Discharge and Sediment Redistribution in the Lower Niger Delta and Implications for Pollutant Evacuation in Tidal Estuaries

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Abstract
The Niger Delta is the ultimate receptacle of the waters and sediments transported by the Niger and Benue River systems; receiving more than 26,000 m^3/s during peak flows. Analysis of historical Niger River discharge distribution between 1953-2014 implicate the morphormetrics at the Asamabiri bifurcation into Forcados and Nun Rivers, the effects of which are manifested in changes in flood depth, water and sediment distribution, standing period of floods, changes in coastal erosion patterns, freshwater-saline water interfaces. The paper assesses the impact of dredging which disproportionately deepened the Nun, thereby increasing the bathymetric cross-sectional area and as a consequence allowed for a larger share of the Niger River discharge. The trajectory of flood water emanating from the Niger River through Orashi River to Sombreiro River at peak flow was explored for its benefits in flood impact mitigations. The relationship between sediment load and discharge for rivers in the Niger was analyzed, leading to empirical descriptive equations that correlate both. Ebb and flood tidal discharges for major river estuaries in the Niger delta were utilized in developing a flux efficiency index which determined the efficiency of coastal rivers in disposing of pollutants.
Keywords: Niger delta, discharge distribution, flux efficiency

Introduction
The Niger Delta is the ultimate receptacle of much of the waters and sediments transported by the Niger and Benue River systems. The Niger River traverses about 4,180 km, with a drainage basin of 2,117,700 km^2 in area and has a maximum discharge of 27,600 m^3/s. The Benué River on the other hand, is the major tributary of the Niger River and is approximately 1,400 kilometres long. It rises in the Adamawa Plateau of northern Cameroon, from where it flows west, and through the town of Garoua and Lagdo Reservoir, into Nigeria south of the Mandara mountains, and through Jimeta, Ibi and Makurdi before meeting the Niger at Lokoja. Large tributaries are the Gongola River and the Mayo Kebbi, which connects it with

the Logone River (part of the Lake Chad system) during floods. Other tributaries are Taraba River and River katsina Ala. This runoff comes mostly from the contributions of 5,589 m^3/s from the Niger and 3,400 m^3/s from Benue Rivers. Reports compiled by Chisholm in 1911 indicated that the Benué exceeded the Niger by volume at the point of confluence at peak flood with the additional contributions from its several tributaries. According to him, the mean discharge before 1960 was 3,400 m^3/s for the Benué and 2,500 m^3/s for the Niger. The large volume of water arriving the delta is redistributed by a network of at least 21no. distributary rivers (NEDECO, 1961) and creeks into the Atlantic ocean. Not having a substantive understanding of the distribution of these waters can frustrate mitigation efforts during floods as was recently experienced in 2012 when the vulnerability of the region to flood disasters was demonstrated. That flood event attained an unprecedented height, affected 2,389 communities in 231 Local Governments and killed about 431, injuring 29,680 persons and displacing 1,341,179 people in 35 of the 36 States of Nigeria. In addition it resulted in loss of properties, loss of agricultural yield and access to food, water and sanitation, education, crops and livestock, severe health impacts. Every sector of Nigeria's national life suffered set-backs attributed to this flood incident.

Geomorphology of the Niger Delta

Sediment originating in a vast and geologically complex hinterland is dispersed through the delta by river, tidal, wave, and ocean currents resulting in lithofacies that includes: channels, and point bars, back swamps as well as the alluvial and hydromorphic soils seen on the surface, which are subject to morphological changes. Lithofacies of this suite grade upward from open shelf clays, through pro-delta slope layered clays, silts, and sands, to well-bedded sands formed on the delta-front platform, river mouth bars, and beaches. Behind beach ridge barrier islands fringing the visible part of the delta occur tidal mangrove swamps in which organic-rich sands and silts are being deposited. Cross-stratified river bar sands are accumulating in association with top-stratum silts and clays in the delta floodplain environment. Sexton and Murday (1994) described the coastal geomorphology and sediment characteristics of the ND as consisting of three distinct morphological units: the Arcuate, Western and Eastern Deltas (Fig. 1).

