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INVISIBLE BUT INDISPENSABLE: GROUNDWATER, WELLS, AND THE ENVIRONMENTAL LEGACY WE MUST BUILD

BY:

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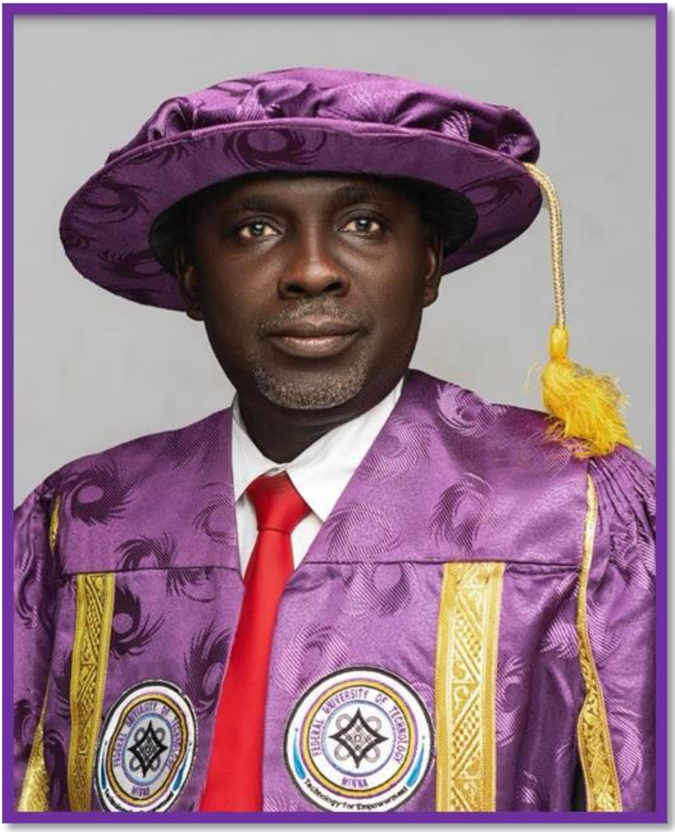

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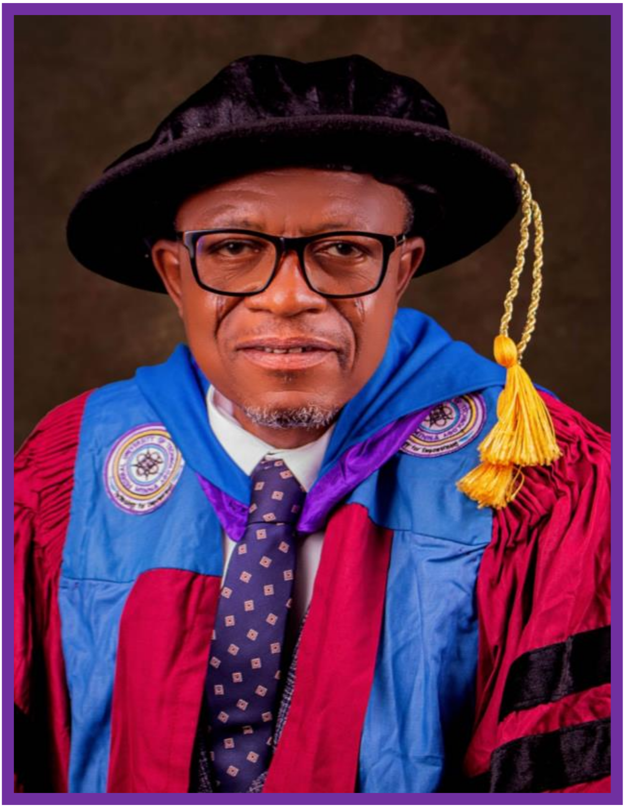

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1.0 BACKGROUND

Water is fundamental to the survival of mankind and has played critical roles in the management of our ecosystem. Water predominates the earth's surface and covers 71.4% of the Earth. Fresh groundwater is the source of 30.1% of all fresh water on Earth. (Fitts, 2002) and contributes 95% of available freshwater. 97% of the water on the Earth is salt water and only 3% is fresh water; slightly over two thirds of this is frozen in glaciers and polar ice caps.
The remaining unfrozen freshwater is found mainly as groundwater, with only a small fraction present above ground or in the air (Figure 1). Groundwater is often called a 'hidden resource' because it cannot be seen in the same way as water in a river, lake, or reservoir. The volumes of groundwater are large; however, it is estimated that there is about one hundred times fresher groundwater on earth than all the fresh water in rivers and lakes (Shiklomanov, 1998). As a result, groundwater is an important source of much of the water used for drinking and irrigation.

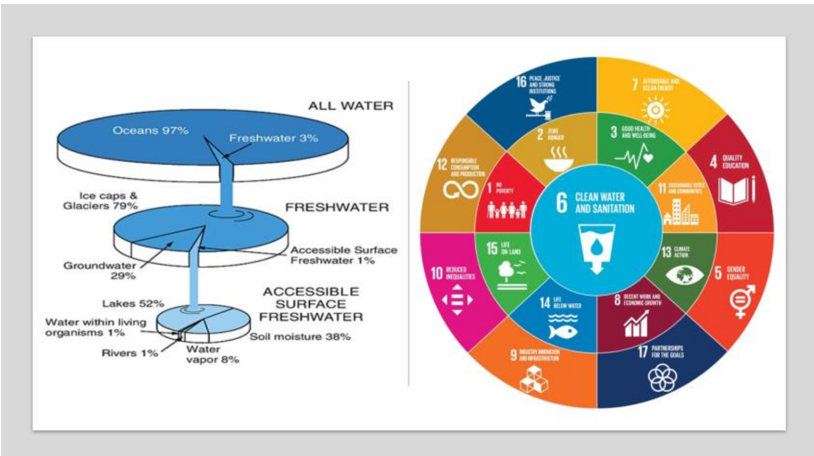

Figure 1: World water resources and the Sustainable Development Goals (https://images.slideplayer.com/39/10933970/slides/slide_3.jpg 2020)

Groundwater is the world's most important source of freshwater. It supplies 2 billion people with drinking water and is used for irrigation of the largest share of the world's food supply.

Groundwater plays a very important role in Engineering, Agriculture, Environmental protection, and can help achieve Goals 1; No Poverty, 2; Zero Hunger, 3; Good Health and Well-being, 4; Quality Education, 6; Clean Water and Sanitation, 11; Sustainable Cities and Communities, 12; Responsible Production and Consumptions, 15; Life on Land, and 17; Partnerships to achieve the Goals. Groundwater is thus fundamental to achieving 9 out of the 17 Goals (Figure 1).

The amount of water on, under, and above the earth's surface remains essentially constant. Although a minor amount of water vapor may escape into space, additional new water is constantly created as juvenile water by chemical reactions during volcanic emissions.

The water cycle (Figure 3) describes how water evaporates from the surface of the earth, rises into the atmosphere, cools, and condenses into rain or snow in clouds, and falls again to the surface as precipitation. The water falling on land collects in rivers and lakes, soils, and porous layers of rock, and much of it flows back into the oceans where it will once more evaporate and restart the cycle.

The mass of water on Earth remains fairly constant over time but the partitioning of the water into the major reservoirs of ice, fresh water, saline water, and atmospheric water is variable depending on a wide

range of climatic variables. The water moves from one reservoir to another, such as from river to ocean, or from the ocean to the atmosphere, by the physical processes of evaporation, condensation, precipitation, infiltration, runoff, and subsurface flow.
Some of the water that falls as rain will be returned back to the atmosphere through processes collectively known as water losses. Depending on the intensity of the rainfall, some of the water immediately starts to percolate into the ground and once the ground is saturated the water begins to flow on the surface as runoff which eventually joins rivers, streams and ultimately to the ocean. Interfering with any part of the cycle can lead to serious consequences like flooding, groundwater depletion, loss of ecosystems, gullying, erosion, and other disastrous environmental problems.

Groundwater is a finite resource, and aquifers can become depleted when extraction rates exceed recharge rates. Despite the huge importance of groundwater, it has been understood poorly and undervalued. Groundwater management requires reliable aquifer characterization, planning, and sustainable development.

2.0 BASIC CONCEPTS OF GROUNDWATER

2.1 Groundwater

Groundwater is water that exists in pore spaces and fractures in rocks and sediments beneath the Earth's surface. It originates as rainfall or snow and then moves through the soil and rock into the groundwater system, where it eventually makes its way back to the surface streams, lakes, or oceans.
Groundwater may be found in one continuous body or in several distinct rock or sediment layers at any one location.

Thickness of the groundwater is governed by:

1. Local geology

2. Availability of pores or openings in the rock formation
3. Recharge
4. Water movement from areas of recharge towards points or areas of discharge.

Groundwater occurs in many types of geological formations; those known as aquifers are of the utmost importance. An aquifer may be defined as a formation that contains sufficient saturated permeable material to yield significant quantities of water to wells and springs. This implies an ability to store and to transmit water; unconsolidated sands and gravel are a typical example. Generally, aquifers are really extensive with well-developed inter-connecting voids and good permeability, such as various sands, gravel, and hard rock with fissure and karst caves. Aquifers may be overlain or underlain by a confined bed, which may be defined as a relatively impermeable material stratigraphically adjacent to one or more aquifers.

