OBAF

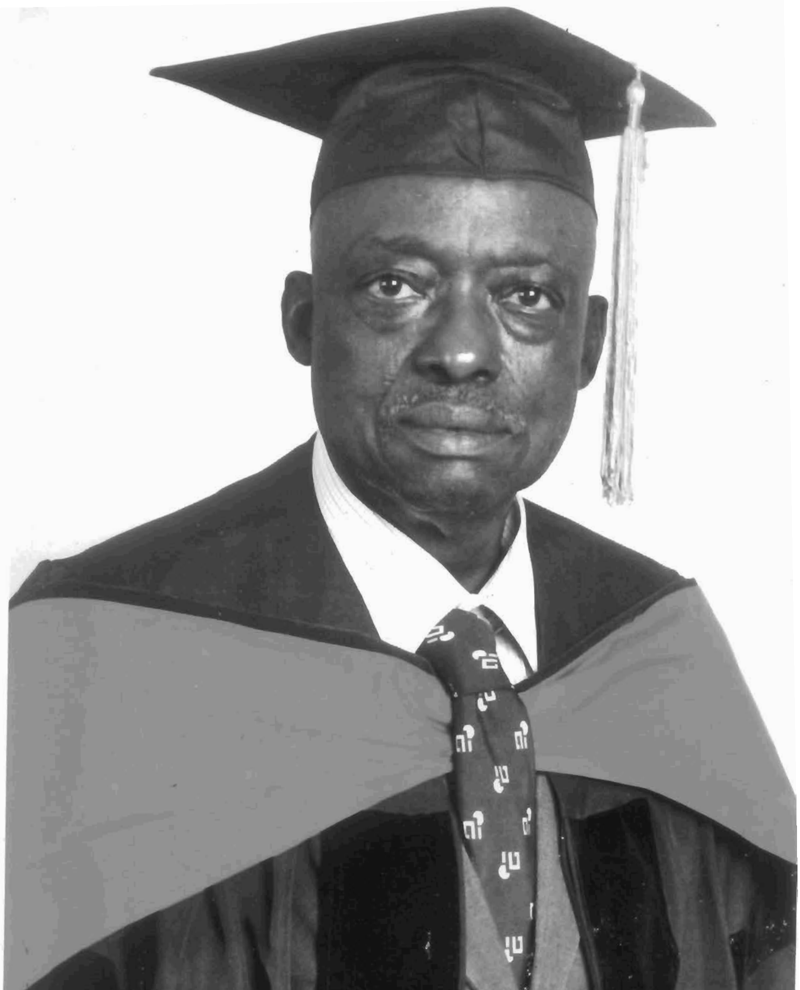
INAUGURAL LECTURE SERIES 301

WATER FROM ROCKS

By

Joseph Owolabi AJAYI
Professor of Geology

OBAFEMI AWOLOWO UNIVERSITY PRESS, ILE-IFE, NIGERIA.



Joseph Owolabi AJAYI

Professor of Geology

WATER FROM ROCKS

**An Inaugural Lecture Delivered at Oduduwa Hall,
Obafemi Awolowo University, Ile-Ife, Nigeria,
on Tuesday, 11th April 2017.**

by

Joseph Owolabi AJAYI
Professor of Geology

Inaugural Lecture Series 301

ISSN 0189-7848

Printed by

Obafemi Awolowo University Press Limited,
Ile-Ife, Nigeria.

WATER FROM ROCKS

1.0 Introduction

The topic of the Inaugural Lecture of today (during the Holy Week of Lent) was actually suggested to me by my current Acting Head of Department, Dr. Solomon Adekola, in his Solomonic Wisdom, when I could not make up my mind as to what the title of my Inaugural Lecture should be. Dr. Adekola is a man after my own heart. I am greatly indebted to him for his steadfast support during my tenure as the Head of the Department of Geology from 1st August 2011 (the Feast of St. Alphonsus Liguori) to 31st July 2014 (the Feast of St. Ignatius of Loyola). St. Ignatius of Loyola is the Patron Saint of my Secondary School, Loyola College, Ibadan. The motto of the school is simply, *Veritas,* a Latin word, translated roughly as *Truth.* Up Loyo!. Truth is so scarce in our dear country, Nigeria, today, as we live in denial of almost everything. For example, government officials claim there is water supply to the people, when there is no water.

Mr. Vice Chancellor, Sir, "**Water from Rocks**," may sound like a contradiction in terms, but rocks do actually contain water in various quantities, among other treasures contained within the earth. Usually rocks are perceived by the layman as impervious or impermeable, incapable or yielding anything, yet there are hidden treasures in the rocks (Ako, 1996; Odebode, 2005; Olarewaju, 2007; Nwachukwu, 2007; Olorunfemi, 2008; Tijani, 2016), mineral resources; (such as ores and rare metals), petroleum hydrocarbons (including bitumen, crude oil and gas); and of course, groundwater. In addition, rocks provide the geomaterials for civil construction and the foundation for most civil engineering construction (Adeyemi, 2013).

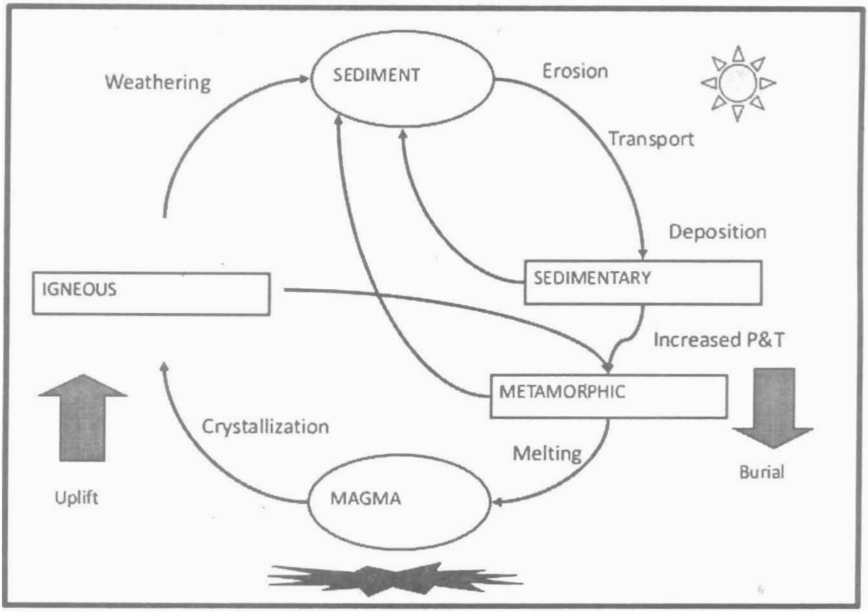
My inaugural lecture will take us through my adventures, trials and tribulations in the areas of water and rock association, interactions, the biophysical environment and human health. Other notable inaugural lectures in my area of specialization in very recent times include Tijani (2016) and Asiwaju-Bello (2017). My research covers the areas of groundwater exploration; assessment or evaluation; exploitation or recovery; conservation and management. More recently, I have participated in flood mitigation efforts (Oyo State Government, 2011, Ajayi *et al.*, 2012).

My foray into the world of Geology, Hydrology, Hydrogeology and the Environment, began several years ago, at least sixty years back. I can remember vividly as a small child of five or six accompanying grownups to fetch water from rivers, dug wells and rock crevices around the ancient City of Abeokuta, a city that nurtured, in his formative years, the only Nobel Laureate Nigeria has produced to date, Emeritus Professor Wole Soyinka (Soyinka, 1981). Considering other notable personalities that come from that part of the country, there must be something about drinking the groundwater of Ake and environs.

2.0 The Rock Cycle

The nonprofessional geologist conceives rocks as the hard materials that we see forming hills, which are the main materials used in all manner of civil works or construction. Rocks contain different minerals. The study of rocks must include the study of the materials found within the rocks where the rocks contain in-homogeneities, such as pore spaces, fissures or joints that can be filled with solid minerals, liquids or gases. Common liquids found within rocks are crude oil or petroleum, natural gas, bitumen and groundwater.

Geologists classify rocks on the genesis or mode of formation into igneous, metamorphic and sedimentary. Some geologists include sediments (accumulations of loose fragments of rock) in this definition. Figure 1 shows the rock cycle, illustrating the transformation of one rock type to another and the mechanism of transformation.



Source: https://www.slideshare.net/vandeco87/rock-cycle-powerpoint

Figure 1 – Rock Cycle

3.0 Water from Rocks in the Holy Scriptures

Throughout several passages in the Holy Bible, from the Book of Genesis to the Book of Revelation, there are numerous references to **water from rocks**. The first time that water is mentioned in the Holy Bible is in the Book of Genesis (all biblical references according to the New Jerusalem Bible (NJB) Standard Edition, 1985:

> ***Gen 1: 1-2.*** *In the beginning God created heaven and earth. Now the earth was a formless void, there was darkness over the deep, with a divine wind sweeping over the waters."*

Actually, from the account of the Holy Bible, God called forth living creatures out of water. Indeed the human body is approximately 75% water, which approximates the amount of the surface of the earth covered by water. The last time that water is mentioned in the Holy Bible is in the Book of Revelations:

> ***Revelations 22:17*** *The Spirit and the Bride say, "Come!" Let everyone who listens answer, "Come."Then* ***let all who are thirsty come****: all who want it may* ***have the water*** *of life, and have it* ***free.***

Usually, the Lord provides **water from rocks**. After the Israelites had wandered in the desert for a while, in spite of manna from above they became thirsty and needed water to wash it down. God provided them with **water from rocks** (groundwater). He simply instructed Moses as contained in the Book of Exodus:

> ***Exodus 17: 5,6*** *Yahweh then said to Moses, "Go on ahead of the people, taking some of the elders of Israel with you; in your hand the staff with which you struck the River, and go. I shall be waiting there before you on the rock (at Horeb). Strike the rock, and water will come out of for the people to drink." This was what Moses did, with the elders of Israel looking on."*

In the Book of Deuteronomy, we get an idea of the type of rock from which Moses obtained water in the desert:

> ***Deuteronomy 8: 15-16*** *Do not then forget Yahweh your God who brought you out of Egypt, out of the place of slave-labour, who guided you through this vast and dreadful desert, a land of fiery snakes, scorpions, thirst; who in this waterless place brought you water out of the* ***flinty rock****; who in this desert fed you with manna unknown to your ancestors, to humble you and test you and so make your future the happier* ***(emphasis supplied.)***

In the Book of Psalms, we encounter groundwater in the form of deep wells and springs thus:

> ***Psalms (78: 15 – 16)*** *"He splits rocks in the desert, let them drink as though from limitless depths; he*

brought forth streams from a rock, made waters flow down in torrents."

The previous Biblical passages quoted above complete the concept of the Water Cycle, according to the Holy Bible.

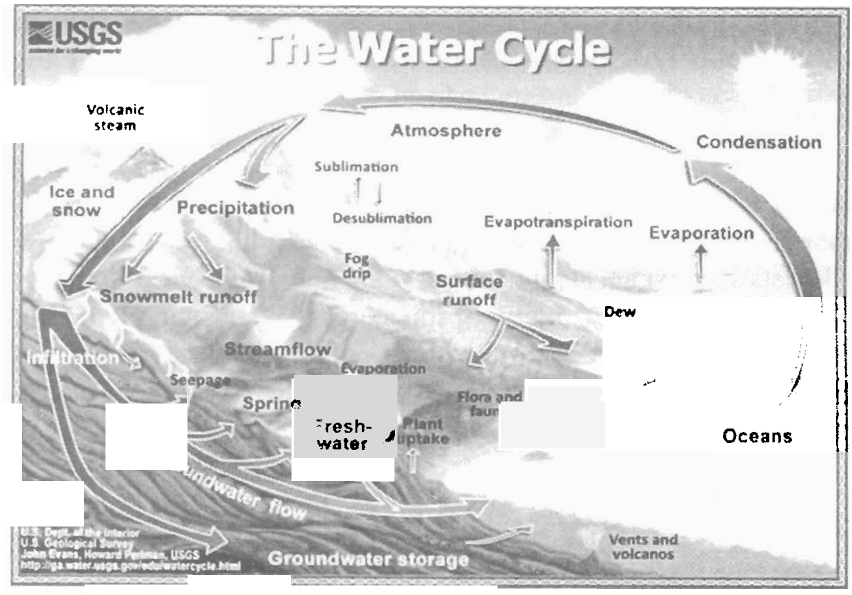
Issar (1989, 2014) provides a more detailed account of **water from rocks.** Prof. Arie Issar was one of my professors during the training course that I attended in Israel in my early days in the profession during the 1972/1973 academic year. Tijani (2016) and Asiwaju-Bello (2017) provide further insightful accounts of the nature of groundwater and rocks from other sources.

Mr. Vice Chancellor, Sir, it is important to bring the world of geology to everyone here present in order to appreciate not just the importance of geology to human existence, but to show how geologists have shaped human existence and I feel very proud to be one of them. The economy of this country rests squarely on the shoulders, sacrifices and exertions of geologists, from oil exploration, mineral exploration to the search for potable water, whether underground or on land (Cooray, 1972).

4.0 The Water Cycle

The Water Cycle (WC), also known as the Hydrologic Cycle in some textbooks, is a concept that explains the occurrence, residence and movement of water throughout the earth. Water occurs in three physico-chemical states or forms as solid (ice), liquid (water) and gas (moisture). Figure 2 shows the concept of the WC according to the United States Geological Survey (USGS), which recognises sixteen (16) components of the WC shown in Table 1. Most of these components are self-explanatory.

Briefly, the WC can be explained as the endless movement of water from the oceans (as a convenient starting point) to the atmosphere, to land, into the subsurface, along the surface of the land and back to the ocean, from where the cycle begins again (Figure 2). Water stays in each of these reservoirs for different lengths of time, which is called the residence time. Water is in flux from one reservoir to another, depending on the hydrodynamic conditions at play. It is important to note that the residence time and the nature of the rocks within which groundwater occurs determine its hydraulic and quality (thermal, geochemical, radiological and microbiological) characteristics. Table 2 shows the distribution of water in the WC.



Source: http://ga.water.usgs.gov/edu/watercycle.html

Figure 2: Water Cycle

Table 1: Main components of the water cycle

SN	Main Component
1	Water Storage in Oceans
2	Evaporation
3	Sublimation
4	Evapotranspiration
5	Water in the Atmosphere
6	Condensation
7	Precipitation
8	Water Storage in Ice and Snow
9	Snowmelt runoff to treams
10	Surface runoff
11	Streamflow
12	Freshwater storage
13	Infiltration
14	Groundwater storage
15	Groundwater Discharge
16	Springs

5.0 Hydrogeology

The discipline of Hydrogeology, also called Groundwater Engineering by Engineers (Kashef, 1987), within the context of the WC, is the study of the occurrence, movement, quality, uses and management of groundwater. Figure 3 shows the groundwater concept. Most economically usable groundwater, however, occurs within a few hundred of metres below the surface of the earth.