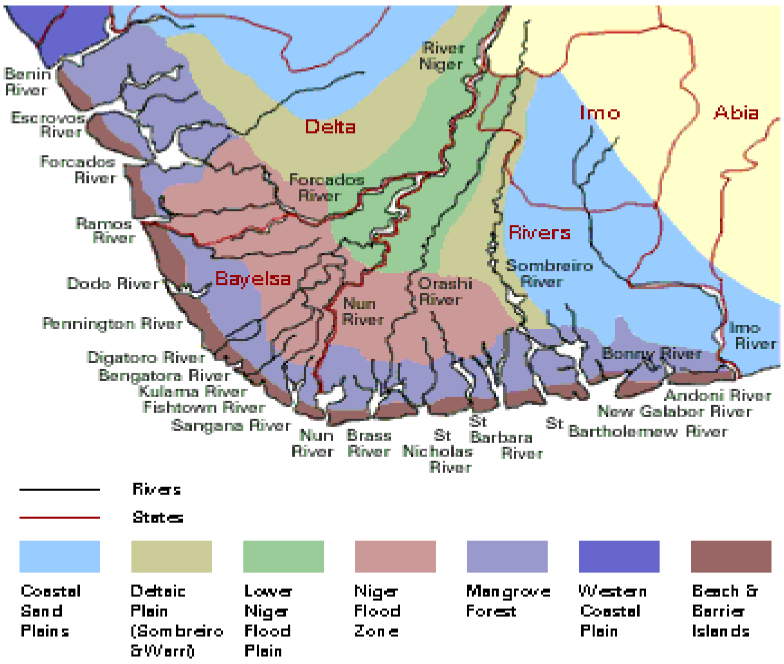

Fig.1: The Niger Delta, showing morphological areas

Over these several decades of human civilization and development, anthropogenic activities have introduced changes to the water balance, manifested as changes in the fluvial and sediment transport regimes of rivers. Several studies at different times show that the fluvial regime of the Nile Delta has been altered during the past 100 years through the intensification of anthropogenic activities, such as dam emplacement at Aswan and a series of barrages along the Nile (Stanley and Warne, 1993, 1998; Frihy *et al*., 1998; Stanley, 1990; Frihy, 1992; Frihy and Komar, 1993). There are reports of reduction in fluvial sand supply and variation in the Nile flooding, as a result of climate variability and relative sea level rise, resulting in the alteration of the Nile Delta coastline. By similar reasoning, the Niger delta cannot be an exception (Fig. 2) as demonstrated by Dada *et al*. (2015). The works of Abam (1999 and 2001), Abam and Beets (1996) and more recently by Itiveh and Bigg (2008); and Dada *et al.* (2015) show evidence of modifications of coastal morphology in response to anthropogenic activities.

The Significance of the Niger River bifurcation at Asamabiri

The distribution of the flood flow of the Niger River at Asamabiri to a large extent determines the extent of flooding in downstream catchments. Table (1) provides historical and recent distributions and demonstrates the changing structural and flow dynamics at the bifurcation. Fig. 3 captures the changing scenario between 1957 and 2014 and depicts the movements and changing shape of the sand bars, which in turn alter the bathymetry and by extension the discharge distribution of the River into Nun and Forcados Rivers. Apart from flood, flow distribution also drives ecological change.