There are several types of confining beds: Aquiclude – a saturated but relatively impermeable material that does not yield appreciable quantities of water to wells, such as clay. Aquifuge – a relatively impermeable formation neither containing nor transmitting water, such as solid granite. Aquitard – a saturated but poorly permeable stratum that impedes groundwater movement and does not yield water freely to wells and may transmit appreciable water to or from storage zone, such as sandy clay.

An aquifer serves two functions, one as a conduit through which flows occur, and the other as a storage reservoir. This is accomplished by means of openings in the rock. The openings include those between individual grains and those present in joints, fractures, tunnels, and solution openings (Figure 3).

There are also artificial openings, such as engineering works, abandoned wells, and mines. The openings are primary if they were formed at the time the rock was deposited and secondary if they developed after lithification.

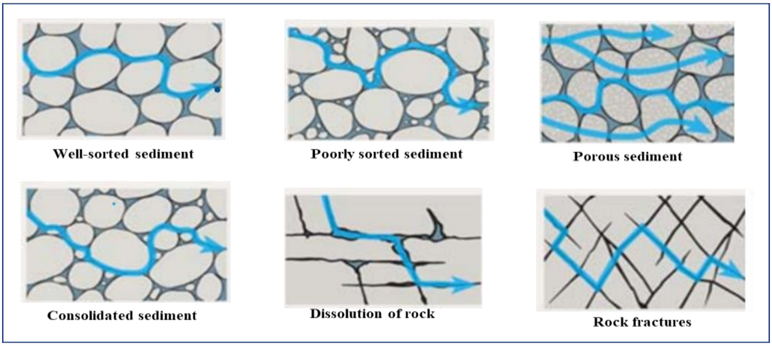

Figure 2: Groundwater occurrence in pore spaces of soil and rock fissures

2.2 Groundwater Recharge

Groundwater is recharged naturally by rain and snow melt and to a smaller extent by surface water (rivers and lakes). Recharge may be impeded somewhat by human activities including paving, development, or logging. These activities can result in loss of topsoil resulting in reduced water infiltration, enhanced surface runoff and reduction in recharge. Use of groundwater, especially for irrigation, may also lower the water tables. Groundwater recharge is an important process for sustainable groundwater management, since the volume-rate abstracted from an aquifer in the long term should be less than or equal to the volume-rate that is recharged.

Water will arrive at some point in an aquifer through one or several means.

1. The major source is direct infiltration of precipitation, which occurs nearly everywhere. Where the water table lies below a

stream or canal, the surface water will infiltrate. This source is an important part of the year in some places (intermittent streams) and is a continuous source in others (ephemeral or losing streams).

2. Interaquifer leakage, or flow from one aquifer to another, is probably the most significant source in deeper, confined aquifers. Likewise, leakage from aquitards is very important where pumping from adjacent aquifers has lowered the head or potentiometric surface sufficiently for leakage to occur.

3. Underflow, which is the normal movement of water through an aquifer, also will transmit groundwater to a specific point.

4. Additionally, water can reach an aquifer through artificial means, such as well-designed recharge wells, leakage from ponds, pits, and lagoons, from sewer lines, and from dry wells, among others.

Climate change significantly impacts the groundwater recharge process through alteration of precipitation patterns, increased evapotranspiration, sea-level rise which can lead to saltwater intrusion into coastal aquifers affecting the quality and quantity of groundwater, changes in snowmelt in regions dependent on snowmelt for groundwater recharge, and extreme weather events such as floods and droughts which can disrupt the natural recharge process. Understanding these effects is crucial for developing strategies to manage and protect groundwater resources in the face of climate change.

Rates of groundwater recharge are difficult to quantify since other related processes, such as evaporation, transpiration (or evapotranspiration) and infiltration processes must first be measured or estimated to determine the balance. These factors have been used along the cause of my research work to determine groundwater recharge for some selected geological terrains.

3.0 GROUNDWATER MANAGEMENT IN NIGERIA

Groundwater has emerged as the primary water source and poverty reduction tool in Nigeria's urban and rural areas. Groundwater is one of the Nigeria's most important natural resources and an important source of water for domestic supply and agriculture. Groundwater has made significant contributions to the growth of Nigeria's economy and has been an important catalyst for its socio-economic development. Its importance as a precious natural resource in the Nigerian context can be gauged from the fact that it accounts for more than 40 percent of the Nation's public water supply. In addition, more than 40 million people, including most of the rural population, supply their own drinking water from domestic wells. It is the Nation's principal reserve of freshwater and represents much of the potential future water supply. Groundwater is a major contributor to flow in many streams and rivers and has a strong influence on river and wetland habitats for plants and animals.

Aside from the aforementioned, certain features make groundwater attractive as a source of potable water supply. Firstly, there are aquifers in several parts of the country that can frequently be tapped at shallow depths close to the water demand centres in response to the dispersed nature of rural settlements. Secondly, water stored in aquifers is for most part protected naturally from evaporation and pollution, and well yields are in many cases adequate, offering water supply security in regions prone to protracted droughts as is common in the northern parts of Nigeria. Thirdly, with adequate aquifer protection, groundwater has excellent microbial and chemical quality and requires minimal or no treatment at all. Fourthly, the capital cost of groundwater development as opposed to the conventional treatment of surface waters is relatively modest and the resource lends itself to flexible development, capable of being phased in with rising demand. Lastly, groundwater development is fast, does not require a large initial financial investment, delivers a better service to the people, and steadily improves social welfare.

In Nigeria the primary responsibilities for water resources development are vested on government agencies including the Federal Ministry of Water Resources, State Ministries of Water, Water Agencies, and non-government agencies such as UNICEF, EU, USAID, and other Developmental partners. Other government agencies not directly concerned with water resources development but carry out water resources developments include the Federal and State Ministries of Agricultures and Environment.

3.1. National Water Supply and Sanitation Policy of 2000/2004/2017

This policy spelt out the Institutional Framework for Water Supply and Development thus;

The Federal Ministry of Water Resources is charged with the responsibilities of policy advice and formulation, data collection, monitoring, and co-ordination of water resources development (of which water supply is a component) at the National level.

1. **The River Basin Development Authorities (RBDAs)** came into existence following the promulgation of Decree 25 of 1976. The current law on RBDAs is the RBDA Act; cap 396 Laws of the Federation of Nigeria, 1990. The authorities are charged with the development, operation, and management of reservoirs for the supply of bulk water for water supply amongst other uses in their areas of jurisdiction.
2. **The National Water Resources Institute (NWRI)** is responsible for manpower training, research, development, and studies under the National Water Supply Training Network in the water supply sector.

3. **The State Water Agencies** are responsible mainly for urban, semi urban, and rural water supplies. In some States separate agencies exist for rural water supplies and urban and semi-urban water supplies.
4. **The Local Government Authorities** are responsible for the provision of potable water to rural communities.
5. **The National Water Policy (NWP) Document of 2004 /2017**. Water abstraction for public water supply is guided by the National Water Policy. In order to meet Nigeria's water supply demand, the policy objectives had been drawn and the guiding principles for implementation.
6. **The proposed Nigeria Water Resources Bill (2016 – 2022)**: The Bill presented to the 9th National Assembly was simply an amalgamation of already existing water resources laws that are presently being used to develop and manage Nigeria's Water Resources as contained in the following: Water Resources Act, Cap W2LFN 2004; The River Basin Development Authority Act, Cap R9LFN 2004; The Nigerian Hydrological Services Agency (Establishment) Act, Cap N1100A, LFN 2004; National Water Resources Institute Act, Cap N83LFN 200. These laws were re-enacted with necessary modifications to bring them in line with current global trends and best practices in Integrated Water Resources Management, IWRM. However, the Bill suffered a serious setback as a result of the belief that it would further centralize the power and resources of the country as it would counter the devolution of power domiciled with the Federal Government.

3.2. General Hydrogeology of Nigeria

Nigeria's geology is made up of two main rock types: Basement complex and the Sedimentary basins, which are roughly in equal

proportions (figure 2). Other minor formations are the volcanic plateau and the river alluvium. The major aquifers in Nigeria are Basement aquifers, Sedimentary basins, Volcanic plateau, and River alluvium.
The geological structure of Nigeria gave rise to two types of groundwater; pore-type water in sedimentary rocks, and fissure-type water found in crystalline rocks.

There are the following aquifer types in Nigeria;

1. Fissure type water in Precambrian crystalline rocks
2. Pore-type water in sedimentary deposits
3. Pore-type water in superficial deposits.

Occurrence of groundwater varies with the geology of the area, in the Basement Complex terrain, groundwater occurs in the weathered regolith and in fractures in the fresh crystalline rocks. Where thick weathered zones or fractures in fresh rocks occur, wells and boreholes tap the groundwater for water supply.

