# Hydrogeology And Groundwater Resources Of Nigeria

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**Abstract:** Nigeria is endowed with enormous groundwater resources, far greater than the surface water resources. Groundwater constitutes an important source of water for domestic supply and agriculture in Nigeria. The occurrence of groundwater is greatly influenced by the local geological conditions which ultimately control yields. Recharge to aquifers, which influences the safe yields of wells, depends on rainfall over the area. Thus, rainfall ultimately controls the amount of groundwater recovered from wells in any given locality. The extent of amount of groundwater storage in Nigeria is not yet known, but available records indicate that major aquifers are located in the sedimentary deposit basins, which cover about 50% of the nation's land area. The remaining 50% is underlain by crystalline rocks of the basement complex. Water supply provision is a major contribution to the Nigerian United Nations Millennium Development Goals (MDGs) and groundwater component is significantly essential. However, the task of providing water supply for citizenry has remained daunting for decades. Quite unfortunately, in spite of the fundamental role groundwater plays in human well being, as well as that of many ecosystems, it is yet to be fully understood, appreciated and adequately managed and protected. It is a well known fact that groundwater basins are difficult to govern and manage, partly because of poor information, and also because of poor visibility of the resource, the need for proper understanding of the resource and information in support of water resource planning is central and vital for sustainability. Sustainable development of the groundwater resource depends on an understanding of groundwater availability and processes through which it is recharged and renewed. This paper therefore gives an overview of the hydrogeology and reviews the groundwater resources potential of Nigeria.

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## Introduction

Groundwater is generally taken as been the "free gift from God" and is often called a "hidden resource" because it cannot be seen in the same way as water in a river, lake or reservoir. "What is essential is invisible to the eye" and this is precisely the case with groundwater. The volumes of groundwater are large, however, it is estimated that there is about one hundred times more fresh groundwater on earth than all the freshwater in rivers and lakes (Shiklomanov, 1998; Cobbing & Davies, 2008). Groundwater resources are gaining increasing importance and they represent an increasing proportion of the water supplies used for different applications (Hernandez, 2005). Groundwater is a vital natural resource for reliable and economic provision of safe water supplies in both the urban and rural environment. Therefore, in the process of exploitation no action is usually taken to protect its quality as well as ensuring the sustainability of the resource (Adelana *et al.,* 2008).

Nigeria is faced with increasing demands for water resources due to high population growth rate and growing prosperity (Nwankwoala, 2011). The importance of groundwater in meeting a substantial percentage of the water need and in the overall development of Nigeria's economy cannot be over-emphasized (Adelana *et al*., 2008). The advantages of groundwater as a source of supply cannot be overstated, particularly where populations are still largely rural and demand is dispersed over large areas. Groundwater is a dependable and assured resource and can be exploited with greater ease and flexibility. Groundwater offers the most abundant source of water to man and it is the cheapest and most constant in quality and quantity. Because it is not visible on the surface and probably because of misinformation about groundwater, many people undervalue the importance of groundwater in sustaining water supply needs (Olasehinde, 2010). Groundwater has gained a vital position in overall water resource development plans and programmes. Natural groundwater storage provides a buffer against climatic variability, quality is often good, and infrastructure is affordable to poor communities. More importantly, groundwater is preferred to surface water because of its relative low costs compared to surface water, availability in most areas, potable without treatment, employs low cost technologies, the frequent drought problems enforce the use of groundwater source as many small intermittent rivers and streams dry out during the dry season.

Groundwater resources are often, but not always, renewable. Groundwater occurrence depends primarily on geology, geomorphology/weathering and rainfall (both current and historic). This interplay of these three factors gives rise to complex hydrogeological environments with countless variations in the quantity, quality, ease of access and renewability of groundwater resources (Adelana and MacDonald, 2008). Hydrogeological conditions and the aquifer system's characteristics have a direct bearing on groundwater management (Zektser & Everett, 2004). Apart from the huge increase in groundwater development that is necessary to meet the MDGs, additional demands will be made on groundwater in many areas of the country in the coming years. This is so because the pattern and level of life development depend to a great extent on the quality, quantity and rate of water supply to the species (Olasehinde, 2010). Civilizations have flourished with the development of reliable water supplies and have collapsed as the water supplies failed (Fetters, 1972; Troften, 1973). Development of groundwater resource therefore depends on an accurate understanding of the hydrogeology. This is imperative because, without accurate data/information, it is difficult to access the success of groundwater supply. In Nigeria, groundwater studies have occurred on an *ad hoc* basis where the funds have allowed researchers to follow an issue of interest. This paper therefore gives a succinct overview of the current hydro-geological settings/conditions of groundwater resources of Nigeria for thorough understanding and management for the benefit of the populace. This is vital because, lack of planning, education, awareness and policies oriented towards agreed water use and preservation jeopardizes the sustainability of aquifer exploitation and creates one of the more serious problems in the medium and long term.

**Location of Nigeria**

Nigeria is located on the west coast of Africa, south of the Sahara between latitudes 4$^{o}$N and 15$^{o}$N and Longitudes 3$^{o}$E and 14$^{o}$E, with the Atlantic Ocean bordering the southern coastal region and Niger Republic at the northern border. The western and eastern boundaries are Benin Republic and Cameroon respectively. Nigeria occupies an area of 923,768 square kilometers, of which 13,000 square kilometers is covered by water (CIA, 2013). Nigeria exhibits a great variety of relief features encompassing uplands of 600 m to 1,300 m on the Jos plateau, the north central and the eastern highlands; and lowlands of less than 20 m in the coastal areas extending as far inland as 60 km from the shoreline. Covering an average distance of 1,120 km from south to north, Nigeria displays physiographic regions of varying characters in relief, nature and spatial distribution.

The climate in Nigeria ranges from semi-arid in the north to humid in the south. The country has a tropical climate characterized by the hot and wet conditions associated with the movement of the Inter-Tropical Convergence Zone (ITCZ), north and south of the equator (Omotosho, 1988). Nigeria experiences consistently high temperatures all year round with mean monthly temperatures during the day sometimes exceeding 36°C, while the mean monthly temperatures at night fall below 22°C. Rainfall distribution over space and time becomes the single most important factor in differentiating the seasons and climatic regions. Except for the coastal zone, where it rains all year round, rainfall is seasonal with distinct wet and dry seasons. The mean annual rainfall along the coast in the south east is 4,800 mm while it is less than 500 mm in the north east (although the recent rainfall at the Maiduguri station measured 670 mm), very much similar to the long-term average and 20 percent higher than the average for the Sahel drought period (Goni *et al*., 2001). But in the extreme north west, close to the border with Niger Republic, approximately 350 mm of rainfall is recorded (Adelana *et al*., 2003).