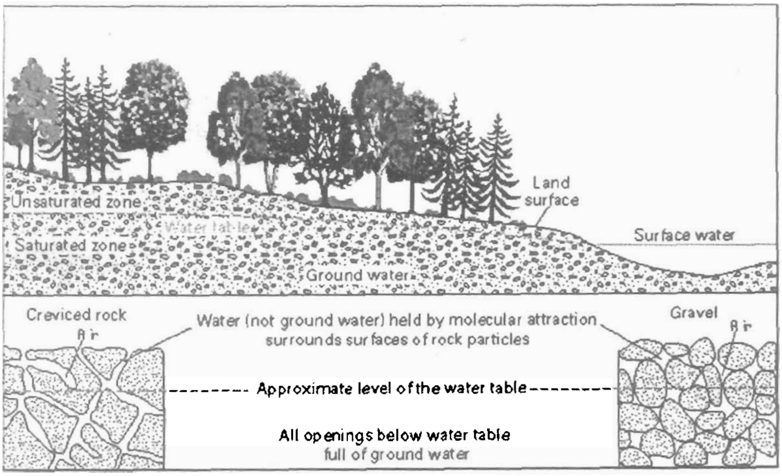
In these parts of the world, precipitation in the form of rainfall is the major source of water sustaining stream flow, rivers and lakes.

Table 2: Distribution of Water in the Water Cycle

Water source	Water volume, in cubic miles	Water volume, in cubic kilometers	Percent of freshwater	Percent of total water
Oceans, Seas, & Bays	321,000,000	1,338,000,000	--	96.5
Ice caps, Glaciers, & Permanent Snow	5,773,000	24,064,000	68.7	1.74
Groundwater	5,614,000	23,400,000	--	1.69
Fresh	2,526,000	10,530,000	30.1	0.76
Saline	3,088,000	12,870,000	--	0.93
Soil Moisture	3,959	16,500	0.05	0.001
Ground Ice & Permafrost	71,970	300,000	0.86	0.022
Lakes	42,320	176,400	--	0.013
Fresh	21,830	91,000	0.26	0.007
Saline	20,490	85,400	--	0.006
Atmosphere	3,095	12,900	0.04	0.001
Swamp Water	2,752	11,470	0.03	0.0008
Rivers	509	2,120	0.006	0.0002
Biological Water	269	1,120	0.003	0.0001

Source: Shiklomanov,1993

Other forms of precipitation in other parts of the world include snow, hail or sleet. Groundwater recharge derives from that portion of rainfall, which does not end up in streams, rivers and lakes. The mechanism is by infiltration through the surface and deep percolation into the subsurface to replenish aquifers. *Springs* are actually manifestations of *groundwater outflow* at the surface of the earth arising from favourable geological, structural, hydrodynamic and geomorphologic conditions.



Source: https://water.usgs.gov/edu/earthgwaquifer.html

Figure 3: Groundwater Concept

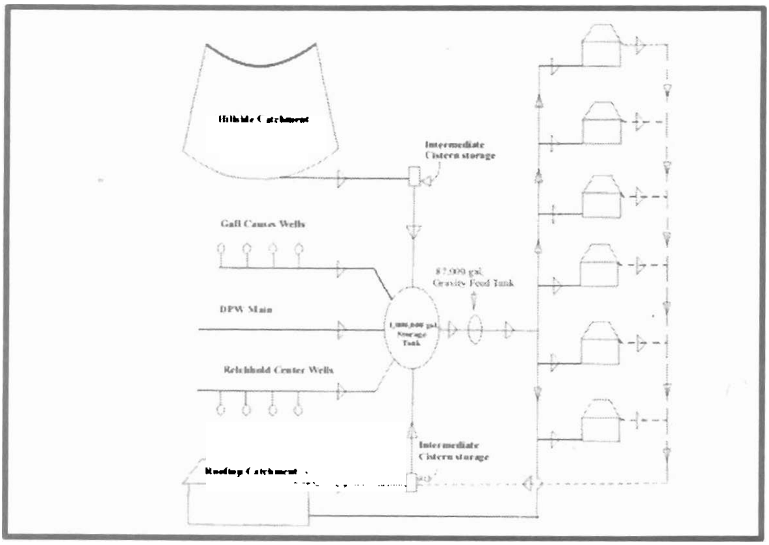
The water supply situation throughout Nigeria is appalling and there is no need delving into statistics to prove this point to a Nigerian audience. However, for the sake of those who require proof, I would like to refer you to the 117th Inaugural Lecture delivered by the Late Prof. M. O. Ogedengbe on the 12th August, 1997, almost twenty years ago, in this same Oduduwa Hall. A no-nonsense scientist and practical engineer to the core, dedicated teacher, erudite scholar, responsible and respected academic trade unionist and consummate family man, he did not waste time on frivolities and went straight to the core of his delivery, in his characteristic manner. The title of his inaugural lecture is "Nigeria's Water Supply Nightmare." Let me quote the first two opening paragraphs of his inaugural lecture and we can move on:

> *Nigeria's water-supply situation seems to have become a monstrosity, characteristic of a nightmare.*
>
> *All over the country, virtually everywhere there is insufficient water to satisfy the basic human needs – drinking, cooking, washing and sanitation, let alone the commercial and agricultural needs. The quantity of*

water supplied in all the thirty-six states of the federation is less than 25 litres per capita per day (lpcd) on the average. The comparable figure in the developed countries of Europe and America is about 400 lcpd. The figure recommended by the World Health Organization (WHO) for countries in Nigeria's level of development is about 180 lcpd (Ogedengbe, 1997, p. 1).

He went on in his inaugural lecture to proffer recommendations to improve the water supply situation. However, between then (1997) and now, I can assure you that the situation has not changed for the better. Were he to give his inaugural address today, or a sequel to it, the title might be "Nigeria's Water Supply Quagmire." Such is the sorry state of water supply today, in our dear country.

Ajayi and Gomez-Gomez (1983) describe the details of a rainwater harvesting system, which served the College (now the University) of the Virgin Islands on St. Thomas (Figure 4). Similar approaches will alleviate the problem of water supply, especially in drought prone areas of the country.



Source: Ajayi and Gomez-Gomez (1983)
Figure 4: Rain Water Harvesting System & Water Supply System

6.0 Previous Studies on the Hydrogeology of Nigeria

6.1 Efforts of the British Hydrogeologists

The Geological Survey Departments (GSD) of British West Africa came into being during the second decade of the 20th century and flourished until independence. The stated objectives of the departments were groundwater mapping and mineral surveys. As a mineral resource, groundwater was from the outset the responsibility of the geological surveys (Hazell, 2004).

In Nigeria, the Mineral Survey Department (MSD) started operations in 1903 and with the addition of groundwater investigations; it transformed into the GSD in 1914. Later, the nomenclature changed to the Geological Survey of Nigeria (GSN). Both the MSD and its successor GSD initially operated out of offices in Britain until 1929 when the administrative and field offices moved to Nigeria.

> *"Between 1930 and 1933, the Geological Survey of Nigeria (Cochran, 1937) experimented and perfected the 'government' 1.2 m diameter lined dug well, which became the standard for anglophone and francophone West Africa. In Nigeria alone, over 1500 'Cochrans' were constructed up to 1939"* (Hazell, 2004, p. 232).

Hazell (2004) summarized the state of groundwater development in Nigeria from about 1923 to 1990.

In spite of all these technical advances in groundwater exploration and development, pioneered by the British geologists and hydrogeologists in Nigeria, the problem of inadequate provision of water from groundwater sources throughout the country persists. This is a problem in managing resources efficiently, which is the bane of the country in several spheres of the economy.

6.2 The Activities of the United States Geological Survey in Nigeria

The British were not the only ones active on the hydrogeological scene in Nigeria. The United States of America (USA) had a collaborative programme with Nigeria and other countries as part of an International Water Resources Program. The United States Geological Survey (USGS) had collaborative efforts with GSN resulting in several hydrogeological studies in Nigeria under bilateral and multilateral assistance programmes involving the United Nations (Taylor, 1976). Between 1961 and 1968, there were fourteen (14) USGS personnel assigned to Nigeria working mostly in Northern Nigeria on groundwater projects.

Indeed, there was a government policy of stabilizing the nomadic population, based on provision of groundwater for livestock and for irrigation in Northern Nigeria, which would have prevented extensive migration in search of forage and water in other parts of the country. Initially, this programme was successful, but abandoned later. This situation has led to the wholesale migration of herdsmen towards the wetter and more fertile areas of both northern and southern Nigeria with attendant communal clashes and security implications for the entire country, which we are all witnessing today.

> *To further its policy of **stabilizing nomadic populations and improving the pastoral economy** of the former Northern Region, the Government of Nigeria (GON) began in the late 1950s an extensive program of **well and borehole construction for village and stock-water supplies**, chiefly in the Chad and Sokoto Basins. Early in 1961 the GON decided to request US AID/Lagos for U.S. technical assistance to review the results of earlier ground-water development and to recommend technical support needed in long-term investigations for guidance of future development* (Tailor, 1976, p.51, ***emphasis added***).

The USGS programme in Water Resources Investigations in Nigeria was not restricted to Northern Nigeria. The programme covered the entire country, even though most of the groundwater development activities were concentrated in the north. The programme was largely successful before its termination around 1968, perhaps due to the Civil War in Nigeria at the time. Tailor (1976) highlight the achievements of the programme.

In 1963, as part of its recommendations for developing the water resources of Nigeria, the USGS made a proposal for establishing a central agency for water-resources information in Nigeria. This proposal is awaiting full implementation as of today, over fifty years later. Most information on water resources of Nigeria are scattered throughout several government agencies, with no standardization of data collection methods or archival and retrieval system. The lack of a central water-resources information agency hampers water resources investigation and research throughout the country.

A major effort towards understanding groundwater resources of Nigeria is the work by Offodile (1992, 2002, 2014). It is a veritable resource material on the hydrogeology and water resources management of Nigeria. Other notable contributions on the hydrogeology of Nigeria are scattered throughout journals and periodicals in Nigeria and overseas and there is no central repository for water-related publications in Nigeria.

7.0 My Modest Research Efforts

7.1 Groundwater Exploration, Exploitation and Resource Evaluation

The bedrock of groundwater research is field data. This point initially hampered my research activities in the US Virgin Islands when I worked on the assessment of groundwater resources there. The field data that existed on water resources for the three major islands making up the US VI (St. Thomas, St. John and St. Croix) were scattered throughout the three islands and in the US mainland. I put together a research proposal, along with another researcher, Mr. Henry H. Smith, (who later became the Director of the US VI Water Resources Research Centre) to compile all available data in one source. The proposal was approved as Agreement No. 14-34-0001—2150 and the funds for the project were provided in part by the United States Department of the Interior, through the Office of Water Research and Technology.

The research titled "Compendium of Water Resources Data for the US Virgin Islands" (Ajayi and Smith, 1983) is available for sale online. Today the USA provides almost all water resources data online, such that at the click of a button you can get access to all the data you need from precipitation data to streamflow and water quality data. Some of these data are not merely historical data but real-time data on precipitation, wind velocity, streamflow and others. The data needed to characterize the water regime is long (Purcell, 1980):

It became possible to conduct the following researches into the water balance of a watershed on the island of St. Thomas (Smith and Ajayi, 1983) as well as evaluate the groundwater resources of the College of the US VI and the surrounding areas (Ajayi and Gomez-Gomez, 1983). The data from the compendium of water resources data produced for the US VI (Ajayi and Smith, 1983) became relevant to these studies. Since 1984, it has not been possible to attract research grants to conduct similar studies even here at Obafemi Awolowo University, despite the acute need for such.

My decision to delve into the area of water management stemmed from a conviction early in my academic life that the problem of provision of adequate water supply in this country lies not with inadequacy of water resources but with a typical lack of the ability to manage the water resources with which this country is abundantly blessed. Most of the places where I had hydrology training, Israel and Arizona (USA) have less annual rainfall than the driest part of Nigeria and they find a way to deliver water to the homes and businesses of their people.

The various efforts at improving the management of water resources in the US Virgin Islands by practitioners and researchers led to the paper: "Managing Water Supply Operations in the US Virgin Islands: Lessons from the US Virgin Islands (Thompson *et al.*, 1983). The study identified several sources of water supply for the islands. The paper concluded that groundwater remains the cheapest alternative source of water supply but it is highly localized.

Another study (Ajayi and Gomez-Gomez, 1983) reviewed the water supply to the College (now University) of the Virgin Islands. Among all the alternative sources of water supply to the College, the groundwater option remains the least-cost alternative. There was no detailed accounting of the water supply and distribution system. The study recommended several measures to ensure continued hitch-free supply of water to the College.

Mr. Vice-Chancellor, Sir, I began my research experience in Nigeria with an application to the University Research Committee (URC) for a mini-research grant to look into the problems of groundwater development in south-western Nigeria. This research proposal was approved in 1985 and it is the only research grant approved for me to date, by the URC. For this assistance, I am eternally grateful. The research grant supported two major research efforts and led to two publications (Ajayi and Adegoke-Anthony, 1988; and Adegoke-Anthony and Ajayi, 1989).

Over the course of my career, I have participated in several studies related to groundwater exploration, assessment and development in Nigeria (Ako *et al.*, 1986; Ajayi and Adegoke-Anthony, 1988; Adegoke-Anthony and Ajayi, 1989; Olorunfemi and Ajayi, 1999; Ajayi *et al.*, 2003). Similar efforts in Ghana include "Banoeng-Yakubo" *et al.*, (2010); and "Banoeng-Yakubo" *et al.*, (2011). In the USA, I participated in the following studies Ajayi and Gomez-Gomez, (1983); and Smith and Ajayi, (1983). In all these studies, the role of groundwater as a veritable source of water supply was established, especially where groundwater is the only viable or economically feasible alternative.

Ako *et al.*, (1986) conducted a landmark review of groundwater prospecting and exploitation involving several case histories throughout the country. A review of the groundwater situation in Nigeria between 1984 and 1990 revealed that there is great reliance on groundwater by majority of the population in Nigeria as a whole and in South-western Nigeria, in particular. Due to logistics and funding problems, we focused our research efforts on the availability of groundwater in south-western Nigeria (Ajayi and Adegoke-Anthony, 1988); on the exploitation of groundwater in south-western Nigeria (Adegoke-Anthony and Ajayi, 1989); and on borehole failures in the region (Abegunrin, 1990; and Ajayi and Abegunrin, 1994). We obtained several lessons from these researches.

Rock weathering plays a very significant role in the accumulation of groundwater in south-western Nigeria. Deep weathering profiles occur throughout the area and are exploited for water supply through shallow dug wells by the rural population. The various factors of weathering assume their most favourable forms in the humid tropical regions (Faniran and Jeje, 1983). The weathering profile established in our study averages 15 metres. The thickest weathering depth is 29 metres. There are reports of deeper weathering profiles in the area, beyond 60 metres in some cases (Olorunfemi, 2017).