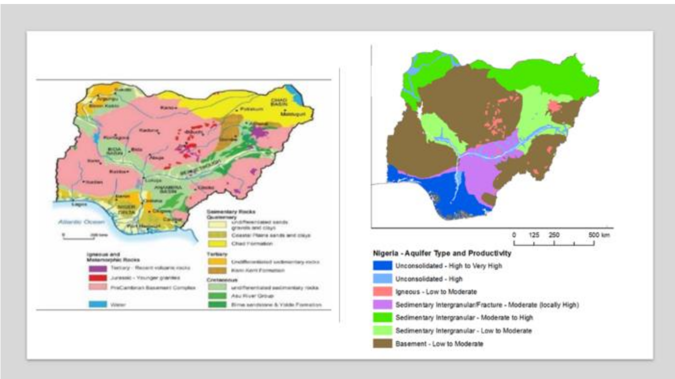

Figure 3: Generalized geological and Hydrogeological maps of Nigeria (Source: Adelana et al., 2008, BGS,2019)

The availability of groundwater in areas underlain by crystalline basement rocks depends on the development of thick soil overburden

(overburden aquifers) or the presence of fractures that are capable of holding water (fractured crystalline aquifers). The storage of groundwater is confined to fractures and fissures in the weathered zone of igneous, metamorphic, and volcanic rocks.

The several sedimentary formations of variable age, mineralogical and geochemical character found in Nigerian basins, affect the quantity and quality of water found in them. These basins include Chad, Sokoto, Benue Trough, Bida, Dahomey, Niger Delta.

3.3 Transboundary Groundwater

A transboundary aquifer is an underground layer of water-bearing rock or sediment that spans the borders of two or more countries. These aquifers are critical sources of water for drinking, irrigation, and industrial use. However, they also require careful international cooperation to ensure that the water resources are managed sustainably and equitably, as the actions of one country can affect the availability and quality of water in the neighboring country.

There are several transboundary aquifers in Nigeria:

1. The Iullemmeden, Taoudeni/Tanezrout Aquifer Systems (ITAS), shared by Algeria, Benin, Burkina Faso, Mali, Mauritania, Niger, and Nigeria.
2. The Chad Basin Aquifer, shared by Cameroon, Central African Republic, Chad, Niger, and Nigeria.
3. The Keta Basin Aquifers, shared by Ghana, Togo, Benin, and Nigeria.
4. The Benue Trough, shared by Cameroon and Nigeria
5. The Rio Del Rey Basin shared by Cameroon and Nigeria along the coast.

A mechanism for the management of the Iullemmeden aquifer is in development, as Nigeria has ratified the Agreement. The Lake Chad

Basin Commission manages issues on the Chad Basin. Groundwater management activities in other Basins are yet to commence.

3.4 Groundwater Quality

The quality of groundwater is determined by the dissolved elements and gases and by the presence of suspended solids, bacteria, and viruses. The quality of groundwater depends upon its natural and physical state and on the changes due to human activity. In its natural state, the dissolved elements and their concentrations depend on the chemical composition of the aquifer and on the travel time of the water through the rock formation.

Groundwater quality is important for many reasons, most notably because of the consequences of contaminated groundwater for human health, agriculture, and the economy. The chemical and microbiological quality of groundwater is central to its utility, yet the resource remains vulnerable to contamination from both natural processes and human activities. Detecting and managing groundwater contaminants requires a different approach than that of surface water. Pollution in surface waters is often easily detectable and can occur quickly and aggressively, but it is largely reversible once the contaminant source is removed. Groundwater pollution has almost opposite characteristics, it tends to happen slowly, but with no less serious consequences; and once the quality is damaged, it takes far longer to recover. Polluted groundwater can remain trapped in aquifers long after the contaminating activity has ceased.

Most groundwater is naturally of good quality, but contamination poses increasing threats in urban and rural areas worldwide. Natural contaminants range from elements, such as iron, to life-threatening substances, such as lead, arsenic, and fluoride. Anthropogenic, or human-generated, contaminants are extremely diverse and can have mild to extreme effects on human health and the environment.

Examples include fertilizers, pesticides, industrial and mining waste, and petroleum.

Generally, groundwater quality is determined by its Physical, Chemical, and Bacteriological composition. The physical properties consist of the pH, Temperature, Electrical Conductivity, Alkalinity, Salinity, Total Dissolved Solids (TDS), Turbidity, Colour, Odour and a host of others. Chemical composition of groundwater consists of the Major elements, Minor and trace elements such as Sodium, Potassium, Calcium, Magnesium, Chloride, Manganese, Fluoride, Lead, Arsenic, amongst others. Bacteria and viruses form the biological components found in groundwater, commonly faecal coliforms, faecal streptococci, and others.

4. MY CONTRIBUTIONS TOWARDS MAKING THE INVICIBLE VISIBLE

The importance of water and its effective management cannot be overemphasized. Inadequate water supply and poor water quality give rise to health and other societal issues, limit agricultural productivity and economic prosperity, and pose national security risk. In order to effectively harness and manage water, there is need to adopt sustainable measures and one of these measures is recognition of the role of Hydrogeologists in the national water supply framework.

In light of the above, what exactly do Hydrogeologists do? The Hydrogeologist studies and examines movement of groundwater in different areas, gathering and analysing samples, monitoring the quality and distribution of groundwater, conducts risk assessments, creates visual models using tools and software. They help in the management of water resources through their research findings and can develop recommendations and strategies that various programs and projects can utilize for their operations.

The fun and challenge of hydrogeology is that each geologic setting, each hole in the ground, each project is different. Hydrogeologic principles are applied to solving problems that always have a degree of uncertainty. The reason is that no one can know exactly what is occurring in the subsurface. Hence, the challenge and fun of it. Those who are fainthearted or cannot live with some amounts of uncertainty are not cut out to be field hydrogeologists.

My work as a Hydrogeologist can broadly be classified as follows;

1. **Groundwater Exploration and Assessment:**
   i. Identifying and evaluating groundwater resources.
   ii. Conducting surveys to locate aquifers and determine their capacity and quality.

2. **Water Resource Management:**
   i. Designing sustainable plans to use and conserve water resources.
   ii. Monitoring groundwater levels and usage to prevent overexploitation.

3. **Environmental Protection:**
   i. Assessing the impact of human activities, such as mining, waste management, and agriculture, on groundwater.
   ii. Developing solutions for groundwater contamination and pollution control.

4. **Site Investigations:**
   i. Evaluating land for construction projects by studying groundwater flow and soil conditions.
   ii. Assessing risks like flooding or land subsidence linked to water dynamics.

5. **Hydrological Modeling and Data Analysis:**
   i. Creating computer models to simulate groundwater flow and predict future conditions.
   ii. Analyzing data from wells, tests, and surveys to inform decisions.

6. **Disaster Preparedness and Climate Adaptation:**
   i. Assisting in drought or flood planning and mitigation strategies.
   ii. Studying the effects of climate change on groundwater systems.

7. **Consultancy and Reporting:**
   i. Providing expert advice to governments, international organisations, Non-Governmental Organisations, industries, and environmental organizations.
   ii. Preparing detailed reports and recommendations based on research findings

In carrying out these activities my work was broken down into the following aspects;

1. Groundwater exploration
2. Groundwater development
3. Groundwater quality and its protection
4. Environmental protection due to over withdrawal of groundwater
5. Management of groundwater problems in construction

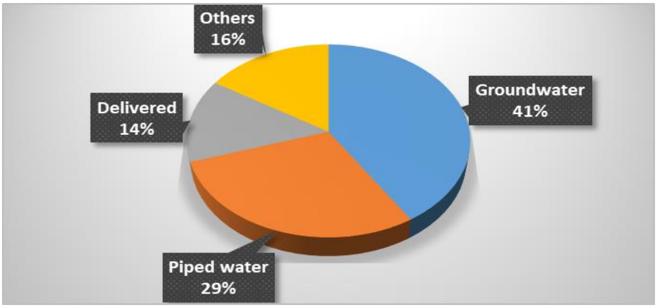

Figure 4: Water sources in Minna, Niger State (2023)

Figure 4, based on a study conducted in 2024 in Minna the Niger state capital, shows a common scenario of access to water supply in most parts of Nigeria. Water supply for domestic and other purposes is commonly sourced from groundwater, consisting of hand dug wells and boreholes (41%). This source is however seasonal for hand dug wells and mostly becomes unavailable during the dry season when the water table has dropped below the levels of the wells and which in any case cannot be dug deeper due to the nature of the geology of the area. Twenty nine percent (29%) of households depend on their water source from pipe borne water supplied by the public water corporation, however water supply from this source is commonly not on a daily basis, users therefore have to put in place storage facilities which sometimes are also poorly maintained and may become potential sources of hazards. While 16% of the populace source their water from other sources like going to houses or areas with water sources to fetch water, 14% depend on water delivered by water tankers and vendors that use carts to deliver water in plastic containers. Delivered water is the preferred source of water during the dry season, the vendors obtain water from commercial borehole owners for deliveries to houses. This has placed many households in severe water stresses as a result of the low purchasing power for adequate water, this leads to limiting water use with toilets becoming the earliest to be sacrificed for other uses like cooking and bathing.

The findings showed that many of the house owners resulted in self-help by digging a well for use by their households. This poses health risk to members of their households when they do not provide good cover for the well as dirt, particles and reptiles/amphibians like frogs/toads can easily find their way into the well. Aside from this, it can also constitute a source of threat to life of members of household/or community if a minor accidentally falls inside the well.

4.1. Demystifying some Misconceptions about groundwater

Throughout my career in hydrogeology, I have encountered numerous myths and misunderstandings about groundwater, many of which hinder effective management and public awareness. Let us take a moment to clarify some of the most common misconceptions:

1. **Groundwater flows in underground rivers and caverns:** This is a widespread myth. In reality, groundwater moves through tiny pores and fractures within soil and rock. Its flow is driven by differences in hydraulic head, moving from areas of higher pressure to lower pressure, not through open channels like rivers.