**Brief Geologic Description of Nigeria**

Geologically (Fig. 1), Nigeria lies within the Pan African mobile belt in between the West African and Congo cratons. The Geology of Nigeria is dominated and made up of two main rock types: Basement complex and the Sedimentary basins, which are equally dispersed. Other minor formations are the Volcanic plateau and the River alluvium. In the basement complex terrain (comprising the west, north central and the south east blocks) rock types are predominantly of migmatitic and granitic gneisses, quartzites, slightly migmatised to unmigmatised meta-sedimentary schists and dioritic rocks (Rahaman, 1989). The sedimentary rocks overlying the basement complex (in the south, north east and north west) consists of arkosic, gravely, poorly sorted and cross-bedded sandstones (Cretaceous and Tertiary).

The three main rock groups in Nigeria include Precambrian and Mesozoic to Tertiary basement complex and volcanic rocks (crystalline metamorphic-igneous-volcanic rocks): Mesozoic to Tertiary sedimentary, younger granites and volcanic; and Quaternary to Recent alluvial deposits (Fig. 1). These groups of rocks can be divided into twelve sub-groups based on rock types and regions (Olasehinde, 2010). These include: (i) The North Central Basement Complex Rocks (ii) The Western Basement Complex Rocks (iii) The Eastern Basement Complex Rocks of Obudu Plateau (iv) The Upper Benue Volcanic Rocks of Biu Hills (v) The North Western Sedimentary

Rocks of Sokoto Area (vi) The North Eastern Sedimentary Rocks of Chad Basin (vii) The Middle Niger Sedimentary Rocks: Nupe Sandstone Basin (viii) The Upper Benue Sedimentary Rocks (ix) The Eastern States Sedimentary Rocks (x) The Coastal Lowland Sedimentary Rocks of Benin Basin (xi) The Coastal Alluvium Mangrove and Freshwater Swamps (xii) The River Course Alluvium. The full description of the geology of Nigeria is reported in Kogbe (1989), Petters (1982), Obaje, (2009), and Adelana *et al.*, 2008).

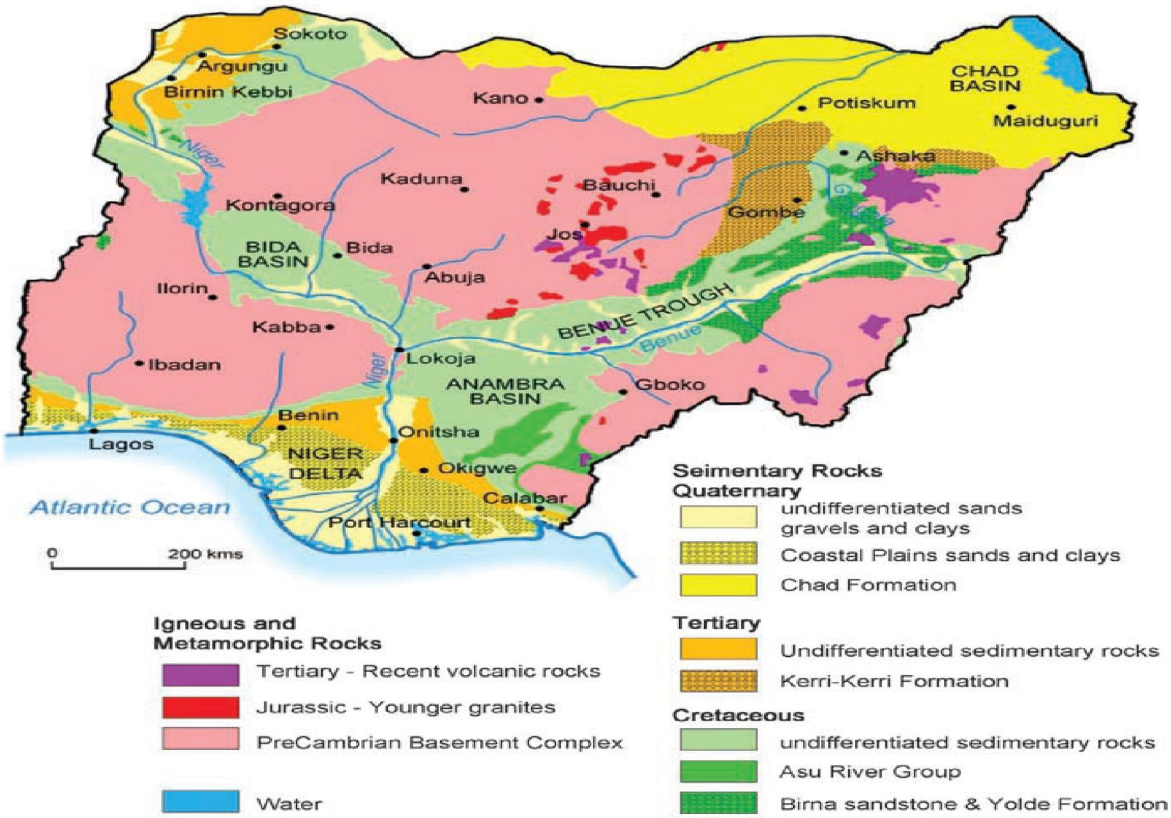


Figure 1: Generalized Geological Map of Nigeria and Groundwater Provinces (After Adelana *et al.,* 2008)

**(1) Basement Complex Rocks**

The Basement Complex of Nigeria lies within the Pan-African terrain with four broad litho-

logical units vis: (i) A polycyclic basement of migmatites and gneisses together with relics of ancient metasediments, (ii) Younger low to medium grade metasediments and metavolcanics, which form distinct NNE-SSW trending within the migmatite-gneiss complex (iii) Syntectonic to late tectonic Older Granite suite which intruded both the migmatite gneiss and the metasediments (iv) Unmetamorphosed alkaline, calc-alkaline volcanic and hypabbysal rocks, which overlie or intrude the basement and sedimentary rocks.

The Basement Complex is comparatively less developed. Olorunfemi and Fasuyi (1993), identified five aquifer types in this formation, which include the weathered aquifer; the weathered/fractured (unconfined) aquifer; the weathered/fractured (confined) aquifer; the weathered/fractured (unconfined)/fractured (confined) aquifer and the fractured (confined) aquifer. The mean groundwater yield for the aquifer types varies from 0.83 l/s for the weathered layer aquifer to 3 l/s for the weathered/fractured (unconfined)/fractured (confined) aquifer. An optimum borehole depth for the typical basement complex is 60-70 m (Olorunfemi and Fasuyi, 1993).

This formation is found in both northern and southern Nigeria. In northern Nigeria, the Precambrian Basement Complex is divided into four distinct groups:

(i) The Kano-Minna comprising of parts of Kano, Katsina, Sokoto, Zamfara, Plateau, Niger, Bauchi, Kaduna,Benue and Kogi states;

(ii) The Lokoja-Ilorin area including parts of Kwara and Kogi states;

(iii) The Gboko-Jalingo area forming parts of Adamawa, Yobe, Benue and Katsina states and

(iv) The Mubi-Gwoza area containing parts of Adamawa, Benue and Katsina states.