From the literature review, up to 1964, there were no records of drilled wells in the basement rocks of south-western Nigeria.

> *There are **no** producing drilled wells on the basement but shallow, hand-dug wells provide the only supplies in many rural areas.... Drilling into the unweathered bedrock to locate groundwater held in joints and fracture zones has not been attempted because of the high cost. In the absence*

> *of favourable geophysical and geological evidence, the chances of obtaining water from these sources are not great.* (Jones and Hockey, 1964, p. 85, **emphasis supplied.)**

This was the groundwater prospects of basement aquifers reported in the literature by 1964, approximately 20 years before my foray into groundwater research in south-western Nigeria. Between 1964 and 1984, the groundwater prospects had improved somewhat based on experience gained from extensive drilling campaigns by the government and private individuals. The technology to drill into the basement was the limiting factor.

Generally, there are calls for detailed investigations prior to drilling successful boreholes in basement complex rocks. Lack of detailed preliminary investigations is one of the reasons adduced for poor yields of wells constructed in the Basement Complex areas. This statement is often generalized to include domestic supplies and industrial supplies from wells dug or drilled in basement rocks.

> *The very high rate of failures experienced in water exploitation in the basement which has caused many* ***water authorities*** *to abandon groundwater sources in favour of dams on crystalline rocks is due to the inadequate exploration preceding the execution of the projects....Detailed geological, hydrogeological, geomorphic, photogeological and geophysical surveys are necessary before accurate predictions can be made about water availability in a particular basement area.* (Oteze, 1977, p. 108, **emphasis supplied.)**

For the records, over two hundred such dug wells were reported in the central part of Ile-Ife town (Onyekwere, 1985) covering an area of 100 km^2, providing water for an estimated 60,000 persons. None of these hand dug wells were the result of detailed geo-investigations. Other investigations from 1984 to date have corroborated this observation. The average yields determined from our various investigations (as much as 290 m^3 day^{-1} or 64,000 Imperial gallons per day, Igpd) are adequate for domestic needs. Table 3 shows the well yield statistics for the basement complex rocks from this study.

Table 3: Well Yield Statistics

	No. of wells			
Range in well Yields (m^3 day^{-1}) or ($x10^3 Iday^{-1}$)	Cumulative Frequency	Frequency frequency (%)		Cumulative frequency (%)
0 - 50	8	8	18	18
50 -100	20	28	44	62
100 - 150	4	32	9	71
150 -200	11	43	24	95
200 - 250	0	43	0	95
250 – 300	2	45	5	100

Source: Ajayi and Adegoke-Anthony, 1988, p. 234

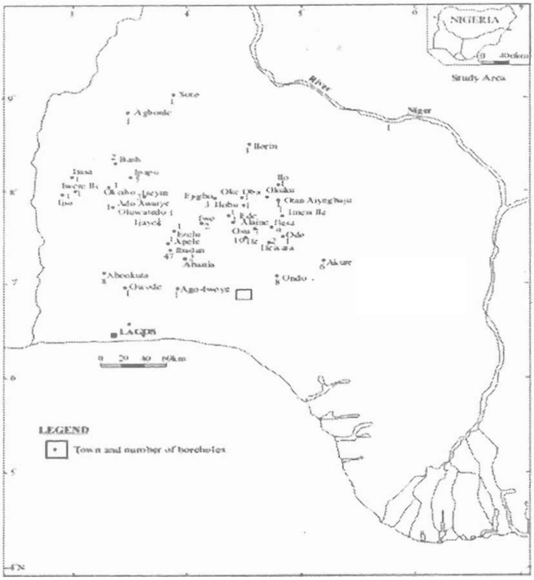
An indication of the amount of groundwater contained in basement rocks is from spring discharges. A spring is a concentrated discharge of groundwater (Rhodes, 1972). Several springs and artesian boreholes exist in the basement complex rocks of Nigeria. The springs at Effon Alaye town are estimated to be capable of yielding over 10,000 m^3 day^{-1}. Approximately 2000 m^3 day^{-1} of this amount supply Ilesha town (Oteze, 1977). At Ikogosi, the spring discharge was estimated at 2,400 m^3 day^{-1} (Rogers *et al.*, 1969). An artesian borehole sunk in charnockitic rocks of the Basement Complex at Ikere was measured at of 1500 m^3 day^{-1} during a fieldwork in 1988. Ako *et al.*, (1986) reported an estimated yield of 930 m^3 day^{-1} for the same well.

The following yields from boreholes in basement rocks, comparable with good yields from good sedimentary aquifers were reported: 430 m^3 day^{-1} at Ilorin; 600-1050 m^3 day^{-1} at Mopa; and 400 m^3 day^{-1}at Osara (Oteze, 1977). It is noteworthy that some towns, including Ikere and Bauchi at one time relied exclusively on groundwater from basement rocks. From the foregoing, it is obvious that Basement Complex rocks can be quite productive aquifers in some cases, especially where geophysical investigations reveal favourable drilling locations instead of wildcat drilling.

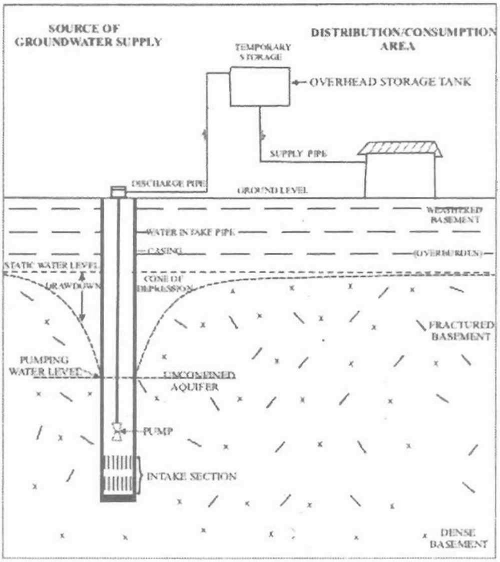
There is wide variation in well yields reflecting the relative contributions of each of these factors to the yield of the wells. However, there are problems of low yield during the peak of the dry season between late December and the onset of rains in mid-March or early April, when the wells have a tendency to dry up completely in some locations. Additional storage facilities will overcome this problem in the dry months, if the supply and demand picture is well known.

In the 1989/1990 session, I put an undergraduate student (now of blessed memory) to work on the problem of borehole failures in the crystalline rocks of Nigeria (Abegunrin, 1990). That was when undergraduate students took their work very seriously. Two hundred and fifty-six (256) boreholes, located throughout SW Nigeria, provided the data for the study (Fig. 5). Some boreholes were functioning properly; others would function properly at the time of construction only to fail within a short time after commissioning. Borehole owners and drilling companies supplied most of the data used for the study. The two sets of data were analysed separately.

The study identified the factors causing borehole failures in crystalline rocks of the basement complex rocks and recommended appropriate strategies to overcome them. Figure 6 shows the component parts of a typical borehole based water supply system. The overhead storage can be replaced with a ground level storage tank or exist side by side with a ground level storage tank in complementary fashion.



Source: Ajayi and Abegunrin (1994, p. 398)
Figure 5: Study Area showing Groundwater Sample Locations



Source: Ajayi and Abegunrin (1994, p. 400)
Figure 6: Component Parts of a Borehole Water Supply System

Prior to 1951 the pioneering British hydrogeologists operating in West Africa had problems with both the appropriate technology for drilling in basement rocks and the local government personnel engaged in drilling:

> *The weathered zone in crystalline terrain was developed for water supplies, but drilling and excavation methods were not capable of penetrating the basal regolith.....*
>
> *From 1951 in Nigeria and from 1964 in Gold Coast **(present day Ghana)**, programmes of rotary drilling by British contractors overtook and ultimately superseded the drilling of individual boreholes by percussion. The latter method was suited to **government employees, as sudden decisions were not needed and supervision was hardly required**. Moreover, until the early 1950s there was no perceived urgency. A driller could go on leave and on return could complete the borehole he left behind* (Hazell, 2004, p. 232 **emphasis supplied.**)

Government employees lack the training, discipline, and rigour for drilling in basement rocks, hence the high rate of borehole failures drilled by government employees, sometimes with attendant damage to drilling equipment and loss of expensive drilling parts. Today, there are expensive drilling bits stuck in abortive holes at two or three locations on this campus. One case involved an abortive borehole drilled at the premises of the Vice Chancellor's Lodge. The other case is located in the premises of the Postgraduate Hall of residence.

The efforts of Prof. Olorunfemi of the Department of Geology, who selected the sites after extensive geophysical investigations, thus came to nought. I joined the team in the field to offer free and honest advice on drilling best practices. Our advice was ignored during the drilling exercise, such that the drilling crew stopped drilling (rotary method), left the borehole overnight and by the time they came back in the morning, the drill stem was stuck in the drilling mud, which had caked somewhat and the hole had to be abandoned together with expensive drilling equipment. There are at least two 'lost' diamond coated, tri-cone drill bits stuck in holes, waiting to be mined on campus for the willing. First, you need to obtain a mining licence; otherwise, you risk arrest for illegal mining!

In a paper (Adegoke-Anthony and Ajayi, 1989), we reviewed the drilling methods and techniques applicable to the basement area in a bid to provide guidance to drillers. The paper is the product of drilling experience involving over forty-five boreholes drilled in the basement complex in Nigeria, under a wide variety of geotechnical conditions.

> *The erratic variability of geotechnical conditions within the Basement areas makes drilling work there highly technically demanding. A "cook-book" drilling procedure should never be applied in the Basement areas unlike in the sedimentary areas where relatively uniform geologic conditions prevail both in the horizontal and vertical directions over comparatively large areas.* ***Drilling in the basement complex therefore poses a great need for effective supervision of the drilling crew by a competent engineer or engineering geologist who can give on-the-spot instructions on required changes in drilling procedures as and when necessary*** (Adegoke-Anthony and Ajayi, 1989, **emphasis provided,**).

There are three typical geotechnical conditions based on the lithological conditions encountered by drilling. Adegoke-Anthony and Ajayi (1989) described these three different classes adequately, with prescriptions for drilling success. Table 4 shows the drilling methods and their applicability in different rock types. Figure 7 shows the three different and typical geotechnical conditions encountered by drilling operations in basement complex terrain. Depending on the degree of weathering, the weathered layer may contain fractured basement material. Table 5 shows the characteristics of the overburden materials. Other research efforts explored the occurrence of groundwater in south-western Nigeria in both the sedimentary and crystalline rock environments (Idowu and Ajayi, 1998; Idowu *et al.*, 1999; and Martins *et al.*, 2000).

Figure 8 shows the typical weathered profiles encountered in lithologic logs of wells drilled in the basement complex. In the basement, Figure 9a shows four layers over the fresh basement and their weathering characteristics. Any one or more of these layers may be absent in a site, giving rise to a variety of situations. The figure shows the range of depths for each layer.

There are two major aquifers in the basement: the weathered basement and the fractured basement. Figure 9b presents a slightly different picture depending on the occurrence of a brecciated vein at depth which is usually water bearing and prolific source of groundwater.

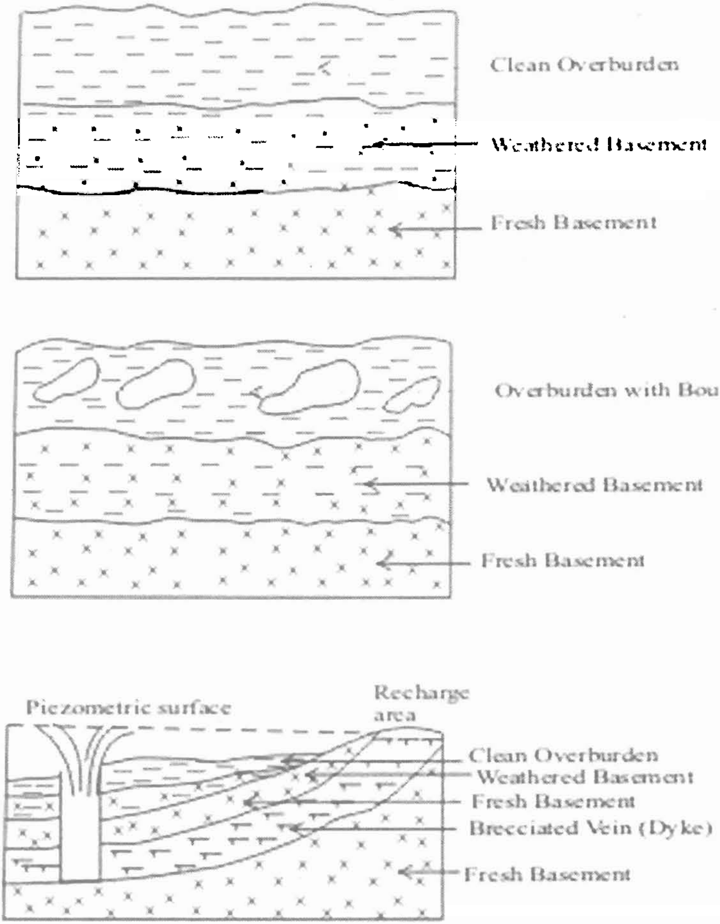
Investigations into the groundwater potential of basement rocks of the Volta River Basin in Ghana, similar to rocks in the Nigerian basement rocks, reveal that the average yields of hand pump wells and fuel pump wells are 25.6 m^3 day^{-1} and 130 m^3 day^{-1}, respectively. (Banoeng-Yakubo *et,al.,* 2010) These yields can serve the domestic water needs of 560 and 2,800 people respectively, based on water use of 4.6×10^{-2} m^3 day^{-1} (10 imperial gallons) per day per person. These yields are similar to those reported in Ajayi and Adegoke-Anthony (1988).

Table 4: Drilling Methods and Suitability in Different Rock Types

METHOD	BEST SUITED FOR DRILLING IN	CRITICAL DEPTH OF WATER TABLE (m)	USUAL MAXIMUM DEPTH (m)	USUAL DIAMETER RANGE (cm)	YIELD (gpm) DEPENDING ON GEOLOGY AND GROUNDWATER AVAILABILITY	REMARKS
Augering (power)	Clayey,Silt and Gravel less than 5 cm.	2 - 15	25	15 - 90	15 - 500	Most effective in penetrating and removing clay. Casing required in loose materials.
Driven(Hand, airhammer)	Silt, Sand gravel less than 5cm.	2 - 5	15	3 - 10	15 - 200	Limited to shallow water table. No large gravels.
Jetted Wells (light, portable rig)	Silt, Sand gravel less than 2 cm	2 - 5	15	4 - 8	15 - 150	Limited to shallow water table. No large gravels
Drilled Wells 1. Cable Tool	Unconsolidated and consolidated medium hard and hard rock	Any depth	450	8 - 60	15 – 15,000	Requires casing in loose material. Special bits available for drilling unconsolidated

						fine to medium sediments.
2. Rotary	Silt, Sand, gravel less than 2 cm; soft to hard consolidated rock.	Any depth	450	8 - 45	15 – 15,000	Fastest method for all except hard rock. Casing usually not necessary during drilling
3. Reverse circulation Rotary	Silt, Sand, Gravel, Cobble.	2 - 30	60	40 - 120	2,500 – 20,000	Effective for large diameter holes in unconsolidated and partially consolidated deposits.
4. Rotary Percussion	Silt, Sand, Gravel less than 5 cm; soft to hard consolidated rock.	Any depth	600	30 - 50	2,500 – 15,000	Very fast drilling. Used in oil exploration. Economical for water well drilling.