2. **The deeper you drill, the more water you'll find:** This may hold true in sedimentary basins with deep, porous aquifers. However, in crystalline rock terrains such as the Basement Complex, this assumption is often false. Water availability depends on the presence of fractures, not depth alone.

3. **Boreholes should not be drilled during the rainy season:** While rainy conditions can hinder access to heavy drilling

equipment, the season itself does not affect the aquifer's productivity. Shallow unconfined aquifers may show seasonal variation, but drilling feasibility is more about logistics than hydrogeology.

4. **Borehole water doesn't need treatment – soil filters everything:** While soil can remove some bacteria, it does not eliminate dissolved minerals, chemicals, or contaminants. Groundwater quality must be tested regularly to ensure safety, especially when used for drinking, irrigation, or industrial purposes.

5. **Groundwater is everywhere – just dig and you'll find it:** This is dangerously misleading. The presence of groundwater is governed by geology. Even in layered sedimentary formations, water availability can vary drastically over short distances. In crystalline terrains, a single meter can determine whether a well is productive or dry.

6. **Groundwater is immune to environmental and human impacts:** Far from it. Human activities—such as pollution, land use changes, and over-abstraction—can severely affect both the quantity and quality of groundwater, regardless of its depth.

7. **Groundwater is abundant and doesn't need conservation:** Groundwater is a finite resource. Over-extraction, especially in densely populated areas tapping the same aquifer, can lead to depletion, reduced pumping rates, and even dry wells. This is particularly common in basement terrains where fractures are limited.

8. **If water is tasteless, colourless, and odourless, it's safe to drink:** Not necessarily. Many harmful substances in

groundwater—such as nitrates, arsenic, or heavy metals—do not alter its taste, colour, or smell. Regular testing is essential to ensure potability.

9. **Geophysical surveys can detect water directly:** Geophysical methods can identify subsurface structures that may hold water, such as fractures or porous zones. However, they cannot confirm the actual presence or quantity of water—only the potential.

10. **Boreholes cause earthquakes and tremors:** This remains a topic of scientific debate. Some experts suggest that excessive groundwater extraction can lead to land subsidence and minor tremors. Others argue that borehole drilling, and abstraction are unlikely to trigger significant seismic events. While minor vibrations may occur, the link to major earthquakes is not conclusively established.

4.2. Groundwater Development

Groundwater development involves a coordinated sequence of activities: exploring subsurface formations to detect viable aquifers, designing and constructing access structures such as boreholes or wells, installing systems to lift water to the surface, and establishing facilities for its storage and use. These processes, exploration, construction, installation, and management are essential for ensuring sustainable access to groundwater resources.

4.2.1. Groundwater exploration

Groundwater exploration is a systematic process that involves studying geological formations and their responses to various forces in order to identify viable aquifers. These investigations form the foundation of my research into locating groundwater and other subsurface resources. The primary goal of groundwater exploration is to understand the nature and characteristics of geological formations with respect to the two principal functions of aquifers: transmission and storage.

In my work, I have adopted a three-pronged approach to groundwater exploration. First, I determine the geology of the area, which provides insight into the types of rocks and sediments present and their potential to host groundwater. Second, I establish the hydrogeological conditions, including water table levels, recharge rates, and aquifer boundaries. Third, I conduct surface geophysical surveys, particularly electrical resistivity methods, to detect subsurface features that may indicate water-bearing zones. For broader regional studies, I have found remote sensing techniques to be especially useful in identifying promising areas for further investigation.

This integrated approach, combining geological, hydrogeological, and geophysical data has proven highly effective over the years in evaluating groundwater potential and guiding well design. However, it is essential to begin any exploration effort by clearly defining the quantity of water required and the purpose for which it is needed, whether for domestic use, irrigation, or industrial applications. Figure 5 is the schematic diagram of a groundwater exploration campaign.

In recent years, there has been a concerning trend toward overreliance on surface geophysical surveys alone, particularly electrical resistivity, often at the expense of geological and hydrogeological assessments. Even more troubling is the increasing use of unverified equipment, often of foreign origin, which lacks a clear scientific basis or validated operating principles. This practice undermines the reliability of exploration results and can lead to poor decision-making in groundwater development.

Ultimately, exploration is the first and most critical step in determining the success of any drilling program. While geophysical surveys can reveal subsurface structures, the accurate interpretation of these results, especially in terms of water presence depends entirely on the skill and experience of the investigator. Both qualitative and quantitative analysis are essential to correctly identify key parameters and ensure that groundwater resources are developed sustainably and effectively.

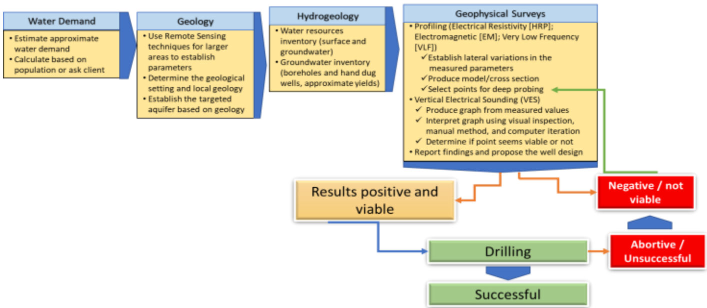

Figure 5: Schematic diagram of groundwater exploration campaign

4.2.2. Groundwater abstraction

Groundwater abstraction refers to the process of extracting freshwater from underground sources, either temporarily or permanently, for various uses. This critical phase of groundwater development must be carefully designed and executed to avoid adverse outcomes such as project failure, aquifer contamination, excessive lowering of the water table (dewatering), and other environmental concerns.

There are several methods of groundwater abstraction, including:

i. Dug wells (hand-dug wells)
ii. Boreholes (drilled wells)
iii. Spring capping
iv. Other methods, such as infiltration galleries and tunnels

In Nigeria, the most commonly used methods are hand-dug wells and boreholes, largely due to the prevailing geology and terrain.

While springs are less widespread, they do occur naturally in certain regions and are sometimes harnessed through spring capping.
Effective groundwater abstraction requires not only technical precision but also a sound understanding of the local hydrogeological conditions. When done properly, it ensures sustainable access to clean water; when poorly executed, it can compromise both water quality and long-term availability.

4.2.2.1 Hand dug wells

Hand-dug wells have been used for thousands of years to access groundwater. They are typically constructed in soft geological materials such as unconsolidated sediments (sand and gravel), weathered basement rocks, or limestone. These wells are only suitable in areas where the groundwater table is shallow. Most hand-dug wells are less than 20 meters deep and 1–2 meters in diameter, though some can be wider and significantly deeper depending on local conditions.

Construction of hand-dug wells requires minimal specialized equipment, just basic digging tools and a method for removing excavated material. To prevent collapse, wells are often lined with materials such as bricks, stones, concrete rings, or even recycled tyres. Because they are open at the surface, these wells are vulnerable to contamination. Installing a concrete apron around the top can significantly reduce this risk.

One advantage of hand-dug wells is their large storage capacity, which makes them more resilient during short-term droughts. However, since they typically tap into shallow aquifers, they are prone to drying up during prolonged dry seasons or extended drought periods.

There are various ways to design and construct hand-dug wells, often guided by local expertise developed through generations of experience. In parts of Niger State, for example, traditional wells exceeding 60 meters in depth have been successfully constructed under my supervision to suit the geological conditions.

Over the years, I have recommended hand-dug wells in areas where borehole drilling is not feasible, such as densely built environments, locations with shallow groundwater, and communities with limited access to drilling equipment. Figure 6 illustrates optimal well designs tailored to different geological terrains.

When constructing hand-dug wells, it is crucial to assess and mitigate potential sources of contamination. These include poorly designed soak-away pits, pit latrines, wastewater pits, inadequate drainage systems, refuse dumps, animal enclosures, and chemical storage sites (including fertilizers). Proper siting and protective measures are essential to ensure the safety and sustainability of the water supply.

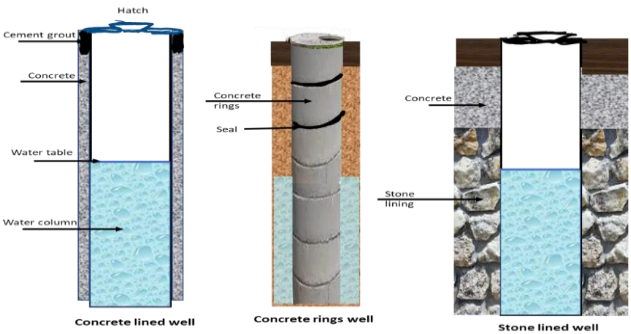

Figure 6: Some hand dug wells design

4.2.2.2. Drilled wells

Boreholes are narrow diameter tubes drilled into the ground, usually vertically. Boreholes are also called tube wells or simply wells. They can be drilled more quickly and go deeper than hand-dug wells, and so can tap deeper, often more sustainable groundwater; they can be drilled though hard rocks, and they can be more easily protected from contamination. There are many different techniques for drilling boreholes, some of which are more suited to certain hydrogeological environments. Usually, a motorised drilling rig is used, operated by specialist drillers. There are also manual drilling techniques.

