GROUNDWATER: THE BURIED VULNERABLE TREASURE

AN INAUGURAL LECTURE, 2015/2016

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GROUNDWATER: THE BURIED VULNERABLE TREASURE

An inaugural lecture delivered at the University of Ibadan

on Thursday, 19 May, 2016

By

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The Vice-Chancellor, Deputy Vice-Chancellor (Administration), Deputy Vice-Chancellor (Academic), Registrar, Librarian, Provost of the College of Medicine, Dean of the Faculty of Science, Dean of the Postgraduate School, Deans of other Faculties and of Students, Directors of Institutes, Distinguished Ladies and Gentlemen.

Preamble

All Glory to the Almighty ALLAH, the most Beneficent, the most Merciful, the Lord of the World and the Fountain of all knowledge; for the opportunity of standing before all of you here today. Many thanks to all my teachers, lecturers and colleagues, from whom I had the opportunity of learning one thing or the other which form parts of my knowledge today.

I feel honoured for the privilege of presenting this inaugural lecture on behalf of the Faculty of Science, especially in a Faculty where there are many senior colleagues who are yet to have the opportunity. I wish to appreciate the Vice-Chancellor and the Dean of Science for facilitating additional slot for Faculty of Science which made it possible for me to stand before this august audience today. This is the 8th Inaugural Lecture from the premier Department of Geology in Nigeria since its inception in 1959/60 academic session. The first inaugural lecture was in 1963 by Professor R.A. Reyment, the foundation Head of Department; followed by that of Professor M.O. Oyawoye in 1970 (table 1). It is worthy of mention here that Professor Oyawoye is the first indigenous Head of Department, and the first African Professor of Geology.

I consider this lecture a unique one due to a number of circumstances:

(a) First, this lecture is coming up eight years after my elevation to the grade of Professor and it is the first lecture in the Hydrogeology/Environmental Geology Option from the Department.

(b) Secondly, this lecture is the 8th in the series of the Inaugural Lectures for the 2015/16 academic session.
(c) Thirdly, this lecture is the first ever from the Faculty of Science to be presided over by an incumbent Vice-Chancellor who is not only from the same Department as the inaugural lecturer of today, but also the first ever Vice-Chancellor from the Faculty of Science.

Table 1: Inaugural Lectures from the Department of Geology, University of Ibadan, 1963 - 2016 (Modified after Olayinka 2010)

S/No.	Inaugural Lecturer	Topic	Sub-discipline	Year
1	Prof. R.A. Reyment	The Future of Geology in Nigeria	Biostartigraphy	1963
2	Prof. M.O. Oyawoye	Politics and Economics of Mineral Resources in Developing Countries	Petrology	1970
3	Prof. E.A. Fayose	Man and Minerals	Biostartigraphy	1979
4	Prof. T.A. Badejoko	Geochemistry: The Heartbeat of Mineral Resources	Geochemistry	1995
5	Prof. A.A. Elueze	Compositional Character: Veritable Tool in the Appraisal of Geomaterials	Economic Geology	2002
6	Prof. A.I. Olayinka	Imaging the Earth's Subsurface	Applied Geophysics	2010
7	Prof. G.O. Adeyemi	Engineering Geology: The Big Heart for Structures and the Environment	Engineering Geology	2013
8*	Prof. M.N. Tijani	Groundwater: The Buried Vulnerable Treasure	Hydrogeology	2016

*This Lecture

Mr. Vice-Chancellor Sir, I consider these as rare divine coincidences in life.

My decision to study Geology after my secondary school education in 1981 was based on my innocent belief that Geology is the most relevant professional course where I can utilize my good background and distinction in O-level Geography. Therefore, without any other form of counselling, I applied to read Geology at the University of Ilorin. With Glory to the Almighty, I became the University Scholar at the end of 100-level and for the remaining periods of my undergraduate programme. My interest in academics was influenced by the disposition and committed efforts of some of my lecturers at the University of Ilorin, notably Professor A.E. Annor (of blessed memory), Professor S.O. Akande, Professor J.I.D. Adekeye and Dr. A.U. Oteri among others. However, my interest in Applied Geology was influenced by my interactions with Dr. A.U. Oteri, my final year project supervisor and mentor, who facilitated a three-month vacation internship for me at the UNICEF-Assisted Water and Sanitation Project (WATSAN) in Ilorin, at the time when Geology was not part of SIWES programme.

As the best graduating student in my set, these fine gentlemen encouraged me to undertake my M.Sc. programme at their Alma mater, University of Ibadan, after the mandatory National Youth Service. At the University of Ibadan, my M.Sc. Class (1988/89 set) was opportuned to have committed lecturers, a number of whom (shortly afterwards by 1990) moved to the private sectors or left the country for greener pastures at the heel of the brain-drain exodus in the Nigerian academia.

Mr. Vice-Chancellor Sir, permit me to recall, at this point, your singular act (as the Postgraduate Coordinator) of providing me with my Departmental M.Sc. transcript (as an advance copy) prior to the final approval by the Board of the Postgraduate School (PGS) sometimes in 1990. This so-called advance copy made it possible for me to submit all necessary documents for a scholarship application to the German Academic Exchange Services (DAAD) before the stipulated deadline. The success of that application, which was meant for a Professional Master in Hydrogeology (of tropical and Sub-tropical Regions) between 1991-1992 at the University of Tuebingen, Germany, paved way for the subsequent DAAD Doctoral scholarship under the supervision of

Professor Eckehardt P. Loehnert at the University of Muenster, Germany, between 1993 and 1997.

I wish to also recall the roles of two of my senior colleagues in respect of my academic career, Professor A.F. Abimbola (of blessed memory), my senior and friend who encouraged me to join the Department on completion of my Ph.D programme and recommended me to Professor A.A. Elueze, who was then the Head of Department. I joined the Department at the peak of "Abacha era" when many lecturers were leaving the academic setting, and thus, I guess it was not too difficult for Professor A.A. Elueze to push the case for my upgrade from Lecture II to Lecturer I (of course with evidence of some scholarly publications) within six months of my assumption of duty in January 1998. This singular effort gave me about two years' advantage in terms of further promotion, Professor T.A. Badejoko provided the fatherly counselling and mentorship with his periodic advice on the need for thorough and publishable research as key ingredients of academic profession. The rest are history of success stories that provided me the opportunity of standing before this august gathering as a professor of Hydrogeology and Environmental Geology today.

The topic of my lecture: "*Groundwater – The Buried Vulnerable Treasure*" is aimed at highlighting some aspects of my research activities on an important element of life – Groundwater. Only few natural resources are as important, or as invisible, as Groundwater:

- Hence, a *buried treasure* because it is hidden below the ground surface and not always easy to find; as such warrants the need for search through hydrogeophysical exploration.
- Once found, groundwater may not be readily accessible, thus warrants the need for some specialized exploitation skills/methods to tap it.
- Also, the buried nature implies that groundwater is always out of our sight and out of our conscious mind; thus, *vulnerable* to abuse through human activities such as contamination, over-exploitation, and so on.

In this lecture, some of the basics of groundwater within the framework of hydrogeological studies are covered. Highlights of my research on environmental hydro-geochemical assessment of groundwater are also presented. The lecture concludes with a synthesis and recommendations in respect of key aspects of Integrated Water Resources Management (IWRM) and environmental sustainability, as well as future outlook regarding impacts of climate change on groundwater resources.

Divine Basis of Groundwater Geology (Hydrogeology)

> *"...... the heaven and the earth were joined together (as one unit of creation), before We clove them asunder? We made from **water** every living thing ...."*
>
> *The Holy Quran*; Chapter 21, Verse 30.

A critical evaluation of the above verse of the Holy Quran gives divine insight into two main aspects of what is regarded as modern scientific facts:

- The fact that the creation of the Earth was based on cloving asunder of the universe, that is, *Big Bang Theory.*
- That all lives began in water i.e. a revered *Theory of Evolution,* which can be simply described with an old Uzbek proverb that says "Where water ends, life ends".

Thus, if the first creation by God, The Almighty, is the Earth as reported in the Holy Books, then the scientific study of the Earth, its make-up and processes within and above it, that is, *Geology* is undoubtedly the oldest profession in the World.

The focus of this lecture is water, albeit, groundwater, the significance of which is clearly expressed by an ancient adage which also says "Water is the blood of Life". No doubt that many ancient civilizations were centred on sources of water;

classical examples are the early civilizations along rivers like the Indus in Indo-Pakistan, the Tigris and Euphrates in Mesopotamia, the Hwang Ho in China, and the Nile in Egypt (Hubbart 2008). However, the divine mystery of water as God's gift to life is evident from a number of references in the Holy Books. *The Holy Quran* among its many references to Noah's prophecy and flood states;

> *"So We open the gates of heaven, with water pouring forth. And We caused the earth to gush forth with springs (water)……"*
> (*The Holy Quran*; Chapter 5, Verses 11-12).

Also on the biblical Noah's flood, the Scripture states:

> *"…….the same day were all the fountains of the great deep (were) broken up and the windows of heaven were opened".* (*Genesis* 7:11).

Opening of *windows or gates of the heaven* implies the torrents of rain from above (sky), and the *breaking or gushing of waters* (springs) from the earth's depths is not only a divine confirmation of the concept of precipitation within the framework of modern hydrologic (water) cycle, but also a divine revelation of the occurrence of groundwater (as spring) within the earth's subsurface.

Furthermore, regarding the sojourns of Prophet Musa (Moses) through the Arabian Desert, *The Holy Quran and Bible*, among many references state:

> *"And remember Moses prayed for water for his people; We said "Strike the rock with thy staff" then gushed forth there-from twelve springs ….."*
> *The Holy Quran*; Chapter 2, Verse 60.

> *"Thou shalt smite the rock and there shall come water out of it that the people may drink"*
> *Exodus* 17 verse 6.

The *striking or smiting* of rock and the resulting *gushing out* of waters (springs) evidently refer not only to a local tradition well known to Arabs and the Jews in the olden days, but also a clear indication of divine revelation to human race that much water is contained in the ground. In the light of these, it will not be out of place to say that *Hydrogeology*, which is the scientific study of understanding of how geologic, hydrologic and hydraulic conditions control the occurrence, distribution and flow (movement) of groundwater within the subsurface aquifer media, is the oldest sub-discipline of Geology.

Why Groundwater?

Groundwater plays a number of very important roles in our environment and in socio-economic development of any society. Groundwater is a valuable natural resource providing a primary source of water for agriculture, domestic and industrial uses throughout the world. Nearly half of all drinking water in the world and about 43% of all water effectively consumed in irrigation (Siebert 2010) is sourced from groundwater. In the environment, groundwater is vital for sustaining many streams, rivers, lakes, wetlands, and other dependent ecosystems (Kløve 2013), most especially during the dry seasons.

The largest reservoir for water in the hydrologic cycle is the ocean, which contains more than 97% of all the water in the system. This means that most of the water in the hydrologic cycle is *saline*; leaving just about 3 percent as *freshwater* (Healy, et al. 2007). However, about 2.14 percent out of the 3 percent freshwater are permanently locked up and not accessible as frozen polar ice sheets (table 2), while only about 0.61 percent of the fresh groundwater systems is available for human consumptions (Loynachan, et al. 1999).

Table 2: Availability Status and Distribution of Global Water Sources (modified after Heath 1983; Healy, et al. 2007)

Water Source	% of Total water	Availability/Status
Oceans	97.24%	Partly accessible but saline with high cost of treatments
Ice caps & glaciers	2.14%	Fresh, but not accessible
Groundwater	0.61%	Fresh, accessible and of good quality and usually less vulnerable to contamination
Freshwater lakes	0.009%	Fresh, accessible, but vulnerable to contamination in most cases
Rivers & Inland seas	0.008%	Fresh, accessible, but vulnerable to contamination in most cases
Atmosphere	0.001%	Not accessible

An estimated 4.2 million cubic kilometers of the world's groundwater is stored within the subsurface. The amount of groundwater in storage is 30 times greater than about 125,000 cubic-kilometers in all the fresh-water lakes and more than the 5,205 cubic kilometers of water in all the world's streams at any given time (fig.1). This implies that only a very small fraction of the water passing through the hydrologic cycle resides in the atmosphere or in surface freshwater bodies such as streams and lakes. *These facts therefore underlie the significance of groundwater as valuable resources for human survival.*

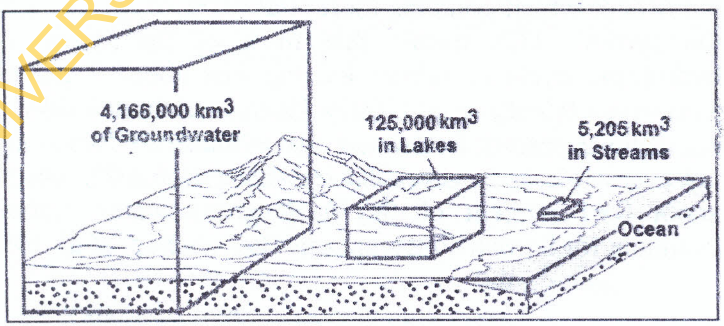


Fig. 1: Comparison of amount of freshwater in storage world-wide. (From USGS - General Interest Publication "Ground Water" - retrieved from *http://pubs.usgs.gov/gip/ gw/compar.html*).

Over 1.5 billion people depend on groundwater for drinking purpose, and many more will in the future. This is more so if the Millennium Development Goals (MDGs) and the follow-up Sustainable Development Goals (SDGs) are to be met, especially in Africa, where increasing reliable water supplies will depend on the development of groundwater (MacDonald and Calow 2009). By and large, the significance of groundwater is due to the fact that:

(a) groundwater can be found in most environments using the appropriate exploration techniques; hence, supplies can be located close to the point of need (MacDonald, et al. 2005) and at lower cost compared to the costs of dam, treatment and piping network associated with surface water supply.
(b) groundwater is usually of very good quality and requires little treatment, if at all, due to natural filtration of many potential contaminants including bacteria and viruses (Edmunds and Smedley 2005).
(c) groundwater source responds much more slowly to meteorological conditions compared to surface water; it thus providing a natural buffer against climate variability, including drought (Calow, et al. 2010).

Nonetheless, the importance or worth of groundwater is often overlooked.

Perhaps, to demonstrate our unconsciousness of the value or worth of water as a divine gift of nature, permit me to ask "*what will be our reactions and that of the Labour Unions if the Federal Government of Nigeria decides to increase the price of Premium Motor Spirit (PMS) from the current □86.50/litre to about □90.00/litre?* It is most likely that the labour leaders will mobilize their members to the streets; meanwhile, a 1-litre of bottled water goes for about □100.00 and possibly more, if refrigerated!

Furthermore, during the frequent cycle of fuel scarcity in Nigeria, most of us talk of the long queues as dreadful and many continue to castigate government for lack of foresight or solution to the unfortunate endemic problem. However, many of us do not realise the fact that there are several millions of innocent and impoverished Nigerian women and children, in many rural communities (fig. 2), who are spending their useful hours, on daily basis, travelling long distances and in long queues in search of this basic need of life (drinking water) for their survival.

Fig. 2: Women and children travelling long distances and in long queues in search of potable water.

Development of Hydrogeology (Groundwater Geology)

Hydrology is the science that deals with all aspects of the water available on the earth, that is, the study of occurrence of surface water, its properties, distribution and circulation within the framework of hydrologic cycle. However, *Hydrogeology*, which draws heavily on geology, is the scientific study of the geologic, hydrologic and hydraulic conditions that control the occurrence, distribution and flow (movement) of groundwater system within the subsurface medium (aquifer), while *Environmental hydrogeology* entails assessments of groundwater interactions with subsurface geologic medium and the natural geochemical processes controlling the chemical evolution as well as human anthropogenic controls on the quality of groundwater.

Mr. Vice-Chancellor Sir, in the following section, a brief synopsis of the historical development of hydrogeology spanning the ancient times to 16th century, through 17th to the 20th century is presented for record purpose:

- In ancient times, human settlements were concentrated along the banks of Rivers like the Nile, Indus, Ganges, Euphrates and Tigris. During the ancient time (14th century), most of the hydrological concepts were speculative, but the trends changed to close observations in the 15th to 16th centuries (Hubbart 2008).
- The seventeenth century saw development of techniques for measurements of rainfall, evaporation, river discharge, among other, which provided proofs of the principle of hydrological cycle. Notable are the works of the Frenchmen Pierre Perault and Edme Marriotte published in the 1670's and 1680's in support of the contention that precipitation was the precursor to stream flow (Nace 1974; Hubbart 2008).
- The eighteenth century was characterised by a number of hydraulic experimental studies (mostly empirical) during which various hydraulic principles were discovered. Notable among them are Bernoullis piezometer, Bernoulli's theorem, Chezy's formula, the Borda and Pitot tubes, among others.
- In the nineteenth century, many of the experimental studies were modernised and this laid the foundation of modern science of quantitative hydrologic studies. In 1856, the French Engineer (Henry Darcy), introduced the law describing groundwater flow through porous media (Nace 1974 and Hubbart 2008). This was followed by a number of other works such as Dupit's well formula, Hagen-Poiseuille's equation of capillary flow and Manning's flow formula.

- In the early and middle decades of the 20th century, many other individuals (such as Hazen, E.J. Gumbel, H.E. Hurst, and W.B. Langbein) contributed their quotas by providing rational solutions to empirical hydrological problems with mathematical analyses. Others such as O.E. Meinzer, C.V. Theis, C.S. Slichter, and M.K. Hubbert pioneered the development of theoretical and practical aspects of groundwater hydraulics while R.S. Garrels contributed to the understanding of water quality (Hubbart 2008).
- In the 1970's and 80's, environmental contamination issues became important as well as research on potential use of geothermal energy. Now, with the development of computers, solutions of complicated mathematical hydrologic theories have become realities.

In this 21st century, current issues and contemporary areas of research studies are:

- Groundwater resource evaluation in relation to quantity, quality and long-term sustainability.
- Environmental contamination of groundwater resources in the face of increasing human activities and associated impacts.
- Effects of long-term impacts of climate change on groundwater resources and implications for water and food security.

Source of Groundwater and the Hydrologic Cycle

> *"And We send down water from the sky (cloud) in due measure and We cause it to soak (infiltrate) into the earth, and verily We are able to drain it off (drainage) with ease"*
>
> *The Holy Quran*; Chapter 23, Verse 18.