In the north, the rocks are composed of gneisses, migmatites and granites, with extensive areas of schists, phylites and quartzites while in the south they consist of migmatite-gneiss complex which is predominantly migmatites, banded gneisses and granite gneisses with relicts of metasedimentary and metavolcanic rocks (Oyawoye, 1972; Rahaman, 1989).

**(2) Sedimentary Basins**

There are seven major sedimentary basins: Calabar Flank, Dahomey and Niger Delta basins which are along the coast and the Benue Trough, Chad, Nupe and Sokoto (SE Iullummeden), more to the interior. The sedimentary formations uncomformably overly the basement and lithologically comprise sandstones, sands, shales, limestones, sandy gravels, siltstones and claystones that are deposited in a wide variety of sedimentary environments.

The north western Nigeria sedimentary basin, which represents the south eastern sector of the Iullemmeden basin (Mali-Niger-Benin-Nigeria) known locally as the Sokoto basin, covers an approximate area of 6,400 $km^2$ (Adelana *et al*., 2008). The sedimentary rocks of the Sokoto basin range in age from Cretaceous to Tertiary and are composed mostly of interbedded sand, clay, and some limestone; with the beds dipping gently towards the north-west. In the north eastern sector of Nigeria, the Bima sandstone is the oldest of the Cretaceous sediments, which is a thick sequence of continental sandstone deposited during the Albian – Cenomanian times. These sediments range from poorly sorted, thick bedded feldspathic sandstones and conglomerates to the fluviatile and deltatic sediments. In southern Nigeria, the sedimentary basin is partially divided into western and eastern portions: The Lagos-Osse and the Niger Delta basins, which were not completely separated from each other, and hence the occurrence of similar stratigraphic units in both basins (Adelana *et al*., 2008; Oboh-Ikuenobe *et al.*, 2005; Oteri, 1988). The Cretaceous sediments of the Benue basin represents a linear stretch of sedimentary basin running from around the present confluence of the rivers Niger and Benue to the north east, and bounded by the basement complex areas in the north and south of the river Benue (Offodile, 1989).

**(3) Volcanic plateau**

Lava flows cover parts of the Jos plateau and extensive areas in other plateaux in Plateau and Bauchi states of Nigeria. In this area, the rock types are mainly olivine basalts, scoriaceous lavas and tuffs (Du Preez and Barbers, 1965). In the Jos plateau, basaltic lavas often overlie coarse alluvium in ancient river valleys. One plateau (Sugu plateau) is formed by a succession of trachytes, rhyolites and tuffs, which occur in association with flat-lying arenaceous sediments, resulting in a sequence over 300 m thick (Du Preez and Barbers, 1965). Others are formed in a similar manner but no sediments associated with their formation. These all formed the Fluvio-Volcanic-Series described by Akujieze *et al*. (2003). Tertiary rocks of the Fluvio-Volcanic-Series occurr as a result of intense chemical weathering and lateritization.

**(4) River alluvium**

The River Course Alluvium constitutes marshy lands and valleys along the major river channels in Nigeria. Alluvial deposits cover the valleys of rivers and streams. Deposits range from the thin discontinuous sands occurring in the smallest streams to the thick alluvial deposits of rivers Niger and Benue; these may occupy strips of country up to 15 km wide on each side of the river (Du Preez and Barbers, 1965). The thickness and nature of the alluvium however varies with the type of rivers. The sediments composing river alluvium include unconsolidated gravel, coarse and fine sand, silt and clays which have high groundwater potential. These sediments are regarded as regressive Tertiary Deltaic sediments (Olasehinde, 2010). Bedding is sometimes complex and are described as lenses of coarse sand of varying thickness and lateral extent alternating with less pervious material or clay. In northern Nigeria, many river channels are underlain by coarse sand, especially in the middle reaches, where marked lowering of hydraulic gradients often occur (Du Preez and Barber, 1965). In places where stream gradients are very low, alluvial sediments consisting of fine sand, silt and clay are present.

**Hydrogeology and Groundwater Occurrence in Nigeria**

Groundwater constitutes an important source of water for domestic supply and agriculture in Nigeria. The distribution and flow of groundwater is controlled by geological factors such as the lithology, texture and structure of the rocks; and also hydrological and meteorological factors such as stream flow and rainfall. 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. The use of surface geophysical techniques coupled with down the-hole-hammer has revolutionized groundwater development in the Basement Complex areas. Many communities now obtain water from boreholes either with hand pumps or motorized pumps (Eduvie, 2006).

Groundwater which can be extracted by boreholes and hand-dug wells occurs in permeable geological formations known as aquifers which have properties that allow storage and movement of water through them. The geological structure of Nigeria gave rise to two types of groundwater pore-type water in sedimentary cover and fissure-type water found in crystalline rocks (Eduvie, 2006). The following aquifer types occur in Nigeria (i) Fissure type water in Precambrian crystalline rocks (ii) Pore-type water in sedimentary deposits (iii) Pore-type water in superficial deposits.

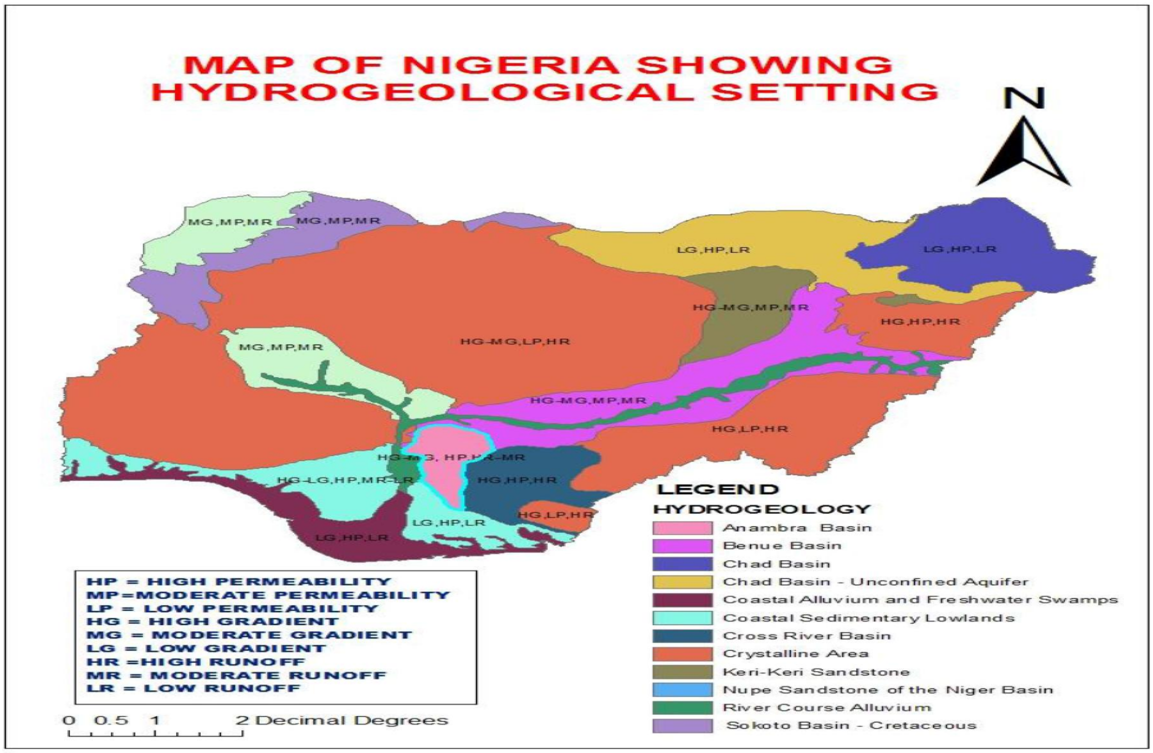


Figure 3: Hydrogeological Setting depicting Relative Permeability and Runoff Potential