I have drilled or supervised the drilling of hundreds of boreholes for over thirty years across different geological terrain in virtually every part Nigeria. Indeed, no two boreholes are exactly the same, even under the same condition, they all come with their challenges warranting different strategies and approach to successfully complete them. In well planning, the key to achieving objectives successfully is to design drilling programs on the basis of anticipation of potential hole problems rather than on caution and containment. Drilling problems can be very costly. Understanding and anticipating drilling problems, understanding their causes, and planning solutions are necessary for overall-well-cost control and for successfully reaching the target zone.

I will briefly outline some geological conditions, and the challenges and techniques required for design and construction.

1. ***Granitic rock***: this is a crystalline rock and underlies the greater part of Nigeria including Minna and the Federal Capital Territory. The rock is hard, and weathering profile seldom exceeds 30m, most commonly between 2 – 15m. Groundwater occurs within the weathered portion (called the overburden) and fracturing that may exist within the rock, these are usually the targets of surface geophysical surveys.

Drilling is done using the air system, employing the use of a drilling rig, air compressor, hammer, and drill bits (roller or drag bit for the overburden and hammer with button bit for breaking and crushing the rock). While roller bit is suitable for weathered material, drag bit is more suitable for clay and soft material. Problems often arise from the nature of finishing of the borehole. Two common finishing types are partially cased (commonly referred to as hanging), and fully cased and gravel packed, figure 9. Drilling through granite can generate a lot of dust before water is encountered, adequate measures should be taken to control the dust.

Improperly designed and constructed borehole in granitic or crystalline rock areas can be prone to silting up of the borehole resulting in reduced yield and eventual loss including pump and accessories. Improperly designed boreholes are also prone to contamination from surface point sources, like sanitation facilities, waste dump, drainages, and others. It is therefore necessary to install cement grouts and sanitary backfills to ensure the quality safety of the borehole and users.

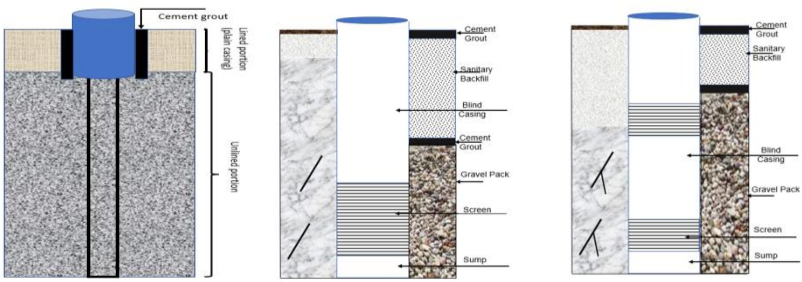

Figure 7: Borehole design in hard rock areas

2. ***Schist***: I am singling out schist because of its complication when it comes to groundwater storage and transmission. Schist is foliated medium grade metamorphic rock. It is formed by metamorphosis of mudstone and shale or some form of igneous rock. There are many types of this rock so they may be named for mineral comprising the rock e.g., Mica schist, green schist, garnet schist etc. hydrogeological capability of the rock lies in its level of weathering and whether the rock is pelitic or not (i.e., whether it contains sand

grains or not). It is usually fissile, with the fissility planes acting as conduits for groundwater. Where the planes are horizontal, water tends to move in that direction, while inclined ones grant better access to storage sites.

The difficulty with groundwater prospection is as a result of the rocks chemical composition, mostly biotite, chlorite, muscovite, and other clay minerals that are conductive. Electrical resistivity surveys will show a rock with electrical characteristics that can mimic groundwater occurrence. Many geologists overlook areas underlain by schist, resulting in incorrect conclusions and failed boreholes.

The Schist Formations I have worked in, and which occur within Niger State and most parts of central Nigeria are the Kushaka and Birnin Gwari Schists.

The groundwater potential of the Kushaka schist formation area has been found to be low to high. Groundwater occurs mostly in the weathered schist, which has been weathered into clay and sand. Higher water yields are obtained in deeply weathered zones than in shallower ones. Groundwater yield is therefore a direct reflection of the depth and intensity of weathering. Surface geophysical surveys using the electromagnetic (EM) and resistivity methods have been found to be very effective in delineating the bedrock structure and thickness of the weathered zone. Borehole logs using Gamma Ray and Resistivity logs also compare favourably well with surface methods in defining the geoelectric boundaries. Hydraulic conductivity and Transmissivity of the weathered schist favours groundwater movement and storage. The underlying fresh schist, even where fractured, contributes little or no significant amount of water to the well, but quartz veins favours groundwater storage in the weathered schist. The water quality is within acceptable limits for potable water (Idris-Nda, 2005)

The principal rock types of the formation consist of phyllite, biotite-quartz-muscovite schist and amphibolite schist. The schist has a dominant strike of 020^0 (NNE-SSW) and a dip of 46^0E ($020^0/46^0$E). The rocks are not hard, but they are impervious and resistant to weathering. The rocks have major fracturing in dip direction while the strike faults are smaller and widely spaced. They have a characteristic low resistivity of between 10-100 ohm-meters (figure 10) and a corresponding high conductivity of 10-25mS/cm. Groundwater yield to wells placed in them is very low, ranging from completely dry to 0.3lt/s (<800m^3/day). Groundwater recharge is through the vertical strike faults, which transmit water from the surface. The water is stored in dip faults and schistocity planes. Groundwater Transmissivity is very low (<0.5m^2/day), (Idris-Nda, 2010). The mineralogy of the rock shows a predominance of the micas, mostly muscovite over the feldspars and quartz in a proportion of 50%, 20% and 10% respectively in hand specimen, with other accessory minerals, mostly platy minerals forming the remaining 10%.

Borehole design is for a fully cased one with alternating screens for the Kushaka schist and bottom level screen for Birnin Gwari schist if it is water bearing.

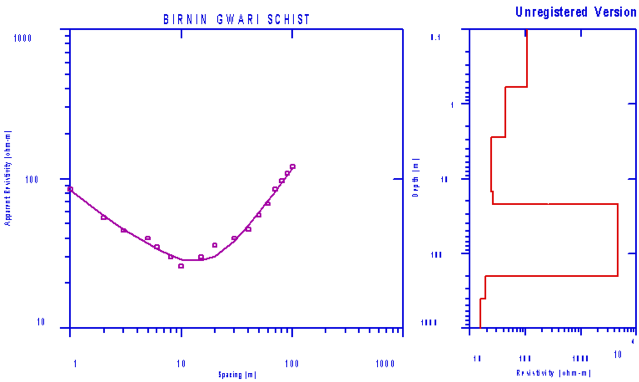

Figure 8: Typical Electrical Resistivity Sounding curve for the Birnin Gwari Schist

3. ***Sedimentary Rocks***: these are rocks that are formed on or near the Earth's surface, in contrast to metamorphic and igneous rocks, which are formed deep within the Earth. The most important geological processes that lead to the creation of sedimentary rocks are erosion, weathering, dissolution, precipitation, and lithification. By origin they could be organic, clastic, or organic. Typical sedimentary rock types include sandstone, mudstone, shale, limestone, chalk, and clay. They are deposited originally as horizontal layers depending on factors like the length of the rivers, volume of water, amount of sediments, and the slope of the river and the earth's surface. Thus, sedimentary deposits consist of alternating layers of sediments with different characteristics one on top of the other. The original horizontal layers may become deformed by tectonic forces, eventually leading to regional or even local variations in the depth and nature of deposition of each rock type.

Sedimentary rocks aquifers consist primarily of sandstone, limestone, and gravel, they have the capacity to hold very large volumes of water with resulting high yields; however, they also represent the terrain that poses the most difficulty in drilling, this has led to high drilling failures, abandoned wells and abortive ones resulting from improper design and finishing. Common problems that arise from drilling include loss of circulation, loss of drilling fluid viscosity, water pressure (in confined aquifers), frequent change of drilling bits, drilling chemicals, availability of water, silting, recovery of drilled depth, pipe sticking, hole deviation, and pipe failure.

Lost circulation is one of the commonest problems and has led to several boreholes being abandoned with some leading to costly losses and even litigation. Loss circulation is defined as the uncontrolled flow of whole mud into a formation, sometimes referred to as a thief zone. Total lost circulation occurs when all the mud flows into a formation with no return to the surface. This situation can sometimes be controlled by thickening the drilling mud; blind drilling can be done when the overlying formation is competent; pumping large amounts of water to saturate the formation (in the case of partial lost circulation); using larger diameter casings to cover the loss circulation zone. Air drilling using low compressed air and water containing surfactants (commonly foam) to drill slowly through competent formations. This method has been used successfully to drill through formations with lost circulation up to the point where conventional drilling can be adopted. The loss circulation is cased off with a large diameter casing, while finishing is done with a smaller diameter casing that can fit into the larger one with sufficient space for gravel packing and grouting.

Borehole design in sedimentary areas is very tricky and requires caution, improper backwashing to remove all drilling chemicals, wrong positioning of the screen and gravel packing will lead to a failed well or one that has a highly reduced yield compared to what it would have produced.

4.2.2.3. Springs

Springs are natural flows of groundwater from the underlying rock or unconsolidated sediment, they represent points or locations at which groundwater encounters the surface. Springs are dependent on the characteristics of the rocks, and their nature and yields are hugely variable. They often occur in specific hydrogeological environments and in some cases may be warm as a result of travelling through areas with elevated temperatures. Because they are open at their source, springs are vulnerable to contamination. No equipment is needed to make a spring, but springs can be improved and made less vulnerable to contamination and drought by various developments, such as constructing a collection tank to store spring water and installing a protective cover over the spring head.