The above quran verse is a divine testimony of the concepts of precipitation, infiltration and run-off (drainage) within the framework of modern hydrologic cycle. The hydrologic cycle (water cycle) is perhaps, the most familiar cycle which describes the fluxes of water between the various reservoirs of the hydrosphere as a component of the earth system. However, there is one aspect of the hydrologic cycle that is invisible and often forgotten i.e. Groundwater. Most of the rainfall will soak into the soil, which acts like a giant sponge. In the soil, some of the water will be taken up by plants through transpiration and the excess water will soak further into the ground – a process called infiltration - and trickle downwards into the rocks to the water level (water table), becoming groundwater (fig. 3).

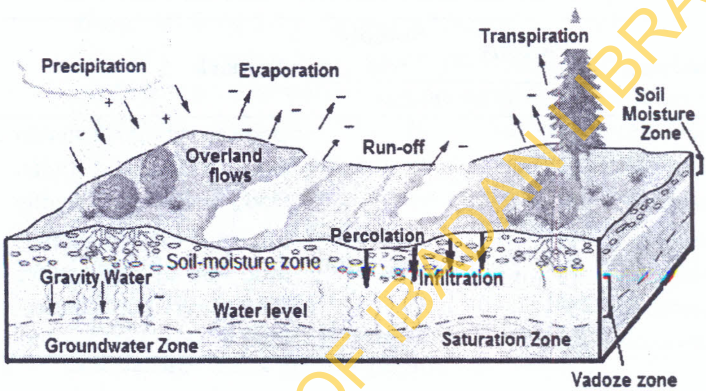


Fig. 3: The hydrologic cycle and catchment water pathways.

Some geological formations are impermeable – meaning that water can hardly flow through them, while some are permeable – thus contain pore spaces or cracks that allow water to flow. Such permeable formations/rocks are known as *aquifers*. The word aquifer comes from two Latin words, *aqua*, that is, water, and *ferre*, meaning to bear or carry. Since groundwater is stored and transmitted by aquifers, the resources can only be understood and managed with some appreciation of Geology. This underlies the basis of the term hydrogeology given to the study of groundwater.

Therefore, depending on the geological setting, some rocks, such as claystone or fresh granite, may have only a few cracks through which water can percolates and transmit only small quantities of water as *poor aquifers (aquicludes)*. By comparison, rocks, such as alluvial sands/gravels, fractured sandstones and cavernous limestone, have large inter-connected openings that permit water to move more freely; such rocks transmit larger quantities of water and are *good aquifers* (table 3). The significance of these lie in the need for detailed understanding of the subsurface medium through hydrological and hydro-geophysical investigations for selection of appropriate sites for wells/boreholes constructions.

Table 3: Porosity and yield Potential of Different Rock/Aquifer Materials (modified from Heath 1983; Danskin 1998)

Materials	Porosity	Specific Yield	Remark
	% by volume		
Sand	25	22	Good to very good aquifer
Gravel	20	19	Good to very good aquifer
Limestone	20	18	Good to very good aquifer
Sandstone	11	6.0	Moderate to good aquifer
Basalt	11	8.0	Moderate to good aquifer
Claystone	50	2.0	Poor to very poor aquifer
Granite	0.10	0.09	Poor to very poor aquifer

By and large, groundwater occurrence depends primarily on geology, associated structural/tectonic features, weathering/ geomorphology and effective rainfall (both current and historic) (Tijani 1994; Chilton and Foster 1995; MacDonald, et al. 2012). Therefore, the starting-point of groundwater resource assessment is an understanding of the local geology, as it is the nature of the subsurface rock medium that controls how and where groundwater will flow as well as how much is really available. In addition, understandings of meteorological and hydrological processes are necessary to investigate the relationship of groundwater to rainfall and surface water. Geochemical knowledge is used to investigate groundwater quality, while engineering skills will be required when drilling boreholes and pumping water out of aquifers.

Hydrogeological Settings and Groundwater Occurrence in Nigeria

The summary of the hydrogeology of the main aquifers in Nigeria as presented in figure 4, highlights a simplified version of the types and respective productivity of the main aquifers. In Nigeria, there are four main aquifer scenario characterised by different hydrogeological settings and groundwater conditions as summarized from MacDonald, et al. 2011 and Tijani, et al. 2016, these are:

(a) *Precambrian crystalline basement rocks* occupy about 50% of Nigeria and characterized by very low primary permeability or porosity. Groundwater occurrences are within the weathered overburden or fractured bedrock. Typical yield of boreholes is usually 0.1–1 l/s, but can occasionally be as high as 10 l/s (fig. 5a).

(b) *Consolidated sedimentary rocks* occupy 35% of Nigeria and characterized most of the inland sedimentary Basins (Sokoto, Borno, Bida, Anambra, eastern Dahomey Basin and Benue Trough, etc). Sandstone units in the basins can store considerable volumes of groundwater and support high yielding boreholes of 10–50 l/s. However, low permeability mudstones and shale units (especially in SE-Nigeria) support low yields of less than 0.5 l/s (fig. 5b).

(c) *Unconsolidated sediments* cover about 10% of Nigeria. These are usually productive with high porosity/storage and are characteristics of the coastal zone (Coastal Plain Sands), including the Tertiary Niger Delta with yields of 5–50 l/s, depending on the depth of individual boreholes (fig. 5c).

(d) *Unconsolidated alluvial sediments* in river valleys constitute about 1% and usually underlain most river valleys. These vary in thickness from few meters to 100 m, and have a high porosity with yield of about 1–10 l/s (fig. 5d).

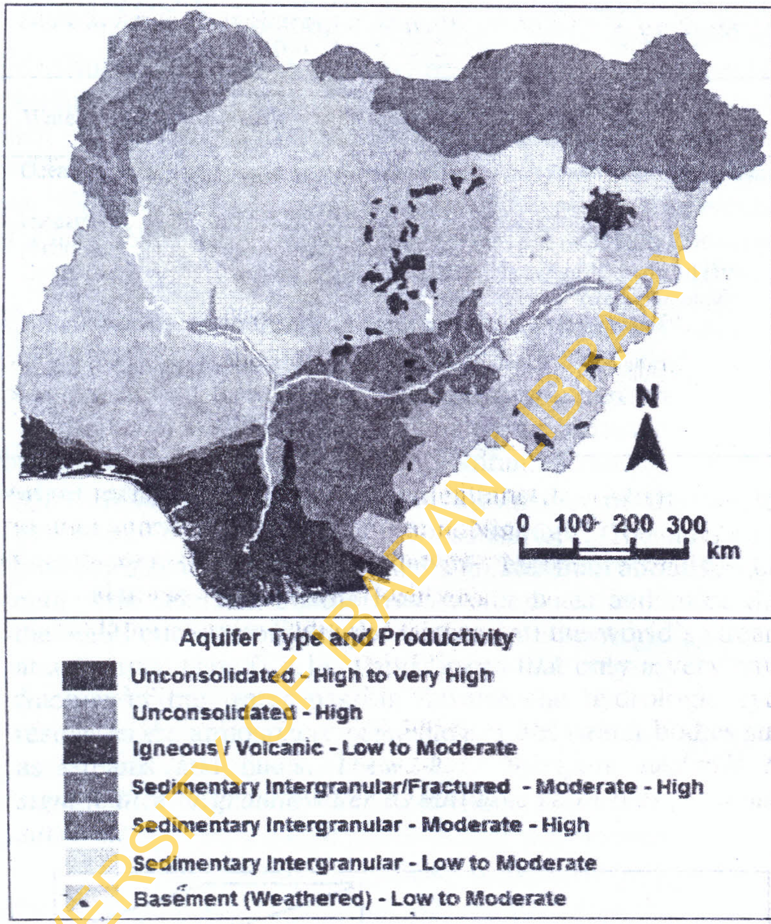


Fig. 4: Simplified hydrogeological Map of Nigeria with main aquifer types and productivity (modified after, Tijani, et al. 2016).

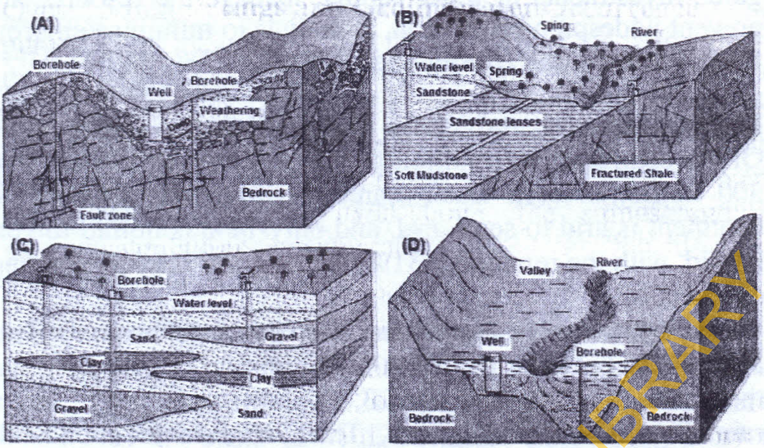


Fig. 5: Diagrammatic representation of the four main hydrogeological environments in Nigeria (adapted and modified after MacDonald, et al. 2011).

In terms of hydrochemical composition, groundwater system in Nigeria can be adjudged to be of good quality. However, it does not mean that groundwater is not vulnerable to contamination. Contaminants can be flushed through the soil into the (groundwater) in the aquifer. For example, in Nigeria, there are cases where saltwater intruded groundwater resources (like in coastal areas of Lagos, Port-Harcourt etc.); biological contaminants through pit latrine and septic tank discharge (like in many shallow dug-well of urban centres in Nigeria); oil and petroleum products contamination through spillage and pipeline vandalisation (like in the Niger Delta region) among others.

Also, groundwater, as a natural solvent, is capable of dissolving other substances, and when passing through the aquifers, it usually undergoes geogenic/natural changes (chemical and physical) through interactions with the minerals in the rocks. Thus, under certain geological situations, groundwater can also contain abnormal concentrations of dissolved constituents like arsenic, cadmium, lead, mercury and fluoride that are known to have serious health implications (Oniawa 2015). Therefore, careful characterisation of the groundwater resource is required to guide investments in water supply, manage the resource and prevent widespread depletion, as well as to minimise environmental degradation (Foster and Chilton 2003).

Water Resources and Water Supply Scenario in Nigeria

Of the estimated 800 million people in the Africa, more than 300 million live in water-scarce environment; 54% of the continent is arid to semi-arid, and only 14% is humid to very humid, with the remaining 31% having good rainfall (Rached, et al. 1996).

In Nigeria, there is temporal and spatial variation in water availability between the north (precipitation of 500 mm) and the south (precipitation over 3,000 mm) with mean annual rainfall of about 1,150 mm. Thus, Nigeria is abundantly blessed with water resources and well drained with a close network of rivers and streams which are delineated into hydrological basins (fig. 6). In addition, Nigeria has extensive groundwater resources, located in eight recognised hydrological areas together with local groundwater in shallow alluvial (fadama) aquifers adjacent to major rivers (table 4):

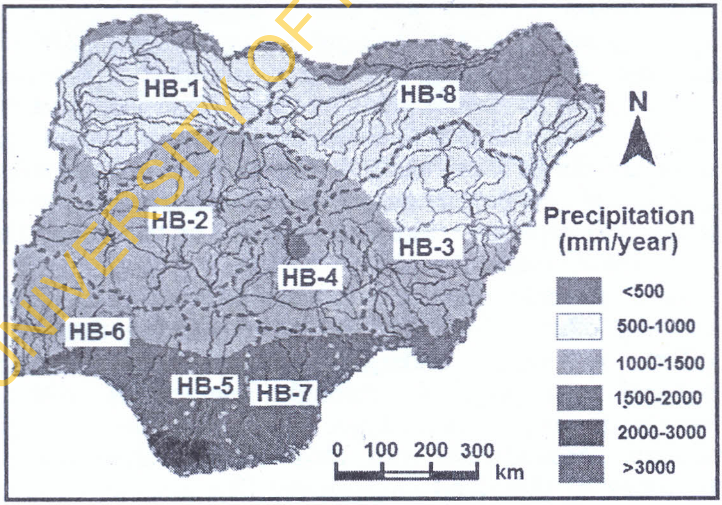


Fig. 6: Hydrological Basins in Nigeria and rainfall distribution pattern in Nigeria (modified after JICA Team 2014).

The total internal generation of the runoff in Nigeria is 244BCM/year while on the basis of the estimated groundwater recharge, the total groundwater resources potential is estimated at 142BCM/year on the basis of estimated groundwater recharge (JICA Team 2014). The question is that with these large volumes of both surface and groundwater potentials, *why is it that many Nigerians are still looking for potable water*?

Table 4: Surface and Groundwater Potentials of the Different Hydrological Basins

S/No	Hydrological Basin (HB)	Approx. Area (Km^2)	Av. Rainfall mm/yr	Av. GW-recharge mm/yr	SW-Potential bcm/yr	GW-Potential bcm/yr	GW yield (l/s)
1	Sokoto Basin (HB–1)	140,200	768	37.0	8.4	5.0	1.0 - 5.0
2	Middle Niger–N-Central Basin (HB–2)	156,500	1,170	132	31.7	20.5	0.7 - 5.0
3	Upper Benue (HB–3)	160,200	1,050	93	34.5	14.5	1.0 - 8.0
4	Middle Benue (HB–4)	74,000	1,341	196	31.0	14.6	1.0 - 8.0
5	Lower Niger–Anambra Basin (HB–5)	55,500	2,132	592	40.1	31.9	3.0 - 7.0
6	South–Western Littoral (HB–6)	101,200	1,541	236	35.6	23.4	1.0 - 3.0
7	Imo–Cross River Basin (HB–7)	58,200	2,106	486	55.8	27.9	1.0 - 4.0
8	Chad Basin (HB–8)	178,000	610	24	7.2	4.3	1.2 - 2.1
TOTAL		**923,800**	**1,148**	**156.0**	**244.3**	**142.1**	

Source: FMWR 2013; JICA Team 2014.

In July 2010, the UN General Assembly recognised the right of every human being to have access to sufficient water for personal and domestic uses (between 50 and 100 litres of water per person, per day), which must be safe, acceptable and affordable (water costs should not exceed three per cent of household income), and physically accessible with collection time not exceeding 30 minutes. Alas, according to Water and Sanitation Media Network (as reported in the *Punch*, 12 February, 2015), the Nigerian case is terrifying with:

35 million Nigerians still defecate in the open; about 90 million are without access to safe drinking water, and 130,000 under-five years' Nigerian children die annually from preventable water borne diseases.

A look at the water supply versus demand projections for 1996 to 2030 (table 5) reveals a total water supply deficit of 8,517.6 MLD as at 2015 while projected supply deficits of 10,820.5 MLD and 17,564.8 MLD are expected for 2020 and 2030 respectively.

Table 5: Rural and Urban Water Supply-Demand Projections in Nigeria (values in MLD = megalitre/day)

Year	Water Supply		Water Demand		Water Supply Deficit	
	Rural[a]	Urban[a]	Rural[b]	Urban[a]	Rural	Urban
1996	363.0	2593.5	1596.0	4905.9	-1233	-2312.4
2000	407.7	3212.2	1792.5	6074.0	-1385	-2866.8
2005	470.6	4199.4	2069.2	7947.3	-1599	-3747.9
2010	542.6	5488.4	2386.0	10386.6	-1843	-4898.2
2015	624.7	7166.1	2746.9	13561.7	-2122	-6395.6
2020	719.6	9386.0	3136.9	17762.8	-2444	8376.8
2025	829.0	12776.0	3645.1	23232.0	-2816	-10956.0
2030	956.7	16040.6	4206.5	30356.5	-3249	-14315.8

Source: Ojo, et al. 2004
Note: (a) Supply and demand of 51.2 litre/person/day for base year - 1996
(b) Demand of 98.6 litre/person/day for base year - 1996.

Therefore, with about 50% of the Nigerian populace in rural areas, there is no doubt that groundwater will contribute significantly to the projected total water demand of about 18,354.4 MLD for the period of 2015-2030. At the end of 2015, it was estimated that less than 34 percent of Nigerians had access to adequate sanitation (deficit of 29%) and about 60 percent had access to safe drinking water (deficit of 15%).

The question is *why this gloomy scenario?* despite a number of proactive measures and huge investments by the different governments over the years. For example, in January 2011, the Federal Government launched the so-called Water Road Map for developing the nation's water resources between 2011 and 2025.

The road-map was backed-up with special intervention funds with the promise that 75 percent of Nigerians would have access to potable water by 2015, and 90 percent by 2020. Included among the several intervention projects are drilling of motorised borehole in each of the 109 senatorial districts, rehabilitation of 1,000 dysfunctional hand pump boreholes in 18 states. This clearly underscores the understanding of the significant roles of groundwater in rural water supply. However, five years down the lane now, it is sad to observe today and in this 21st century, that many women and children in Oke-Ogun area of Oyo State, in Langtang area of Plateau State, in Yobe, Gombe, Zamfara, Ebonyi states and many other peri-urban and rural communities within the country still travel long distances in search of water. Therefore, with the intervention and the purported huge investments, the question once again is; *why is it that the situation about water and sanitation in Nigeria still remains gloomy?* I believe your guess is as good as mine: *Corruption!!!*

Of course, it is also possible to argue that the low and fluctuating budgetary allocations to water and sanitation sector might be a contributory factor. For example, in 2010, the Federal Government budgeted ₦112bn for water and sanitation, and this dropped to ₦62bn in 2011, while by 2012, the budget for water sector was only ₦39bn. There was an increase to ₦84.2bn in 2013, and it dropped to ₦38.4bn in 2014 and ₦13.9bn in 2015. The allocation of ₦44.2bn in 2016 is still a far cry investment if we are to meet the target of 90% access by 2020.

Contribution of Groundwater to Water Supply in Nigeria

> *Groundwater is not a non-renewable resource, such as a mineral or petroleum deposits, nor is it completely renewable in the same manner and timeframe as solar energy.*
>
> Alley, et al. (1999)

There is no doubt as to the fact that groundwater is widely used in Nigeria for domestic, agricultural and industrial purposes. For example, the cities of Calabar and Port Harcourt are totally dependent on groundwater, while rural areas are 95% dependent upon it. In 2006, the National Water Supply and Sanitation Baseline Survey (NWSSBS) of the Federal Ministry of Water Resources revealed a total number of about 38,000 boreholes, with a nationwide operating ratio of 54.3%. As at 2013, there were about 65,000 boreholes or other groundwater points in Nigeria (table 6), extracting an estimated total of 6.34 million m^3/day (JICA 2014; Federal Ministry of Water Resources 2013). Most are used for water supply in rural areas and for small towns.

The statistics in table 6, excluding thousands, if not millions, of un-accounted hand-dug-wells, underscore the significant contribution of groundwater to water supply in Nigeria. Nonetheless, the rather poor functional or operating ratio calls for technical capacity developments in borehole drilling and maintenance technology. This will ensure proper and sustainable exploitation of our huge groundwater resources.