Source (After Todd, 1980)



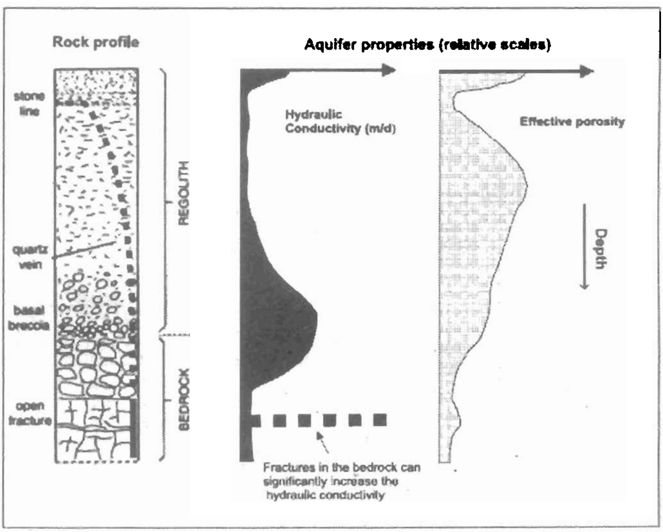
Source: Adegoke-Anthony and Ajayi (1989, p. 1979)

Figure 7: Typical Geotechnical Conditions in the Basement Complex

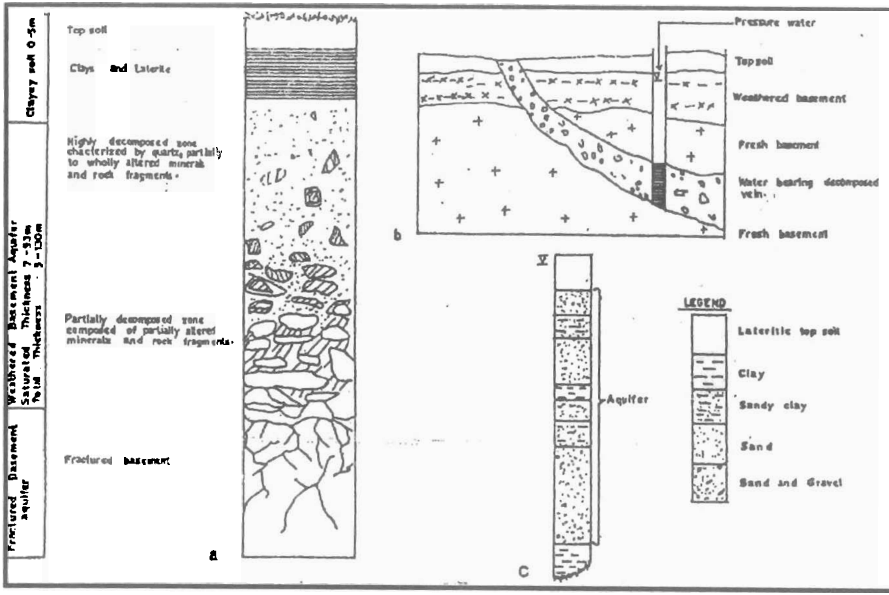
Table 5: Characteristics of the Overburden Material

Range in Overburden Thickness (m) (class)	Frequency	Cummulative	Frequency (%)	Cummulative (%)
0 – 5	6	6	13	13
5 – 10	8	14	18	31
10 – 15	5	19	11	42
15 – 20	12	31	27	69
20 – 25	8	39	18	87
25 – 30	6	45	13	100

Source: Adegoke-Anthony and Ajayi (1989), p. 178.



Source: MacDonald and Davies (2000)
Figure 8: Typical Weathered Profile in Basement Complex Rocks



Source: Idowu and Ajayi (1998, p. 36)
Figure 9: Layers and Weathering Characteristics

Mr. Vice-Chancellor, Sir, the lead author in Banoeng-Yakubo (2010), was a postgraduate student in the Department of Geology at Obafemi Awolowo University. He came into the Department in 1987 on a Commonwealth Postgraduate Scholarship, tenable in Nigeria. He was trained here when the facilities and staffing were acceptable to the Commonwealth. Subsequently, he returned to Ghana where he rose to become the first indigenous Professor of Geology at the Department of Earth Science in the University of Ghana, Accra, Legon, Ghana. He has served his country meritoriously in various capacities. His master's thesis (Banoeng-Yakubo, 1989) formed the basis of his subsequent work and rise to stardom in Ghana. Incidentally, this was his second master's thesis. The first master's thesis relate to gold mineralization in Ghana (Banoeng-Yakubo, 1987). His superiors at Legon were no more interested in digging for gold and off to Nigeria he came to learn about digging for groundwater and finding **water from rocks.** I remember supervising his second master's thesis.

There are several other foreign and Nigerian students that the Department of Geology, at Ife, has trained in the past who provide meritorious services in their various countries and in Nigeria in the past (did I hear something about ***the labours of our heroes past?***). I say this because even our ministries, departments and agencies do not send their staff for the several training opportunities, which we have offered them on a platter of gold. They prefer to send them on overseas training at exorbitant cost to the economy.

One of the problems of groundwater resources assessment involves the characterization of aquifer parameters. Ajayi and Obilade (1989) developed a numerical scheme for determining the aquifer parameters, Transmisivity (T) and Storativity (S), which we did on programmable hand-held calculators without the need for computers that were not readily available to researchers in these parts of the world at that point in time.

I have been a keen student of how other countries have managed to solve their water supply problems and devoted a lot of time and resources, including my PhD thesis (Ajayi, 1982) to this subject. Time and space will not permit me to delve into the full scope of the subject matter.

In one study (Idowu *et al.*, 1999), the records of one hundred and fifty-three boreholes located in the Nigerian sector of the Dahomey Basin reveal five major aquifers.

Table 6 shows the results of the investigation for the five aquifers identified in the study area which covers approximately 10,000 km^2. The results of water balance studies on the Yewa Basin, 95% of which lies within the study area, indicate the disposition of average annual rainfall of 1314 mm, as follows: runoff at 2%; groundwater recharge at 12%; and actual evapotranspiration at 88%. This translates to 1.55×10^9 m^3 of groundwater recharge annually over the study area.

Table 7 shows a summary of the groundwater chemistry. Generally the groundwater quality is good for most purposes, although the groundwater contained in the Ewekoro Formation tends to be hard, which is not surprising considering that the host rock is limestone. Based on this and other studies in southern Nigeria (Idowu *et al.*, 1998; Martins *et al.*, 2000; Ajayi and Umoh, 1998; and Ajayi, 1998), there is abundant groundwater in south-western Nigeria of acceptable quality for most uses.

A detailed comparison of groundwater prospects in two different geological environments using data from 234 boreholes (80 in basement area and 154 in sedimentary area), reveal that there is adequate groundwater in the two environments to meet domestic and small-scale industrial needs (Idowu and Ajayi, 1998). The yield, transmissivity and specific capacity are generally higher in the sedimentary aquifers than in the basement aquifers (Table 8).

The lead author has since become a Professor of Hydrology and Water Management at the Federal University of Agriculture, Abeokuta. He had some of his postgraduate training in the

Department and obtained his M.Sc. degree here in 1992, before proceeding to South Africa for his Ph.D. degree in Hydrogeology. He once told me that the training he got here from the department and his master's thesis formed the bedrock of his future endeavours which included four or five journal articles, in one form or another, emanating from that master's thesis (Idowu, 1992). I collaborated with him on some of them. Prof. Idowu is right here in the audience. I also remember supervising this thesis.

7.2 Groundwater Quality and Human Health

In evaluating groundwater resource, it is not enough to find the groundwater or develop it. Equally important is the chemical quality of the groundwater. Groundwater may be present in good quantities, but if it is unfit for its intended purpose, then it is useless. For instance, there are international standards for drinking, or potable water. The World Health Organization (WHO) published in 1971 international standards for drinking water (WHO, 1971), revised periodically. Other publications from WHO include the guidelines for drinking water quality, first released in 1984 (WHO, 1984) and the latest versions WHO (1996, 2008, 2011).

> *Access to safe drinking-water is important as a health and development issue at a national, regional and local level. In some regions, it has been shown that investments in water supply and sanitation can yield a net economic benefit, since the reductions in adverse health effects and health care costs outweigh the costs of undertaking the interventions. This is true for major water supply infrastructure investments through to water treatment in the home. Experience has also shown that interventions in improving access to safe water favour the poor in particular, whether in rural or urban areas, and can be an effective part of poverty alleviation strategies.* (WHO, 2008)

Table 6: Summary of Aquifer Properties

PROPERTIES	ABEOKUTA FORMATION			EWEKORO FORMATION			ILARO FORMATION			COASTAL PLAIN SANDS			ALLUVIAL DEPOSITS		
	RANGE	MEAN	B/h NOS	RANGE	MEAN	B/h NOS.	RANGE	MEAN	B/h NOS.	RANGE	MEAN	B/h NOS.	RANGE	MEAN	B/h NOS.
AQUIFER DEPTH (m)	3.0-76.2	26.8	25	84.7-186.0	128.2	5	23.0-25.0	24	2	12.1-33.5	26.1	12	6.1-24.4	16.9	6
AQUIFER THICKNESS (m)	2.1-109.8	41.7	25	12.0-32.0	20	5	15.0-30.0	22.5	2	4.6-45.7	27.0	12	8.5-38.0	30.0	6
STATIC WATER LEVEL (m)	1.2-57.3	24.6	48	25.7-80.2	55.7	6	16.2-21.3	19.1	5	4.6-40.8	22.8	21	2.6-14.8	15.6	11
	4 FREE FLOWING AT CONSTRUCTION TIME			2 FREE FLOWING AT CONSTRUCTION TIME			NON FREE FLOWING AT CONSTRUCTION TIME			NON FREE FLOWING AT CONSTRUCTION TIME			1 FREE FLOWING AT CONSTRUCTION TIME		
BOREHOLE YIELD ($m^3 hr^{-1}$)	2.3-181.6	36.8	48	4.1-34.7	20.1	12	2.9-91.1	30.8	8	3.0-77.6	36.4	23	9.7-77.6	36.8	12
TRANSMISSIVITY ($m^3 hr^{-1}$)	0.4-44.6	13.3	6	3.1014.1	8.6	2	3.2-13.0	8.1	2	9.9-33.9	19.6	4	359.8-959.0	659.4	2
SPECIFIC CAPACITY ($m^3 hr^{-1}$)	0.7-2.6	2.1	7	0.5-1.7	0.9	3	0.6	0.6	1	1.7-36.9	14.2	7	32.9-52.9	42.9	2

Source: Idowu *et. al.*, 1999, p. 234

Table 7: Summary of the Groundwater Chemistry (in ppm)

	Abeokuta Formation			Ewekoro Formation			Ilaro Formation			Coastal Plains Sands			Alluvial Deposit		
Chemistry	Range	Mean	B/h No.	Range	Mean	B/h No.	Range	Mean	B/h No.	Range	Mean	B/h No	Range	Mean	B/h No.
Total Hard-ness as $CaCO_3$	2.9-225.0	49.3	12	125.0-778.0	375.3	3		32.0	1	13.0-37.0	28.2	7	62.0-175.0	118.0	2
Iron	0.01-2.0	1.1	8	6.0-7.6	0.2	2		0.5	1	0.2-0.4	2.3	6	0.2-2.0	1.3	2
pH	6.0-7.8	6.2	12	28.0-93.9	6.8	2		7.2	1	5.8-7.4	6.4	10	5.4-7.4	6.4	2
Chloride	5.0-17.0	11.3	12		45.6	3		26.0	1	6.9-10.1	7.1	6	8.0-14.3	11.1	2
Nitrate	0.1-5.2	2.0	8	2.5-5.0	3.8	2		12.0	1	8.0-50.0	8.0	6		30.0	2
Sodium	3.0-7.0	5.0	7	6.1.12.2	9.1	2				2.6-6.6	4.7	6	5.4-9.3	7.3	2
Silica	1.9-16.0	9.9	8		10.0	2				8.0-16.0	12.0	6	16.0-20.0	18.0	2
Colour	5.0-10.0	5.9	7		2					5.0-10.0	6.2	7	5.0-10.0	6.3	2

Source: Idowu et al., 1999, p. 235

Table 8: Comparive Yield and other Properties of Basement and Sedimentary Aquifers

Properties	Basement Aquifers			Sedimentary Aquifers		
	Range	Mean	Well Nos	Range	Means	Well Nos
Yield (m^3hr^{-1})	0.24-65.00	7.33	72	2.34-181.61	31.47	130
Trasmissivity (m^2day^{-1})	0.61-5.32	2.30	6	0.43-958.96	89.27	17
Specific capacity at 0.5 hr (m^2 day^{-1})	0.01-2.24	0.83	6	0.52-52.90	9.33	22
Aquifer depth (m)	3.05-73.15	23.14	24	3.00-166.00	35.95	48
Aquifer thickness (m)	11.00-92.97	49.92	24	4.57-109.73	33.82	48
Overburden thickness (m)	6.10-136.40	45.17	47			

Source: Idowu and Ajayi (1998, p. 39).

Water quality is very important to human, plant and animal health. Indeed, water is life. The human body is composed, on the average, of seventy-five percent water. Table 9 illustrates the water contents of the various components of the human anatomy and cells. There is a lower limit of water, below which the human body (and its component cells) cannot function. At this limit, life ceases to exist. The same is true for plants, animals and other cellular organisms.

Table 9: Water Content of Human Organs

Organ	**Percentage Water**
Brain	73
Heart	73
Kidneys	79
Liver	71
Lungs	83
Muscle	79
Skeleton (Bones, Teeth)	31
Skin	64

Source: Mitchell (1945).

The basic material of living cells is the Protoplasm, composed of proteins, carbohydrates, fats, salts, and other elements combined with water. The solvent, which transports and is involved in chemical breakdown of these substances in order to derive beneficial, life sustaining nutrients to the body is water.

The cell exchanges elements with its surroundings by electrolysis. When there is acute water shortage for cellular functions, electrolysis is inhibited, our cells become dry, wither and die. Our cells must be constantly hydrated for electrochemical balance, not just to stay alive, but for us to be in a healthy state (of mind and body).