Generally, aquifer distribution in Nigeria is categorized into two systems: basement fluvio-volcanic aquifers and sedimentary aquifers. 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 thickness of which range from <10 - 60 m in arid and humid rain forest. The groundwater resources here are usually limited (Eduvie, 2006).

Similarly, groundwater found in sedimentary deposits is mainly the pore-type, so also the one found in alluvial deposits where Aeolian and fluvial sediments are found, which collectively form primary aquifers because the water is contained in their primary pore spaces. 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 (Eduvie, 2006). These basins include Chad, Sokoto and Benue Trough, among others. The biggest water bearing units in Nigeria include: Chad, Kerri Kerri, Nsukka, Benin and Abeokuta Formations. This is because they are largely formed from sandstones, alluvial deposits and other related arenaceous sedimentary rocks. Shales, clays, and limestones are generally poor aquifers due to their argillaceous nature. There is little groundwater in them, the one found is only confined to their fracture and weathered zones. These rocks only help to confine an aquifer.

Groundwater tapped from confined aquifers is sometimes artesian in nature. Details of the various hydro-geological basins are presented in Offodile (1992) and Akujieze *et al.* (2003).

According to Jim (2008), Nigeria has extensive groundwater resources, located in eight recognized hydro-geological areas together with local groundwater in shallow alluvial (Fadama) aquifers adjacent to major rivers thus;

(i) The Sokoto Basin Zone (yield range from below 1.0 to 5.0 liters per second L/s).

(ii) The Chad Basin Zone (yields are about 1.2 to 1.6 L/s from the Upper unconfined aquifer and 1.5 to 2.1 L/s from the Middle aquifer).

(iii) The Middle Niger Basin Zone (yields between 0.7 and 5.0 L/s and in the Niger valley is between 7.5 and 37.0 L/s).

(iv) The Benue Basin Zone (yields between 1.0 and 8.0 L/s).

(v) The South-western Zone comprises sedimentary rocks bounded in the south by the coastal Alluvium and in the north by the Basement Complex.

(vi) The South-Central Zone (yields are from 3.0 to 7.0 L/s.)

(vii) The South-eastern Zone comprises Cretaceous sediments in the Anambra and Cross River basins.

(viii) The Basement Complex (yields between 1.0 and 2.0 L/s).

Various authors, Adeyemi (1987 and 1988), Sule (2003), Sule & Okeola, (2010), Maduabuchi, (2004), Hanidu, (1990), Rijswlk (1981), Akujieze, *et al*., (2003), and Goni, (2006) gave empirical figures which suggest high groundwater resources potential for Nigeria. Groundwater potential in Nigeria is far greater than the surface water resources, estimated to be 224 trillion l/year (Hanidu, 1990). Rijswlk (1981) estimated groundwater resources at 0-50m depth in Nigeria to be 6 x 10km$^3$ (6 x10$^{18}$m$^3$). However, from the eight aquifers in Nigeria (Akujieze, *et al.,* 2003), the Ajali Sandstone aquifer yields 7 - 10 l/s, the Benin Formation (Coastal Plain Sands) aquifer yields 6 - 9 l/s, the Upper aquifer 2.5 – 30 l/s, the Middle aquifer 24 – 32 l/s, the Lower aquifer with yields of 10 – 35 l/s (of the Chad Formation), the Gwandu Formation aquifer with yields of 8 – 15 l/s, the Kerrikerri Sandstone aquifer with yields of 1.25 – 9.5 l/s and the crystalline fluvio-volcanic aquifer with a 15 l/s yield in the Jos Plateau region; groundwater occurrence is not limited to only 50m b.g.l (below ground level). These eight mega regional aquifers have an effective average thickness range of 360m, with a thickness range of 15 – 3,000m at a depth range of 0 – 630m b.g.l with an average depth of 220m (Akujieze *et al.,* 2003). Reserves of groundwater are considerable in large sedimentary basins, which cover some 40% of the country. The potential annual groundwater resources are estimated at 51.93 x10$^9$m$^3$, out of which the sedimentary basins account for 67% (FMWRRD, 1995). From National Water Resources Master Plan completed in 1995, surface water is about 267 billion cubic meters with groundwater resources estimated at 52 billion cubic meters of replenishable yield per year.

The sedimentary basins generally form the most prolific aquifers. The depth of the water table in unconfined parts of the Sokoto basin is typically 15 - 75 m (Adelana and Vrbka, 2005). Artesian conditions occur in confined aquifers at 75 - 100 m depth at the eastern edge of the basin especially around Argungu but with piezometric levels going down further west to about 50 m below surface (Adelana *et al.*, 2002, 2003, 2006a). Significant groundwater ages (in excess of 3000 years) have been found for some confined groundwaters from the Sokoto basin (Geyh and Wirth, 1980; Oteze, 1989a,b, 1991; Bassey *et al*., 1999). Artesian conditions also exist in the Chad basin, where three main aquifers have been identified:

(i) an upper aquifer at 30-100 m depth,

(ii) a middle aquifer (eastern part of the basin) some 40-100 m thick occurring from 230 m depth near Maiduguri and

(iii) a lower aquifer consisting of 100 m of medium to coarse sands and clays at a depth of 425-530 m.

The upper and middle aquifers are exploited intensively in the Maiduguri area (UN, 1988). Overexploitation of the aquifers in the Chad basin has led to a recent decline in groundwater levels and has necessitated drilling to greater depths in order to tap the lower aquifer (Goni, 2008). Isotopic evidence suggests that groundwater from the middle and lower aquifers are old (20,000 years or more) and are not being actively replenished by modern recharge (Maduabuchi *et al*., 2003; Edmunds *et al*., 2002). In the Anambra basin south east of Lokoja, coarse Cretaceous sandstones form a good aquifer which is largely unconfined in its northern part but becomes artesian further south (UN, 1988). Groundwater levels are typically 60-150 m deep. Prolific aquifers are also present in the Tertiary and Quaternary sediments of the southern coastal areas, the best being the Tertiary ‘Illaro Formation’ composed of sands with occasional beds of clay and shale. An unconfined shallow aquifer also exists at less than 30 m in much of the area near the coastal area (UN, 1988). Table 1 shows the regional aquifer systems and yields in Nigeria while Table 2 shows the hydro-geological Areas of Nigeria.