Table 6: Summary of Distribution and Operating Ratio of Boreholes in Nigeria

Borehole Type	2006	2013
Boreholes (with motorized pump)	12,421	19,758
Functional/Operating ratio (%)	47.0	-
Boreholes (with hand pump)	25,470	44,736
Functional/Operating ratio (%)	57.9	-

Source: JICA 2014.

Perhaps to further highlight the significance of groundwater, let me refer to the results of the 2013 *NOIPolls* survey of drinking water sources in Nigerian homes (fig. 7). With a cumulative value of 38% for groundwater sources (private/ public wells and boreholes); the results clearly underscore the greater contribution of groundwater to household water supply.

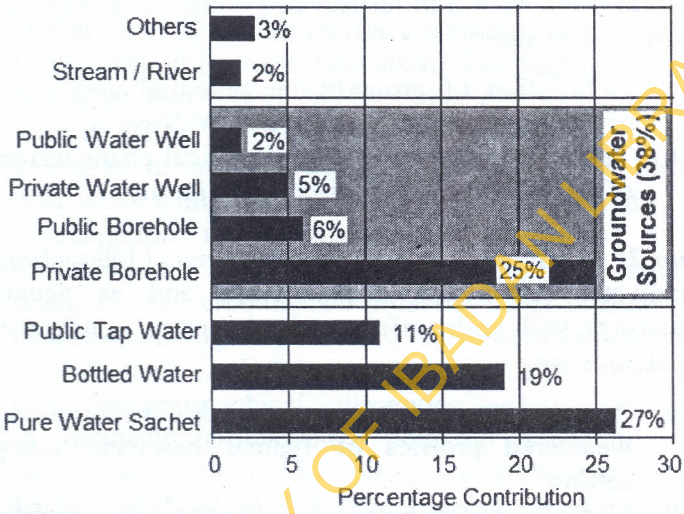


Fig. 7: Sources of drinking water in Nigerian households (Modified after *NOIPolls* 2013).

The contribution will definitely be much higher (possibly up to 60%) if we consider the fact that greater percentages of the sachet and bottled waters are also sourced from groundwater system. Mr. Vice-Chancellor Sir, I doubt if most of our children born here in Ibadan after 1980 (and of course in many other major towns and cities in Nigeria) ever experienced the so-called running tap water in homes or public places apart from dug-well and borehole waters. Unfortunate as this may be, it is still a pointer to the major roles of groundwater in sustaining water supply for greater percentage of the Nigerian populace.

My Contribution to the Understanding of Groundwater System

The focus of my hydrogeological and environmental research studies of groundwater system will be addressed under the following main groupings:

Group 1: Assessment of the diverse and complex nature of the subsurface geology (rock types, stratigraphy and structural frameworks) in respect of groundwater occurrence. Case studies include:

(a) Delineation of groundwater potential zones in the crystalline basement terrain of SW-Nigeria.
(b) Textural, hydraulic and geochemical characterization of Ajali Sandstone Aquifer, SE-Nigeria.

Group 2: Assessments of natural geochemical interactions of groundwater (as a universal solvent and as agent of weathering), with both surface and subsurface aquifer media. Case studies are:

(a) Assessment of lithogenic metal concentrations in weathered profiles of typical basement complex setting.
(b) Genesis, hydrochemical evolution and traditional processing techniques of saline groundwaters (brines) in the Benue-Trough, Nigeria.

Group 3: Assessment of the impacts of anthropogenic activities, modifying the natural geogenic quality of the groundwater system, including surface (water) drainage networks. Case studies include:

(a) Study of irrigation-induced contamination of soils and shallow groundwater system.
(b) Assessment of anthropogenic impacts on urban surface and groundwater qualities.

Group 4: Assessment of the impacts of climate change and climate variability on groundwater system. Case studies include:

(a) Assessments of groundwater resilience to climate change and climate variability.
(b) Assessment of impacts of Climate Change on Coastal Groundwater Quality

Delineation of Groundwater Potential Zones in the Crystalline Basement Terrain of SW-Nigeria

It is a known fact in geology that due to the complex and erratic nature of groundwater occurrences in crystalline basement terrains, its development in form of boreholes or drill-wells without the necessary pre-drilling hydrogeological investigations usually results in failure. There is the need, therefore, for adequate characterization of aquifers and delineation of groundwater potential zones in such crystalline basement setting. My research team employed the integration of multi-criteria decision analysis (MCDA), remote sensing (RS) and geographical information system (GIS) techniques to delineate groundwater potential zones in crystalline basement terrain of SW-Nigeria (Talabi and Tijani 2011; Fashae, et al. 2013). We integrated nine (9) different thematic layers (geology, rainfall, geomorphology, soil, drainage density, lineament density, land-use, slope and drainage proximity) based on weights assignment and normalization with respect to the relative contribution of the different themes to groundwater occurrence. The result revealed that the study area can be categorised into three different groundwater potential zones: high, medium and low (fig. 8).

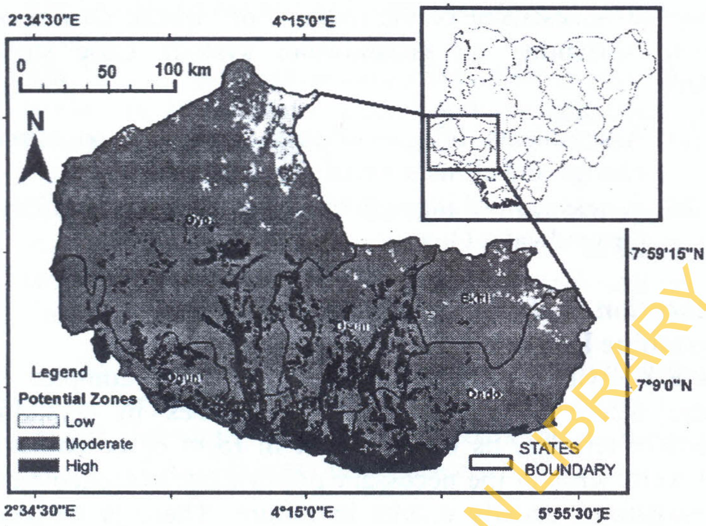


Fig. 8: Map of the potential groundwater zones of SW-Nigeria (Fashae, et al. 2013).

Greater portion of the study area (84,121.8 km^2), representing about 79.5 % of the total area, falls within the medium groundwater potential zone which is generally underlain by medium-porphyritic granite, biotite-hornblende granite and granite gneiss bedrock settings. About 18,239.7 km^2 (17.2 %) fall under high groundwater potential zone which is characterised by weathered/fractured quartzite, quartz-schist, amphibole-schist and phyllite bedrock settings. However, areas of low groundwater potentials constitute only 3.2 % (3,416.54 km^2) of the total study area and are mostly underlain by migmatite, banded and augen gneiss bedrock settings. Subsequent validation with boreholes/well yield data revealed a good correlation with respect to the observed groundwater potential zonation as presented in table 7.

Our findings clearly highlight the efficacy of the modern integrated MCDA, RS and GIS methods employed in terms of providing quick prospective guides for groundwater exploration and exploitation aimed at reducing incidence of abortive boreholes in the crystalline basement setting of SW-Nigeria.

Table 7: Delineated Groundwater Potential, Yield Class and Associated Bedrock Type

Potential zones	Area (km^2)	Yield Class (m^3/day)	Associated rock units
Low	3,416.54 (3.4%)	<75 (Low)	Migmatite, banded and augen gneiss
Moderate	84,121.75 (79.5%)	75-150 (Medium)	Weathered/fractured quartzite, quartz-schist, amphibolite and phyllitic schist.
High	18,239.71 (17.2%)	>150 (High)	Porphyritic granite, biotite-hornblende granite and granite gneiss

Textural, Hydraulic and Geochemical Characterization of Ajali Sandstone Aquifer, SE-Nigeria

Long-term sustainable management of groundwater resources, in terms of quantity and quality require reliable knowledge of textural and hydraulic characteristics of the aquifer with respect to groundwater flow/storage (Uma, et al. 1989) and natural geogenic/geochemical interactions between the aquifer matrix and groundwater (Tijani, et al. 2009).

In this respect, our research team (Tijani and Nton 2009; Tijani, et al. 2009), conducted textural-hydraulic characterisation of the regional aquiferous Ajali Sandstone, SE-Nigeria. Field traverse of the outcrops at Agenebode - Fugar area in the west extending eastward to Ankpa, Anyigba, Otukpa axis and to Nsukka-Enugu-Udi escarpment and then southwards to Uturu-Okigwe area formed a typical "question mark" shape (fig. 9). Ajali Sandstone aquifer is a Maastrichtian sandy unit which consists of white, thick friable, poorly sorted, cross-bedded sands and characterised by the occurrence of deep and thick semi-confined to confined aquifer system (Tijani and Nton 2009).

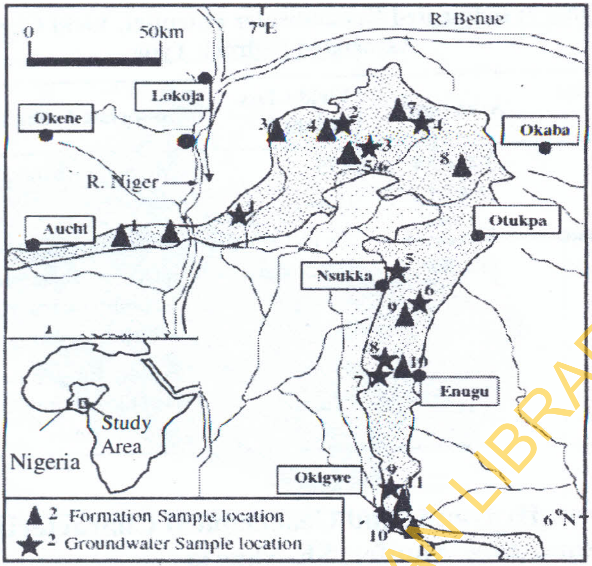


Fig. 9: Outcrop Map of Ajali Sandstone, Anambra Basin, SE-Nigeria, with sample locations for rock units and groundwater.

The results of sieve analyses, evaluated textural parameters and hydraulic permeability tests indicate that the Ajali aquifer is well sorted, fine to medium grained sands, with minor amounts of silt (fig. 10). These are indications of high aquiferous potentials of the Ajali Sandstone aquifer in terms of the groundwater occurrence.

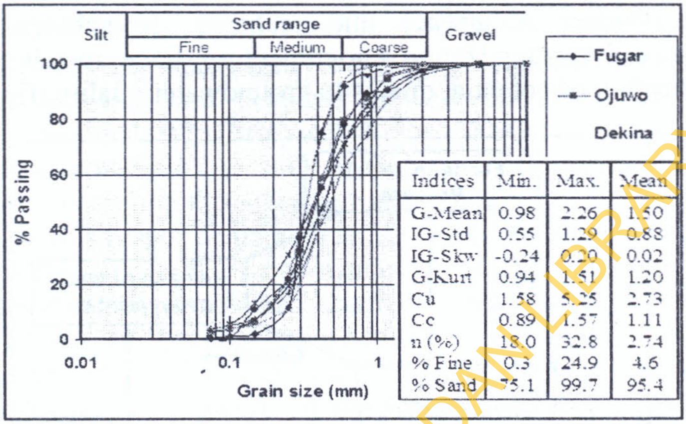
Our studies point out that the friable and permeable characters of the Ajali Sandstone are consequential to:

(a) environmental land degradation in form of damaging gully erosions in a number of the outcrop areas in southeast-Nigeria.

(b) lack of shallow groundwater system in many areas, due to complete vertical drainage of water to the deeper section of the Ajali Sandstone aquifer.

In addition, utilizing a geochemical approach, Tijani, et al. (2009) also assessed the geogenic ferruginization-induced trace metal enrichments and mobilization with respect to the groundwater quality of the Ajali Sandstone (table 8).

Evaluation of the results revealed higher values of chemical index of weathering (CIW) of 98.3–99.6 and Fe/Mg ratio of 81.3–98.7, for the ferruginized samples. There are clear indications of the weathering/ferruginization process.



Indices	Min.	Max.	Mean
G-Mean	0.98	2.26	1.50
IG-Std	0.55	1.29	0.88
IG-Skw	-0.24	0.20	0.02
G-Kurt	0.94	1.51	1.20
Cu	1.58	5.25	2.73
Cc	0.89	1.57	1.11
n (%)	18.0	32.8	2.74
% Fine	0.3	24.9	4.6
% Sand	75.1	99.7	95.4

Fig. 10: Grain size distribution and textural characteristics of Ajali sandstone aquifer, SE-Nigeria.

Table 8: Distribution of Trace Metals in Fresh and Weathered Ajali Sandstone Units

Sample	Status	Cu	Pb	Zn	Ni	Co	Cr	Rb
AJSt-01	Fresh	0.01	2.1	4.4	2.3	0.01	5.5	1.2
AJSt-04a	Fresh	0.01	3.1	4.1	3.7	0.62	11.1	62.1
AJSt-05a	Fresh	0.68	4.4	3.9	1.5	0.66	11.9	1.6
AJSt-06a	Fresh	0.01	3.4	6.8	2.3	0.01	12.0	1.4
AJSt-09a	Fresh	0.01	3.5	3.1	3.2	0.17	12.8	123
AJSt-10a	Fresh	0.01	2.1	2.7	2.1	0.01	5.1	51.5
AJSt-12	Fresh	1.16	2.7	5.7	2.6	0.08	7.6	0.7
AJSt-07	Ferrug.	***3.64***	***13.3***	***12.5***	***10.2***	***1.97***	***52.4***	4.1
AJSt-11a	Ferrug.	***3.07***	***8.0***	***7.2***	***5.4***	***0.78***	***18.0***	3.4
AJSt-14a	Ferrug.	***3.73***	***15.6***	***15.2***	***12.4***	***2.79***	***58.5***	3.6

To further highlight the impacts of the secondary weathering-ferruginisation process, summary of the analysed trace metal (table 8) revealed 2–5 folds concentrations of the trace metals, (Cu, Pb, Zn, Cr, Co, and Ni) for the ferruginised units compared to the fresh Ajali sandstone units. This is also consistent with the estimated normalized enrichment factor (EF) of 1.01–50.24 for Fe, Mn, Co and Cr in the ferruginised Ajali Sandstone units. Therefore, our study concluded that textural hydraulic characteristics exert positive impacts on groundwater occurrence and recharge. Nonetheless, the observed ferruginization enrichment of trace metals is an indication of potential threats to groundwater quality (fig. 11).

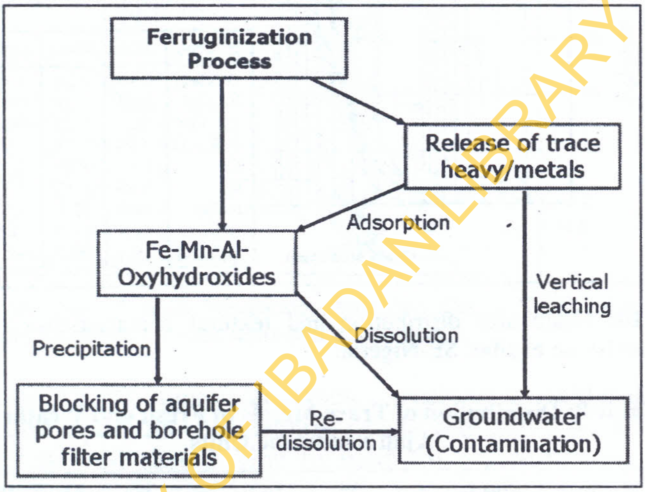


Fig. 11: Ferruginization induced mobilization of trace metals and groundwater contamination and aquifer encrustation problem.

The geochemical profiles of the ferruginised Ajali Sandstone suggest weathering–induced enrichment of contaminant trace metals. The environmental implication is that such geochemical processes will constitute potential aquifer management problems (fig. 11) in terms of:

(a) water quality deterioration, through leaching/ mobilization of metals into the groundwater system and
(b) borehole deterioration, through encrustation/ clogging of the effective interstitial pore spaces and/ or filter packs.

Assessment of Lithogenic Metal Concentrations in Weathered Profiles of typical Basement Complex Setting

Rock weathering and soil formation are important geological processes associated with lithogenic release of trace metals into the environment (Sharma and Rajamani 2000; Zhang, et al. 2002; Bruand 2002). The release of trace metals associated with such geo-pedological weathering processes could have both positive and negative impacts on the environment (Fergusson 1990; Price and Velbel 2003) as a source of essential nutrients in soils and as an input source of toxic trace metals into the ecosystem respectively.

In this respect, Tijani, et al. (2006) assessed the lithogenic concentrations of trace metals in soils and weathered saprolites over selected bedrock units (schist-quartzite, pegmatite and granite-gneiss) within Ibadan metropolis, SW-Nigeria (fig. 12). The intent was to assess the natural geogenic trace metals release under different bedrocks consequent to geo-pedological weathering processes using geochemical approach.

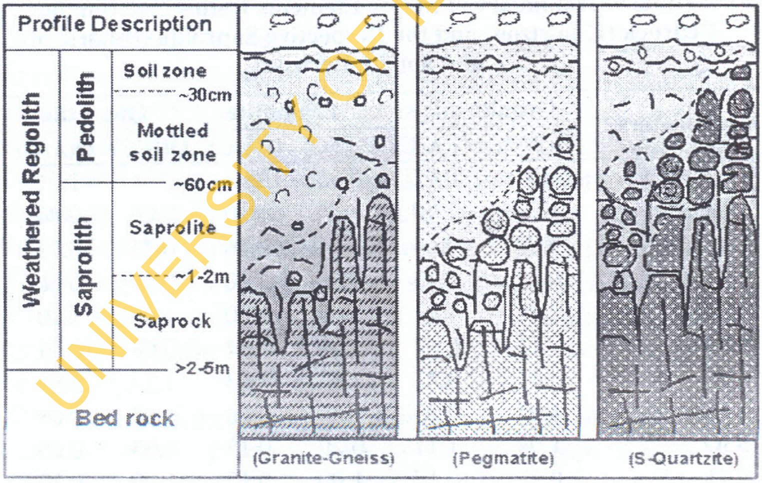


Fig. 12: Diagramatic sketches of the study representative weathered profiles over the different bedrock types.

The concentrations of elements in the soil and weathered saprolite samples were correlated to the respective elemental composition of the underlying parent bedrock units. Our data evaluation involved:

(a) estimation of the metal loss/enrichment from the weathered units with respect to the parent bedrocks.
(b) estimation of the metal mobilization into the shallow groundwater and surface water within the catchment area of Ibadan metropolis.