Water dissociates or ionizes into H^+ and OH- ions according to the well-known formula:

$$2H_2O_{(l)} \rightleftharpoons H_3O^+_{(aq)} + OH^-_{(aq)}$$

The ion product constant of water:

$$K_w = [H_3O^+]\,[OH^-] = 1 \text{ X } 10^{-14}$$

is the basis for the pH scale (Fig. 10).

The pH is the most important parameter or index of the electrolytic state of water contained in the human body. The pH is a direct measure of the concentration of the hydrogen ion (H^+) and an indirect measure of the concentration of the hydrozyl (OH^-) ion in water. The two concentrations are complementary. Increase in one leads to a decrease in the other. The pH scale ranges from zero (0) to fourteen (14) as shown in Figure 10.

The pH of healthy blood is alkaline and is constant at 7.365. Most of the foods we eat and the drinks we consume have acidic pH in the range < 7.0. Most bodily fluids whether intracellular or extracellular, must stay in the alkaline range of pH (> 7.0) for good health. A decrease in pH of the blood leads to release of calcium from the teeth and bones and release of magnesium from the muscles to counterbalance the decrease in pH. This leads to degenerative diseases, such as osteoporosis.

The percentage composition of water in various organs of the human body (Table 9) varies from 39 % in the bones to 83 % in the lungs (Mitchell, 1945). The human body uses water to regulate body temperature and maintain other bodily functions. Water forms saliva and is the starting point for the digestive process. Water is lost from the human body through respiration, perspiration, urination, in the digestive process and excreta. In order to maintain good health, it is important to replenish or rehydrate the human body by drinking plenty of fluids and eating foods containing plenty of water.

In a study, WHO (2003a; 2003b) related diseases to demineralised and polluted water.

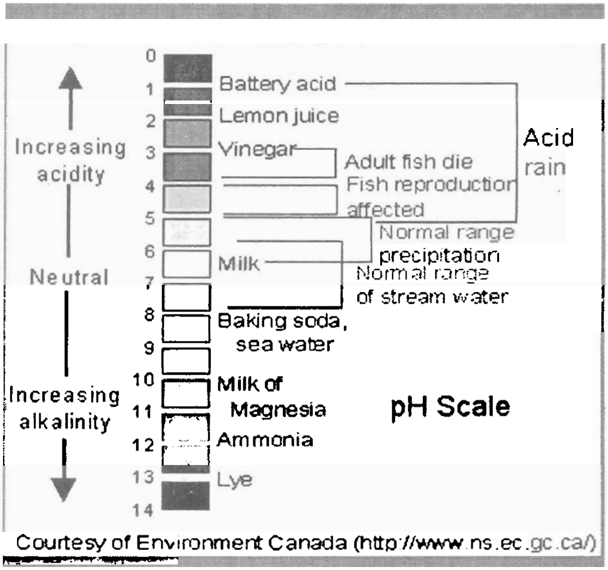


Figure 10: pH Scale

> *Eighty percent (80%) of human diseases are related to water. The resources of the water we drink daily has been polluted. Water occupies 60-70% of human bodies; it is the basis of life and health. The water we drink will largely determine our health and life. According to scientific research, cell water is the activated water that contains high energy. The water is not only clear and pure, it is also full of activated energy.*

In order to protect the human population from health risks arising from ingestion or contact with unsafe water, WHO justified its recommendations for surveillance of water quality:

> *Diseases related to contamination of drinking-water constitute a major burden on human health. Interventions to improve the quality of drinking-water provide significant benefits to health. Surveillance of drinking-water quality can be*

defined as "the continuous and vigilant public health assessment and review of the safety and acceptability of drinking-water supplies" (WHO, 1976).

Ajayi (1998) investigated the quality of groundwater in the Agbabu area of the bitumen belt. The study involved the interpretation of twenty-three water quality data from seven rivers, eight springs and eight wells or boreholes. The water will need treatment as the interpretation of the results of the groundwater data indicates groundwater of poor quality.

The results of the groundwater quality exceeded several potable Water criteria of the WHO (1984) and the more recent guideline values (WHO, 2004, 2011). Using other parameters, the groundwater is not suitable for irrigation and other uses, without treatment. The Piper trilinear plot shows that all three boreholes are NACl-type water, indicating brackish conditions and possible salt-water intrusion into the coastal aquifer.

The Technical Sub-committee of the Committee for the Implementation of the Bitumen Project (CIBP, 1993), on whose behalf I carried out the investigations, accepted my recommendations to cap the boreholes to prevent further decline of formation pressure, which might be required as a natural drive in the recovery of bitumen in future.

Ajayi and Umoh (1998) investigated the groundwater quality of the coastal aquifer in Akwa Ibom State. Figure 11 shows the study area and sample locations. Umoh (1993) had previously investigated the characteristics of the coastal aquifer for his M. Sc. Thesis, under my tutelage. The aquifer is a major source of groundwater for the population. The paper recommended monitoring the groundwater quality near the coastal area to detect the onset of saline water intrusion into the coastal aquifer.

Table 10: Results of Chemical Analysis of Groundwater in Coastal Aquifer

Location borehole number	$Na^{+} + K^{+}$		Geotechnical Ca^{2+}		Mg^{2+}		Constituents HCO_3^{-}	CO_3^{2-}	Cl^{-}			SO_4^{2-}	Water type
	meq/l	%	meq/l	%	meq/l	%	meq/l	%	meq/l	%	meq/l	%	
AKG 1	1.1351	46.4	0.1597	6.51	1.1516	47.07	0.2622	82.3	0.0564	71.7	0	0	$Mg(HCO_3)_2$
AKG 2	0.2541	43.93	0.1597	27.62	0.1645	28.45	0.0983	63.54	0.0564	36.46	0	0	$NaHCO_3$
AKG 3	0.1315	31.63	0.1198	28.81	0.1645	39.56	0.1967	87.46	0.0282	12.64	0	0	$Mg(HCO_3)_2$
AKG 4	0.1863	40.84	0.1198	24.93	0.1645	34.23	0.656	39.93	0.0987	60.07	0	0	NaCl
AKG 5	1.2008	43.49	0.0789	2.89	1.4807	53.62	0.3606	86.47	0.0564	13.53	0	0	$Mg(HCO_3)_2$
AKG 6	0.4106	47.78	0.1198	13.94	0.329	38.28	0.0656	53.77	0.0564	46.23	0	0	$NaHCO_3$
AKG 7	0.2263	38.33	0.1996	33.81	0.1645	27.86	0.0328	15.32	0.0564	26.34	0.12	58.34	Na_2SO_4
AKG 8	0.4277	41.37	0.3593	34.76	0.2468	23.87	0.6556	77.71	0.0423	5.01	0.15	17.27	$NaHCO_3$
AKG 9	0.3865	48.74	0.1597	20.14	0.2468	31.12	0.6556	53.77	0.0564	46.23	0	0	$NaHCO_3$
AKG 10	0.1686	27.31	0.1198	19.4	0.329	53.29	0.3278	85.32	0.0564	14.68	0	0	$Mg(HCO_3)_2$
AKG 11	0.0725	37.7	0.1198	62.3	0	0	0.0328	22.64	0.0705	48.65	0.04	28.71	$MgCl_2$
AKG 12	0.8747	41.91	0.1996	8.58	1.1516	49.51	0.4589	89.05	0.0564	10.95	0	0	$Mg(HCO_3)_2$
AKG 13	0.1766	41.96	0.0789	18.96	0.1645	39.08	0.0983	63.54	0.0564	36.46	0	0	$NaHCO_3$
AKG 14	0.066	45.27	0.0788	54.73	0	0	0.0656	60.8	0.0423	39.2	0	0	$Ca(HCO_3)_2$
AKG 15	0.2245	48.12	0.1597	34.23	0.0823	17.64	0.0656	69.94	0.0282	30.06	0	0	$NaHCO_3$
AKG 16	0.298	47.89	0.1597	25.67	0.1645	26.44	0.0656	60.8	0.0423	39.2	0	0	$NaHCO_3$
AKG 17	0.4732	47.01	0.0399	3.96	0.4936	49.03	0.0656	43.68	0.0846	56.32	0	0	$CaCl_2$
AKG 18	0.0526	30.51	0.1198	69.49	0	0	0.0983	63.54	0.0564	36.46	0	0	$Ca(HCO_3)_2$
AKG 19	0.2283	48.31	0.0798	16.89	0.1645	34.8	0.0656	60.8	0.0423	39.2	0	0	$NaHCO_3$
AKG 20	0.1079	47.39	0.1198	52.61	0	0	0.0656	69.94	0.0282	30.06	0	0	$Ca(HCO_3)_2$
AKG 21	0.3327	47.42	0.0399	5.69	0.329	46.89	0.0656	53.77	0.0564	46.23	0	0	$NaHCO_3$
AKG 22	0.2683	48.56	0.1198	21.68	0.1645	29.77	0.0656	60.8	0.0423	39.2	0	0	$NaHCO_3$
AKG 23	0.4069	26.02	0.998	63.51	0.1645	10.47	0.8195	93.56	0.0564	6.44	0	0	$Ca(HCO_3)_2$
AKG 24	0.9623	49.98	0.7984	41.47	0.1646	8.54	0.0328	43.68	0.0423	56.32	0	0	NaCl
AKG 25	0.8449	48.35	0.0798	4.57	0.8226	47.08	0.1311	82.3	0.0282	17.7	0	0	$NaHCO_3$
AKG 26	0.1558	43.84	0.1996	56.16	0	0	0.0656	53.77	0.0564	46.23	0	0	$Ca(HCO_3)_2$
AKG 27	0.3567	46.6	0.0798	10.42	0.329	42.98	0.0983	69.91	0.0423	30.09	0	0	$NaHCO_3$
AKG 28	0.195	44.39	0.0798	10.42	0.1645	37.44	0.0983	77.71	0.0282	22.29	0	0	$NaHCO_3$
AKG 29	0.1686	39.91	0.1198	25.32	0.1645	34.77	0.1311	75.61	0.0423	24.39	0	0	$NaHCO_3$
AKG 30	0.2359	39.32	0.1996	33.27	0.1646	27.42	0.1639	79.49	0.0423	20.51	0	0	$NaHCO_3$
AKG 31	0.1813	47.29	0.1198	31.25	0.0823	21.46	0.0656	60.8	0.0423	39.2	0	0	$NaHCO_3$
AKG 32	1.3655	49.45	0.0798	2.89	1.3162	47.66	0.0656	60.8	0.0423	39.2	0	0	$NaHCO_3$
AKG 33	0.1942	49	0.1198	30.23	0.0823	20.77	0.0328	43.68	0.0423	56.32	0	0	NaCl
AKG 34	0.0588	32.92	0.1198	67.08	0	0	0.1311	75.61	0.0423	24.39	0	0	$Ca(HCO_3)_2$
AKG 35	0.1504	42.97	0.1996	57.03	0	0	0.0656	48.2	0.0705	51.8	0	0	$CaCl_2$
AKG 36	2.143	48.69	0.1198	2.72	2.1388	48.59	0.1311	65.03	0.0705	34.97	0	0	
AKG 37	0.5188	47.5	0.0798	7.31	0.4936	45.19	0.0983	69.91	0.0423	30.09	0	0	$NaHCO_3$
AKG 38	0.0941	38.84	0.1198	9.42	0.6581	51.74	0.3278	88.57	0.0423	11.43	0	0	$Mg(HCO_3)_2$
AKG 39	1.0537	43.1	0.2395	9.8	1.1516	47.1	0.0656	13.3	0.2821	57.17	0.15	29.53	$MgCl_2$
AKG 40	0.0638	34.75	0.1198	65.25	0	0	0.0983	63.54	0.0564	36.46	0	0	$Ca(HCO_3)_2$
AKG 41	0.1555	38.89	0.0798	19.96	0.1645	41.15	0.0656	34.31	0.0423	22.12	0.08	43.57	$MgSO_4$
AKG 42	0.0899	42.87	0.1198	57.13	0	0	0.0656	53.77	0.0564	46.23	0	0	$Ca(HCO_3)_2$
AKG 43	0.3055	42.91	0.1597	22.43	0.2468	34.66	0.1311	75.61	0.0423	24.39	0	0	$NaHCO_3$
AKG 44	0.2092	46.13	0.0798	17.6	0.1645	36.27	0.0328	27.94	0.0846	72.06	0	0	NaCl

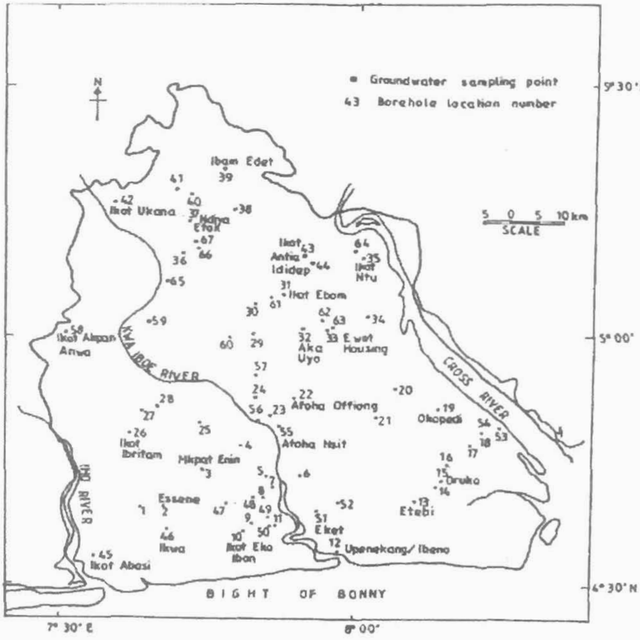
Source: Ajayi and Umoh (1998, p. 271

In another study on groundwater quality, twenty water samples were obtained from Akungba-Akoko for water quality investigations (Taiwo *et. al.*, 2015). Thirteen samples came from hand-dug wells, five samples were collected from boreholes and the remaining two sample were collected from the sources of springs in the vicinity. As such the samples all have a groundwater origin.

The results of the analyses were compared with WHO (2008) guidelines. High levels of nitrate occur in some of the samples, attributed to anthropogenic effects. Other parameters fall within the WHO (2008) guidelines. The study concluded that in order to keep the groundwater in Akungba Akoko within safe limits for consumption, adequate measures must be taken to significantly reduce anthropogenic inputs into the groundwater environment.

7.3 Groundwater and Environmental Management

The scope of environmental management includes the provision of adequate water supply; sanitary disposal of stormwater and wastewater; solid waste disposal; provision of sanitation services; and the promotion of good public health and best hygiene practices (Ajayi, 1996).