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

| Main aquifers | Yield (L s-1) |
|---|---|
| Ajali Sandstone aquifer | 7 – 10 |
| Benin Formation (coastal plain sands) aquifer | 6 - 9 |
| The Upper aquifer (Chad Formation) | 2.5 – 30 |
| The Middle aquifer (Chad Formation) | 24 – 32 |
| The Lower aquifer (Chad Formation) | 10 – 35 |
| Gwandu Formation aquifer | 8 - 15 |
| The Kerrikerri Sandstone aquifer | 1.25 - 9.5 |
| Crystalline fluvio–volcanic aquifer | 15 |

Table 2: Hydro-geological Areas of Nigeria (Source: FMWRRD, 1995)

| | Region | Area ($km^2$) |
|---|---|---|
| 1. | Sokoto Basin Area (Sokoto Sedimentary Area) | 63,700 |
| 2. | Chad Basin Area (Chad Sedimentary Area) | 120,400 |
| 3. | Niger Basin Area (Upper Niger Sedimentary Area) | 38,300 |
| 4. | Benue Basin Area (Benue Sedimentary Area) | 116,300 |
| 5. | South Western Area (Ogun / Osun Sedimentary Area) | |
| 6. | South Central Area (Lower Niger Sedimentary Area) | 110,300 |
| 7. | South Eastern Area (Cross River Sedimentary Area) | 29,700 |
| 8. | Basement Complex Area (Crystalline Rock Area) | 445,100` |
| | **Total** | **923,800** |

**Hydrology and Groundwater Recharge Estimates**

Surface water flowing from Nigeria to the sea is estimated at 263km$^3$/annum (FAO, 2005). Nigeria is blessed with numerous rivers and streams, the largest of which are the Niger and Benue which are transboundary water bodies. The Benue itself is a part of the Niger River Basin and the flood events within this basin are influenced by factors operating from outside Nigeria. Some of the runoff generated as far away as the foothills of the Futa Jalon Mountains in the Republic of Guinea may end up in the Niger Delta in Nigeria. Thus some parts of Nigeria are precariously placed in terms of flood vulnerability because the forces generating the floods impacting on them are from areas outside the territorial boundaries of Nigeria and therefore cannot be controlled without regional agreements and co-operation.

Nigeria can be divided into eight contiguous hydrological catchments designated as Hydrological Areas I – VIII (Fig.3) and these serve as units for scientific assessments and management of water resources. They are also the building blocks of all hydrological evaluations Figure 1 shows the hydrogeological setting of Nigeria, while Fig.3 shows the eight hydrological areas with the drainage network.

The average annual rainfall ranges from about 500mm in the north to over 2,000mm in the south. Uneven distribution of rainfall across Nigeria reflects a significant variation in the surplus when viewing different parts of the country. This rainfall distribution generates the arid and semi-arid conditions of the north, the wet south and the coastal aquifer environments of Nigeria. With consideration of the hydrologic cycle, each of these four major environments has their hydrological challenges. While the northern part of Nigeria is dominated by the problems of aridity–semi-aridity, which limits the volume of water available for recharge to the aquifers, the south is saddled with the problems of flooded terrains, saltwater intrusion, and environmental and ground degradation due to the activities of the petroleum industries (Akujieze, *et al*., 2003).

Recent recharge estimates use a combination of simplified empirical equations, stream-flow hydrographs, water table fluctuations, base-flow recession methods (Adelana *et al.*, 2006a) as well as chloride-based methods supported by stable isotope data (Adelana *et al.,* 2006b). Groundwater recharge conditions in the crystalline basement of south western Nigeria are crucial for understanding the groundwater flow regime and infiltrating conditions. Studies in north western Nigeria showed considerable depletion in isotopic content (18O and 2H) and low deuterium excess in groundwater, reflecting the contribution of old meteoric water that recharged the Cretaceous aquifers in Pluvial times (between 5000 and 15000 year BP) (Adelana *et al.,* 2002). However, present day recharge has been demonstrated for the alluvial aquifer in the area. Estimates from chloride mass balance method confirmed recharge rates are unevenly distributed over the area. In the Chad basin in north east Nigeria, there was also isotopic evidence of palaeo-recharge in the deep confined aquifers (Edmunds *et al.,* 2002, Maduabuchi *et al.,* 2006).

**The River Basin Development Authorities (RBDAs) in Nigeria**

This 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. There are eleven River Basin Development Authorities (RBDA's) in Nigeria. These were established to manage and monitor activities in the river catchments and the management units. The river basin authorities do not have sufficient scope and coverage of hydro-geological units that could facilitate proficient groundwater management.

Decentralization is the defining feature of water administration in Nigeria, leading to different ministries and agencies at different levels, administering laws but lacking adequate co-ordination (FAO, 2005). The functions of the RBDAs related to irrigation are defined in the River Basin Development Authorities Act No. 35 of 1986. The traditional institutional separation of surface water from groundwater has created fundamental communication barriers that extend from technical expertise to policy developers, operational managers and water users. These barriers impede the understanding of the processes and consequences of groundwater-surface water interactions (Owen *et al*., 2008). Considering the nation's River Basin Development Authority (RBDAs) and their associated groundwater basin (Table 3) and the river basins and hydrological areas in Nigeria (Fig. 3), the disproportionate management of surface water resources without the groundwater counterpart has contributed significantly to unsustainable and inadequate water supply.