The ratios of the major elements of the sampled weathered profiles revealed higher metal enrichments in the intermediate saprolite horizons compared to the upper topsoil zones (table 9a), a situation that was attributed to vertical translocation, by leaching process. Nonetheless, the trace metal distribution shows similar patterns and positive correlations for the weathered units and the respective fresh parent rocks for the three bedrock types (table 9b).

Table 9a: Summary of Major Elements Ratios between the Bedrock (C-horizon) and the Respective Saprolite (B-horizon) and Soil (A-horizon)

Parameters	Granite-gneiss		Pegmatite		Quartzite	
	G(B/C)	G(A/C)	P(B/C)	P(A/C)	Q(B/C)	Q(A/C)
SiO_2	0.95	0.92	0.95	0.94	0.91	1.01
Al_2O_3	1.27	1.40	1.06	1.10	0.66	0.84
Fe_2O_3	0.99	0.64	2.14	2.16	0.73	0.71
TiO_2	0.88	0.73	3.60	3.90	0.61	0.66
MnO	2.11	1.11	1.00	1.00	1.00	1.00
MgO	1.11	0.67	4.71	7.07	0.63	0.74
CaO	0.41	0.41	2.83	4.63	1.23	5.87
Na_2O	1.04	0.73	1.55	0.86	1.18	0.88
K_2O	1.04	1.17	0.29	0.13	1.03	0.65
P_2O_5	0.33	0.17	1.00	0.12	1.00	0.36

G = Granite-gneiss, P = Pegmatite, Q = Quartzite, C = Bedrock, B = Saprolite zone, A = Weathered soil zone/pedolith.

Table 9b: Summary of Trace Metals Ratios between the Bedrock (C-horizon) and the Respective Saprolite (B-horizon) and Soil (A-horizon)

Parameters	Granite-gneiss		Pegmatite		Quartzite	
	G(B/C)	G(A/C)	P(B/C)	P(A/C)	Q(B/C)	Q(A/C)
Mn	2.11	1.11	1.00	1.00	1.00	1.00
Cu	0.63	0.26	2.24	0.44	0.91	0.83
Pb	1.23	1.19	0.58	0.45	0.89	0.67
Zn	0.91	0.62	2.20	2.21	0.86	0.86
Ni	4.79	6.85	1.31	3.10	0.80	0.90
Cr	1.95	0.92	1.13	2.00	0.95	1.13
Co	4.80	3.05	1.23	2.26	0.69	1.01
V	1.51	1.28	1.77	2.67	0.62	0.81
Rb	1.22	1.02	0.34	0.21	0.99	0.97
Sr	0.98	1.11	0.99	1.04	0.87	0.57
Ba	0.98	1.46	0.31	0.58	1.21	0.15
Zr	0.79	0.42	0.88	0.37	0.93	0.50

G = Granite-gneiss, P = Pegmatite, Q = Quartzite while appendages, C = Bedrock, B = Saprolite zone, A = Weathered soil zone/pedolith.

The distribution patterns of the major elements as observed are reflections of the compositional changes during chemical weathering with resultant lithogenic (natural) release and enrichment of elements within the weathered saprolite unit (Tijani, et al. 2006). The implication in terms of groundwater quality is that such processes are usually characterised by progressive loss of the alkalis (CaO, MgO, Na_2O and K_2O) and enrichment of sesquioxides (Al_2O_3, TiO_2, FeO and MnO) and simultaneous release/enrichment of the associated trace elements depending on the lithology of the parent rocks.

Overall assessment revealed that weathering and leaching/ erosion constitute a major source of metal inputs into the environment. However, direct effects of rock weathering and metal mobility are usually reflected in the composition of soils and surface water (Taylor and Eggleton 2001). Depending on the climatic condition, such effects can easily extend to the groundwater systems through leaching by percolating/recharging water as highlighted in figure 13.

In summary, it can be inferred that weathering-induced release of metals and subsequent re-distribution or mobilisation by other pedogenic leaching/dissolution processes are responsible for mobilization of contaminant trace metals in surface water and shallow groundwater systems (fig. 13) as it is the case for the bedrock settings of Ibadan metropolis, even at a low degree of chemical weathering. The environmental significance of this study emphasizes the fact that proper understanding of natural geogenic controls on mobility and background distribution of trace metals will serve as a yardstick for assessment of the possible (future) anthropogenic inputs into surface and shallow groundwater systems.

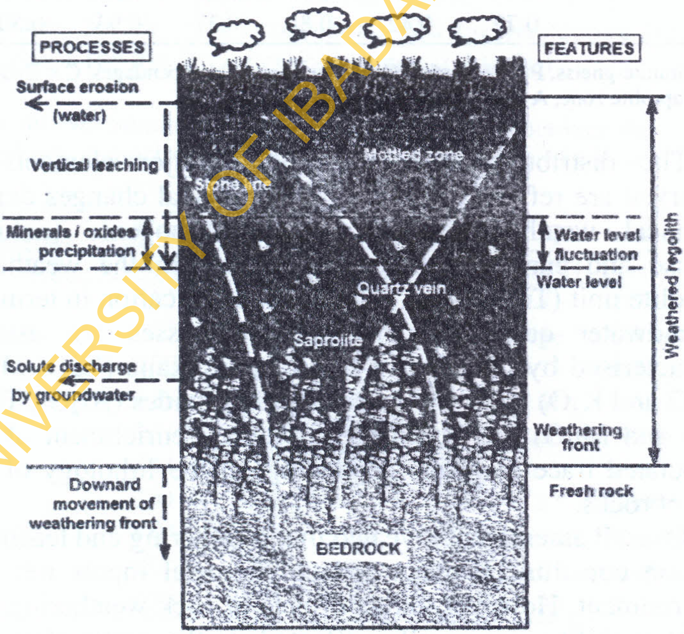


Fig. 13: A conceptual representation of geo-pedological processes controlling the release of trace metals within a typical weathering profile under tropical humid climatic conditions (modified after Taylor and Eggleton 2001).

Genesis, Hydrochemical Evolution and Traditional Processing Techniques of Saline Groundwaters (brines) in the Benue-Trough, Nigeria

Have you considered the water which you drink?
Is it you that send it down from the clouds or We?
If We wanted, We can make it salty (and bitter).......

(*The Holy Quran*; Chapter 56, Verses 68-70).

The evolution of subsurface brines in sedimentary basins, especially in relation to the source of primary salinity, has always been a widely debated topic, most especially in geological settings related to marine or non-marine evaporite deposits (Uma and Loehnert 1992; Tijani 2004; Tijani and Loehnert 2004). Apart from chemical characterisation of the brines, the critical issue has always been the genesis of primary salinity especially in many geological settings where the occurrences of the brines cannot be directly associated with any evaporite deposit (marine or non-marine).

Mr. Vice-Chancellor Sir, it was on the basis of above premise that we undertook a series of both field and laboratory studies between 1994 and 1997 in respect of hydrochemical and isotopic evolution of saline groundwaters and brines in the Benue-Trough of Nigeria (fig. 14) with emphasis on:

(a) genetic source of the primary salinity of the saline groundwaters and brines.
(b) possible hydrochemical evolution processes responsible for the observed chemical characters.

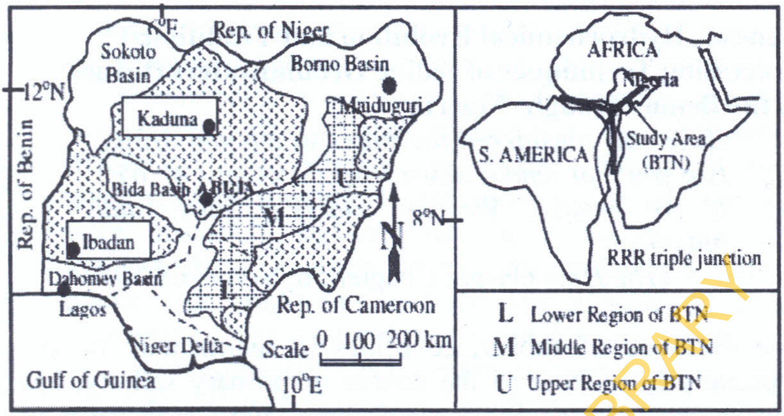


Fig. 14: Location and geologic setting of the Benue-Trough, Nigeria.

Depending on the local geologic settings, the brines occur as saline springs or salt ponds (where the fractures intercept the surface) or as subsurface brines as dug-holes or shafts (Tijani 1997; Tijani, et al. 1996; Tijani 2004; Tijani and Loehnert 2004). The hydrochemical results including ionic ratios calculated with respect to seawater (table 10) revealed that the saline groundwaters are predominantly Na–Cl type, with Na and Cl representing about 75% and 85%, respectively, of the total cations and anions in both regions of the Benue-Trough.

Furthermore, the enrichment of Ca and Sr and depletion of Mg and SO_4 as revealed by the data suggested a marine source and hydrochemical evolution controlled not only by the chemistry of the original (initial) source-fluid but also to some extent by water–rock interactions. Also, hydrochemical assessments using ionic ratios with respect to seawater and Na–Cl–Br relationships revealed a strong linkage between fossil (Cretaceous) seawater and dissolution of disseminated/ intergranular halite as the primary source of salinity for the brines in the Benue-Trough (fig. 15).

Table 10: Summary of the Results of Hydrochemical Analyses and Seawater Data

Parameters	Lower Region		Middle Region		Sea-water*
	Range	Mean	Range	Mean	
Temp.°C	21.0- 32.5	28.3	22.6 - 43.7	34.0	
pH	4.9- 8.0	6.7	5.8 - 8.95	6.8	
EC uS/cm	7900 - 115000	56319	10100 - 72000	22242	
Ca^{2+}	41.6 - 4439.0	1407.4	54.4 - 1465	304.5	400
Mg^{2+}	12.0 - 502.0	144.1	17.9 - 137.2	56.0	1,350
Na^{+}	1,429 - 29,072	12951.3	1,999 - 17,311	4854.1	10,500
K^{+}	20.4 - 778.0	305.7	55.2 - 761	170.8	380
Ba^{2+}	0.9 - 353.6	125.7	1.0 - 97.6	28.1	
Sr^{2+}	4.1 - 495.8	153.2	5.9 - 465.4	36.5	8.0
HCO_3^-	0.0 - 605.7	250.7	38.4 - 696.6	448.1	
Cl^-	2152 - 57688	22773	2340 - 26400	7640	19,000
SO_4^{2-}	0.0 - 910.0	245.0	5.4 - 335	45.6	2,700
Br^-	1.0 - 33.1	13.2	1.0 - 13.8	4.7	64.6
Na/Cl	0.630 - 1.687	0.916	0.747 - 1.723	1.048	0.853
Ca/Cl	0.028 - 0.180	0.108	0.040 - 0.148	0.069	0.037
Mg/Cl	0.005 - 0.077	0.021	0.014 - 0.035	0.022	0.210
Mg/Ca	0.130 - 0.077	0.190	0.156 - 0.544	0.343	5.533
Sr/Cl	0.001 - 0.008	0.005	0.001 - 0.007	0.003	0.0001
Cl /Br	1,377 - 9,852	4,792	2,194 - 7,199	4,479	500

* Data source, Collins 1975

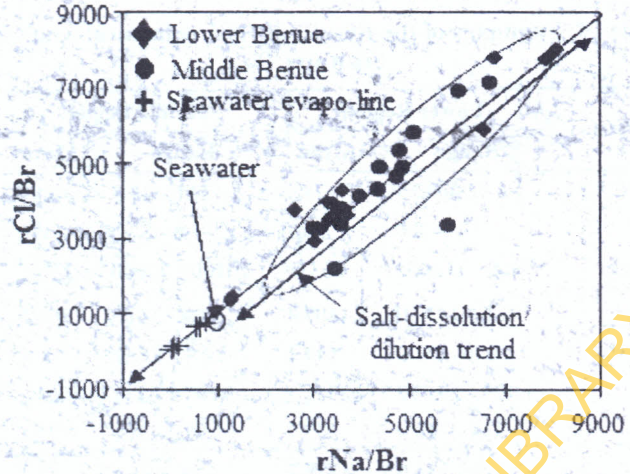


Fig. 15: Na/Br versus rCl/Br indicting salt dissolution trend.

Based on further data evaluation using complementary isotopes data, startigraphic analyses, the study concluded as follows:

(a) the original brines and/or saline groundwaters were initially confined to the marine Albian–Cenomanian units in the depth range of about 3000–5500 m below the ground surface.

(b) Compaction created by the overlying Turonian–Coniacian units (about 2000 m thick) was responsible for the early diagenetic modification of the original marine characteristics of the brine.

(c) Subsequent compressional folding and fracturing during the Santonian was responsible for upward migration and in-flow (through the fracture systems) into the overlying Turonian–Coniacian units (as springs, or salt ponds or in dug-holes or shafts).

In summary, the original source-fluid that resulted in the present-day saline groundwaters (brines) originated as connate Cretaceous seawater entrapped syngenetically during sedimentation in the Trough. However, water-rock interactions (involving cation exchange with clay minerals, dolomitization of limestone, among others) during subsequent diagenetic compaction were responsible for the prevalent chemical characteristics and salinity.

Furthermore, the socio-economic impacts of these saline water occurrences in some of the villages within the Benue Trough were also investigated, especially as they affect the livelihood of the womenfolk (Tijani 1997; Tijani and Loehnert 2004). We investigated the age-long exploitation and local processing techniques of edible brine salt productions in some of the rural communities in Ogoja (Olachor-Abachor) area in the Lower region and Lafia (Azara-Awe-Keana) area, in the Middle region of the Benue-Trough (fig. 16).

The flowchart of the stages of brine salt local processing techniques (fig. 17) and photographic images of the processing stages (fig. 18) are clear demonstrations of application of ingenious local or indigenous knowledge by the rural community to harness the brines.

The study recommended improvement of the existing traditional production techniques within the frameworks of the socio-economic and literacy background of the women-folk. We were careful not to recommend complete modernization of the processing techniques; a situation that would affect the means of livelihood of the rural women and thus create social imbalance within the associated communities. In addition, considering the environmental implication of the firewood employed as energy source for the evaporative boiling of the brine, in terms of deforestation, our study recommended that a form of locally manufactured vacuum or pressure boiler be employed. Such boiler is expected to use coal briquettes or solar powered and thus safe time, in terms of energy efficiency and also protects the environment by curtailing deforestation.

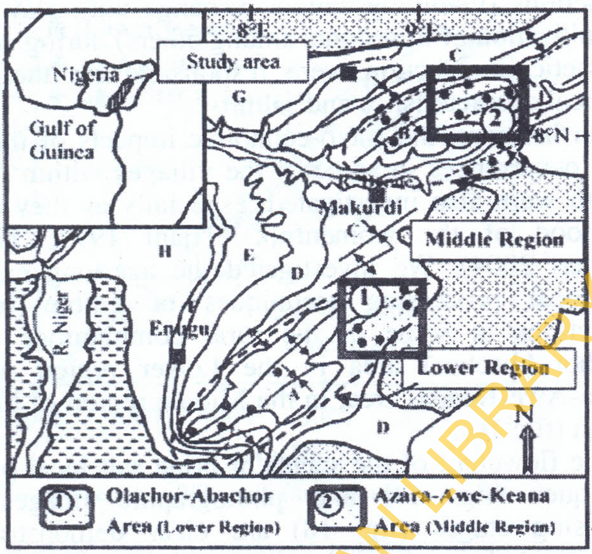


Fig. 16: Location of brines salt productions in the Benue-Trough, Nigeria (modified after Tijani and Loehnert 2004).

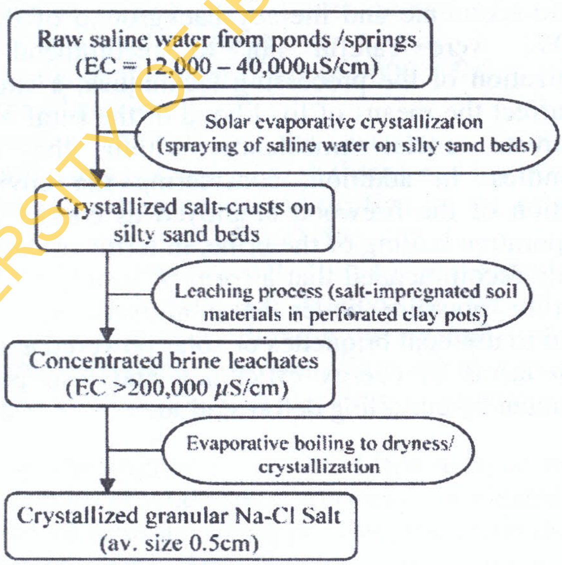


Fig. 17: Flowchart of local salt production techniques.

Fig. 18: Photographic images of local salt production techniques in parts of Benue-Trough, Nigeria.

Mr. Vice-Chancellor Sir, worthy of note here is the social arrangement of orderly and equitable access to the saline groundwater (brines) among the womenfolk without any squabbles over real ownership. This is a case of how natural resources could be used as means of community cohesion rather than an instrument of discord under the quest for resource control.

Study of Irrigation-induced Contamination of Soils and Shallow Groundwater System

In addition to the natural geogenic weathering-pedological (geogenic) constraints on groundwater quality as highlighted in the earlier case studies, anthropogenic sources through agricultural practices also significantly account for elevated trace metals, concentrations in soils and shallow groundwater systems (Singh, et al. 2004; Mapanda, et al. 2005; Tijani 2009). The drivers of such anthropogenic contaminations under irrigated agricultural fields are related to:

- Increasing population and the need to increase food production through applications of fertilizers, sewage sludge/biosolids and other related soil amendments.
- Increasing use of contaminated surface water and treated/untreated wastewater as irrigation water sources.

In other words, under agricultural fields, soils are not medium for plants growth only, but can also serve as contaminant metals transfer between soils, plants, surface and groundwater systems (fig. 19).

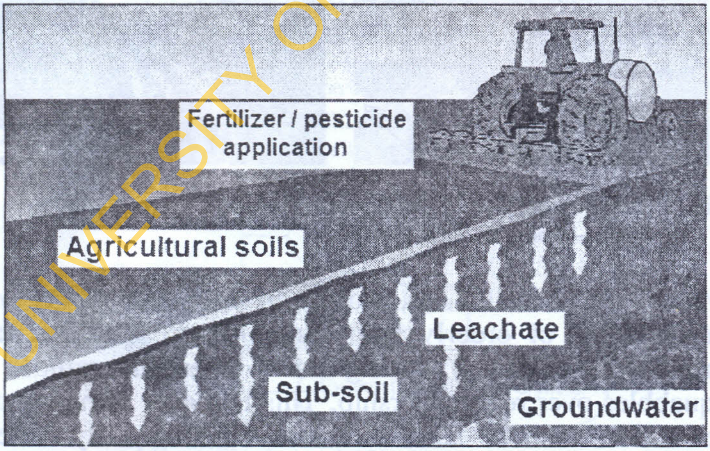


Fig. 19: Infiltration or irrigation-induced vertical leaching soil amendment/fertilizers and pesticides under amended agricultural fields (modified after Loynachan, et al. 1999).