Source: Ajayi and Umoh (1998, p. 260)

Figure 11: Study Area showing Groundwater Sample Locations

7.4 Groundwater Seepage and Flooding

Groundwater, if not properly controlled can constitute a menace. Anomalous groundwater seepage into the mill furnace and basement foundations of the Osogbo Steel Rolling Company (OSRC) Limited affected mill operations. This problem necessitated combined geophysical and geological investigations to find a lasting solution to the problem (Olorunfemi and Ajayi, 1999). Substantial parts of the mill structure were located up to 15 metres below ground level. Pumping water from underground cellars and sealing of seepage joints in the basement areas with bitumen were some of the remedial measures adopted in the past, as a temporary mitigation measure. This is a case of groundwater flooding. McKenzie *et al.* (2010) developed a model to predict areas at risk of groundwater flooding.

Based on physical simulation of the groundwater levels, three strategically located boreholes comprise the dewatering scheme. This scheme successfully lowered the groundwater levels below the floor of the mill furnace and the basement foundation. The recommendation to use the groundwater was ignored and the recovered groundwater was simply pumped to waste, safely away from the mill buildings and the factory premises.

Olorunfemi *et al.*, (2000a & 2000b) investigated the integrity of existing dam structures in Katsina State. The electrical resistivity and electromagnetic methods of geophysical prospecting were used to investigate the failed Koza and Nassarawa earth dams, located around Katsina, Northern Nigeria.

The results delineated two anomalous seepage zones beneath Koza dam spillway foundation and embankment. The seepage precipitated settlement and differential settlement due to the underlying clayey substratum. These were responsible for the failure of the spillway structure.

The results of the investigation revealed that the embankment core consisted of sandy clay in some locations and clayey sand at other locations. The integrity rating of the embankment, based on the composition of the core materials was fair to fairly good. Five zones of discontinuity were delineated within and beneath the dam embankment, with two of the zones existing as seepage zones. These seepage zones constitute major threat to the embankment and remedial measures were proposed.

In another study, an integrated geophysical and geotechnical investigation of a proposed damsite across River Mayo Ini, Jada, approximately 10 km southeast of Yola, the Adamawa State capital was conducted (Ajayi, *et al.*, 2005). The primary aim of the investigation was to determine the depth to the competent bedrock on which the dam foundation will be firmly anchored for safety reasons.

Although the study area lies in the dry, semi-arid part of the country one of the major findings of the study was the discovery of a buried, former river channel underneath the proposed dam axis, which is not visible from the surface, apart from the existing river channel which is visible at the surface. The study identified a high risk of groundwater seepage beneath the dam axis through the delineated buried river channel and unconfined/confined underlying fractures.

The general characteristics of the subsurface materials show that they are competent to host the dam. However, the configuration of the basement relief may aid groundwater flow into the buried river channel, which would definitely have devastating consequences for the integrity of the dam foundations.

I delivered a technical presentation on the Jada study and its findings at the Annual International Conference of the Nigerian Mining and Geosciences Society (NMGS) in the serene City of Maiduguri in 2004. The paper won the Elf/Total sponsored prize for best technical presentation at the Maiduguri Conference. The prize included an all-expenses paid trip to Elf/Total laboratories in France in 2005. That trip enabled me to arrange a visit, with the approval of my sponsors, to Dijon where one of the most famous hydrogeologists, Henry Darcy conducted his experiments on the law governing the flow of fluids in porous media, Dariy's Law, which bears his name to this date.

7.5 Conjunctive Use of Surface Water and Groundwater

Ajayi *et al.*, (2003) investigated the problem of supplying potable water to Nigerians through conjunctive development of surface and groundwater resources in the country. As water is an essential element for primary health care and social welfare, the study recommended partial subsidy of water supply due to the low per capita income of majority of the population. The practicality of conjunctive use of surface water and groundwater was presented in Ajayi *et al.*, (2003).

The strategy for water resources administration practiced in other countries were reviewed to provide an alternative framework for efficient and effective water administration in Nigeria (Ajayi, 1982, 2006).

8.0 Services to the Community and the Nation

The expectations from an academic in Nigeria revolve around teaching, research and community service or service to the nation at large. Over the years, I have taught several generations of undergraduate students "Hydrology and Hydraulics" in both the Department of Agricultural Engineering and the Department of Civil Engineering, OAU.

This "cross-posting" is not new at Ife. In the 1971/72 academic session, Prof. Turgut Dincer, an agricultural engineer in the Department of Agricultural Engineering taught us Fundamentals of Hydrogeology, in the absence of a substantive lecturer in that field in the Department of Geology. So I take this as pay-back time to the Department of Agricultural Engineering, until they could recruit a lecturer in that specialty. Over the years, I have done my best to serve my people and the country in my areas of expertise. The university has supported and assisted by releasing me for these national assignments.

8.1 Service to the Profession of Geology

During my final year as an undergraduate, I was elected by my peers to serve as the President of the Student Chapter of the Nigerian Mining and Geosciences Society (NMGS) in 1971/72. I have since gone further to serve the profession of geology as the Secretary and later Chairman of the Ibadan Chapter of NMGS

(2009 - 2011) of the Ibadan Chapter of the Nigerian Mining and Geosciences Society.

I served in the Council of NMGS as the National Publicity Secretary in 2003-2004. In that capacity, I assisted to organize the Conference of the Society in the serene city of Maiduguri in April 2004, which was well attended by local and foreign participants, including most of the expatriate Managing Directors of International Oil Companies (IOCs). Alhaji Ali Monguno, Senator Jibril Aminu and the five-time Honourable Minister, Ambassador Bunu Sheriff Musa, were there, live and in person, to receive their honorary awards as Fellows of the NMGS.

8.2 Service to the National Council on Water Resources

My first national assignment came on invitation to serve on the National Technical Committee on Water Resources (NTCWR) of the National Council on Water Resources (NCWR) in 1986 on the recommendation of Mr. J. A. Hanidu, an alumnus of the Department of Geology and one of my early mentors in the profession. The other mentor I had, even from my undergraduate days, is Mr. Bankole D. Ako, who became the first occupant of the Office of the Shell Professor of Geophysics in the Department of Geology. I owe a lot of my career progression to his brotherly mentorship.

I am currently the National Chairman of the Technical Subcommittee of the NTCWR on Manpower Development and Funding of Water Sector Research. Most of the activities of this sub-committee is funded by the National Water Resources Institute (NWRI), previously under the able leadership of Dr. O. Bamgboye as Executive Director and now under his able successor, Dr. E. A. Adanu.

During one of the meetings of the NTCWR in Kano in 1988, I met the late Dr. J. O. Sonuga, a Civil Engineer, Founding Partner of ENPLAN Group Consulting Engineers and Planners. Dr. Sonuga was then the Chairman of the Technical Sub-committee on Dams and Reservoirs and requested his counterpart in H & H to release one of his members who was versed in groundwater flow to assist his sub-committee on dams. Mr. Hanidu sent me to the sub-committee and this began a long-term attachment, not only to the sub-committee, and to several members of that sub-committee, but to Dr. Sonuga himself, his firm ENPLAN Group, which has continued until this day. I learnt a lot from Dr. Sonuga as a thoroughbred engineer, academic and professional. Dr. Sonuga was a role model to me in several ways.

Later, Dr. Sonuga provided us with the opportunities to work on environmental projects (Ajayi, 1996) and dam site investigations (Olorunfemi *et al.*, 2000a; Olorunfemi *et al.*, 2000b; and Ajayi *et al.*, 2005). These studies were funded through his consulting firm with the full support of his son, Engr. Femi Sonuga, who was the Resident Partner of the firm based in Katsina at the time. I later had the opportunity to spend my sabbatical leave with the firm in 1999.

All expenses connected with my publications in foreign journals were fully paid for by EG during this period. EG would send my paper by DHL to France and I would find the cost of courier would be approximately half on my monthly salary! There is no way I would have published in foreign journals without their support. In addition, I received generous support from the EG to attend local and international conferences.

The university would not fund research, would not pay for postage of journal articles or even purchase volumes in which our articles appear. For example, I had to bear the full cost of printing this inaugural lecture whose sales would not cover have of the cost of printing!

I have had the opportunities to go on sabbatical leave when I worked outside the university system on two occasions. On the first of these occasions, I worked at ENPLAN GROUP Consulting Engineers and Planners, as Visiting Engineer and Project Manager. I worked on the National Water Rehabilitation Project in

Abeokuta, Ogun State in 1999, and at the SPDC (2006), where I occupied the position of Senior Environmental Adviser.

I cannot provide details of my assignment while on Sabbatical Leave in 2006/2007 in SPDC for proprietary reasons. As my title suggests, I was Senior Environmental Adviser to SPDC and this implies that I worked on issues affecting the environment in the areas of operations of SPDC in the Niger Delta. This is similar to the experience I had in the Caribbean during 1982-1984 while working on sensitive water and environmental issues in the US Caribbean.

8.3 Service on the Bitumen Committee

In 1989, the Military Administrator of Ogun State, Navy Captain Mohammed A. Lawal, nominated me to represent Ogun State on a Presidential Committee on the Implementation of the Bitumen Project (CIBP). The Military President, General Ibrahim B. Babangida (1985 – 1993) established the Presidential Commission, in response to the demands of the state governments in the bitumen areas (Ogun, Ondo including present Ekiti State, Bendel comprising modern Edo and Delta States).

8.4 Establishment of UNESCO Category 2 Centre for Integrated River Basin Management

I was the Chairman of a Technical Committee which led to the establishment of the UNESCO Category 2 Regional Centre for Integrated River Basin Management (UNESCO RC-IRBM) located within the premises of the NWRI, Mando Road, Kaduna (Ajayi et al., 2010). The Centre is now fully established and well on its way to fulfill its mandate.

8.5 Service to Oyo State Government

In the last few years I have had the opportunity to put some of my environmental training and practical experience in assisting the government of Oyo State to find solutions to the flood menace which has taken its toll on lives, livelihoods and property in Oyo State. His Excellency, the Executive Governor of Oyo State, Senator Abiola Ajimobi, appointed me along with others to serve on the Oyo State Government Task Force on Flood in Ibadan after the devastating flood of August 2011 in which several lives were lost and estimated property damage is over 1 billion naira.

This assignment (Government of Oyo State, 2011, Agbola *et al.*, 2012, Ajayi *et al.*, 2012) led the World Bank to embark on a programme to make our cities flood resilient with Ibadan, capital of Oyo State as the pilot study. Again, His Excellency has appointed me to serve on the Independent Advisory Group (IAG), which serves as the independent body monitoring project implementation, which will cost over USD 200 million. I appreciate the approval of Mr. Vice Chancellor for me to participate in these adult services to the community and nation at large.

9.0 Concluding Remarks

Mr. Vice-Chancellor, Sir, please permit me to pay deserved tribute to some of my teachers and mentors during this rather long, but eventful, journey to one of the Chairs of Geology at Ife. It all began at the Methodist Primary School, Akintola Road, Ekotedo, Ibadan, where I had my elementary education, I had dedicated teachers who went beyond the call of duty to ensure that I could realize my full potentials. My Headmaster, the late Mr. Odunlami was a brilliant teacher, administrator and strict disciplinarian. I remember a few of them, such as Mrs. Ogunlesi and Mrs. Koleosho for their dedication to duty.

Those were the days when primary school teachers arrived before 7 o'clock in the morning, one hour before classes will resume and left at 4:30 pm in the evening long after the last classes for the day had ended at about 2 pm. In the extra hours they spent in school, class assignments were graded (in school) and notes of lessons for the next day were prepared and vetted by the Headmaster himself who may not leave until 5 pm, each day doing one administrative duty or the other.

In the secondary school, I met even more dedicated and devoted teachers. Let me take you down memory lane for my sojourn at Loyola College, Ibadan from 1962 to 1967 It was at Loyola College that I first understood the meaning of the phrase "dedication beyond the call of duty." I would not have gained admission to Ife and certainly I would not be here today delivering this Inaugural Lecture if I did not pass through the Primary School and the Secondary School that prepared me for university education in the first instance and ultimately for the event of today.

In 1961, the authorities of Loyola College, Ibadan and other secondary schools in the old Western Region of Nigeria, not only conducted post common entrance examination screening tests but also conducted **live** interviews for admission into the secondary schools. I and the other applicants went through three stages of general entrance examination, screening tests and interview just for admission into Form 1 in secondary school.

In 2016, the Federal Minister of Education withdrew the right of Universities and other tertiary institutions from conducting screening tests for candidates seeking admission after the entrance examination conducted by JAMB. Now the universities cannot conduct screening tests! This policy needs revisiting in order to allow each university separate the wheat from the chaff! Loyola College admitted nothing but the best and this is reflected in the school anthem and the performance of its products over the years until the government took over the school and ran it aground.

Loyola College had the best teachers and facilities that any secondary school preparing candidates for the university could offer. The teachers, among whom were expatriates and missionary Catholic priests, had Master's degrees in their chosen fields, including the Rev. Father teachers, and were as well educated as they were brilliant and dedicated. For instance, Rev. Fr. Mackle, The Principal, had a degree in Physics. His assistant, who later became Principal, Rev. Fr. M. K. Kennedy, had a Master's degree in Chemistry. The school laboratories were well equipped and better than what I met at the temporary make-shift campus of the then University of Ife at the old site of the Nigerian College of Arts and Science, Ibadan, which now houses The Polytechnic, Ibadan. We had the privilege of learning the English Language from native English speakers who, in addition, hold first and second degrees in the English Language.

The Nigerian and African teachers among them were also well educated and a lot of them would go on to teach in the universities, ending up as Professors. Whilst teaching us in the secondary school, several of them were pursuing postgraduate training, earning Masters and Doctorate degrees in the process. Mr. Segun Adesina (of blessed memory) went on to become a Professor of Education and at one time was Rector of the Adeyemi College of Education, Ondo, Ondo State. Mr. Joseph Obemeata, would also end up and retire as Professor of Education at the University of Ibadan, Ibadan. Mr. & Mrs. Ntshona, refugees from apartheid South Africa, who taught us Biology and Chemistry respectively, would end up as lecturers at the University of Ibadan. The list is endless.

I have given these examples to show that there is something rather strange, when a dedicated teacher in a secondary school is not permitted, by the conditions of service in force, from pursuing higher education, as is presently the case at the Obafemi Awolowo University International School. Several teachers have been sacked for doing just that, including one teacher who won the Best Teacher Award, the previous year before she was unceremoniously sacked by the system, for daring to improve herself academically. The system did not encourage self-advancement .and rewards those who spend their after school hours buying and selling recharge cards, biscuits and refreshments.

I was admitted to the University of Ife, Ibadan Campus, in September 1968 and left with a degree in Geology, four years later. In January 1970, the Department of Geology moved from its temporary site at Ibadan to the permanent site at Ile-Ife. The facilities were world class. I had intended to read for a first degree in either Chemistry or Mathematics, but my path crossed that of Prof. Allen S. Rogers, an American and the Head of Department of Geology, who convinced me and some other impressionable youths who had never heard of the word Geology, to pursue a career in Geology instead.