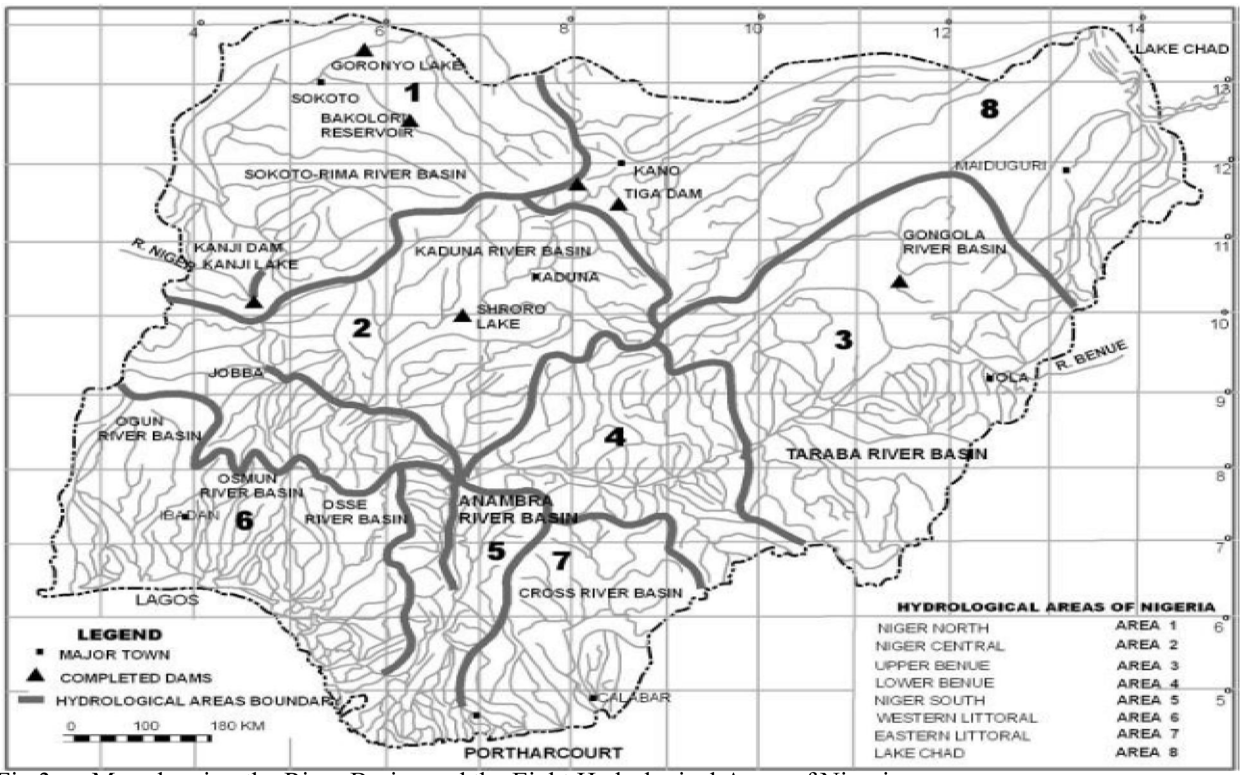


Fig.3: Map showing the River Basins and the Eight Hydrological Areas of Nigeria

Table 3: River Basin Development Authorities and Associated Groundwater Basins

| S/N | **River Basin Development Authority** | **Groundwater Basins** |
|---|---|---|
| 1. | Sokoto Rima River Basin Authority | Sokoto Basin (Tertiary)<br>Sokoto Basin (Cretaceous) |
| 2. | Hadejia-Jamare River Basin | Chad Basin (Unconfined)<br>Part of Basement Complex<br>Part of Keri Keri Basin |
| 3. | Lake Chad Basin | Chad Basin (Unconfined)<br>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<br>Part of Basement |
| 8. | Ogun Oshun River Basin Coastal Sedimentary | |
| 9. | Benue River Basin Coastal Sedimentary | |
| 10 | Niger Delta Coastal Alluvium Mangrove | Coastal Sedimentary |

**Economics of Groundwater Resources /Future Perspectives**

In Nigeria water resources, including rain harvesting, surface water and groundwater are obtainable in varying quantity from place to place. The least of these is the groundwater source, yet it is the most abundant, most reliable and cheapest to harness. While access to drinking water is often said to be related to poverty, very few studies show the importance of groundwater resources in achieving the United Nations Millennium Goals: halving the number of people who suffer from malnourishment by 2015 (Llamas, 2005). Groundwater is already playing a key role in meeting the MDGs. Groundwater irrigated surface has increased by over forty million hectares during the last decades (Deb Roy & Shah 2003). Largely as a consequence, Nigeria can achieve food security in practice and become an important grain exporter.

Groundwater irrigation has proven an excellent catalyst for the positive social transition of farmers in arid and semiarid regions worldwide (Moench, 2003; Steenberger & Shah, 2003). This is largely a consequence of groundwater's resilience against drought. Secured access to water during dry periods removes a sense of risk from farmers' minds. Thus, they are more willing to invest in new technologies, both from the agricultural (selective seeds, agrochemicals) and the technical point of view (drip irrigation). Increased revenues result, and allow for a greater degree of social welfare. In addition, farmers become able to provide a better education for their children, who may either move on to other economic sectors or return to agriculture with a more productive outlook.

Hydro-geological education appears a must, not only aiming at high-level water decision-makers, but also at the general public and more importantly to farmers (generally the main groundwater users and polluters). Generally speaking, water managers and decision-makers have traditionally been trained to build and operate large surface water infrastructures. As a result, the importance of groundwater resources is often overlooked or even disregarded. This may provide an explanation for the generalized lack of accurate groundwater data. Besides, it appears to be the reason of the huge gap that currently separates water decision-makers from the main actors. Last, but not least, corruption is increasingly recognized as a potential 'cancer' for democratic systems (OECD, 2000; United Nations, 2003). Water resources are not an exception. As stated by the Valencia Declaration (Sahuquillo *et al.,* 2005), groundwater is less prone to corruption than large surface water infrastructures. This obeys two main reasons. First, implementation of groundwater development presents a comparatively shorter timeframe (often weeks or months in comparison with several decades taken to implement a surface water system based on dams and canals). Second, investments in groundwater development are generally much smaller, and usually carried out by individuals with little or no public funding. In contrast, large surface water infrastructures frequently require significant public subsidies or donations from international organizations. This setting (long implementation time, significant funds) allows more room for unethical practices.

It is extremely difficult to provide a 'general guide to groundwater sustainability' as complying with the dimensions may not be possible in most cases. Emphasis on one or another is likely to depend on economic, social, cultural and political constraints. Groundwater management requires a higher degree of user involvement than surface water developments. Experience shows that sustainable aquifer use cannot be solely achieved by means of top-down "control and command" measures. A frequently quoted aspect of 'sustainability' is that the potential future needs should be born in mind before launching into any development. In other words, the current generation should strive to preserve the world's natural resources so that coming generations may be able to take advantage of them.

User participation requires a degree of hydro-geological education which is still absent in most places in Nigeria. Steps should be taken to make the peculiarities of groundwater resources known to all, from politicians and water decision makers to direct users as well as the general public. This should begin at the school level. Appropriate groundwater management requires a significant degree of trust among stakeholders. This implies that groundwater data should be transparent and widely available (via the internet, for instance). In addition, the system should be able to punish those who act against the general interest.

Existing groundwater data is often scarce or laden with uncertainty. This is largely a consequence of the relative novelty of intensive groundwater development, a phenomenon that has only become commonplace in the last four or five decades. Secondly, intensive groundwater use has been often carried out with little or no planning or control on the part of public water agencies, leading to chaotic development in most cases. Causes should be found in the historical past: for thousands of years (although more particularly in the 19th Century), water managers and decision makers have been trained to build and operate surface water infrastructures, while 'invisible' groundwater resources have received less attention. On the other hand, the private initiative has traditionally been the main driving development, particularly in arid and semiarid regions where irrigation is necessary for agriculture. Millions of farmers, modest for the most force behind intensive groundwater part, today drill their wells and pump groundwater at their own expense. Uncontrolled drilling and pumping has led to problems in some places. While some of these constitute an undeniable matter of concern, the majority have been magnified due to ignorance, institutional inertia, vested interests and corruption.