It was on this basis that we conducted a pilot experimental (greenhouse) study of organo-mineral amended test plots/troughs (40cm x 47cm x 46cm) planted with two common vegetable crops (*Amaranthus hybridus and Abelmoschus esculentus*) and irrigated with waste water (Tijani and Agakwu 2008; Tijani 2009) (fig. 20). The study aimed at among others:

(a) the possible enrichment and accumulation of organo-mineral fertilizer in the irrigated agricultural soils, and
(b) the potential impacts of irrigation-induced infiltration and leaching of contaminant trace metals on the quality of shallow groundwater systems.

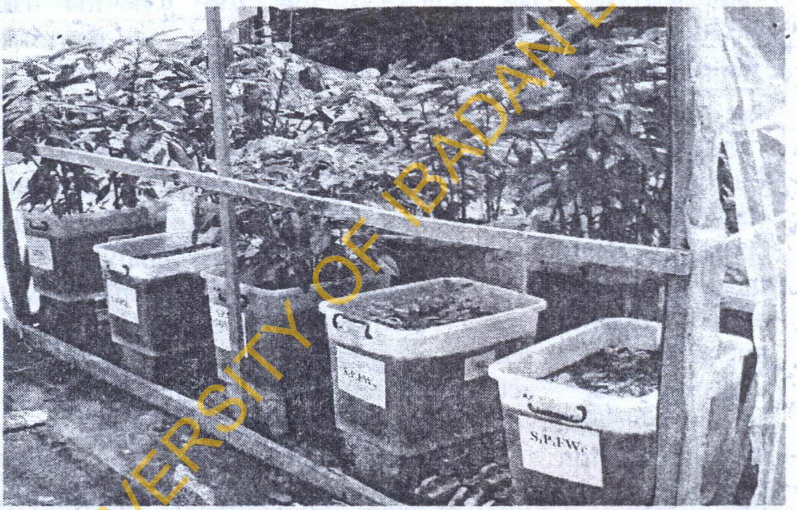


Fig. 20: The set-up of the experimental pilot green house.

As presented in table 11, our results revealed increase in concentrations of some analysed trace metals (Cu, Pb, Zn, Mo, and Cd) in the organo-mineral amended soils compared to the initial un-amended control soil. However, a comparison between the initial amended soils and residual soils (after harvesting) showed a depletion of about 20–40% with respect to Cd, Cu, Pb, Mo, and Zn in the residual fallow soils. Such depletion represents the proportion taken up by plants and/or possibly leached by irrigation water to the underlying shallow groundwater system.

Table 11: Trace Metals Concentrations (mg/kg) and Contamination Indices for Soil Media and Vegetable Crops

Elements	Cu	Pb	Zn	Cr	Co	Ni	Mo	Cd
Virgin Soil	12.9	12.2	24.6	21.2	14.2	13.9	0.28	0.05
Organo-mineral	212	36	315	22.7	4.3	8.8	1.2	0.24
Amended Soil	20	16.7	51.1	20.6	12.4	11.7	0.48	0.07
Enrichment factor	1.6	1.4	2.1	0.97	0.87	0.84	1.7	1.4
RS-*Amaranthus*	13.9	14.2	30.7	20.8	13.5	12.7	0.32	0.05
Enrichment factor	1.08	1.16	1.25	0.98	0.95	0.91	1.14	1.00
RS-*Abelmoschus*	13.0	13.9	28.7	19.4	13.3	12.7	0.32	0.06
Enrichment factor	1.0	1.14	1.17	0.92	0.94	0.91	1.13	1.20

RS = residual fallow soil (after harvesting).

Furthermore, the results of the hydrochemical studies (table 12) on irrigation leachate samples (collected during the sprouting stage) revealed that most of the analysed trace metals exhibited 2–10 folds depletion (except Cu and Co with enrichment of about 1.5 – 3 folds) compared to the initial input wastewater used for irrigation. This was attributed to interplay of active uptake/bioaccumulation during sprouting/vegetative stage and possible selective enrichment and attenuation in the soil column during percolation. However, higher concentrations of trace elements in the leachate samples collected during harvesting stage compared to that of the sprouting/vegetative stage (table 12) are indications of active vertical leaching and mobilization of the residual organo-mineral amendment by infiltrating irrigation water.

Further data evaluation using enrichment factor (EF) indicated depletion or no contamination with respect to Pb, Zn, Mo, Ni and Cd in the leachates despite the observed enrichment in the amended soils (fig. 21). Such depletion is clearly indicative of uptake by the test vegetable plants (*A. hybridus* and *A. esculentus*) and enrichment in the soil column (after harvesting).

Table 12: Trace Metals Concentrations (µg/l) and Contamination Indices for Irrigation Water and Leachates

Elements [a]	Cu	Pb	Zn	Cr	Co	Ni	Mo	Cd	TDS
Irrigation Water	<2	70	2470	20	<2	37	<5	2.0	567
L1 (*Amaranthus*)	6.0	<10	66	<20	3.0	13	<5	<2	1,073
EF (Leachate-1)	3.0	0.7	0.03	1.0	1.5	0.35	1.0	1.0	
L1 (*Abelmoschus*)	6.0	<10	244	<20	2.0	14	<5	<2	1,969
EF (Leachate-1)	3.0	0.7	0.09	1.0	1.0	0.38	1.0	1.0	
Control Leachate	<2	<10	63	<20	3.0	<5	<5	<2	1,177
EF-control	1.0	0.7	0.03	1.0	1.5	0.1	1.0	1.0	
L2 (*Amaranthus*)	11	<10	59	<20	6.0	34	<5	<2	3,707
EF (Leachate-2)	5.5	0.7	0.02	1.0	3.0	0.92	1.0	1.0	
L2 (*Abelmoschus*)	13	<10	105	<20	5.0	37	<5	<2	3,693
EF (Leachate-2)	6.5	0.7	0.04	1.0	2.5	1.0	1.0	1.0	
Control Leachate	7.0	<10	21	<20	4.0	7.0	<5	<2	402
EF-control	3.5	0.7	0.01	1.0	2.0	0.2	1.0	1.0	
IWQ-Criteria [b]	200	500	2000	100	-	200	10	100	<1000

[a] L1 = leachate at vegetative stage; L2 = leachate at harvesting stage.
[b] IWQ = Irrigation water quality criteria (*Source*: Pescod 1992).

The implication is that there is high possibility that such metals enriched fallow soils may act as sources of shallow groundwater contamination, under agricultural fields, through rain-induced leaching of residual trace metals, even long after harvesting. A reality of this possibility is reflected by low total dissolved solids (TDS) of 402–780 mg/l for leachates from the control (freshwater irrigation) compared to TDS >1,000–3,700 mg/l for leachates under wastewater irrigation.

This study clearly demonstrated the obvious environmental impacts of organo-mineral amendments in terms of enrichment of trace metals in soils and possible contamination of shallow groundwater system through irrigation-induced vertical leaching. *These, however, do not necessarily imply a correlative increase of trace metals concentrations in plants.*

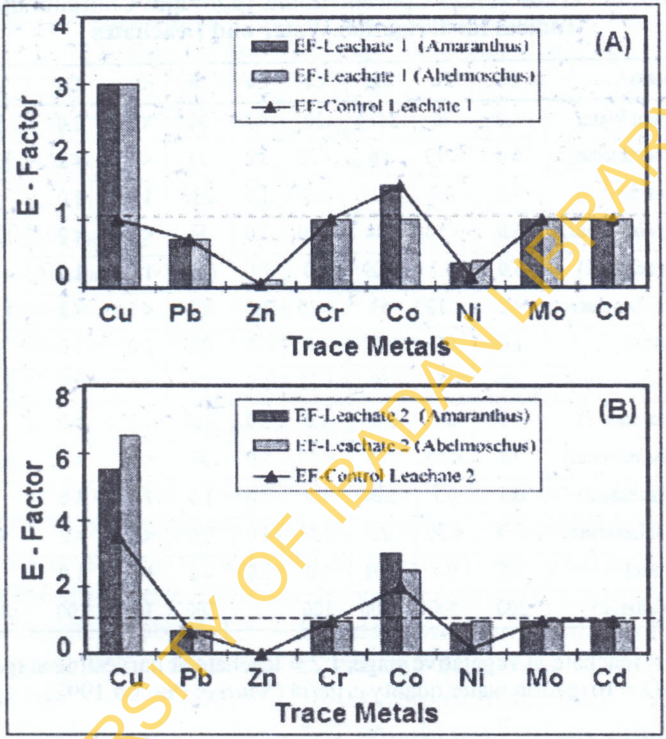


Fig. 21: Enrichment profiles of trace metals in the leachates during (a) sprouting/vegetative stage; (b) harvesting/maturity stage.

Mr. Vice-Chancellor Sir, I wish to stress here that our quest for food security as a nation, in the face climate change impacts on rainfed-agriculture, will greatly depend on groundwater-based irrigation by the small and medium scale farm-holders as revealed in our collaborative studies with the International Water Management Institute (IWMI), Colombo, Sri Lanka (Tijani, et al. 2011; Tijani, et al. 2015). In summary, our study underscores:

(a) the need to evolve sustainable agricultural and irrigation water management practices that will ensure adequate measure of amendments with permissible trace metals concentrations for crop production,
(b) the need for regulation and enforcement of the chemical quality standards for irrigation wastewater (treated and untreated) as part of our wastewater management policy in Nigeria.

Assessment of Anthropogenic Impacts on Urban Surface and Groundwater Qualities

In most developing countries, like Nigeria, surface and groundwater contaminations are mostly related to the consequences of population growth, urbanization, agricultural activities and development of new industrial zones (Olade 1987; Koudio and Trefry 1987; Mogollon, et al. 1996). In the last three to four decades, population increase due to rural-urban migration, poor land-use plan, and lack of proper waste disposal practices characterised most of the big cities and urban centres in Nigeria leading to the so-called "human and traffic jams" in cities like Lagos, Kano, Kaduna, and Port-Harcourt (Tijani and Onodera 2004; Tijani, et al. 2004). Coupled with low public awareness in terms of environmental health, this has led to systematic degradation of environment, especially the drainage networks in urban centres.

Consequently, between 2003 and 2008, we undertook series of hydrogeochemical assessments of groundwater and urban drainage systems (including bottom sediments) within major urban centres in south-western Nigeria notably, Ibadan metropolis, Abeokuta and Osogbo township among others (Tijani and Onodera 2005; Tijani, et al. 2006; Tijani and Onodera 2009). The intent was to highlight the impacts of urbanized anthropogenic activities on shallow groundwater systems, surface water and bottom sediments of the drainage networks.

In Ibadan metropolis, SW-Nigeria (fig. 22) like many urban centres in Nigeria (Tijani, et al. 2004), direct discharge of sewage water and dumping of domestic wastes/refuse into the drainage channels like Ogunpa and other streams are common practices (fig. 23).

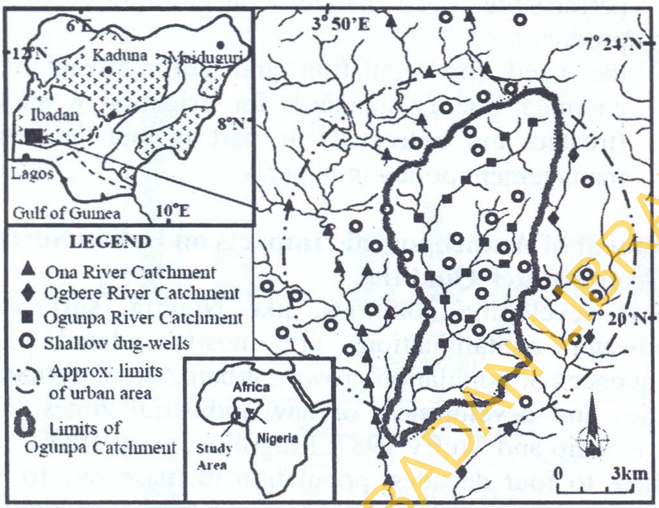


Fig. 22: Map of Ibadan metropolis showing the drainage networks and sampling points for both surface and groundwaters.

Fig. 23: Examples of waste/refuse dumps into the drainage channels within Ibadan metropolis.

For the shallow groundwater system, the chemical analyses results revealed that the concentrations of the major ions within Ibadan metropolis are within the WHO limits with the exception of NO_3 as the main critical quality index (table 13). It was observed that shallow dug-wells (of less than 5 m deep) have NO_3 of more than 15 mg/l out of which about 50% have NO_3 of greater than 50 mg/l; above the WHO (1998) recommended limit for drinking water.

Table 13: Summary of the Hydrochemical Data for Surface and Groundwater Systems (values in mg/l, unless otherwise stated)

Parameters	Groundwater		Surface Water		WHO Standard
	Range	Mean	Range	Mean	
Temp.°C	27.0-30.5	28.7	25.7-37.4	30.5	Variable
pH	5.9-8.3	7.4	5.9-8.9	7.4	6.5-9.5
EC uS/cm	105-1679	586.7	164-1878	821	400-1480
TDS	66-1063	373.5	103-1188	5167	500.100
Ca^{2+}	0.8-132.0	23.9	2.0-72.6	30.9	75-200
Mg^{2+}	0.8-41.1	15.0	2.0-31.1	14.7	50-150
Na^{+}	6.2-204.4	41.2	17.8-383.4	92.1	20-200
K^{+}	0.5-86.4	16.4	17.8-178.5	41.9	10-12
Fe^{2+}	0.01-4.4	0.37	0.03-23.9	1.8	0.3-1.0
HCO_3^-	34.0-100.0	65.3	38.0-118.0	67.1	Variable
Cl^-	21.0-84.0	49.2	25.0-150.0	74.8	250-600
SO_4^{2-}	13.0-45.0	29.9	10.0-49.0	29. 3	250-400
NO_3^-	17.2-412.0	112.3	22.8-366.0	104.3	25-50

In general, nitrate concentrations of 17.2 to 412mg/l (av. 112.3mg/l) are clear indications of shallow groundwater contamination. Our field observations revealed that NO_3 contaminations in the dug-wells are related to inputs of leachates from household septic tanks and pit latrines. This is also consistent with variable electrical conductivity (EC) of 100 - 2000 μS/cm for shallow dug-wells (fig. 24a) compared to relatively deeper wells (>5–14 m) that are characterized by low EC and low NO_3 (fig. 24b). Thus, deeper dug-wells tapping saprock units are relatively free from infiltrating contaminants from the upper weathered regolith unit.

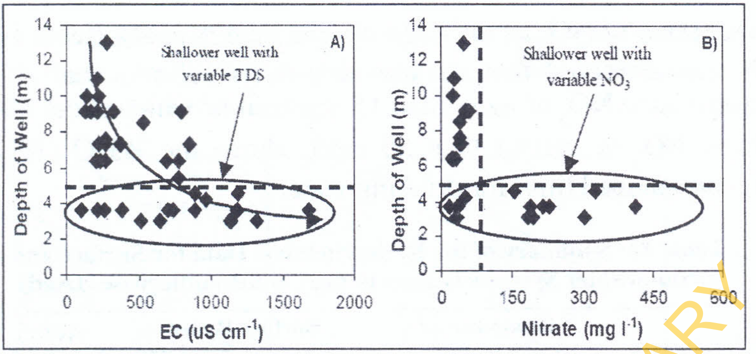


Fig. 24: Plot of depths of water wells in Ibadan metropolis against (A) electrical conductivity and (B) nitrate concentrations.

For the surface drainage system, isolated locations within the stretches of the sampled Ogunpa drainage system are characterized by EC>800mg/l and higher NO_3 concentrations of 80 to 366 mg/l. This can be clearly attributed to the discharge of untreated domestic/municipal sewage water as well as refuse dumps into the drainage channels of Ogunpa stream, especially within the stretches of urban old city centres (fig. 25).

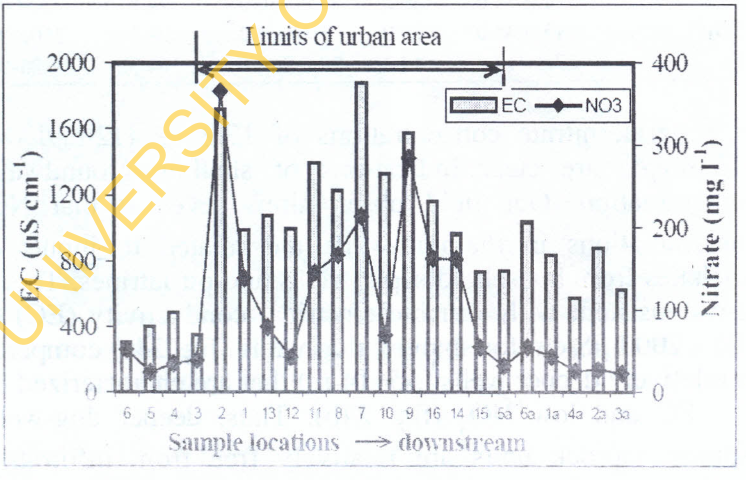


Fig. 25: Profiles of EC and NO_3 along the urban stretches of Ogunpa River, within Ibadan metropolis.

Similar trends were also observed within the populated centre in Osogbo Township (Tijani and Onodera 2005) with respect to anthropogenic factor (AF) and geo-accumulation index (I-geo) for the bottom sediments of the urban drainage channels (fig. 26). These also suggest impacts of domestic/ municipal sewage water as well as refuse dumps into the urban drainage channels. The situation is not peculiar to the urban areas in SW-Nigeria alone. Many rivers and surface waters in urban centres of Kano, Kaduna, Ibadan, Lagos, Aba, Onitsha etc are equally not spared of recklessly-dumping of domestic and industrial wastes (Egboka 2015). This is not to talk of the well-known polluted Ogoni-land and other parts of the Niger Delta area!