At the time, we had excellent teachers, in and outside the Department of Geology, who motivated us by their brilliance, dedication and conduct. Outside the Department of Geology, we had the Rev. Fr. Gabiola, a mathematics lecturer; Dr. Etim Etim, a Physics lecturer and the irrepressible Dr. 'Layi Ogunkoya who taught us Chemistry. He would later become a Professor of Chemistry and Vice Chancellor of Ogun State University (now Olabisi Onabanjo University), Ago Iwoye, where I spent my last sabbatical leave. It was Dr. Ogunkoya, an Organic Chemist, who would leave an indelible imprint in my young, impressionable, mind in one of his lectures on organic synthesis. He promoted active participation among students during his lectures and when many a student will suggest incorrect answers to a synthesis problem, rather than scold the student, like most of us do these days, he would ask rhetorically, "My friend (yes, his students were his friends), are you helping with the solution, or are you contributing to the problem?" The "Ogunkoya Question," was first posed to me in 1969 or thereabouts is what I ask every time I join others to look for solutions to *seemingly intractable* problems of our society. If I may ask, my dear friends and listeners at this inaugural lecture:

> *In the matter of corruption (and other societal problems) bedevilling our country Nigeria, "Are you helping with the solution or are you contributing to the problem?" Let us search our consciences!*

After graduation in 1972 and in spite of several job offers from the oil industry and the Geological Survey of Nigeria, I succumbed to the pressures from my university teachers to join the teaching staff at Ife. The legendary Prof. O. S. Adegoke, recently appointed

Emeritus Professor of Geology in March 2017, some twenty-six years after retiring from the Department, spearheaded this effort.

Prof. Adegoke had arranged an overseas training position for me in the State of Israel, even before I had completed my undergraduate training in the department. I graduated from the Department of Geology in May/June 1972 and joined the academic staff as a Graduate Assistant on 1st October 1972. Less than four weeks later, I was on board a flight to Tel Aviv to attend a UNESCO Postgraduate Training Course at the Groundwater Research Centre of the Hebrew University of Jerusalem, Israel.

After my training in Israel in Groundwater Research, I was billed to go directly from Israel to the UK in August 1973 for further postgraduate studies, having secured admission to the University College, London. However, I was recalled to Ife, following a shortage of staff due to resignations and the introduction of a new B. Sc. degree programme in Applied Geophysics at the beginning of the 1973/74 Session when the department needed all hands on deck. So my further training was put on hold. I assisted in teaching the first set of undergraduate students in the Applied Geophysics Programme who graduated at the end of the 1975/76 Session.

Mr. Vice Chancellor, Sir, I have given an account of my stewardship in the quest for **water from rocks** and I would like to make some concluding remarks arising from my experience in the educational system of the country, my profession of geology and my specialty of hydrology and hydrogeology. Firstly, the Nigeria educational system has broken down and it needs fixing. At the tertiary level, several educational summits have been organized by the Academic Staff Union of Universities (ASUU) and the Federal Government to find a fix. Frankly, I think the efforts are largely a waste and the funds and energy could be better utilized in other promising ventures, like providing seeds and seed money to farmers to grow local rice!

When I entered the university as a seventeen year old in 1968, I was more than prepared to engage in whatever I met on ground in the university. The same thing goes for all the intakes in that year, the preceding years, and shortly after, such that the failure rate was rather low. Then the intake quality was very high. Nowadays the intake quality is abysmally poor. I do not know any of my cohorts who came in with anything less than five credits at one sitting and at *one single attempt*. Now we get intakes with five credits at two sittings with about five attempts and you expect those intakes to excel in the university and pass seven subjects every semester without carry over? The reason the quality of intake was so high in our time is traceable to the high quality and dedication of the teachers in the primary and secondary school levels. If tertiary education needs a fix, do it at the lower levels. Time and space do not permit me to explain the apt Yoruba proverb of *Amukun*. This allegory explains the predicament in tertiary education. Recently, employers of labour complain about the non-employability of university graduates, but then it is a *GIGO* situation, as the old programmers would say.

One other problem we have at the tertiary level is the integrity in the system. In the early days, young Graduate Assistants under 25 years old were entrusted with question papers (days before the examination is to take place) to travel as far as Kaduna, Enugu, Benin, Ibadan and Lagos from Ile-Ife to conduct Preliminary Entrance Examinations without incidents of examination leakage or examination malpractice. Today we have cases of examination leakages from one office to the examination hall within the same building!

Mr. Vice-Chancellor. Sir, we need not live in denial, but must be bold and courageous in confronting the ills within the system, *without fear or favour*. This was the creed by which we lived and operated at the now rested Cobra Magazine, published by the Cobra News Agency (CNA) at Ife during my formative years, when I was the Business Manager (1969-1972). I worked with several illustrious colleagues. My Editors during the period were K. O. Bakare (1968 – 1971) and Biodun Atafo (1971-72). Tokunbo

Aofolaju (of blessed memory) took over as Editor in 1972-73, ably assisted by 'Bayo Williams as Deputy Editor. Senator Mazi Sam Ohuabunwa, former MD Pfizer; Professor Inonaya Onogie (former Minister of Education); and Williams later became Editor and his Deputy 'Bunmi Olaopa', who later became the MD of Glaxo Company, were the idealist young men of yore on the CNA. The old CNA would have been at the forefront to expose these ills and their perpetrators. Alas!

Our motto at Ife is **For Learning and Culture**. It seems to me that the agitations by the various unions operating on campus have succeeded in deleting the 'L' from Learning and the 'ure' from Culture, leaving the word Lure. I can give another lecture on the "Lure of Earning and Cult", but then my time is nearly up. One can only hope that the new Governing Council of Obafemi Awolowo University, under the able and capable leadership of Dr. 'Yemi Ogunbiyi, himself a man of learning and culture, will do everything to restore our motto at OAU.

During the tenure of Prof. Roger Makanjuola as Vice-Chancellor of Great Ife, he took Culture to greater heights. It was during this time that we had the major cultural events. A major cultural exposition – **Masks Unmasked** – had different people from all over the planet bringing the world of masks and masquerades to Ife. It was a festival to behold. Then Prof. Makanjuola appointed *Artistes – in – Residence* to promote our cultural values. I remember the one and only Jimi Solanke as one of the *Artistes-in-Residence.* I understand that he is no longer in residence. Has his residence collapsed? Mr. Vice Chancellor, Sir, please bring back the masks and masquerades, masked or unmasked! *Egun de!*

10.0 Recommendations

At this point, I think we all need to take a pause before we get to recommendations. In my undergraduate days, I attended all the Inaugural Lectures given by Professors on this campus. Professor P. G. Cooray of the Department of Geology gave the very first inaugural lecture in the Department of Geology on 18th January 1972. Prof. Cooray was Sri Lankan (old name Ceylon). He was the

Head of Department when I graduated. It was the second inaugural lecture overall. I was there. I still have my own copy of the lecture. It is here with me. The lecture was on "The Geological Sciences in the Service of Nigeria." After an erudite exposition of the subject he proceeded to make several recommendations, none of which has been implemented to date. His concluding remarks:

> *I would therefore like to end this Inaugural Address with the plea that instead of geology being a highly specialized subject taught to a very small minority at university level, earth science should not only form an essential part of the basic studies in the university, but it should also permeate more and more into education at secondary school level. It is here that an integrated earth science course, oriented towards the local environment, should form an essential part of the child's curriculum of learning. The earth is the background to so much human activity – agriculture, settlement, industrialization, movements of population, engineering, administration, economics, planning – that a proper understanding of the environment must ultimately lead to a richer and fuller living. Is this, after all, what mankind is striving to attain?* Cooray, 1972).

We are still waiting for the fulfilment of his dreams. There have been lots of inaugural lectures form this university, this being the 301st. From the Department of Geology, we have had about twelve inaugural lectures or so with everyone concluding with brilliant recommendations, which were never implemented by those in positions to do so. One of the more recent Inaugural Lectures was given by one of the pioneer undergraduates of the Applied Geophysics programme at OAU (Class of 1972 – 1976). These are some of his observations just before the Conclusions at his inaugural lecture given on 11th March 2008:

> *However, I make bold to say that it has become virtually impossible to properly train postgraduate students. The facilities are just not there and the financial support is*

> *virtually nil. I have had to offset bills of research materials for my students. I have also, in some cases, had to secure attachments with the private sector to assist with field work programmes.*
>
> *Experience over the years has shown that neither the university, nor the Postgraduate College (from tuition fee), the Department and the overburdened Supervisor stand in good stead to adequately fund postgraduate education. Somebody therefore has to pick up the bill, if we seriously want to continue with postgraduate training. The private sector remains a veritable vehicle in postgraduate training, most especially in the developed countries of the world. The earlier we start to pursue this reality, the better for our postgraduate programme and the nation* (Olorunfemi, 2008, p. 52).

It all sounds like a passage from the Book of Lamentations!. Olorunfemi (2008) went on to make four major recommendations requiring action by the university; local, state and federal governments; and the private sector. I will not comment on the actions at the various levels of government. It was the Nobel Laureate himself, Emeritus Professor Wole Soyinka, who once famously declared that he does not speak with deaf people after he was challenged about keeping quiet on national affairs. *I too, would rather not speak to deaf people.* But one of the recommendations that Prof. Olorunfemi made in his inaugural lecture, indeed the very first one required action by the university authorities and I quote:

> *The geophysics programme of the Department of Geology, offers Engineering and Environmental courses that should be audited by students in the Civil Engineering and Institute of Ecology/ Natural History Museum respectively. Postgraduate students at the Natural History Museum would find the environmental geophysics course very useful in pre-excavation feasibility study* (Olorunfemi, 2008, p. 54).

Ten years on and counting, nothing has come out of these recommendations from the university authorities.

Mr. Vice-Chancellor, Sir, now I am in a dilemma as I am fully conscious that whatever recommendations I make will most likely fall on deaf ears, especially with governments at all levels who have been deafened by the noise of electricity generators! But the university authorities? Someone said that we are part of the larger society. I refuse to be that part of the larger society. The irrepressible second Vice-Chancellor of this great University, Prof. H. A. Oluwasanmi, refused to be part of the larger society. Until those of us in the university refuse to be part of the larger society, our dear nation is going nowhere! Let the university set up a panel to collate recommendations from past inaugural lectures and implement those concerning it and remind the government at all levels about all the recommendations emanating from these Inaugural lectures that can move the nation forward.

By the very nature of my presentation, I have identified certain problems and proffered solutions. From time immemorial, it is the intellectual class that has shone light on how the society in which they live rise above the mundane. We must dare to be that shining light to our nation and let the change begin with us in the ivory towers for a renaissance that will pull this country out of the woods. *This is my only recommendation and challenge to my colleagues in this audience.*

Mr. Vice-Chancellor, Sir, with the recent developments in the Department of Geology, of which the University Administration is fully aware and in the University as a whole, I feel a sense of betrayal. This is definitely not the same university environment that I stepped into, as a young lad not quite eighteen years old, in September 1968. In a few days' time we will hear the immortal words, following the greatest betrayal on earth: "*The deed is done. It is finished.*" I too am done. But not quite finished. I thank you all for your presence at this Inaugural Lecture. Nigeria go better.

To God be the glory, great things He has done.....

List of References

Abegunrin, O.O. 1990. Causes of Borehole Failures in the Basement Complex Rocks of SW Nigeria, Unpublished B.Sc. Thesis, Department of Geology, Obafemi Awolowo University, Ile-Ife, 56 pp.

Adegoke-Anthony C. W. and **O. Ajayi,** 1989. "Drilling Techniques for Groundwater in the Basement Complex Rocks of Southwestern Nigeria." *Journal of Mining and Geology,* Vol. 25 Nos. 1&2, 171-181.

Adeyemi, G. O. 2013. Engineering Geology: The Big Heart for Structures and the Environment. An Inaugural Lecture, University of Ibadan, 21 February, University of Ibadan, 91 pp.

Agbola, B. S., **O. Ajayi,** O. J. Taiwo, and B. Wahab. 2012. "The August 2011 Flood in Ibadan, Nigeria: Anthropogenic Causes and Consequences." *International Journal of Disaster Risk Science* 3 (4): 207 – 214. doi 10.1007/s13753-012-0021-3.

Ajayi, O. 1982. Institutional Models for Water Resources Administration in Developing Countries, Case Example: Nigeria, Unpublished Ph. D. Dissertation, The University of Arizona, Tucson, Arizona, USA, 372 pp. http://hdl.handle.net/10150/282086

Ajayi, O. 1996. "Environmental Management in Katsina State: Private Sector Participation and Options for Cost Recovery," in Proceedings of the Workshop on Katsina First Multi-State Water Supply Project - Environmental Sanitation and Hygiene Education, Nov. 13, 1996, Liyafa Palace Hotel, Katsina, *Published by ENPLAN Group, Katsina* pp. 71-78.

Ajayi, O. 1998. "Quality of groundwater in the Agbabu Oil Sands area of the Ondo State, Nigeria", *Journal of African Earth Sciences,* Vol. 27, No. 2, 299-305.

Ajayi, O. 2006. Strategy for effective administration of water resources development in Nigeria, *Journal of Mining and Geology,* Vol. 42 No. 1, March.

Ajayi, O. and O. O. Abegunrin, 1994. "Borehole Failures in Crystalline Rocks of Southwestern Nigeria." *Geo Journal,* Vol. 34, No. 4, 397-405.

Ajayi, O. and C. W. Adegoke-Anthony, 1988. "Groundwater Prospects in the Basement Complex Rocks of Southwestern Nigeria." *Journal of African Earth Sciences,* Vol. 7(1) 227-235.

Ajayi, O. and F. Gomez-Gomez. 1983. "Water Resources Appraisal of the College of the Virgin Islands Area, St. Thomas." *Technical Report No. 11,* Caribbean Research Institute, College of the Virgin Islands (CRI-CVI), St. Thomas, US Virgin Islands, USA, 70 pp.
http://www.uvi.edu/sites/uvi/Pages/WRRI-Project_Completion_Reports.aspx?s=RE

Ajayi, O. and T. O. Obilade, 1989. "Numerical Estimation of Aquifer Parameters." *Journal of Hydraulic Engineering,* American Society of Civil Engineers, Vol. 115 (7) 982-988.

Ajayi, O. and H. Smith, 1983. "Compendium of Water Resources Data for the U.S. Virgin Islands." *Technical Report No. 12,* Caribbean Research Institute, College of the Virgin Islands (CRI-CVI), St. Thomas, US Virgin Islands, USA, 114 pp.
http://www.uvi.edu/sites/uvi/Pages/WRRI-Project_Completion_Reports.aspx?s=RE

Ajayi, O. and O. Umoh, 1998. "Quality of groundwater in the Coastal Plain Sands Aquifer of Akwa Ibom State, Nigeria." *Journal of African Earth Sciences,* Vol. 27, No. 2, 259-275.