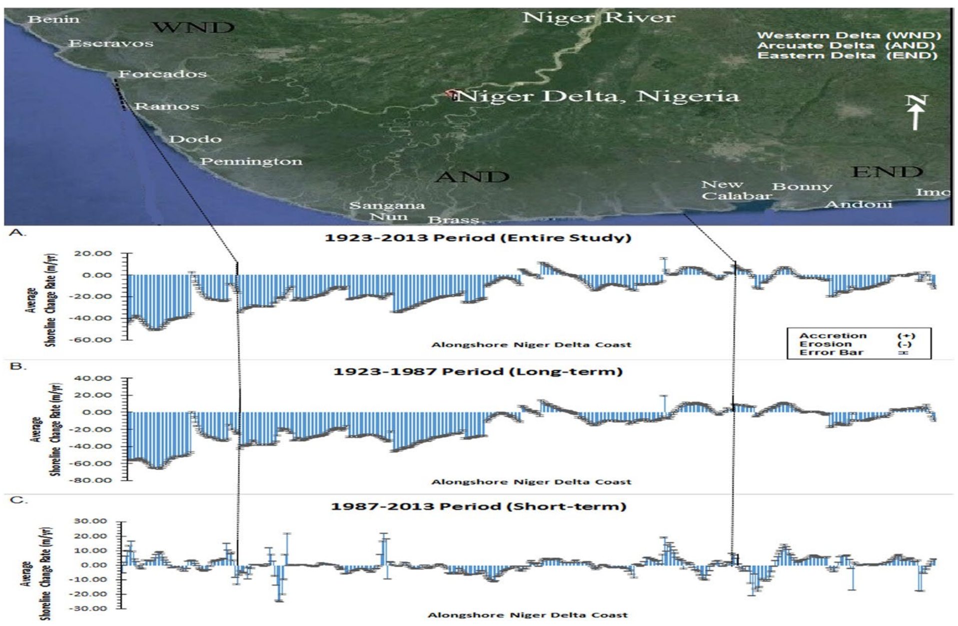

Fig. 2: Niger Delta linked to (A.) 1923–2013 (Entire) period; (B.) 1923–1987 (Long term) period; and (C.) 1987–2013 (Short-term) period shoreline change rates (m/year) for the Niger Delta, after Dada *et al.* (2015)

By altering the volume of water available for various ecological uses and functions, the standing period of water, saline/fresh water interfaces, fish nursery ground, plant speciation can be affected. It follows therefore, that activities with potential to alter bathymetry, also exercise the capacity to cause flood downstream or upstream as the case may be, as well as induce ecological change. The prolonged flooding of vast sections of River Nun flood plain was attributed to the OMPADEC dredging of Agbere/Odoni located at the Niger River Bifurcation at Asamabiri in 1998 (Abam, 2004).

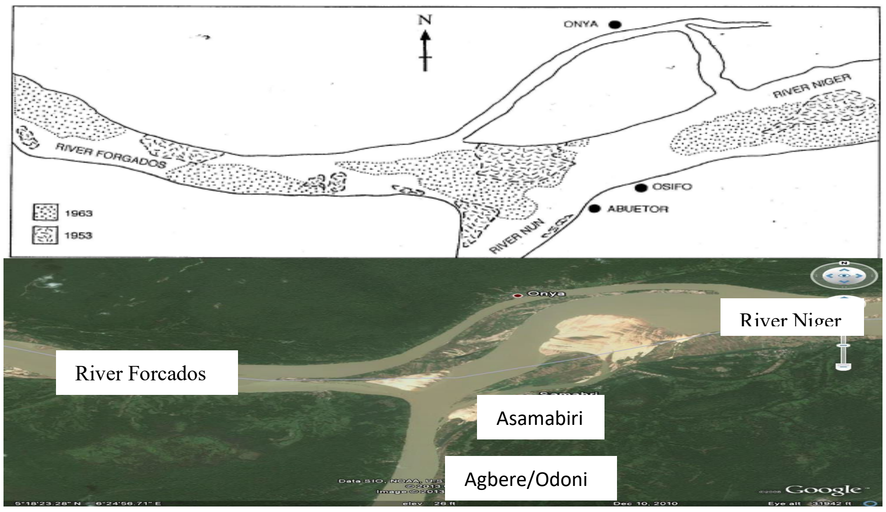

Fig. 3: The changing scenario of the Niger River bifurcation at Asamabiri

Rivers Forcados and Nun distribute nearly 100% of the Niger River waters arriving the bifurcation in proportions that reflect the bathymetric configuration at Asamabiri, to the south west and south east of the lower Niger delta, respectively (Fig. 4). Percentage distribution of the Niger River waters into Nun and Forcados prior to construction of Kainji dam was measured by NEDECO (1961). The discharge distribution in the years following Kainji dam commissioning up to 1998 is summarized in Table (1).