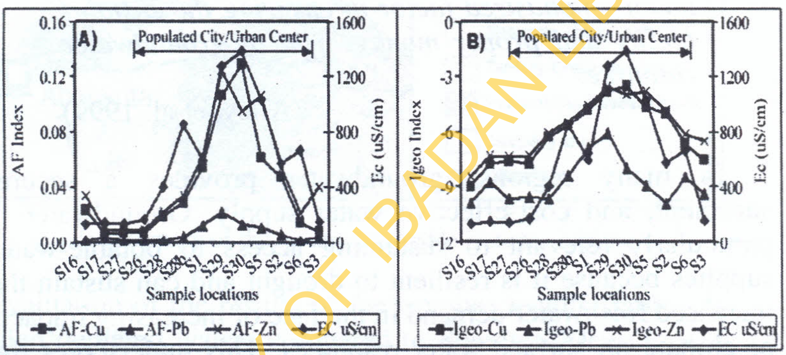


Fig. 26: Profiles of EC (μS/cm) against (A) Anthropogenic factor (B) Geo-accumulation Index along the urban stretches of the drainage system in Osogbo Township.

Nonetheless, the question at this point is: "*Who should be blamed?*"

- when road sides become waste dumps and incineration sites,
- when stream channels become waste dumps and sewage lines for household/municipal and industrial waste waters and
- when urban drains are not for storm (rain) water, but as refuse/waste transport channels.

Are we to blame the inefficient management authorities, or rather the impoverished and environmentally "in-sensitive" populace?

Mr. Vice-Chancellor Sir, whatever the situation, the answer lies in the need for us as a nation to integrate water resources management with proper infrastructural/land-use planning, appropriate sanitation and waste disposal practices in our major towns and cities.

Assessments of Groundwater Resilience to Climate Change using Isotopes Studies

> *The consideration of climate can be a key, but under-emphasized factor in ensuring the sustain-ability and proper management of groundwater resource.*
>
> (Alley, et al. 1999)

In many regions, groundwater provides a secure, sufficient, and cost-effective water supply. Groundwater is particularly relevant to sustaining access to potable-water supplies because it is resilient to drought and can sustain the increased freshwater demand in the face of increasing impacts of climate on surface water resources. This underscores the focus of an international research project aimed at exploring the resilience of shallow groundwater (borehole depth (<50 m) to climate variability in West Africa (MacDonald, et al. 2011).

My humble self was part of the team that conducted the studies in three localities across the different climatic zones in Nigeria (fig. 27). The study climatic zones cut across humid rainforest zone in Abeokuta area (rainfall >1,500mm); guinea savannah zone in Minna area (rainfall: 1000 - 1,500mm); and Sahel savannah zone in Gusau area (rainfall: 500 – 1,000mm). The study (as reported in Lapworth, et al. 2011; Lapworth, et al. 2013) involved sampling of forty-two shallow hand-pump boreholes from both weathered basement and sandstone aquifers in each of the study localities followed by laboratory water analyses of sulphur hexafluoride (SF_6) and Chloroflorocarbon (CFC) tracers, stable isotopes (Oxygen-18 and Deuterium) and radioactive isotope (Tritium, ^3H).

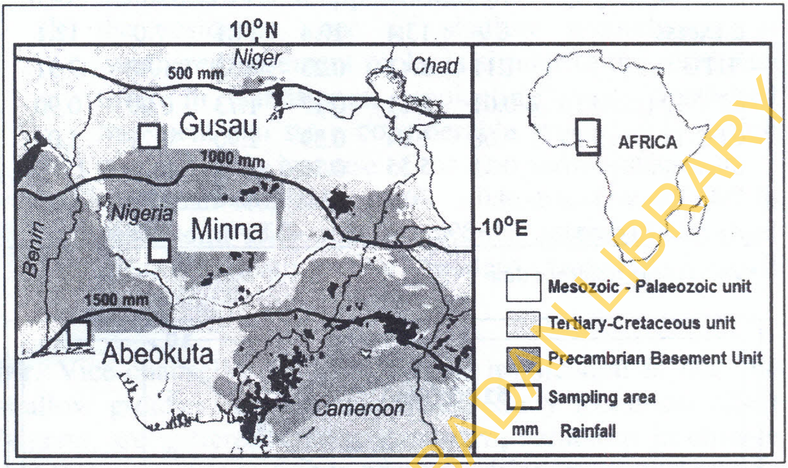


Fig. 27: Summary of the tracers and stable isotopes analyses.

Evaluation of the results of the isotopes results (table 14) revealed depleted waters compared to Standard Mean Ocean Water (SMOW), while the plot of the samples along the GMWL (fig. 28), indicated meteoric source (recharge). In addition, the low tritium value for Abeokuta zone is consistent with depletion of stable isotopes and decreasing rainfall as it tracks northward inland from the coastline (Gulf of Guinea).

Table 14: Summary of the Tracers and Stable Isotopes

Parameter	Abeokuta		Minna		Gasau	
	Min.	Max.	Min.	Max.	Min.	Max.
$d^{18}O$ (‰)	-3.80	-2.35	-4.16	-3.30	-4.67	-2.72
d^2H (‰)	-18.3	-9.90	-21.5	-13.9	-26.2	-14.0
d-excess	8.9	13.4	10.4	14.1	7.0	12.1
^3HTU	1.11	3.41	0.23	5.52	1.32	7.31
CFC-12 (pmol/L)	0.01	0.81	0.17	1.73	0.09	0.90
CFC-11 (pmol/L)	0.08	1.64	0.59	1.90	0.21	1.04
SF_6 (fmol/L)	0.31	5.55	0.36	4.53	0.30	19.21
*MRT (years)	4.0	70.0	23.0	60.0	15.0	66.0
Av. MRT (years)	39.8		42.8		46.3	

*MRT=Mean residence time

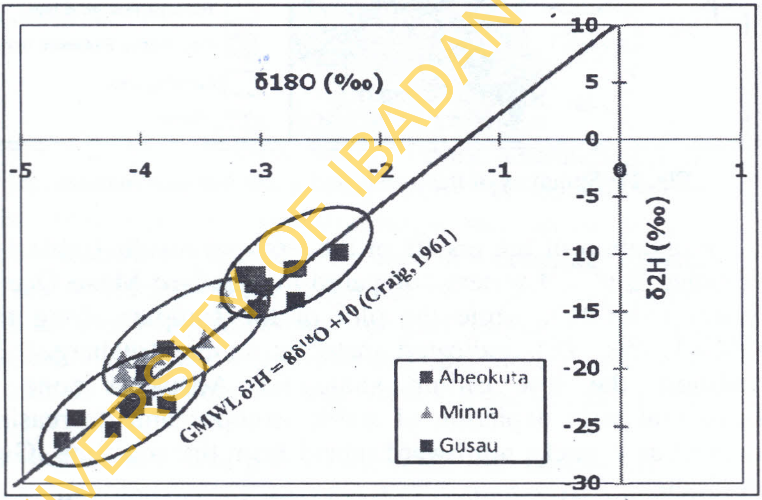


Fig. 28: Plot of Deuterium (δ^2H) versus Oxygen-18 ($\delta^{18}O$).

This is also a reflection of increasing depletion in isotopes with increasing distance from the coastline (see fig. 28) which can be attributed to the so-called latitude effect (Lapworth, et al. 2011). Our findings demonstrated a high degree of resilience to climate change for hand pump supplies across the different climatic zones and sampled aquifers and specifically that:

(a) the groundwaters in shallow aquifers (<50 m) are a product of waters of different ages with a mean residence time of approximately 20–70 years.
(b) the residence time of shallow groundwater in weathered basement rocks is similar to the residence time in sandstones, indicating that weathered basement can store considerable groundwater which moves slowly because of the low permeability.
(c) the mean residence times of unstressed aquifers in sahel/semi arid areas are similar to those of humid areas, indicating that modern recharge is still occurring in the drier region.

Mr. Vice-chancellor Sir, the overall implication is that the shallow groundwater systems in the study localities, albeit Nigeria, are buffered against short-term variations in climate and that even if the climate becomes drier, many rural water supplies are likely to remain functional. Once again, this underscores the significant role of groundwater in mitigating and adaptation to climate variability. Therefore, there is the need to highlight the role of groundwater resources in global climate change negotiations and mitigation solutions.

Assessment of impacts of Climate Change on Coastal Groundwater Quality

There is no doubt as to the effects of climate change and it is expected that the manifestation of the climate change impacts will be felt by humans mainly with respect to water resources specifically in the water scare region of Africa and Middle-east. Nigeria is said to be highly vulnerable to the impacts of climate change, according to the third and fourth Assessment Reports of the Intergovernmental Panel on Climate Change (IPCC), (IPCC 2001, 2007). This assertion is consequent to the fact that with long (that is 853km) coastline, large populations of coastal communities in Nigeria are vulnerable to sea level rise, storm surges and coastal erosions (NEST 2004). In essence, climate change-driven sea level rise constitutes a major problem in terms of water quality due to saline water intrusion, thus threatening the coastal freshwater aquifers.

It was on the basis of this that our team carried out a preliminary hydrochemical assessment of the Igbokoda area in Ondo State (fig. 29). The intent was to assess the possible impacts of sea level rise (SLR) on the qualty of groundwater system (Talabi, et al. 2012) using hydrochemical evaluation.

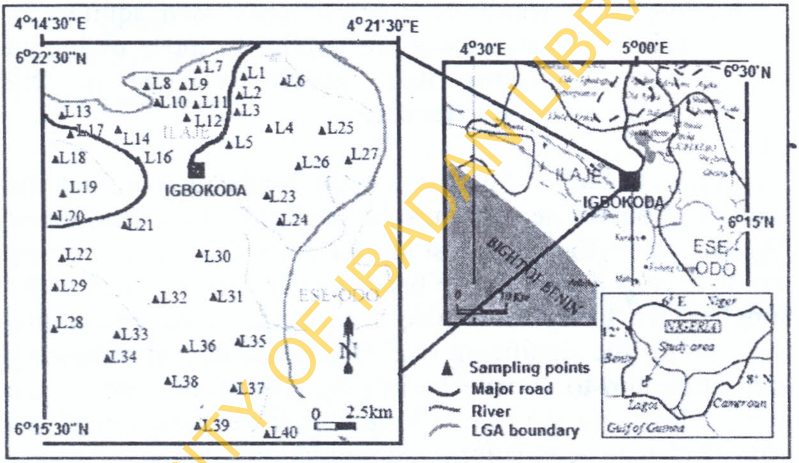


Fig. 29: Location Map of the study area indicating sampling points.

The results of water analyses as presented in table 15 revealed a Na-Cl dominated water type suggesting impact of salt water on the groundwater system, apparently due to sea level rise. Furthermore, our study revealed that deep wells and boreholes exhibited higher sodium (261.5 mg/l Na^+) and chloride ion (av. 1,082 mg/l Cl^-) concentrations compared to shallow dug wells with average value of 57.4 mg/l Na^+ and 220.7mg/l Cl^-.

Table 15: Summary of the Hydrochemical Analyses Results of the Groundwater Samples (in mg/l)

Parameters	Shallow Dug-Wells (N=30)			Boreholes / Deep Wells (N=10)		
	Min.	Max.	Mean	Min.	Max.	Mean
Temp.(°C)	28.3	32.0	29.8	28.3	33.5	29.9
pH	6.8	9.3	8.0	7.2	9.8	8.6
EC (μS/cm)	67.0	641.0	278.4	516.0	2440.0	965.9
TDS (mg/L)	43.6	416.7	181.0	335.4	1586.0	627.8
Ca^{2+}	19.2	104.3	45.0	24.3	63.9	37.9
Mg^{2+}	3.4	14.7	9.0	7.0	75.0	23.7
Na^{+}	3.6	172.5	57.4	**82.4**	**624.1**	**261.5**
K^{+}	1.5	42.1	13.6	9.2	62.9	36.6
Fe^{2+}	0.01	13.74	1.84	1.30	12.35	4.18
Mn^{4+}	0.01	1.00	0.12	0.03	0.75	0.37
HCO_3^-	15.3	91.5	44.7	30.5	152.5	76.3
Cl^-	72.0	432.0	229.7	**450.0**	**2592.0**	**1082.0**
SO_4^{2-}	0.01	5.32	1.27	0.32	1.70	0.98
NO_3^-	0.01	4.39	0.63	0.04	0.71	0.22

These are clear indications of impacts of climate-induced sea level rise affecting the coastal aquifer in the study area. Also, the estimated major ionic ratios such as Mg/Ca (0.13 – 3.09), and Cl/HCO_3 (1.18 – 25.50) signify brackish water in most of the sampled locations which further confirm the impact of saltwater intrusion in the study area. This is also clearly reflected in the water characterization that revealed largely Na-(K)-Cl-SO_4 water type as brackish water and minor occurrence of Ca-(Mg)-HCO_3 water type as freshwater sources.

Mr. Vice-Chancellor Sir, the results of the above preliminary study and the need to assess the impacts of natural and anthropogenic induced climate and land use changes on our coastal environments form the basis of our on-going research work titled: *Impacts of Land-Use and Climate Induced Changes on Coastal Environment: An Integrated Hydro-geological, GIS-based Vulnerability and Social-Economic/Livelihood Assessments of Coastal Environment of SW-Nigeria.* It worthy of mention that this on-going intergrated research study is supported by UI-Research Foundation (UI-RF).

In concluding this section, I wish to emphasize that a key component of our future research will focus on the need to define the impact of climate change/variability on water resources, and intervention plan/strategies for mitigating the likely impacts. A cursory look at the above topic of our on-going research clearly highlights the cross-cutting and interdisciplinary nature of socio-economic and environmental dimensions of climate change. Hence, there is no doubt that our research activities on groundwater and environmental sustainability must, of necessity and in the face of emerging reality of modern science, be interdisciplinary in nature.

Our need and ability to cooperate with other colleagues (such as: geographers, climatologists, and sociologists, among others) will be our strength for further active research. In order to promote such active interdisciplinary research, it is my opinion that the grading system regarding multiple-authored publications as stipulated in the current Appointment and Promotion Guidelines should be reviewed. It is my hope that our Faculty (Faculty of Science), as a pioneering Faculty in this University, will not shy away from her leadership role in this regard.

Inferences and Synthesis

So far, I have engaged your time and patience to highlight a couple of aspects of my research contributions, focusing on natural geogenic controls on one hand and impacts of human activities on groundwater system on the other hand. A number of the studies presented have highlighted the significance of natural geogenic controls on groundwater occurrences, resources evaluation, quality and usability. However, those that highlighted the impacts of human-induced activities signify the need for sustainable management of our groundwater resources. The BIG question is: *"What do all these add up to?"*

It all adds up to the fact that we need to understand that there are three (3) critical attributes of water, as a resource in general;

- If it is *too little*, it will constitute problems relating to scarcity for humans, plants and animal uses, and other associated environmental problems like desertification.
- If it is *too much*, it will constitute problems relating to environmental hazards such as flooding, gully erosion, and the like.
- If it is *too dirty*, it will also constitute problems relating to quality status and attendant environmental contamination/health impacts.

Therefore, a more holistic approach to sustainable resources development and management should encompass land, water, biological and even human resources as components of the overall local resource (fig. 30).

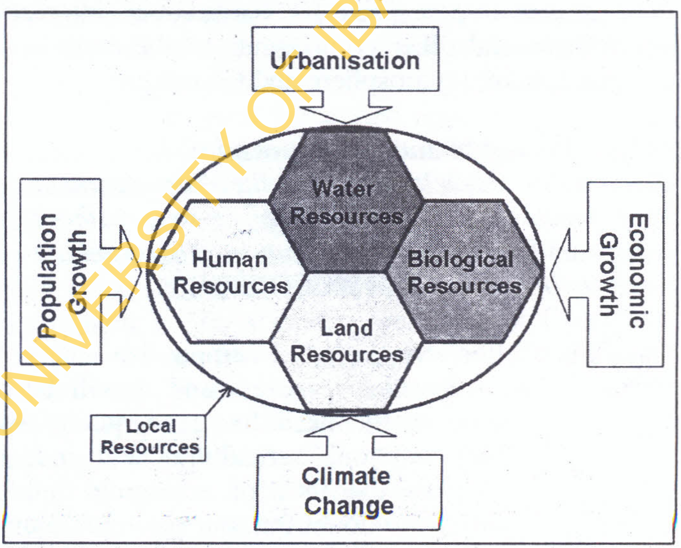


Fig. 30: Relationship between components of local resources and climatic/socio-economic factors in respect of sustainable resources management.

By and large, it is obvious that population growth, urbanisation, economic development and global climate changes are drivers for environmental changes with resultant land degradation, water contamination and groundwater depletion. In essence, the sustainability of groundwater resources development and management in the future will be a function of addressing the following hydrological conditions:

- decrease in groundwater storage and reduction in stream flow and lake levels in face of climate change,
- environmental degradation of water quality and possible loss of riparian ecosystems, and
- saltwater intrusion in coastal environments and related impacts on water quality.

Ironically, the foregoing issues have direct or indirect link with the emerging realities of climate change, climate variability and attendant impacts as highlighted earlier. This is also a pointer to the need for harmonious interactions between humans and other components of the earth system (that is, Atmosphere, Hydrosphere and Geosphere).

Concluding Thoughts and Recommendations

> *Sustainable Development is the "development that meets the needs of the present without compromising the ability of future generations to meet their own needs"* (WCED 1987)

Mr. Vice-Chancellor Sir, may I emphasize here that groundwater is an important resource, and it will become more so in the future as the need for good quality water increases due to urbanisation, agricultural and industrial production, especially in the face of emerging threat of climate change. There is no doubt that our rural communities are 90% dependent on groundwater, while about 60-70% of the urban population in Nigeria also depends on groundwater in form of boreholes and dug-wells in the face of failing public water supply services.

However, it should be noted that key principles of Sustainable Development is the recognition of the fact that:

(a) fresh water is a finite and vulnerable resource, thus effective management requires a holistic approach.
(b) water has significant economic value, and thus should be regarded as an economic good.

According to an excerpt from the UN-Dublin Statement on Water and Sustainable Development, scarcity and misuse of fresh water pose a serious and growing threat to sustainable development and protection of the environment. Human welfare, food security, and the overall ecosystems are all at risk, unless water and land resources are managed more effectively. In essence, the sustainability of our groundwater resource development and management must be based on an integrated approach encompassing hydrogeological factors, as well as socio-economic factors (such as capacity-building, appropriate technology and institutional/legal frameworks among others) (Tijani 2006).

The success of such integrated approach to sustainable water resources management in a developing country like Nigeria warrants a clear reflection and definition of our goals and priorities (as a nation) as to: *Where we are now?*, *Where are we going?*, *and Where should we actually be going:* in terms of sustainability of our environment at large (fig. 31). As highlighted in the scenario presented in figure 31, the issue is that we are now at a point where the influence of human activities, in the drive for development, is impacting on other components of the earth system (lithosphere, atmosphere, and hydrosphere, including groundwater).