**Conclusion**

Groundwater resources – the guarantee of a sustainable future has fallen noticeably behind in basic issues as education (both formal and informal) about water use, knowledge of the characteristics of groundwater resources, efficient public policies, the presence of the government as a controlling entity of the social use of water, together with a growing pauperization of the population and a lack of user participation in the management of resources. Quite unfortunately, in spite of the fundamental role groundwater plays in human well being, as well as that of many ecosystems, it is yet to be fully appreciated and adequately managed and protected, both within the country and regionally. It is a well known fact that groundwater basins are difficult to govern and manage, partly because of poor information, and also because of poor visibility of the resource, the need for reliable data and accurate information and appropriate expertise in support of water resource planning is central to any strategy. Monitoring of Water Resources of the country in quantity and quality should also be pursued as integral component of the various water resources development programs and projects.

**References**


1. Adelana, S.M.A and Vrbka, P. (2005). Hydrogeological and isotopic research in the semi-arid area of northwestern Nigeria. Proc. Biennial Ground Water Conference, Pretoria, 7-9 March.
2. Adelana, S.M.A; Olasehinde, P.I and Vrbka, P. (2002). Groundwater recharge in the Cretaceous and Tertiary sediment aquifers of northwestern Nigeria, using hydrochemical and isotopic techniques.
3. Adelana, S.M.A; Olasehinde, P.I and Vrbka, P. (2003). Isotopes and geochemical characterization of surface and subsurface waters in the semi-arid Sokoto Basin, Nigeria. *African Journal of Science and Technology*, 4(2): 76-85.
4. Adelana SMA, Olasehinde P.I and Vrbka P. (2006a). A quantitative estimation of groundwater recharge in parts of Sokoto Basin, Nigeria. *Journal Environmental Hydrology,* 14(5):1-17.
5. Adelana, S.M.A; Olasehinde, P.I and Vrbka, P. (2006b). Identification of groundwater recharge conditions in crystalline basement rock aquifers of the southwestern Nigeria. In: Special UNESCO Volume: Recharge systems for protecting and enhancing groundwater resources, IHP-VI, Series on Groundwater No.13, 649-655, UNESCO, Paris.
6. Adelana, S.M.A; Olasehinde, P.I; Bale, R.B; Vrbka, P; Goni, I.B and Edet, A.E. (2008). An overview of the geology and hydrogeology of Nigeria. In: (Adelana SMA and MacDonald AM eds.). Applied Groundwater Studies in Africa. IAH Selected Papers on Hydrogeology, Volume 13: 171-197, CRC Press/Balkema, London.
7. Adeyemi, S.O. (1987). Water policies for the future. Convocation lecture. University of Maiduguri, Maiduguri, Nigeria.
8. Adeyemi, S.O. (1988). Nation's quest for water. 31st Inaugural lecture. University of Ilorin, Ilorin, Nigeria.
9. Akujieze, C.N; Coker, S.J.L. and Oteze, G.E. (2003). Groundwater in Nigeria. A Millennium Experience–Distribution, Practice, Problems and Solutions. Hydrogeology Journal. 11:259-274.
10. CIA (2013). The World Fact Book (http:/www.odci.gov/cia/publications/factbook/index.html.
11. Crisis? In: *Water Crisis: Myth or Reality?*, Rogers et al. (eds.), pp. 181-195.
12. Cobbing, J.E and Davies, J (2008). The benefits of a scientific approach to sustainable development of groundwater in Sub- Saharan Africa. In: Adelana, S.M.A & MacDonald, A.M (ed.) Applied Groundwater Studies in Africa. CRC Press, Taylor and Francis Group: A Balkema Book.
13. Deb Roy, A. and Shah, T. (2003). Socio-ecology of groundwater irrigations in India, in Intensive Use of Groundwater, Llamas, M.R and Custodio, E (eds)., pp. 307-336.
14. Du Preez, J.W and Barber, W. (1965). The distribution and chemical quality of groundwater in northern Nigeria. Geological Survey of Nigeria Bulletin No.36: 93.
15. Edmunds, W; Fellman E; Goni, I and Prudhomme, C. (2002). Spatial and temporal distribution of groundwater recharge in northern Nigeria. *Hydrogeol. Journal,* 10 (1):205-215.
16. Eduvie, M.O. (2009). Approaches to cost-effective borehole drilling in Nigeria. nwri.gov.ng/userfiles/extracted on 24/03/2010.
17. Eduvie, M.O (2006). Borehole failures in Nigeria. Paper presented at a National Seminar

held on the Occasion of Water Africa Exhibition (Nigeria 2006) at Eko Hotels & Suites, Victoria Island, Lagos, on 15th November, 2006.

