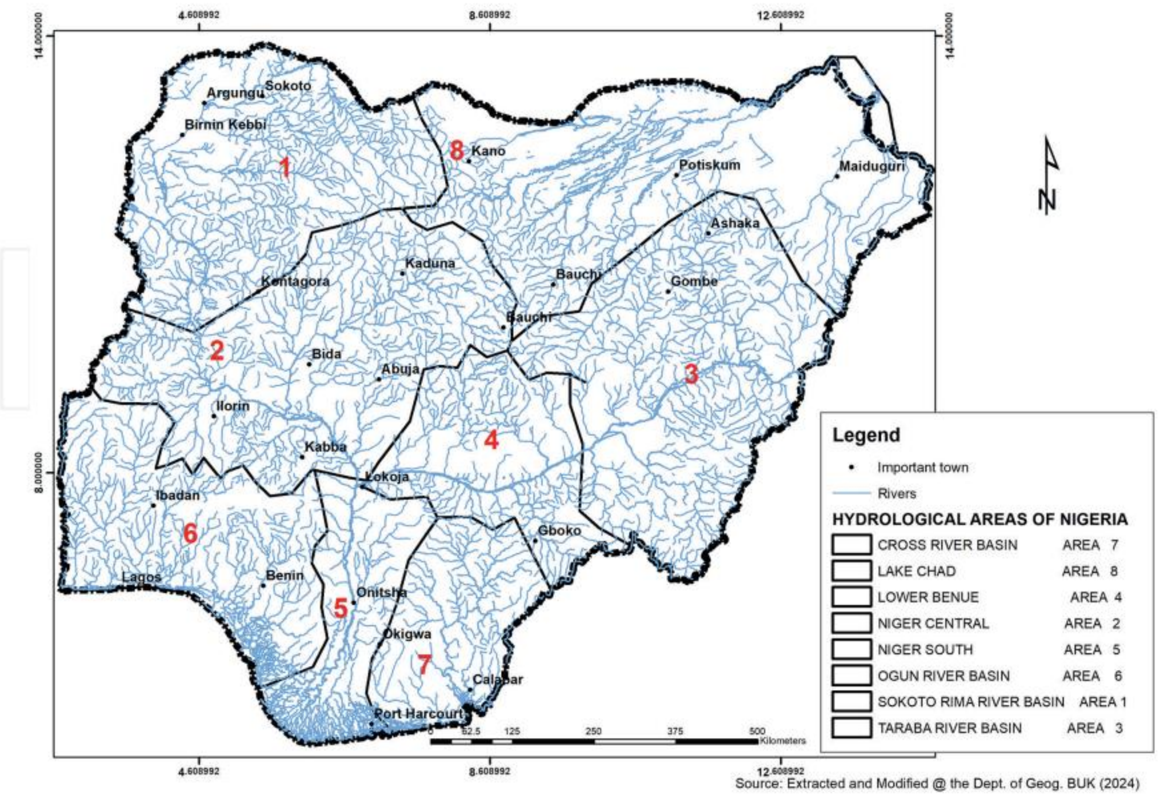

Fig.3: The River Basins and their hydrological areas in Nigeria (Nwankwoala, 2015)

Table 3 presents an overview of Nigeria's major regional groundwater basins and their corresponding development authorities. These river basin authorities were established to manage water resources within their respective hydrological and geological domains. The table categorizes each authority based on its geographic jurisdiction and the underlying geological formations that control the distribution, availability, and productivity of groundwater in that area. This classification provides valuable insight into the hydrogeological diversity across Nigeria and highlights the need for region-specific groundwater development strategies, especially in the context of increasing water demand, population growth, and climate variability.

The table identifies ten major river basin development authorities in Nigeria, each associated with distinct hydrogeological units. These units include sedimentary basins of varying geologic ages (Cretaceous, Tertiary), confined and unconfined aquifers, alluvial deposits, and parts of the crystalline basement complex.

For instance, the Sokoto Rima River Basin Authority governs areas underlain by both Cretaceous and Tertiary sediments of the Sokoto Basin, which are known to host productive confined aquifers. These formations typically provide good groundwater yields and support both domestic and agricultural water use in northwestern Nigeria.

Similarly, the Lake Chad Basin Authority encompasses both confined and unconfined aquifers of the Chad Basin. The unconfined aquifers in this region are relatively accessible and recharged seasonally by rainfall, while the deeper confined aquifers contain fossil groundwater that is less renewable but often tapped for large-scale irrigation.

The Hadejia-Jama'are River Basin spans a more complex geological environment, incorporating unconfined Chad Basin aquifers, sections of the Keri Keri Formation, and parts of the Basement Complex. This diversity introduces variability in groundwater quality and yield, requiring integrated management approaches that account for both sedimentary and crystalline hydrogeology. The Niger River Basin Authority covers areas with river course alluvium, Nupe Sandstone, and parts of the Basement Complex. This mixed hydrogeological setting reflects the composite nature of many Nigerian river basins where both primary porosity (in sandstones and alluvium) and secondary porosity (in fractured basement rocks) coexist.