Ajayi, O. Sonuga, F.A., Aliboh, O. P. and Oloke, D. A., 2003. "Sustainable potable water supply to Nigerians through conjunctive development of surface and groundwater resources." *In: Contributions of Geosciences and Mining to National Development, A. A. Elueze (editor).* Published by Nigerian Mining and Geosciences Society, pp 9-17.

Ajayi, O., M. O. Olorunfemi, J. S. Ojo, C. W. Adegoke-Anthony, K. K. Chikwendu, M. I. Oladapo, A. I. Idornigie, and F. Akinluyi, 2005. "Integrated Geophysical and Geotechnical Investigation of a Dam Site on River Ini, Adamawa State, Northern Nigeria," *Africa Geoscience Review,* Vol. 12, No. 3, pp. 179-188.

Ajayi, O., Bamgboye, O. and Bashir, D. 2010. "A UNESCO Regional Centre for Integrated River Basin Management in sub-Saharan Africa: NWRI Kaduna, Nigeria," In: *Hydrocomplexity: New Tools for Solving Wicked Water Problems - Kovaks Colloquium, IAHS Publication 338,* p. 173.

Ajayi, O., S. B. Agbola, B. F. Olokesusi, B. Wahab, O. J. Taiwo, M. Gbadegesin, D. O. Taiwo, O. Kolawole, A. Muili, M. A. Adeola, O. G. Olutade, F. Shiji, and N. A. Abiola. 2012. "Flood Management in an Urban Setting: Case Study of Ibadan Metropolis." *In: Hydrology for Disaster Management, Special Publication of the Nigerian Association of Hydrological Sciences (NAHS),* pp. 65 – 81.

Ako, B. D., O. S. Adegoke, T. R. Ajayi, J. **O. Ajayi,** and M. A. Rahaman, 1986. "Groundwater Prospecting and Exploration in Nigeria." **In: 1st Annual Symposium and Exhibition, Ground Water Resources in Nigeria,** July 23-25, Ikeja, Nigerian Water and Sanitation Association (NIWASA), Ikeja, pp. 3-44.

Ako, B. D. 1996. Applied Geophysics: The Subsurface and the Treasures. An Inaugural Lecture delivered at the Obafemi Awolowo University, Ile-Ife, on 12th March 1996, Inaugural Lecture Series 113. Obafemi Awolowo University Press, Ile-Ife, Nigeria. 42 pp.

Asiwaju-Bello, Y. A. 2017. Water-Rock Association: A Bond of Mutual Wholesomeness Under Stress by Man. An Inaugural Lecture delivered at the Federal University of Technology, Akure, on 10th January 2017, Inaugural Lecture Series 79. 50 pp.

Banoeng-Yakubo B., **O. Ajayi**, D. Asiedu, Y. Loh, S. M. Yidana. 2010. "Groundwater Potential of Basement Rocks in Parts of Volta River Basin in Ghana." *Africa Geoscience Review,* Vol. 17, No. 1, 1-20.

Banoeng-Yakubo B., S. M. Yidana, J. **O. Ajayi,** Y. Loh, D. Asiedu. 2011. "Hydrogeology and Groundwater Resources of Ghana: A Review of the Hydrogeology and Hydrochemistry of Ghana." *In: McMann J.M. (ed), Potable Water and Sanitation.* ISBN 978-1-61122-319-4, Nova Publishers, New York.

Banoeng-Yakubo, B. K. 1987. Structure, Petrology and gold-mineralization of the Birimian-Tarkwaian Formations of the Asuokoo Area, Ghana. *Unpublished M.Sc. Thesis Results,* University of Ghana, Department of Geology, 146 pp.

Banoeng-Yakubo, B. K. (1989) Occurrence of Groundwater in Basement Complex Rocks of the Upper Regions of Ghana. *Unpublished M.Sc. Thesis* Obafemi Awolowo University, Ile-Ife, Nigeria. 198 pp.

CIBP. 1993. Report on the detailed analysis of the water flowing from the three Artesian Wells located approximately 2 km from Agbabu Town on the landed property of the Committee on the Implementation of the Bitumen Project (CIBP). Lighthouse Petroleum Engineering Company Limited, Warri, Nigeria, 16 pp.

Cochran H. A. 1937. The Technique of Well Sinking in Nigeria. Geological Survey of Nigeria Bulletin No. 16.

Cooray, P. G. 1972. The Geological Sciences in the Service of Nigeria. An Inaugural Lecture delivered at the University of Ife (now Obafemi Awolowo University), Ile-Ife, on 18h January 1972, Inaugural Lecture Series 2. University of Ife Press, Ile-Ife, Nigeria. 14 pp.

Faniran A. and L. K. Jeje. 1983. Humid Tropical Geomorphology. Longman, London.

Government of Oyo State. 2011. Government of Oyo State Report on the Assessment of the 26th August 2011 Flood Disaster in Ibadan Metropolis. Oyo State Task Force on Flood Prevention and Management. Ibadan: Oyo State. Government of Oyo State (2011). Government of Oyo State report on the Assessment of the 26th August 2011 Flood Disaster in Ibadan Metropolis. Report prepared for the Government by the Oyo State Task Force on Flood Prevention and Management. Members: B. Wahab, T. Agbola, O. Ajayi, F. Olokesusi, M. Gbadegesin, S. Taiwo, O. Kolawole, A. Muili, M. Adeola, G. Olutade, F. Shiji and N. Abiola. 78 pp.

Hazell, R. 2004. British Hydrogeologists in West Africa – An Historical Evaluation of their Role and Contribution. In: Mather, J. D. (ed.) 200 Years of British Hydrogeology, *Geological Society of London, Special Publications,* The Geological Society of London, 225: 229 – 237.

Idowu, O. A. and **O. Ajayi,** 1998. "Groundwater Occurrence in Southwestern Nigeria: A Comparison of two Geological Environments." *Water Resources,* Vol. 9, 33-40.

Idowu, O. A., **O. Ajayi** and O. Martins, 1999. "Occurrence of Groundwater in Parts of the Dahomey Basin, Southwestern Nigeria." Journal of Mining and Geology, Vol. 35, No. 2, 229-236.

Idowu, O. A. 1992. An Assessment of Groundwater in Ogun State. Unpublished M. Sc. Thesis, Department of Geology, Obafemi Awolowo University, Ile-Ife.

Issar, A. S. 1989. Water Shall Flow from the Rock. *Sub-title* Hydrogeology and Climate in the Lands of the Bible. Springer-Verlag Berlin and Heidelberg GmbH & Co. KG, 224 pp.

Issar, A. S. 2014. Strike the Rock and There Shall Come Water: Climate Changes, Water Resources and History of the Lands of the Bible. Publisher Springer International Publishing AG,127 pp.

Jones, H. A. and Hockey, R. D. 1964. The Geology of Part of Southwestern Nigeria, Geological Survey of Nigeria Bulletin No. 31.

Kashef, A. I. 1987. Groundwater Engineering. McGraw-Hill, Singapore. 512 pp.

MacDonald, A. M. and Davies, J. 2000. A brief Review of Groundwater for Rural Water Supply in sub-Saharan Africa. BGS Technical Report WC/00/33. 30 pp.

Martins, O., **O. Ajayi** and O. A. Idowu. 2000. "Factors Influencing Yields of Boreholes in Basement Complex Aquifers in

Parts of Southwestern Nigeria." *Nigerian Journal of Science,* Vol. 34, No.2, 109-115.

McKenzie, A. A., Rutter, H. K., Hulbert, A. G. 2010. The use of elevation models to predict areas at risk of groundwater flooding. In: Fleming, C., Marsh, S. H., Giles, J. R. A.., (eds.) *Elevation models for geosciences.* Geological Society of London, 75 -79, Geological Society Special Publications, 345.

New Jerusalem Bible. 1985. NJB Standard Edition.

Nwachukwu, J. I. 2007. Organic Matter: The Source of Our Wealth. An Inaugural Lecture delivered at the Obafemi Awolowo University, Ile-Ife, on 9th October 2007, Inaugural Lecture Series 206. Obafemi Awolowo University Press, Ile-Ife, Nigeria. 60 pp.

Odebode, M. O. 2005. Tiny Ancient Organism in Rocks: Their Role in the Nigerian Economy. An Inaugural Lecture delivered at the Obafemi Awolowo University, Ile-Ife, on 10th May 2005, Inaugural Lecture Series 177. Obafemi Awolowo University Press, Ile-Ife, Nigeria. 59 pp.

Offodile, M. E. 1992. An approach to ground water study and development in Nigeria. MECON Services Limited, Jos, Nigeria. 247 pp.

Offodile, M. E. 2002. Ground Water Study and Development in Nigeria. MECON Services Limited, Jos, Nigeria. 453 pp.

Offodile, M. E. 2014. Hydrogeology: Ground Water Study and Development in Nigeria, 3rd Edition, MECON Services Limited, Jos, Nigeria. 636 pp.

Ogedengbe, M. O. 1987. Nigeria's Water-Supply Nightmare. An Inaugural Lecture delivered at the Obafemi Awolowo

University, Ile-Ife, on 12th August 1997, Inaugural Lecture Series 117. Obafemi Awolowo University Press, Ile-Ife, Nigeria. 16 pp.

Olarewaju, V. O. 2007. Rocks: Their Beauty, Language and Roles as Resources of Economic Development. An Inaugural Lecture delivered at the Obafemi Awolowo University, Ile-Ife, on 13h November 2007, Inaugural Lecture Series 208. Obafemi Awolowo University Press, Ile-Ife, Nigeria. 54 pp.

Olorunfemi, M. O and **O. Ajayi,** 1999. "Geophysical and Borehole Investigations of Groundwater Seepage into Mill Furnace and Basement Foundations of the Steel Rolling Company, Oshogbo, Southwestern Nigeria." *Water Resources,* Vol. 10, 62-67.

Olorunfemi, M. O., Ojo, J. S., Sonuga, F. A., **Ajayi, O.** and Oladapo, M. I. 2000a. Geoelectric and Electromagnetic Investigation of the Failed Koza and Nassarawa Earth Dams around Katsina, Northern Nigeria. *Journal of Mining and Geology 36* (1), pp. 51 – 65.

Olorunfemi, M. O., Ojo, J. S., Sonuga, F. A., **Ajayi, O.** and Oladapo, M. I. 2000b. Geophysical Investigation of Karkarku Earth Dam Embankment, *Global Journal of Pure and Applied Sciences 6* (1), pp. 117 – 124.

Olorunfemi, M. O. 2008. Voyage on the Skin of the Earth: A Geophysical Experience. An Inaugural Lecture delivered at the Obafemi Awolowo University, Ile-Ife, on 11th March 2008, Inaugural Lecture Series 211. Obafemi Awolowo University Press, Ile Ife, Nigeria. 75 pp.

Olorunfemi, M. O. 2017. Written Communication.

Onyekwere, C. U. N. 1985. Characteristic depth-to-water table in Ile-Ife Town. Unpublished B.Sc. Thesis. Department of Geology University of Ife, Ile-Ife, Nigeria.

Oteze, G. E. 1977. Water resources and supply in Nigeria. *In: Proceedings of the National Engineering Conference, NSE,* pp. 104 - 118.

Purcell, T. W. 1980. The Effects of Rainfall on Two Undeveloped Tropical Bays in St. John, U. S. Virgin Islands, *Technical Report* No. 5, Caribbean Research Institute, St. Thomas, U. S. Virgin Islands.

Rhodes, H. T. 1972. Geology. Golden Press, New York.

Todd, D. K. 1980. Groundwater Hydrology, 2nd edition. John Wiley, New York. 535 pp.

Rogers, A.S., A.M.A. Imevbore and O.S. Adegoke, 1969. Physical and chemical properties of the Ikogosi Warm Spring, Western Nigeria. Journal of Mining and Geology. 4: 69-81.

Smith, H., and **O. Ajayi,** 1983. "Land Use, Runoff and Recharge on Selected Watersheds in the U.S. Virgin Islands," *Technical Report No. 13,* Caribbean Research Institute, College of the Virgin Islands (CRI-CVI), St. Thomas, US Virgin Islands, USA, 1983, 57 pp.
http://www.uvi.edu/sites/uvi/Pages/WRRI-Project_Completion_Reports.aspx?s=

Soyinka, W. 1981. Ake – The Years of Childhood. Random House Inc., New York, NY.

Tailor, G. C. Jr. 1976. Historical review of the international water-resources program of the U.S. Geological Survey, 1940-70. US Geological Survey Professional Paper 911, 156 pp.

Thompson, T. P. T., D. Francois, and **O. Ajayi,** 1983. "Managing Water Supply Operations in the Caribbean: Lessons from the U.S. Virgin Islands," *Natural Resources Forum,* Vol. 7(4) 351-362.

Tijani, M. N. 2016. Groundwater: The Buried Vulnerable Treasure. An Inaugural Lecture delivered at the University of Ibadan, Ibadan, on 19th May 2016, Ibadan University Press, Ibadan, Nigeria. 80 pp.

Umoh, O. A. 1993. Characterisation of the coastal aquifer of Akwa Ibom State, Nigeria. Unpublished M. Sc. Thesis, Department of Geology, Obafemi Awolowo University, Ile-lfe, Nigeria, 234 pp.

WHO. 1971. Intemational Standards for Drinking Water. World Health Organisation. Geneva. 70 pp.

WHO. 1976. Surveillance of Drinking Water Quality. World Health Organisation. Geneva. 134 pp.

WHO. 1984. Guidelines for Drinking-Water Quality - Vol. I: Recommendations, World Health Organisation. Geneva. 130 pp.

WHO. 1985. Guidelines for Drinking-Water Quality - Vol. 3: Drinking-water Quality Control in Small Community Supplies, World Health Organisation. Geneva. 136 pp.

WHO. 1994. Intemational Standards for Drinking Water. World Health Organisation. Geneva. 70 pp.

WHO. 1996. Guidelines for drinking-water quality, 2nd ed. Vol. 2. Health criteria and other supporting information. World Health Organization, Geneva, 1996.

WHO. 2002. Guidelines for Drinking-water Quality – Second Edition Addendum, Microbiological Agents in Drinking Water , World Health Organisation. Geneva.

WHO. 2003a. Emerging issues in water and infectious disease. Geneva, World Health Organization.

WHO. 2003b. Report of the WHO workshop: Nutrient minerals in drinking water and the potential health consequences of long-term consumption of demineralized and remineralized and altered mineral content drinking waters. Rome, 11–13 November 2003 (SDE/WSH/04.01).

WHO. 2007. pH in drinking-water. Background document for preparation of WHO Guidelines for drinking-water quality. Geneva, World Health Organization (WHO/SDE/WSH/07.01/1).

WHO. 2008. Guidelines for Drinking-water Quality – Third Edition Incorporating the First and Second Addenda, Volume 1 - Recommendations, World Health Organisation. Geneva.

WHO. 2011. Guidelines for Drinking-water Quality – Fourth Edition, World Health Organisation. Geneva. 564 pp.