Some streams or rivers that have a sustainable flow throughout the year (perennial streams) often derive their water from groundwater sources. Groundwater contribution to river flows, generally called **base flows**, often accounts for a significant proportion of total flow rate, especially during the dry season. Streams gain water from the inflow of groundwater through the streambed (gaining stream), streams lose water to groundwater by outflow through the streambed (losing stream), or they do both, gaining in some reaches and losing in other reaches.
This is quite significant in maintaining balance between groundwater and surface water systems, as well as in the maintenance of the ecosystem.

When water is being over pumped it can have adverse effects on surface water, likewise when surface water is mismanaged it can have adverse effects on groundwater. This is what gave rise to the concept of conjunctive water use.

4.2.3. Determination of the yield of the borehole

In order to gauge the yield of a water borehole most accurately, an aquifer test is performed. This involves installing a test pump and pumping borehole water for a fixed set of variables; a given time at a given rate and then assessing the test's impact on the water level in the borehole.
Common tests carried out in the line of my work to determine the yield of a drilled well include; Pumping Test, Aquifer Test, Proving Test and Yield Test.

1. ***Pumping Test***; this is usually conducted to determine the yield of the borehole and the capacity of pump to be installed on it. This test is also used to determine the type of finishing to be done on the storage facilities, for example the client may be advised based on this test to install surface tank near the well to receive the pumped water before transporting it to other storage facilities.
2. ***Aquifer Test***: this test is conducted to determine the hydraulic parameters of the aquifer, like its Transmissivity and Hydraulic Conductivity. These are used by Hydrogeologists to calculate the rate of flow of water through the aquifer and how safely it can be abstracted without adversely affecting the water balance. If the rate of removal of water from the aquifer is higher than what it is capable of storing and transmitting, the resulting effect will be over pumping. This has various effects not only on the yield of the aquifer but on dewatering of the area and lowering of the general water table of the area. This test requires information on the casing and gravel packing design and finishing of the borehole.
3. ***Proving Test***: this type of type is used to resolve contractual agreements between the client and the service provider. The client required a particular yield and to prove that the contractual agreement has been met, a proving test is conducted.
4. ***Licensing Test***: the Licensing test is conducted for the purposes of issuing license for water use and extraction. This is done in countries where borehole drilling and use is highly regulated in order to protect the resource from contamination and over abstraction.

4.2.4. Well installation

Completed wells need to be installed with suitable mechanisms to bring the water from the depths of its occurrence to the point of use, the surface. Wells are commonly installed with mechanical or electrical pumps.

1. ***Mechanical Pumps*** (Hand Pumps): these are commonly used for both community supply and self-supply of water and can be installed on *boreholes* or hand-dug wells. Hand pumps use human power and mechanical advantage to move water from boreholes/wells to the surface with minimal effort. Common problems with hand pumps amongst others arise from low water level that leads to difficulty in lifting water to the surface; wearing of cup washers; rusted and broken pipes, and improper usage of the facility.

2. ***Electrical pumps***: these consist of electrical or solar powered pumps generally referred to as submersible pumps. The pump is usually installed almost to the bottom of the well, it is connected to riser pipes (which can be uPVC, Stainless Steel, API, Galvanized Iron or even a hose, as is commonly done these days). The pump consists of an impeller connected to an electric motor which is in turn connected to the surface through a cable and secured using a marine rope or flexible steel cable, depending on the pump type.
3. Common problems with this type of installation arise from the following: wrong pump capacity choice, using inferior cable, power surges, drop in water level below the pump while it is still running, use of nonprofessional personnel to install, and type of pump.
4. Boreholes installed with electrical submersible pumps require external storage facilities, like overhead, surface, or

underground facilities. This will require constant maintenance to keep them clean and safe at all times.

4.3. Groundwater Quality and its Protection

The quality of groundwater is almost as important as the yield of a source. In most cases, groundwater from a properly constructed borehole is of excellent quality and suitable for drinking without any treatment, but some natural elements and pollutants can make groundwater smell or taste unacceptable or even make it harmful to health. Evaluating the chemical and bacteriological quality of groundwater is therefore always highly recommended. The World Health Organisation (WHO) and the Nigerian Standards Organisation (NSO, NSDWQ) sets guidelines for drinking water quality.

Groundwater chemistry is commonly because of two factors: Geogenic (natural), and anthropogenic (human-caused). Geologic processes and lithological and pedological factors, climate change, environmentally unfriendly agricultural activities, poor sanitation practices and waste management are the most dominant factors that impact groundwater quality.

Analysis of groundwater quality indicators carried out over the years shows a gradual deterioration in quality mostly as a result of anthropogenic activities. Faecal Coliforms, E-Coli, bacteria, viruses, and Nitrates have shown a marked increase chiefly as a result of poor design and construction of sanitation facilities, which consequently lead to contaminated water migrating from these sources into the groundwater system. This may not be unrelated to the incessant outbreaks of water-related diseases that has claimed many lives over the years in Minna and other parts of Nigeria because people rely more on water from hand dug wells and boreholes.

In addition to these, indiscriminate dumping of solid and liquid waste, poor wastewater management, unregulated waste disposal from mechanical workshops, poor agricultural practices in the handling of agricultural chemicals, hospital waste, and unregulated mining activities have, among others led to a gradual deterioration of groundwater quality, especially in areas underlain by the basement complex rocks.

These have resulted in a significant increase in the concentration of heavy metals like lead, arsenic, chromium, and others in the groundwater system.

Artisanal mining of gold and other minerals involves various stages that include crushing, milling, washing of the dugout materials and application of chemicals (chiefly mercury, in the case of gold) to recover the mineral of value. Washing and panning is done in open water bodies, this process releases the heavy metals into the surface water system and eventually into the groundwater, thereby significantly increasing the concentration in both media.

Surface water bodies in and around large urban areas in Nigeria are frequently of poor quality due to pollution. As a result of the connection between surface and groundwater, it becomes easier for some of the contaminants to migrate downwards into the groundwater system. It is far much easier to treat contaminated surface water than groundwater.

The high level of water pollution is mostly caused by:

1. Indiscriminate disposal of both solid and liquid household waste in storm drains that eventually discharge into these streams.

2. Central sewerage systems with associated sewage treatment sites are rare in Nigeria resulting in the general use of septic tanks.
3. Lack of proper sewerage dumping sites resulting in emptying septic tanks into water bodies, open lands, and other sites in waterways around other cities.
4. unregulated cottage industries and automotive repair shops resulting in industries sited around and close to urban centres discharging oils and chemicals into water bodies.
5. Poor mining control resulting in oil spillage and heavy ion poisoning like lead etc.
6. Open air defecation is common in many places, especially in rural, suburban, and even urban areas.

Groundwater in urban areas, especially downstream of industrial areas, is also severely polluted to varying degrees, mostly due to some of the problems mentioned above. Most common sources of water to the urban poor - who live in shanties and peri-urban areas is the unprotected open well dug by individual household owners. The groundwater table in some areas where hand-dug wells are sited is most times as high as the bottom of the septic tank system. In addition, some of these wells are down gradient of large clusters of septic tanks in high-density residential areas.

In fact, in areas with high population density, significant levels of faecal bacterial pollution have migrated from poorly designed septic tank clusters into the groundwater.

4.3.1. Pathways of groundwater contamination

Figure 11 is a schematic diagram of groundwater contamination pathways in a typical basement complex terrain, in a sedimentary rock terrain contaminant might keep migrating vertically until an impermeable barrier is reached, such as clay or shale, then migration becomes lateral.

Unlined or poorly constructed wastewater drainage systems, including canals, have become sites for dumping various household refuse including materials like batteries and chemicals like pesticides, herbicides, insecticides that are considered as dangerous to the environment and human health. These eventually find their way vertically downwards through relatively permeable geological materials until they get to a geological barrier, such as basement rock, where lateral migration begins. Though some of the harmful materials are removed through natural processes, some, like the heavy metals, will persist and eventually end up in the groundwater system and become potentially harmful when ingested. Heavy metals like Arsenic (As), Lead (Pb), Cadmium (Cd) and others are very harmful to health even at low concentrations.

Septic tanks and pit latrines are one of the commonest pathways of microbes and viruses getting into the groundwater system. Pit latrines and even septic tanks and constructed directly on the basement rock (where it is shallow). Because most often than not they are poorly designed, constructed and maintained, they are easily in direct contact with groundwater, especially in the rainy season when water table is high. The effluent contained in them easily becomes mixed with groundwater and is carried away to other water sources. This often leads to illnesses like diarrhea, dysentery and other related diseases that sometimes become endemic and results in significant loss of life.

Open refuse dumps are a common site in both rural, peri-urban, and urban areas in Nigeria, this is most often due to the absence of proper collection systems and well designed and managed dumping sites. Leachate from refuse dumps contains materials that can be highly toxic when ingested or if it comes in contact with the skin. Such materials will migrate vertically with the leachate until it gets the groundwater system where it contaminates the sources. Leachate can also lower the pH of the water, which gives it more corrosive power and enables it to mobilise some dangerous elements contained in the geological materials (rocks and soil) and into the groundwater. During rainy season leachate is carried through runoff to surface water bodies, thereby leading to its further contamination. Also, water level rises sometimes almost to the waste dump level, increasing chances of further groundwater contamination.