If we continue in such a manner of "*business as usual*", we risk moving towards un-sustainable path, thus endangering other spheres of the earth system and human existence.

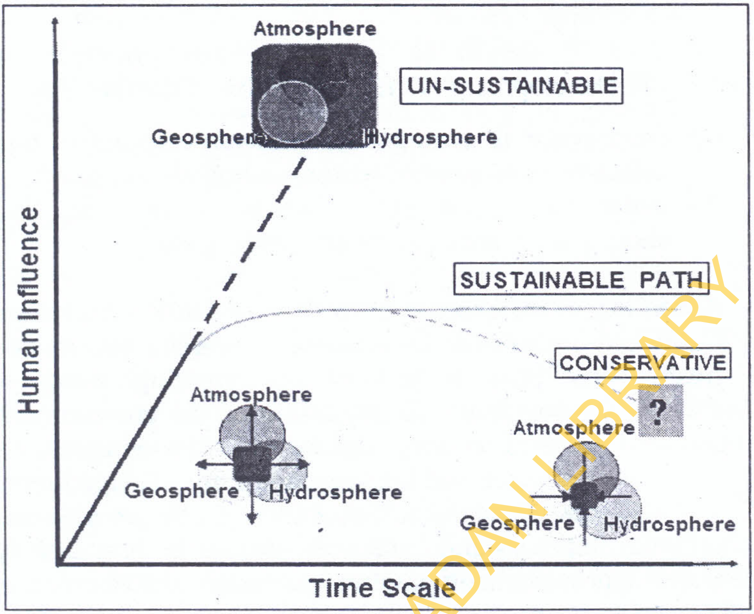


Fig. 31: Model of sustainability scenario of human impacts on environmental spheres.

Therefore, considering the Earth as a storage tank (of surface and groundwater resources) with a big tap to cater for the ever-increasing human population and the ecosystems, un-sustainable depletion or over-exploitation of the water resources will lead to environmental tragedy (hazard) (fig. 32). In addition, the various glooming scenarios of impacts of climate change in terms of sea-level rise, desertification, among other environmental hazards, can be seen as the products of the "business as usual approach" to resources and environmental management.

However, if we adapt and give due consideration to integrated scientific approach in our developmental efforts, then we will be on course to sustainability, not only of water resource development/management, but that of the totality of our environment.

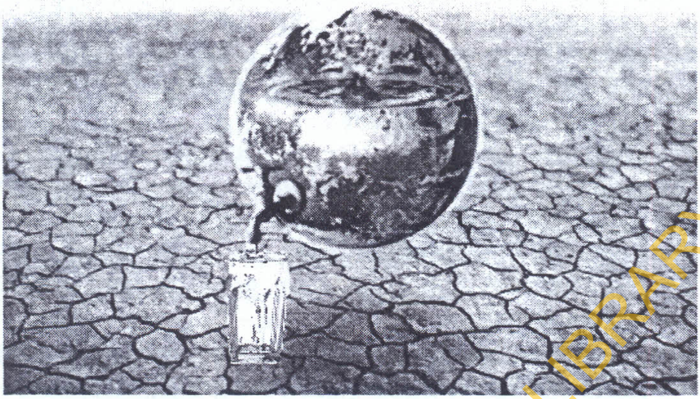


Fig. 32: The drying big tap and implication for environmental sustainability.

Therefore, the governments at the different levels of administration in Nigeria need to be proactive in terms of assessments of water scarcity and strategies to achieve water security. This is a key to our sustainable socio-economic development since there cannot be *food security* without *water security*. Therefore, in the emerging era of resurgence in epidemics like Ebola and other contagious bacterial/viral diseases, the government at all levels should consider access to clean and safe water, a matter of national security.

Other Recommendations

- There is the need for government at all levels and water-related agencies to implement a programme of groundwater data collection, monitoring network and evaluation in respect of quantity and quality of our groundwater resources. Through such, sound groundwater management decisions to achieve effective groundwater management/sustainability could be addressed.

- There is the need to involve experts in hydrogeology or groundwater resources in exploration, exploitation and management of groundwater resources. This will control the present all-comers affair in borehole siting and drilling and also curtail incidences of borehole failures or abandonment.
- There is the need for appropriate policy, legal, regulatory and institutional intervention by the relevant government agencies regarding the creation of data base for boreholes, registration of borehole drilling companies, regulation of groundwater pumping, among others.
- There is the need for appropriate capacity development (training of water quality experts, technologists, technicians, etc.) to provide man-power base for the sustenance of proper maintenance structure for boreholes and water projects.
- There should also be due-process in the award and execution of water projects, as well as participatory approach by involving end-users (especially women) in the design stage or execution/monitoring stage. This will help to forestall the incidence of abandoned boreholes and other water-supply projects, while cases of the so-called constituency boreholes projects that break down a few days or a couple of months after commissioning will also be avoided.
- There is the need for the management authorities to evolve proper waste disposal and sewage treatment practices in our urban areas in order to prevent contaminations of our surface and groundwater resources.
- Also, there is the need for education and social awareness regarding water conservation and protection while discouraging wastages and environmental contamination. This invariably will warrant involvement of non-governmental organizations and community-based advocacy groups to drive the social attitudinal changes needed.

Mr. Vice-Chancellor Sir, I have listened to a number of inaugural lectures in this historic hall over the past fifteen years. It is more or less a ritual that inaugural lecturers present their recommendations, just as I have done now. In the light of this, my concluding recommendation will be to suggest the possibility of synthesizing all the recommendations of our inaugural lectures and producing a policy brief for the government on different thematic issues relating to education, research and national development agenda that will move the nation forward. After all, it is a well known fact that the greatest asset of a nation is her human capacity.

Once again, I want to draw attention to the fact that "Water is a renewable and reusable resource". However, the extent to which we are able to ensure adequate and sustainable availability and quality of this invaluable natural resource will define the quality of our livelihood and biodiversity of our environment. In other words, while we must sustain the present generation, there is the need to also guarantee the existence and survival of the future generations. As the legendry Fela Anikulapo Kuti puts it: "Water e no get enemy". Therefore, let us remember, We are all Water Creatures; water makes up 60% of our body, 70% of our brain and 80% of our blood.

On a final note,

> *When you talk you are only repeating what you know (already). But if you listen you may have learnt something new* - (Dalai Lama).

With this adage in mind, while I have just repeated here today what I have already known in the course of my academic career, I have no doubt that the wonderful audience here have also learnt something new today.

Acknowledgements

First and foremost, I thank the Almighty ALLAH; The Creator of Life who deemed it fit to shower His blessings on me and granted me sufficient Grace to be what I am thus far. For me this is the most difficult task today due to time

constraint and the dilemma of who and who to be recognized. Therefore, My Vice-Chancellor Sir, before acknowledging certain individuals and groups, kindly permit me to seek your indulgence to collectively appreciate all men and women of good-will, old and young, living or departed and of whatever social status who, in whatever little ways, had impacted my life positively for being part of today's success story. May the Almighty ALLAH reward all of them abundantly.

I acknowledge with gratitude my lovely parents, Alhaji Ishola Tijani (of blessed memory) and Alhaja Alake Tijani who brought me up and instilled virtues of honesty, hardwork and above all, the fear of God in me. I equally express my appreciations to the patriarch our family, Alhaji Raheem Ola (aka Alafia-Tayo) for providing the lifeline for my undergraduate education, my siblings notably my elder sister, Mrs. Abiatu Tiamiyu, my uncles, cousins and other members of my close and extended family many of whom are here today, for their supports and prayers over the years.

I thank all my teachers and lecturers (who are too numerous to be mentioned individually) for laying the foundation of my academic and professional achievements. Notable among them are Chief R.A. Akande and Mr. G. Adeniran (both retired PS). The continued moral and fatherly support of my Ph.D supervisor (Doktorvater) in person of Emeritus Professor E.P. Loehnert is also worthy of special note. Many thanks to my senior colleagues in the Department: Professor A.A. Elueze, Professor A.I. Olayinka, (the current VC) and Professor G.O. Adeyemi. Of note are the good-will and moral support of Professor T.A. Badejoko (retired) for his mentorship role and periodic fatherly counselling.

I appreciate other academic staff of Geology Department (Professors O.A. Okunlola, O.A. Ehinola and Drs. M.E. Nton, I.M. Akaegbobi, A.O. Boboye, A.T. Bolarinwa, A. Omotogun, M.A. Oladunjoye, A.S. Olatunji, I.A. Oyediran, O.C. Adeigbe, A.M. Adeleye, O.O. Osinowo, and A. Jayeoba) for creating an enabling environment for research and academic discourse over the years. The good will and supports of non-academic staff of Geology Department ably coordinated by Mrs. Bademosi are highly appreciated.

Thanks to my students (both former and present) ably coordinated by Dr. Abel Talabi (EKSU), Mr. J.A. Aladejana and Mr. L. Kolawole. Many other students, friends and well-wishers as well as the Faculty Officer (Mrs. Francisca Ayodele) and her team who worked tirelessly behind the scene to see to the success of today's event, are also acknowledged.

My sincere gratitude to both junior and senior colleagues in the Faculty of Science for their positive influence which had contributed to the success story of today; notable among them are my respected Professors A.A. Adesomoju, B.B. Adeleke, O. Ekundayo, R.A. Oderinde, L. Hussein, G.O.S Ekhaguere, K.O. Adebowale, A. Onilude (current Dean), O.E. Fagade, P.A. Oyelaran, I.P. Farai, P.C. Onianwa, J.O.A. Woods, J.O. Babalola (my brother) and O.O. Sonibare. Others including but not limited to Drs. A.M. Salam, O.I. Shittu, I.A. Oladosun, G.O. Adewuyi, O.F.W. Onifade, F.J. Ayoola and Bola Adeyi are all appreciate.

Within the University, I wish to appreciate the supports of the immediate past VC, Professor I.F. Adewole, Professor Akinboade (for fatherly counselling), Professor A. Olatunbosun, Professor S.B. Agbola, Professor E.A. Bamigboye, Professor A.O. Olorunnisola, Professor A. Aderinto, Professor M.O. Abatan, Professor S.A. Isenhunwa, Professor O.A. Agbede, Professor T.A. Akanji, Professor R.A. Alada, Professor R.A. Aderinoye and Malam Yussuf Abdulahi (Kaduna), my sister and classmate Dr. Bola Olaniyan, Dr. Gani Adeniran, Dr. W.B. Wahab, Dr. R.A. Okunola, Dr. Ibidun Adelekan, Dr. Olutoyin Fashae, Mrs. Bimbo Oduwole, Dr. Abdul Jeleel Bello and Mr. S.O. Oyewumi. I wish to also appreciate Professor A.S. Gbadegesin (VC of LAUTECH) and Professor Samson Ayanlaja (former VC Crawford University). Of special note is the effort of Professor M.A. Kehinde for proof reading the draft of this lecture. I also appreciate with many thanks the benefaction from Mr. Kolawole S. Israel (Easy-Kay Drilling Co.), Mr. Michael Ale (MALE Integrated Drilling Co.) and Prince and Mrs. A.A. Adeleye.

The supports and benefactions from a number of Institutions and Organizations, notably German Academic

Exchange (DAAD), Matsumae International Foundation (MIF)-Japan, Japan Society for Promotion of Science (JSPS), UNESCO, British Geological Survey (BGS), International Water Management Institute (IWMI) and Council for the Development of Social Science Research in Africa (CODESRIA) during the course of my academic career, are highly appreciated. I wish to recognize many of my collaborators – Professors K. Jinno, S. Onodera and M. Saito in Japan, Professors W. Coldewey, J.-F. Wagner, Heinrich Bahlburg and Dr. P. Goebel in Germany; Paul Pavalec in India and Allan MacDonald, Richard Taylor and Dan Lapworth in UK, Drs. Obayelu and Sobowale of FUNAAB as well as Dr. Tayo Olaleye – for their supports and collaborations over the years.

In addition, I wish to appreciate my former student colleagues and friends in Germany; Drs. Michael Lange, Barbara Hellebrandt, Hans-Juergen Donath, Ingrid Brinkmaier, Frank Stiller as well as the family of Mr. Karsten Timmermann and Dr. (Mrs.) Marion Schulte, Dr. Ludwig Heimann and family and Frau Redies and colleagues at the Rational Verschischerung GmbH for their supports and hospitality during my so called "*annual pilgrimage*" to Germany, *Vielen Dank!*

I thank in a special way, Professor M.O. Oyawoye and family for their support to the Department during my tenure as HOD. Our worthy Alumna and Alumnae notably Professor Omar Rahaman, Professor C.S. Teme, Dr. Lambert Aikhionbare, Dr. Kunle Adesida, Chief J. Falore, Messrs Jim Orife, Sam Coker, Issac Odedere, Carim Akintunde, Doja Ojelabi, Segun Obilaja and several others who have been generous to the Department are also appreciated.

Geology has a big family; to those "*geological*" colleagues at other Universities and Establishments like Nigeria Geological Survey Agency (NGSA) – Professor Owolabi Ajayi, Professor M.O. Olorunfemi, Professor V.O. Olarewaju, Professor B.D. Ako, Professor S. Malomo, Professor K. Uma (of blessed memory), Professor S.C. Teme, Professor E. Esu, Professor A.E. Edet, Professor Y. Asiwaju-Bello, Professor O. Ogunsanwo, Dr. R.B. Bale, Dr. I.

Okunlola and Mr. Alex Uwegbu, Mr. and Dr. (Mrs.) Ayo Akanbi, Alhaji Tunde Arisekola, Mr. Aiyegbusi, Dr. Wole Oyedeji, Engr. S. Nkom, Engr. Alagada, among many others – your partnership and good-will over the years are well appreciated.

To my kinsmen and home-based friends, I say thank you for your prayer, supports and best wishes over the years. Notable among this group are De-Constellation Club, Saki, 81-graduating set of AUD High School Saki, the Old Students' Association of AUD, Saki, the Saki Elites Ibadan Branch. Of note are my elder brothers and uncles from Saki; Barr. Adebayo Shittu (the Hon. Minister of Communications), His Excellency Otunba Moses Alake Adeyemo (The Deputy Governor of Oyo State), my Lord, Hon. Justice Moukthar Abimbola (The Chief Judge of Oyo State), High Chief Abdur-Rasheed G. Adegoke (The Bagii of Saki), HRH Oba Dr. Abodunrin Oyebisi Kofoworola, (The Aare of Ago-Are), Hon. Kareem Adegoke (Care-taker Chairman Saki-West Local Government Area), Alhaji Moshood Adeleke, Engr. Yunus Gbadamosi, Alhaji G.A. Oyinlola, Alhaji B.O.A. Oke, Alhaji S. Olaiya, Mr. Nasiru Tjani, and Mr. Rasak Olubodun; I appreciate all of you for your kind gesture and best wishes, all the time. I also appreciate Alfa Jeleel Idowu, Ganiyu Akorede and colleagues for their moral supports. I wish to appreciate all the members of staff of the Department of Agricultural Extension and Rural Management for their supports and care for my family. I also recognise my friends and neighbours of Oke-Ibadan Residents Association at Akobo-Ojurin area for their best wishes, as well as Mr. and Mrs. Banjo Olona for their moral supports.

I appreciate my childhood and family friends for their supports and for being part of today's success story notably: Engr. Omirinde Bashir, Mr. Rufai Fatai, Engr. K.A. Shittu, Messrs H.A. Tijani Asoroda, R.A. Lawal, Audu Saliu, Zakariyau Abdul-Quadri, Bode Bolaji, Audu Yisau as well as Dr. Femi Olugbemiro, and many others not on this list for their constant supports and prayers. At this point I wish to also remember a number of departed friends and colleagues who had contributed in one way or the other (during their lifetimes) to the success story of today, notably, Professor A.F. Abimbola, Dr. S.I. Nurudeen, Dr. Fatai Ahmed and Mr. S.A. Raji. May their souls rest in perfect peace (Ameen).

With deep sense of responsibility, I recognize the tremendous home-front supports of members of my nuclear family; Dr. (Mrs.) S. Tijani, Master Sheriff Bidemi, Mubarak Yamato and baby of the house, Fawaz Adetayo; thanks for giving me happiness all the time. To this distinguished and wonderful audience; I thank you for your patience and attention. I feel honoured with your presence, may the Almighty ALLAH honour all of you too.

Finally, in the words of Eric Hoffer, *Change is an ordeal and its only cure is Action*". Therefore in the spirit of the moment, let us remember that *Actions shall be judged according to their intentions and Men shall be rewarded of their actions according to their intentions (Hadith Al-Nawawi).* So let us fear The Almighty, be positive and do good for the sustenance of our environment (soil, air, water) and mankind.

Many Thanks and God Bless!!!

References

Alley, W.M., Reilly, T.E. and Franke, O.L. (1999) Sustainability of Groundwater Resources. *U.S. Geological Survey Circular 1186*; 70p. Dever Colorado.

Bruand, A. (2002) Concentration and mobility of lithogenic trace metals in soils: Significance of anthropogenic lateral distribution. *C.R. Geosci.* 334: 581-582.

Calow, R.C., MacDonald, A.M., Nicol, A.L. and Robins, N.S. (2010) Ground water security and drought in Africa: Linking availability, access and demand. *Ground Water* 48: 246-56.

Chilton, P.J. and Foster, S.S.D. (1995) Hydrogeological characterization and water-supply potential of basement aquifers in tropical Africa. *Hydrogeology Journal* 3(1): 36-49.

Collins, A.G. (1975) *Geochemistry of oilfield brines*. Elsevier, Amsterdam 496pp.