In the southern part of the country, the Niger Delta Basin, Ogun-Osun Basin, and Cross River Basin are largely underlain by coastal sedimentary and alluvial deposits. These formations often support high-yielding aquifers due to their high permeability, making them vital for urban water supply in rapidly growing cities such as Port Harcourt, Calabar, and Lagos.

Notably, the Benue River Basin is listed under "Coastal Sedimentary," which may be an oversimplification. Geologically, much of the Benue Trough consists of Cretaceous sediments with complex structural and stratigraphic characteristics, suggesting the need for more precise hydrogeological delineation in planning groundwater development.

This table thus illustrates the spatial variability of aquifer systems across Nigeria and emphasizes the importance of aligning basin development policies with geological realities. It also underscores the need for inter-agency coordination between geological surveys and river basin authorities to ensure effective groundwater governance, particularly as the impacts of climate change intensify water stress in many regions.

3.3 Economics of groundwater resources /future perspectives

Water resources in Nigeria, such as surface water, groundwater, and rainwater, are available in different amounts depending on the location. The groundwater supply is the least of these, but it is also the most plentiful, dependable, and affordable to use. There aren't many studies that show how important groundwater resources are to achieving the UN Millennium Goals, such lowering the number of malnourished people by 2015. despite the fact that access to drinking water is frequently linked to poverty (Llamas, 2005). The MDGs are already being met in large part because to groundwater. Over the past few decades, the area that is irrigated by groundwater has grown by more than 40 million hectares (Deb Roy & Shah 2003).

Table 3: Associated Regional Ground Water Basin and their Development Authorities (Nwankwoala, 2015)

S/N	River Basin Development Authority	Associated Groundwater Basin
1	Sokoto Rima River Basin Authority	Sokoto Basin (Tertiary) Sokoto Basin (Cretaceous)
2	Hadejia-Jamare River Basin	Chad Basin (Unconfined) Part of the Basement Complex Part of the Keri Keri Basin
3	Lake Chad Basin	Chad Basin (Unconfined) Chad Basin (Confined)
4	Upper Benue River Basin	Part of Keri Keri Basin Part of Benue Basin
5	Cross River Basin	Coastal Sedimentary Cross River Basin
6	Anambra-Imo River Basin	Part of River Course Alluvium Anambra Basin
7	Niger River Basin	Part of River Course Alluvium Nupe Sandstone Part of Basement
8	Ogun-Oshun River Basin	Coastal Sedimentary
9	Benue River Basin	Coastal Sedimentary
10	Niger Delta	Coastal Alluvium Mangrove Coastal Sedimentary

Groundwater remains available during periods of drought, it has played a significant role in improving the livelihoods of farmers in dryland regions globally (Moench, 2003; Steenberger & Shah, 2003). Its reliability during dry spells helps reduce the uncertainty farmers face, encouraging them to adopt innovative agricultural practices—such as improved seed varieties, chemical inputs, and efficient irrigation systems like drip technology. The resulting boost in farm income often contributes to better living standards and community well-being. Moreover, experts in Agricultural sciences should encourage their wards/ children to pursue careers in agricultural courses. In addition to high-level water decision-makers, hydro-geological education seems to be essential for the general population and, more crucially, farmers, who are typically the primary users and polluters of groundwater. Large surface water infrastructure construction and operation have historically been the focus of training for water managers and decision-makers. Because of this, groundwater resources are frequently undervalued or even ignored. This could explain why there is a widespread deficiency of reliable groundwater data (Agboola et al., 2024). Furthermore, it seems to be the cause of the significant distance that now exists between the key players and water decision-makers.

This situation allows illicit conduct. It is very challenging to present a 'overall roadmap to subsurface long-term viability' as meeting with the requirements might not be feasible in many instances. One of the most often cited aspects of "sustainability" is that before beginning any development, the possible demands of the future should be considered.In Nigeria, where inadequate planning, institutional negligence, and uncontrolled private use have resulted in unsustainable extraction and data gaps, enhanced public awareness, accountability, and education are particularly important for protecting groundwater for future use (Adetoro & Akanni, 2018).

4.0 Conclusion

For both urban and rural communities to have dependable and affordable water supply, groundwater is needed. It comprises water that is found below the water table, above the water table (capillary fringe), and in the unsaturated zone (soil). Groundwater resources, and the certainty of their sustainable future, have lagged behind in fundamental areas such as traditional and non- traditional education regarding subsurface water use, understanding the properties of subsurface resources, effective public policies, the government's role as a regulator of social water use, the population's increasing poverty, and a lack of user involvement in resource management. Despite the fact that groundwater is essential to human health and the health of many ecosystems, it is still not properly understood, regulated, or protected on a national and regional level.

It is commonly known that groundwater basins are challenging to control and regulate, in part due to inadequate information and in part to the resource's low visibility. As such, any strategy supporting water resource planning must have accurate information, trustworthy data, and the right kind of expertise. Monitoring the amount and quality of the country's water resources should be a priority as part of the numerous plans and programs for their development.

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