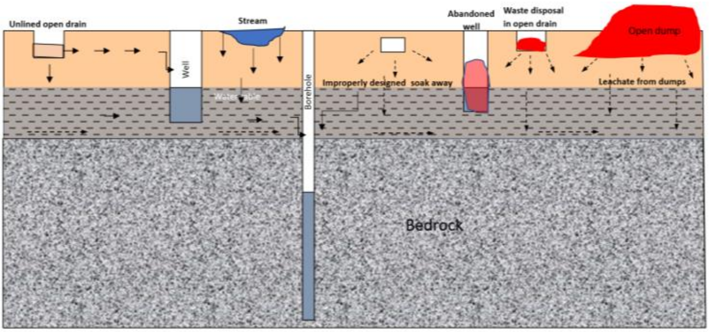

Figure 9: Pathways of groundwater contamination in urban settings in a basement terrain

Combined, these pathways make shallow wells and spring sources particularly vulnerable to contamination and are increased during high water table conditions or when soil infiltration capacity is exceeded. Horizontal saturated groundwater flow, both in the lower permeability horizon above the weathered basement and in the weathered basement and fractured basement is a pathway which can affect deeper groundwater sources such as boreholes. These pathways are slower and longer and provide the greatest attenuation potential for hazards.

Surface pathways include surface runoff which can contaminate surface waters and poorly constructed wells, bypass pathways for contamination of wells and spring collectors by ropes, buckets used to draw water. Shallow sub-surface pathways include vertical water flow from surface and subsurface sources where there is hydraulic continuity, e.g., from a liquid discharge or from a buried source such as a pit latrine, cemetery or buried waste and even mechanic workshops where engine oil and other chemicals are discharged into the environment.

4.3.2. Septic tanks and pit latrine designs

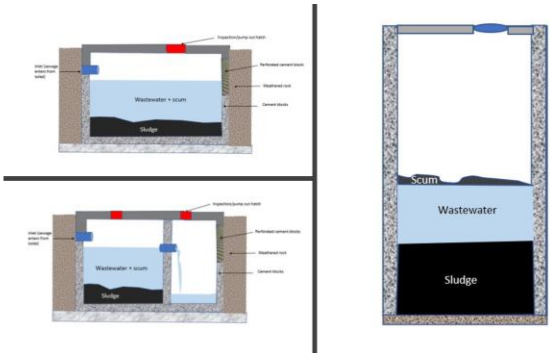

Figure 10: Schematic diagram of common septic tank and pit latrines designs

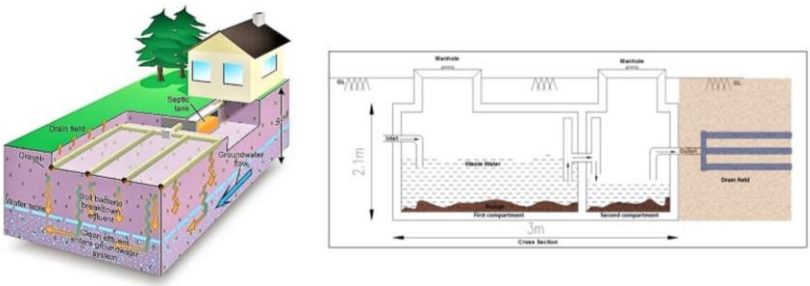

Figure 11: Recommended septic tank design

4.4. Recharge Problems Due to Land Use

To date very few studies have focused on urban recharge processes in Africa. Urbanization affects both the quantity and quality of underlying aquifer systems by radically changing patterns and rates of aquifer recharge, increased withdrawal, and adversely affecting groundwater quality.

Recharge patterns can be affected by modifications to the natural infiltration system, by changes in natural drainage (for example by less permeable surfaces), increased runoff and groundwater flooding in oversaturated areas. Studies have shown a steady decline in groundwater storage and yield as a result of large withdrawals of groundwater due to high demand. In Minna, studies have shown a decrease in water level for the past thirty years (1993 – 2023) from a shallow depth of 15 – 25m in 1993 to 80 – 140m in 2023. Most boreholes drilled to shallow depths (15 – 60m) yield water only during the rainy season and dry up at the onset of the dry season, this has led to targeting deeper aquifers at 180 – 200m or even higher. It has therefore become necessary to start a deliberate effort at recharging the depleted aquifers artificially. Based on this I proposed an Artificial Groundwater Recharge (AGR) design for rainwater catchment, as is shown in figure 12. Artificial Groundwater Recharge can also be done using treated wastewater based on the design in figure 12. Wastewater is a very common site in Nigeria and its management has posed serious challenges to town planners and health departments as a result of the negative impacts on the society.

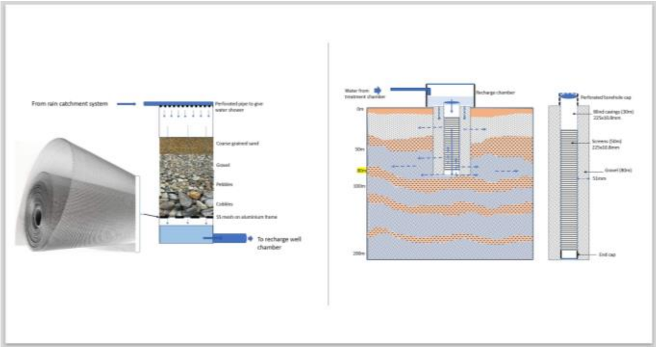

Figure 12: Artificial Groundwater Recharge design using rainfall

The main purpose of artificial aquifer recharge technology is to store excess water for later use. The method will ensure that groundwater levels are maintained while improving the water quality of the wastewater as it undergoes natural treatment before joining the groundwater system.

4.5. Groundwater Value Chain Development

The economic value of groundwater is best understood through the value chain approach, which seeks to identify the key actors that operate within the groundwater industry from input to end users. The value chain for groundwater development involves a variety of actors, each playing a crucial role in ensuring sustainable and efficient use of this resource. The key actors include the followin:

1. **Primary Actors:**
   i. Farmers and Landowners: Utilize groundwater for irrigation and other agricultural purposes.
   ii. Industries: Use groundwater for manufacturing and processing activities.
   iii. Households: Depend on groundwater for domestic needs.
2. **Service Providers:**

i. ***Drilling Companies***: Responsible for constructing boreholes and wells.
ii. ***Well Diggers***: Responsible for manual digging of hand dug wells
iii. ***Equipment Suppliers***: Provide pumps, pipes, and other necessary tools for groundwater extraction and distribution.
iv. ***Consultants and Engineers***: Offer expertise in groundwater exploration, management, and infrastructure development.

3. Regulators and Policymakers:

i. ***Government Agencies***: Develop policies, regulations, and guidelines for sustainable groundwater use.
ii. ***Environmental Organizations***: Advocate for the protection of aquifers and recharge zones.

4. Financial Institutions:

Provide funding and loans for groundwater development projects.

5. Research and Academic Institutions:

Conduct studies on groundwater resources, usage patterns, and sustainability.

6. Community-Based Organizations:

Engage local communities in groundwater management and conservation efforts.

Each of these actors contributes to different stages of the value chain, from exploration and development to utilization and management. Each actor in the groundwater value chain can contribute to creating employment opportunities while ensuring sustainable use of this valuable resource.

Developing the value chain of the various actors in the groundwater industry has the potential to create employment for the teeming youths in the country and rechanneling efforts into the local production of materials and accessories as well as expanding the supply chain of products derived from groundwater for various uses.

Understanding the role of value chain governance is fundamental to the value chain approach. Governance describes which sectors within a value chain set and enforce the parameters under which others in the chain operate. Presently there is no real synergy and governance between the various actors in the value chain, each sector operates independently and rarely interdependently.
It is therefore necessary to bring together all the various actors under operational units like cooperatives societies, this will help in accessing loans and other facilities necessary for growth and development of the various sectors of the value chain.

4.5.4. Regulatory framework and quality control

Regulatory framework for groundwater governance in Nigeria is based on the National Water Policy (NWP) of 2004/2017 which spelt out all issues involved in abstraction and use of water resources, including groundwater.

The main professional association in the groundwater sector in Nigeria is the Nigerian Association of Hydrogeologists **(NAH)** which is the association of all professionals involved in groundwater management. The association also publishes a peer reviewed journal for over thirty years known as the Water Resources Journal. The association is a specialist body of Nigeria Mining and Geosciences Society (**NMGS**) and International Association of Hydrogeologists (**IAH**) and the only recognised professional association by the Council for Mining Engineers and Geoscientists (**COMEG**) which is the regulatory body of the extractive sector in Nigeria.

Other associations of professionals and artisanal drillers of boreholes include Borehole Drillers Association of Nigeria **(BODAN**) and Association of Water Well Drilling Rig Owners and Practitioners (***AWDROP***).

5. CONCLUSION

In conclusion, most of our water reserves are hidden underground and most of our groundwater abstractions rates exceed groundwater renewing rates, leading to depletion. The growing demand and the expected climate change bring our groundwater reserves under mounting pressure. More than two-thirds of all abstracted groundwater is used for food production. Every year the world's population grows by 83 million people.