Danskin, W.R. (1998) Evaluation of the hydrologic system and selected water Management alternatives in the Owens Valley, California: *USGS Water-Supply Paper 2370,* 175p.
Edmunds, W.M. and Smedley, P.L. (2005) *Fluoride in natural waters essentials of medical geology* (ed.) B.J. Alloway and O. Selinus (London: Elsevier) pp. 301-29.
Egboka, B.C.E. (2015) Problems of Water Resources, Supplies and Management in Nigeria. Retrieved June 12, 2015 from *http://theunion.com.ng/opinion/problems-of-water-resources-supplies-and-management-in-nigeria-1*
Fashae, O.A., Tijani, M.N., Talabi, A.O. and Adedeji, O.I. (2014) Delineation of Groundwater potential zones in the crystalline basement terrain of SW-Nigeria: An integrated GIS and remote sensing approach. *Applied Water Science* 4: 19-38.
Federal Ministry of Water Resources (2013) National Water Resources Master Plan.
Foster, S.S.D. and Chilton, P.J. (2003) Groundwater: The processes and global significance of aquifer degradation. *Phil. Trans. R. Soc.* B 258: 1957-72.
Fergusson, J.E. (1990) *The heavy elements–Chemistry, environmental impact and health effects*. OX-UK: Pergamon Press.
Healy, R.W., Winter, T.C., LaBaugh, J.W. and Franke, O.L. (2007) Water budgets: Foundations for effective water-resources and environmental management: *USGS Circular* 1308: 90p.
Heath, R.C. (1983) Basic groundwater hydrology. *USGS Water Supply Paper 2220:* 84p. Denver, C.O.
Hubbart, J.A. (2008) *History of Hydrology*. Retrieved from *http://www.eoearth.org/view/article/153525* (Dec., 2015).
IPCC (2001) Climate Change 2001: Working Group II: Impacts, Adaptation and Vulnerability.
__________(2007) Climate Change - Fourth Assessment Report. Working Group I Report: The Physical Science Basis. Chpt. 11.1. 866p.
JICA (2014) The project for review and update of Nigeria national water resources master plan; Vol. 2. Japan International Cooperation Agency: Yachiyo Engineering Co., Ltd.: CTI Engineering International Co., Ltd.: Sanyu Consultants Inc.
Kløve, B. (2013) Climate Change Impacts on Groundwater and Dependent Ecosystems. *J. Hydrol.* doi:10.1016/j.jhydrol. 2013. 06.037.
Koudio, I. and Trefry, J.H. (1987) Sediment trace metal contamination in the Ivory Coast, West Africa. *Water Air Soil Pollut.* 32: 145-154.

Lapworth, D.J., MacDonald, A.M., Bonsor, H., Tijani, M.N. and Calow, R.C. (2011) Preliminary results from a Water Economy and Livelihoods Survey (WELS) in Nigeria and Mali, sub-Saharan Africa: Investigating Water Security across a Rainfall transect. *British Geological Survey Open Report*, OR/11/018. 74p.

Lapworth, D.J., MacDonald, A.M., Tijani, M.N., Darling, W.G., Gooddy, D.C., Bonsor, H.C. and Araguás-Araguás, L.J. (2013) Residence times of shallow groundwater in West Africa: Implications for hydrogeology and resilience to future changes in climate. *Hydrogeology Journal* 21: 673-686.

Loynachan, T.E., Brown, K.W., Cooper, T.H. and Milford, M.H. (1999) Sustaining our Soils and Society. *AGI environmental Awareness Series 2;* Alexandria, Virginia; 64p.

MacDonald, A., Davies, J., Calow, R. and Chilton, J. (2005) Developing groundwater: A guide for rural water supply. ITDG Publ. UK, 358p.

MacDonald, A.M. and Calow, R.C. (2009) Developing groundwater for secure water supplies in Africa. *Desalination* 248: 546-56.

MacDonald, A.M., Bonsor, H.C., Calow, R.C., Taylor, R.G., Lapworth, D.J., Maurice, L., Tucker, J. and Ó Dochartaigh, B.É. (2011) Groundwater resilience to climate change in Africa. *British Geological Survey Open Report*, OR/11/031. 25 pp.

MacDonald, A.M., Bonsor, H.C., Dochartaigh, B.E.O. and Taylor, R.G. (2012) Quantitative maps of groundwater resources in Africa. *Environ. Res. Lett.* 7 024009 (7pp) doi:10.1088/ 1748-9326/7/2/024009.

Mapanda, F., Mangwayana, E.N., Nyamangara, J. and Giller, K.E. (2005) The effect of long-term irrigation using wastewater on heavy metal contents of soils under vegetables in Harare, Zimbabwe. *Agric. Ecosyst. Environ.* 107: 151-165.

Mogollon, J.L., Bifano, C. and Davies, B.E. (1996) Geochemistry and anthropogenic inputs of metals in a tropical lake in Venezuela. *Appl Geochem.* 11: 605-616.

Nace, R.L. (1974) *General Evolution of the Concept of the Hydrological Cycle. Three Centuries of Scientific Hydrology.* UNESCO-World Meteorological Organization-*International Association of Hydrological Sciences,* Paris, pp. 40-48.

Nigerian Environmental Study/Action Team (NEST) (2004) "Climate Change and Nigeria: A Guide for Policymakers." Ibadan, Nigeria.

NOIPolls Limited (2015) Access to Clean Water Remains a Major issue: 'Pure water' Main Source of Drinking Water (A poll on access to clean water and sanitation). Retrieved from; *www.noi-polls.com*, February, 2016.

Ojo, O., Gbuyiro, S.O. and Okoloye, C.U. (2004) Implications of climatic variability and climate change for water resources availability and management in West Africa. *GeoJournal* 61: 111-119.

Olade, M.A. (1987) Heavy metal pollution and the need for monitoring: illustrated for developing countries in West Africa. In: *Lead, Mercury, Cadmium and Arsenic in the Environment* (ed. by T. Hutchinson & K. Meema) *Scope*, 335–341. John Wiley and Sons, Chichester, UK.

Olayinka, A.I. (2010) *Imaging the Subsurface*. Inaugural Lecture, University of Ibadan, Ibadan University Press.

Oniawa, P.C. (2015) *Chemical Environmental Pollution: How Significant is the Local Contribution?* Inaugural Lecture, University of Ibadan, Ibadan University Press.

Price, J.R. and Velbel, M.A. (2003) Chemical weathering indices applied to weathering profiles developed on heterogeneous felsic metamorphic parent rocks. *Chem. Geol.* 202: 397-416.

Rached, E., Rathgeber, E. and Brooks, D.B. (1996) *Water Management in Africa and the Middle East: Challenges and Opportunities.* IDRC Books, Ottawa, Canada.

Sharma, A. and Rajamani, V. (2000) Weathering of gneissic rocks in the upper reaches of Cauvery River, south India: implications to neotectonics of the region. *Chem Geol*. 166: 203-223.

Siebert, S. (2010) Groundwater use for irrigation – A global inventory. *Hydrol. Earth Syst. Sci.* 14: 1863-1880.

Singh, K.P., Mohon, D., Sinha, S. and Dalwani, R. (2004) Impact assessment of treated/untreated wastewater toxicants discharge by sewage treatment plants on health, agricultural, and environmental quality in wastewater disposal area. *Chemos* 55: 227-255.

Talabi, A.O. and Tijani, M.N. (2011) Integrated remote sensing and GIS approach to groundwater potential assessment in the basement terrain of Ekiti area Southwestern Nigeria. *RMZ – Materials and Geoenvironment* 58(3): 303-328.

Talabi, A.O., Tijani, M.N. and Aladejana, J.A. (2012) Assessment of impact of climatic change on groundwater quality around Igbokoda Coastal area, Southwestern Nigeria. *Journal of Environment and Earth Science* 2(11): 39-49.

Taylor, G.R. and Eggleton, R.A. (2001) *Regolith geology and geomorphology*. Wiley, NY, 375p.

Tijani, M.N. (1994) Hydrochemical Assessment of Groundwater in Moro area, Kwara State, Nigeria. - *Environmental Geol.* 24(3): 194-202.

__________ (1997) Beitrag zur Genese salziger Grundwaesser im Benue-Trog, Nigeria. *Muenstersche Forsch. Geol. Palaeontol.* 83; (172p., Muenster).

__________ (2004) Evolution of saline waters and brines in the Benue-Trough, Nigeria. *Applied Geochemistry* 19: 1355-1365.

__________ (2006) The need for Action-driven Vision and sustainable Management of Water Resources in Nigeria. *Jour. Mining & Geol.* 42(1): 31-40.

__________ (2009) Contamination of shallow groundwater system and soil-plant transfer of trace metals under amended irrigated fields. *Agric. Water Managt.* 96: 434-444.

Tijani, M.N., Löhnert, E.P. and Uma, K.O. (1996) Origin of saline Groundwaters in the Ogoja area, Lower Benue Trough, Nigeria. *Jour. Afr. Earth Sci.* 23(2): 237-252.

Tijani, M.N., Jinno, K. and Hiroshiro, Y. (2004) Environmental Impact of heavy metals distribution in water and sediments of Ogunpa River, Ibadan, South-western Nigeria. *Jour. Mining & Geol.* 40(1): 73-83.

Tijani, M.N. and Loehnert, E.P. (2004) Exploitation and traditional processing techniques of brine salt in parts of the Benue-Trough, Nigeria. *Int'l. Jour. Mineral Process* 74: 157-167.

Tijani, M.N. and Onodera, S. (2004) Quality Assessment of Stream water and bed-sediments: A case Study of Urbanization Impacts in a Developing Country. In: J. L. D'Ambrosio (Ed.): Proceedings Self-sustaining Solutions for Streams, Wetlands and Watersheds, Sept., 2004; St. Paul Minnesota, USA; pp.77-84.

__________ (2005) Surface and groundwater qualities in an urbanized catchment: Scenario from a developing country. In: Thomson, N.R. (Ed.): Proceedings, GQ2004 – Bringing Groundwater Quality Research to the Watershed Scale, Waterloo, Canada, July 2004; IAHS Publ. 297: 506-516.

Tijani, M.N. and Onodera, S. (2009) Hydrogeochemical Assessment of Metals Contamination in an Urban Drainage System: A case study of Osogbo Township, SW-Nigeria. *Jour. Water Res. And Protection* 3: 164-173.

Tijani, M.N., Okunlola, O.A. and Abimbola, A.F. (2006) Lithogenic concentrations of trace metals in soils and saprolites over crystalline basement rocks: A case study from SW Nigeria. *Jour. Afr Earth Sci.* 46: 427-438.

Tijani, M.N. and Agakwu, A.A. (2008) Irrigation-induced Infiltration and Recharge: Implication for Groundwater Quality. *Jour. Environ Sci. and Tech.* 1(2): 65-72.

Tijani, M.N. and Nton, M.E. (2009) Hydraulic, textural and geochemical characteristics of the Ajali Formation, Anambra Basin, Nigeria: Implication for groundwater quality. *Environ Geol.* 56: 935-951.

Tijani, M.N., Nton, M.E. and Kitagawa, R. (2009) Textural and geochemical characteristics of the Ajali Sandstone, Anambra Basin, SE Nigeria: Implication for its provenance. *Comptes Rendus Geoscience,* 342: 136-150.

Tijani, M.N., Obayelu, A.E., Olatunji, A.S., Sobowale, A., Aladejana, J. and Oke, S. (2011) *Livelihood impacts of improved on-farm water control in sub-Saharan Africa: An empirical investigation of three modes of small-holder agricultural water management* (Final Report, Project 058-01-01-ROF-PR-M615). Submitted to International Water Management Institute (IWMI) Colombo, Sri Lanka, 75p.

Tijani, M.N., Obayelu, A.E., Sobowale, A. and Olatunji, A.S. (2015) Welfare Analysis of Smallholder Farmers by Irrigation Systems and Factors Affecting their Production Outputs in Nigeria. *Sustainability of Water Quality and Ecology*: DOI: 10.1016/j.swaqe.2014.12.002.

Tijani, M.N., Crane, E., Upton, K. and Ó Dochartaigh, B.É. (2016) Africa Groundwater Atlas: Hydrogeology of Nigeria. British Geological Survey. Accessed, March, 2016: *http://earthwise.bgs.ac.uk/index.php/Hydrogeology_of_Nigeria*

Uma, K.O., Egboka, B.C.E. and Onuoha, K.M. (1989) New statistical grain size method for evaluating the hydraulic conductivity of sandy aquifers. *Jour. Hydrol* 108: 343-366.

Uma, K. and Loehnert, E.P. (1992) Research on the saline groundwaters in the Benue-Trough, Nigeria: Preliminary results and projections. *Zbl. Geol. Palaeont. Teil I*; Heft 11, Stuttgart, pp. 2751-2756.

WHO (1998) Guidelines for drinking-water quality, health criteria and other information. 2nd edition, Geneva, Switzerland, pp.2 81-283.

World Commission on Environment and Development (1987) *Our Common Future.* NY- Oxford University Press.

Zhang, X.P., Deng, W. and Yang, X.M. (2002) The background concentrations of 13 soil trace elements and their relationship to parent materials and vegetation in Xizang (Tibet), China. *J. Asian Earth Sci.* 21: 167-174.

BIODATA OF
PROFESSOR MOSHOOD NIYI TIJANI

Professor Moshood Niyi Tijani was born on the 3rd of June, 1965 into the family of Alhaji Ishola Tijani of Baba Ode's Compound, Ago-Oluwabi Area, of Saki in Saki-West LGA of Oyo State. His early childhood and primary education was characterized by good moral and disciplined upbringing. On completion of his primary education at the Baptist Primary School, Kinnikinni, Saki, he proceeded to the Ansar-Ur-Deen High School Saki for his secondary education from 1975 to 1981. He then gained admission to the University of Ilorin, Ilorin Kwara State in 1982 to study Geology and Mineral Sciences. At the end of the programme, he bagged a B.Sc. (Hons) Degree in Geology (Second Class Upper Division) as the best graduating student in 1986. After the mandatory National Youth Service at the Niger State Water Board, Minna, Niger State, he enrolled for a postgraduate Master's programme in Hydrogeology and Engineering Geology at the premier University of Ibadan, Ibadan and graduated in 1990 with a Ph.D grade. Barely a year later, he won a German Government (DAAD) Scholarship to undertake a professional postgraduate programme in Hydrogeology and Engineering Geology (with special reference to tropical and sub-tropical regions) at the University of Tuebingen, Germany between 1991 and 1992. The success of the programme culminated in another scholarship for a Doctorate Degree in Hydrogeology/Environmental Geology at the University of Muenster, Germany between 1993 and 1997.

Professor Tijani was a student trainee in the UNICEF-Assisted Water and Sanitation Project in Kwara State in 1985 and worked with Niger State Water Board as a Corp member in 1986–1987. He was employed as a Hydrogeologist by GEOSCIENCES Nig. Ltd (1987–1988) and NIGERHOPE Nig. Ltd. Drilling Engineers (1990–1991). On completion of his Ph.D programme in 1997, he was employed by the University of Ibadan in 1998 as a Lecturer II, became

Lecturer I in the same year, Senior Lecturer in 2002 and Reader in 2005 and was promoted a full Professor in 2008.

Professor Moshood Tijani is a recipient of a number of awards and prizes among which are: the University Scholar Award, University of Ilorin, Ilorin for three consecutive years (1984–1986); Departmental Prize for best Final year Student in 1986; German Academic Exchange (DAAD) Scholarship Award for Postgraduate Programme (1991–1997); Post-Doctoral Research Fellowship Award of the Matsumae International Foundation, Tokyo Japan (July–Dec. 2001) and Japanese Society for the Promotion of Science (2003–2005). In addition, Professor Tijani is a three-time winner of the NMGS-TOTAL AWARD for the best technical paper at the NMGS Annual Conferences i.e. First Prize in 2002, Third Prize in 2005 and Second Prize in 2015. He had also received a number of UNESCO and DAAD travel grants for International Conferences among which are Berlin, Germany (2005); Phoenix, Arizona, USA (2007); Siegen and Munich, Germany (2008); Ilmenau, German (2009); Braunschweig, Germany (2009), Abu-Dhabi, UAE (2010); Ilmenau and Berlin, German (2011); Kenya (2012); as well as Berlin and Munich (2014).

As an experienced Geoscientist, Professor Tijani is a Registered Geoscientist with the Nigerian Council of Mining Engineers and Geoscientist (COMEG), Member; Nigerian Mining and Geosciences Society (NMGS), Nigerian Association of Hydrogeologists (NAH), International Association of Hydrogeologists (IAH), International Association of Hydrological Society (IAHS). He is also a Life Member of Geological Society of Africa (GSAf) and Association of Geoscientists for International Development (AGID) as well as National Representative of the World Association of Soil and Water Conservation (WASWC). He is an Associate Editor of the Hydrogeology Journal (HJ), a publication of the International Association of Hydrogeologists (IAH) and he is currently the Editor-In-Chief of the Journal of Mining and Geology (JMG), a professional publication of the Nigerian Mining and

Geosciences Society (NMGS). He is also currently serving as the representative of the West African Anglophone on the Governing Board of the African Network of Earth Science Institutions (ANESI), UNESCO Office, Nairobi Kenya.

Professor Tijani's research is centered on Hydrogeology, Engineering Geology and Environmental Geology. He has (to-date) over 60 publications in learned journals and edited proceedings and has attended and presented papers at numerous international and local conferences. In addition to several B.Sc. projects, he has supervised about 50 M.Sc projects in Hydrogeology and 1 Ph.D thesis, while 5 others are at different levels of completion. He had collaborated with a number on international organizations on research studies notably; the British Geological Survey (BGS), National Research Foundation, UK, International Water Management Institute (IWMI), Council for the Development of Social Science Research in Africa (CODESRIA).

Professor Tijani had served the University of Ibadan in a number of capacities; as a member of a number of committees both at the Faculty and at the University levels. Professor Tijani also served as the Acting Head of Department of Geology, University of Ibadan, Ibadan from August, 2010 to April 2012 and appointed full Head of Department since May, 2012; a position he is holding till July 31, 2016. Outside the University of Ibadan, Professor Tijani served as examiner and external assessor to a number of other Universities, namely, Ahmadu Bello University, Zaria; Federal University of Technology, Akure; Federal University of Technology, Minna; Obafemi Awolowo University, Ile-Ife; Olabisi Onabanjo, University, Ago-Iwoye and University of Calabar, Calabar. He also served on several occasions as resource person to the Nigeria Geological Survey Agency (NGSA) on project reviews. Professor Tijani believes in family as well as community values and he is happily married to Dr. Sarafat A. Tijani of the Department of Agricultural Extension and Rural Management, University of Ibadan, Ibadan. The marriage is blessed with 3 promising boys.

NATIONAL ANTHEM

Arise, O compatriots
Nigeria's call obey
To serve our fatherland
With love and strength and faith
The labour of our heroes' past
Shall never be in vain
To serve with heart and might
One nation bound in freedom
Peace and unity

O God of creation
Direct our noble cause
Guide thou our leaders right
Help our youths the truth to know
In love and honesty to grow
And living just and true
Great lofty heights attain
To build a nation where peace
And justice shall reign

UNIVERSITY OF IBADAN ANTHEM

Unibadan, Fountainhead
Of true learning, deep and sound
Soothing spring for all who thirst
Bounds of knowledge to advance
Pledge to serve our cherished goals!
Self-reliance, unity
That our nation may with pride
Help to build a world that is truly free

Unibadan, first and best
Raise true minds for a noble cause
Social justice, equal chance
Greatness won with honest toil
Guide our people this to know
Wisdom's best to service turned
Help enshrine the right to learn
For a mind that knows is a mind that's free