18. FAO. (2005). Irrigation in Africa in figures – AQUASTAT Survey: Nigeria. Food and Agricultural Organisation, Rome, Italy, pp433-446.
19. Fetters, C.W (1972). Applied Hydrogeology, 3rd Edition, Prentice Hall, USA, pp 115 – 124.
20. FMWRRD (1995). The Study on the National Water Resources Master Plan. Japan International Cooperation (JICA) and Federal Ministry of Water Resources and Rural Development, Federal Republic of Nigeria, Abuja.
21. Geyh, M.A and Wirth, K. (1980). 14C ages of confined groundwater from the Gwandu Aquifer, Sokoto Basin, Northern Nigeria. *Journal of Hydrology*, 48:281-288.
22. Goni, I.B; Fellman, E and Edmunds, W.M. (2001). A geochemical study of rainfall in the Sahel region of northern Nigeria. *Atmospheric Environments*, 35:4331-4339.
23. Goni, I.B. (2008). Estimating groundwater recharge in the Nigerian sector of the Chad basin using chloride data. In: Adelana, SMA (ed.) Applied groundwater studies in Africa, CRC Group, London.
24. Goni, I.B. (2006). The challenges of meeting domestic water supply in Nigeria. J. Min. Geol. 42(1): 51–55.
25. Hanidu, J.A. (1990). National growth, water demand and supply strategies in Nigeria in the 1990s. *Water Resources,* 2:1–6.
26. Hernández-Mora, N; Martínez-Cortina, L. and Fornés, J. (2003). Intensive Groundwater Aquifer Over-Exploitation. Implications for Water Policy in Southern Europe. In: *Agricultural Use of Groundwater. Towards Integration between Agricultural Policy and Water Resources Management* (ed. C. Dosi), Kluwer Academic Publishers, pp. 107-125.
27. Ibe, Sr K.M; Nwankwor, G.I and Onyekuru, S.O. (2003). Groundwater pollution vulnerability and groundwater protection strategy for the Owerri area, southeastern Nigeria. Water Resources Systems- Water Availability and Global Change (Proceedings of symposium I IS0 2a held during 1UGG2003 al Sapporo). IAHS Publ. no. 280, 2003.
28. Kogbe, C.A. 1989. Geology of Nigeria. (Ed.) Rock View Publ. Co., Nigeria.
29. Kretsinger, V.G; and Narasimhan, T. N. (2005). Sustaining groundwater resources: California's shift toward more effective groundwater management. Southwest Hydrol., 4: 18-19.
30. Llamas, M.R. (2005) "Foreword" in Groundwater Intensive Use, Sahuquillo et al. (eds.). Internacional Association of Hydrogeologists No. 7, Selected Papers, Balkema Publishers, Leiden, pp. XIII-XIV.
31. Llamas, M.R. and Martínez-Santos, P. (2005) "Intensive Groundwater Use: Silent Revolution and Potential Source of Social Conflicts". Journal of Water Resources Planning and Management, American Society of Civil Engineers, September/October 2005, pp.337-341.
32. Maduabuchi, C; Faye, S and Maloszewski, P. (2006). Isotope evidence of palaeorecharge and palaeoclimate in the deep confined aquifers of the Chad Basin, NE Nigeria. *Science of the Total Environment*, doi:10.1016/j.scitotenv.2006.08.015.
33. Maduabuchi, C; Maloszewski, P; Stichler, W and Eduvie, M. (2003). Preliminary interpretation of environmental isotope data in the Chad Basin aquifers, NE Nigeria. International symposium on isotope hydrology and integrated water resources management, 19–23 May, Vienna, Austria.
34. Maduabuchi, C.M. (2004). Surface and Groundwater Resources Monitoring and Management in Nigeria. Paper Presented at the United Nations/Austria/ESA Symposium on Space Applications for Sustainable Development to Support the Plan of Implementation of the World Summit on Sustainable Development "Water for the World: Space Solutions for Water Management".
35. Moench, M. (2003) "Groundwater and Poverty: Exploring the connections" in Intensive Use of Groundwater, Llamas and Custodio (eds.), pp. 441-455.
36. Nwankwoala, H. O. (2011). An integrated approach to sustainable groundwater development and management in Nigeria. Journal of Geology and Mining Research (3)5: 123 – 130.
37. Obaje, N.G. (2009). Geology and Mineral resources of Nigeria. Lecture Notes in Earth Sciences, Springer, 221pp.
38. Oboh-Ikuenobe, F.E; Obi, C.G and Jaramillo, C.A. (2005). Lithofacies, palynofacies, and sequence stratigraphy of Palaeogene strata in Southeastern Nigeria. *Journal of African Earth Sciences*, 41:79–101.
39. OECD (2000) "No longer business as usual: Fighting Poverty and Corruption" OECD, París, 276 p.
40. Offodile, M.E. (1989). A review of the geology of the Cretaceous of the Benue valley. In:

Geology of Nigeria, CA Kogbe (eds.). Rock View (Nigeria) Limited. pp 365-376.
41. Offodile, M.E. (1992). An approach to ground water study and development in Nigeria. Mecon, Jos, 247 pp.
42. Olasehinde, P.I (2010). The groundwaters of Nigeria: A solution to sustainable national water needs. Inaugural Lecture Series 17, Federal University of Technology, Minna, Nigeria.
43. Olorunfemi, M.O and Fasuyi, S.A. (1993). Aquifer types and the geoelectric/ hydrogeologic characteristics of part of the central basement terrain of Nigeria. *Journal of African Earth Sciences*, 16(3): 309-317.
44. Omotosho, J.B. (1988). Spatial variation of rainfall in Nigeria during the little dry season. *Atm Res.,* 22(2):137-147.
45. Oteri, A.U (1988). Electrical log interpretation for the evaluation of saltwater intrusion in the eastern Niger Delta. Hydrological Sciences Journal. 33(1/2): 19 - 30.
46. Oteze, G.E. (1989a). Environmental Isotope Hydrology of the main Rima Aquifer Waters. *Jour. Min. Geol*., 25(1&2):205-210.
47. Oteze, G.E. (1989b). The Hydrogeology of the North-Western Nigeria Basin. In: Geology of Nigeria. CA. Kogbe (eds.), Jos, Rock View (Nigeria) Limited: 455-472.
48. Oteze, G.E. (1991). Potability of groundwater from the Rima Group aquifer in the Sokoto Basin Nigeria. *J Mining Geol*., 27:12-23.
49. Owen, R., Mirghani, M., Diene, M., Tuinhof, A. and Taylor, P (2010). Groundwater Management in IWRM Training Manual in the water industry. In: *Navigating Rough Waters*. Davis C.K. and McGinn, R.E. In: (Bocanegra E, Martinez D and Massone H eds.). Groundwater and Human Development, Mar de Plata, Argentina, pp 907-915.
50. Oyawoye, M.O. (1972). The Basement Complex of Nigeria. Ibadan, Geol. Dept. Univ. Ibadan, Nigeria. *Papers on Aquifer Overexploitation*, (Simmers, Villarroya, Rebollo, ed.), Hydrogeology, Selected Paper, Vol. 3, Heise, Hannover, pp. 69-86. París.
51. Petters, S.W. (1982). Central West African Cretaceous – Tertiary Benthic Foraminifera and Stratigraphy. Palaeontographica Abt A. Ed. 179:1-104., Stuttgart, Germany.
52. Rahaman, M.A. (1989). Review of the Basement geology of South-western Nigeria. In: Geology of Nigeria, Kogbe CA (ed.), Rock View (Nigeria) Limited. pp39-56.
53. Rijswlk, K. (1981). Small Community Water Supplies. IRC Technical Paper Series, No.18. The Netherlands.
54. RIM (Resource Inventory Management Limited). (1992). Nigerian Livestock Resources. Report submitted to the Federal Government of Nigeria.
55. Sahuquillo, A., Capilla, J., Martínez-Cortina, L. and Sánchez-Vila, X. (2005) "Groundwater Intensive Use". Selected Papers on Hydrogeology, No. 7, International Association of Hydrogeologist, Balkema Publisher, Leiden, 393 pp.
56. Steenberger, F. and Shah, T. (2003) "Rules rather then rights: self-regulations in intensively used groundwater systems" in Intensive Use of Groundwater, Llamas and Custodio (eds.), pp. 241-256.
57. Sule, B. F. and O.G. Okeola. (2010). Measuring willingness to pay for improved urban water supply in Offa city, Kwara state. Nigeria. Water Science and Technology: Water Supply. (10):2 pp 933 -941.
58. Sule, B.F. (2003) Water security: Now and the future. $65^{th}$ Inaugural lecture, University of Ilorin, Nigeria. Nigeria.
59. Troften, P.F (1973). Groundwater Utilization in Hard Rocks, Atlas Copco MCT AB-Stockholm, Sweden, AHB 35 – 15, Printed Matter No. 15317a48pp.
60. UN (1988). Ground Water in North and West Africa. Natural Resources Water Series, 18, United Nations, New York.
61. World Bank (2003) Water resources sector strategy: Strategic directions for World Bank engagement. Washington, DC.
62. Zektser, I.S and Everett, L.G (2004). Groundwater resources of the world and their use. IHP – VI Series on Groundwater, 6, 346pp.


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