Improving our knowledge about how much water we can use in the near future while avoiding negative environmental and socio-economic impacts is therefore extremely important. A study like this contributes to the knowledge gap and can help guide towards sustainable water use worldwide to overcome potential political water conflicts and reduce potential socio-economic friction, as well as to secure future food production.

To strengthen water security against the backdrop of increasing demand, water scarcity, growing uncertainty, greater extremes, and fragmentation challenges, clients will need to invest in institutional strengthening, information management, and (natural and man-made) infrastructure development. Institutional tools such as legal and regulatory frameworks, water pricing, and incentives are needed to better allocate, regulate, and conserve water resources. Information systems are needed for resource monitoring, decision making under uncertainty, systems analyses, and hydro-meteorological forecast and warning. Investments in innovative technologies for enhancing productivity, conserving, and protecting resources, recycling storm water and wastewater, and developing non-conventional water sources should be explored in addition to seeking opportunities for enhanced water storage, including aquifer recharge and recovery. Ensuring rapid dissemination and appropriate adaptation or application of these advances will be a key to strengthening global water security.

These agencies and private individuals carry out water resources development projects in an uncoordinated manner with each not taking into consideration the activities of the other. In most cases quality control and assurances were downplayed with emphasis on the number of communities covered rather than water supply system efficiency. Water Schemes sustainability involving ownership, operation and maintenance structure are not properly addressed in planning. Consequently, water supply projects benefits are short lived.

Recommendations

Based on the foregoing, Vice Chancellor, Sir, distinguished guests, I respectfully recommend the following:

1. Policy Enforcement for Groundwater Protection

The provisions of the National Water Policy should be actively enforced to safeguard groundwater resources from overexploitation and contamination. This includes integrating groundwater protection into environmental regulations, land use planning, and water resource management frameworks.

Responsible Entities: Federal Ministry of Water Resources, Nigeria Integrated Water Resources Management Commission (NIWRMC), State Ministries of Water Resources, Environmental Protection Agencies.

2. Professional Oversight in Groundwater Development

Only certified hydrogeologists should be engaged in the planning, design, and execution of groundwater-related projects. Their expertise is critical in ensuring proper site selection, drilling supervision, pump installation, facility maintenance, and waste hazard mitigation. Hydrogeologists should also be part of approval processes for urban expansion and infrastructure development. ***Responsible Entities:*** Council of Nigerian Mining Engineers and Geoscientists (COMEG), Nigerian Association of Hydrogeologists (NAH), State Urban Planning Boards, Federal and State Water Agencies.

3. Regulation and Licensing of Borehole Drilling

Government should establish a licensing framework to regulate borehole drilling activities. This will help monitor groundwater abstraction, prevent indiscriminate drilling, and ensure compliance with technical and environmental standards. A centralized database of licensed drillers and borehole locations should be maintained. ***Responsible Entities:*** Federal Ministry of Water Resources, NIWRMC, State Water Boards, Local Government Health and Environmental Departments.

4. Groundwater Recharge and Urban Planning Innovations

To address the depletion of groundwater due to overdependence, cities should be designed to facilitate natural recharge. This includes installing recharge wells, creating infiltration zones, and reducing impermeable surfaces like concrete pavements and rooftops. Adoption of green infrastructure and permeable technologies should be incentivized.

Responsible Entities: Federal Ministry of Environment, State Ministries of Urban and Regional Planning, Nigerian Institute of Town Planners (NITP), Local Planning Authorities.

5. Industrial Pollution Risk Assessment and Monitoring

In areas with significant industrial activity near domestic and public wells, regular groundwater pollution surveys and risk assessments must be conducted. Industries such as fuel depots, chemical plants, dry cleaners, and tanneries should be closely monitored for discharge of toxic substances. Mitigation plans and emergency response protocols should be developed.
Responsible Entities: National Environmental Standards and Regulations Enforcement Agency (NESREA), Department of Petroleum Resources (DPR), Federal and State Ministries of Environment, State Environmental Protection Agencies.

6. Water Quality Testing and Data Standardization

Boreholes and hand-dug wells should undergo water quality testing at least twice annually. Samples should be collected both at the pump exit and at the point of use to detect contamination from aquifers or storage facilities. Tests should cover physical, biological, and chemical parameters. Standardized data collection and capacity building should be supported with adequate funding to align with SDG 6.
Responsible Entities: Federal Ministry of Water Resources, Nigerian Hydrological Services Agency (NIHSA), National Water Resources Institute (NWRI), State Water Agencies, Research Institutions.

7. Development of the Water Supply Value Chain

The water sector holds immense potential for job creation, livelihood improvement, and economic growth. Government should invest in developing the full water supply value chain—from groundwater exploration and infrastructure development to water treatment, distribution, and maintenance services. This will also promote public health and food security.

Responsible Entities: Federal Ministry of Water Resources, Ministry of Labour and Employment, Ministry of Agriculture and Rural Development, Relevant State Agencies.

8. Groundwater Resilience in the Face of Climate Change
Strengthen groundwater resilience by integrating climate adaptation strategies into water resource planning. This includes mapping vulnerable aquifers, promoting conjunctive use of surface and groundwater, enhancing recharge zones, and building community awareness on climate impacts.

Responsible Entities: Federal Ministry of Water Resources, Federal Ministry of Environment, NIHSA, Climate Change Department, Research Institutions, State Water and Environment Agencies.

Call to Action

Groundwater is invisible, yet indispensable. It sustains lives, livelihoods, and ecosystems, but its vulnerability is growing in the face of climate change, urban expansion, and unchecked exploitation.

The time to act is now.

I call upon policymakers, researchers, practitioners, and community leaders to rise to the challenge by translating policy into meaningful practice, empowering professionals to lead with expertise, investing in data, innovation, and resilience, and protecting groundwater not merely as a resource but as a legacy for future generations.

Let us commit to building a future where groundwater is understood, respected, and sustainably managed – for ourselves and generations yet unborn.

Areas of ongoing and future research

1. Production of electrical resistivity interpretation software to take into consideration the local geology, climate, expected nature of aquifer and time of year.
2. Development of groundwater flow models suitable for teaching groundwater flow, contaminant movement and other parameters through various media that can be changed under various hydraulic gradients that are controllable. This will aid simulation of movement through various geological media.

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PROFILE OF THE INAUGURAL LECTURER

Prof. Idris Nda Abdullahi was born on November 14, 1967, in Minna, the capital of Niger State, Nigeria. He hails from Chanchaga Local Government Area and is the son of the late Mallam Ndanusa Idris Abdullahi and Habiba Abdullahi (née Catherine Akanya).

Education

His academic journey began at Madaki Primary School, Minna (1973–1979), followed by Government Secondary School, Kontagora (1979–1984). He proceeded to the School of Basic Studies at Ahmadu Bello University (ABU), Zaria (1985–1986), and earned a B.Sc. (Hons) in Geology from ABU Zaria (1987–1990), supported by a scholarship from Gulf Oil Company of Nigeria (GOCON), now Chevron Corporation. He later obtained a Master of Technology (MTech) in Hydrogeology (1998–2000) and a Ph.D. in Geology (2010), both from the Federal University of Technology, Minna.

Professional Experience

Prof. Idris began his career as a Machine Assistant at the Nigerian Security Printing and Minting Company (NSPMC), Victoria Island, Lagos, in 1985. During his National Youth Service Corps (NYSC) year (1990–1991), he worked at the Benue Cement Company PLC Quarry in Gboko.

From 1992 to 2002, he served with the UNICEF-assisted Niger State Rural Water Supply and Sanitation Project (RUWATSAN), rising from Assistant Geologist to Senior Geologist. On October 1, 2002, he joined the Federal University of Technology, Minna, as an Assistant Lecturer and ascended to the rank of Professor of Geology in 2019.

Leadership & Public Service

Prof. Idris has held several key academic and administrative roles: Level Adviser (2002–2007), Departmental Fieldwork Coordinator (2007–2010), Examination Officer (2010–2012), Head of Department, Geology (2012–2017), Director, Advancement Office (2018–present)

He has served on numerous university committees, including those on Advancement Policy, Student Support Services, One Programme One Product (OPOP), Illegal Mining, and Conditions of Service.
In public service, he was appointed Senior Special Assistant (SSA) on Boreholes and Water Supply to the Governor of Niger State (2008–2011). He also contributed to state-level committees on hydrocarbon exploration in the Bida Basin and the development of sustainable water supply strategies.

Academic Contributions
Prof. Idris has supervised numerous undergraduate and postgraduate students (B.Tech, MTech, and PhD) in Geology. He has served as an external examiner for M.Sc. and PhD theses across various universities and has assessed candidates for professorial appointments.

Editorial Roles
He currently serves as Editor-in-Chief for several prestigious academic journals, including Journal of Mining and Geology, Water Resources, and Minna Journal of Geosciences
These roles reflect his commitment to advancing scholarly research and maintaining high standards in geoscientific publishing.

Research & Publications
His research focuses on evaluating environmental impacts of human activities. He has authored over 80 scholarly articles published in reputable national and international journals. Additionally, he has produced technical reports for global organizations such as the International Labour Organization (ILO), UNESCO, and the World Health Organization (WHO).

Personal Life
Prof. Idris Nda Abdullahi is married and blessed with children.