Table (1) Distribution of Discharge between Forcados and Nun Rivers

Survey Yr	Annual Discharge	Discharge through	Discharge through Nun (%)
1953/1954	NA	55	45
1959/1960	NA	60	40
1978	2499	55	45
1979	2464	55	45
1980	2358	55	45
1981	2364	55.01	44.09
1982	1871	54	46
1983	1267	55.01	44.99
1984	1353	55	45
1985-1997	NA	NA	NA
1998	5189	46	54

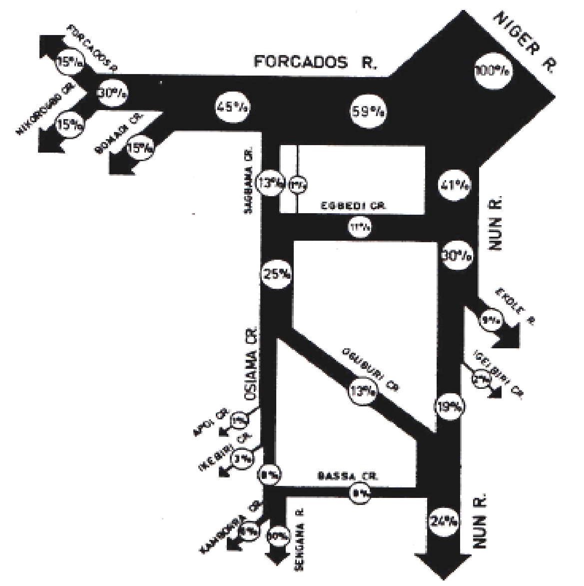

Fig. 4: Model of Niger Delta drainage Network showing pre-dam percentage discharge (NEDECO 1961)

The redistribution of the Niger River waters into secondary and tertiary distributaries is summarized in Table 2 for 1961, 1998 and 2012 to provide a comparative assessment of the volumes involved and the potential flooding impact that can arise. The average flow velocities for each of the secondary/tertiary river systems have also been measured to give an indication of the efficiency of the flush as well as the potential erosivity of the river/creek. Table (1) indicates that Forcados River transported a larger percentage of the Niger River waters prior to Kainji dam construction in 1968 and even up to 1998, when the river bed of was dredged around the Niger River bifurcation point near Agbere/Odoni. The dredging disproportionately deepened the Nun, thereby increasing the bathymetric cross-sectional area and as a consequence allowed for a larger share of the Niger River discharge. It is observed (Table 1) that the years following the commissioning of Kainji dam witnessed progressively smaller discharges until 1998 when a fairly high discharge was observed. This discharge resulted in extensive flood, especially on the Nun River and distributary areas. In 2012, Nigeria Hydrological Services Agency reported a record peak flow of 16,365m^3/s at Makurdi on the Benue River, just before the confluence. This peak discharge which was associated with the sudden opening of the spillway of Lagdo dam on the Benue River caused extensive flooding downstream.

Table 2: Discharge distribution in the Niger delta

Name of River/Creek	Flow velocity (m/s)	Volume (m^3/s)	% Discharge of Niger River by 1961	Average Post Kainji Dam Discharge (m^3/s)	Post (Agbere/Odoni) Dredge Discharge Distribution in 1998 (m^3/s)	2012 Discharge Volumes (m^3/s)
Forcados River at Asamabiri	1.14	9,200	57.5	3,680.00	2,386.94	10,120.00
Egbedi CR	1.18	4,700	29.375	1,880.00	1,936.72	8,211.18
Sagbama CR	1.24	2,200	13.75	880.00	570.79	2,420.00
Oguburi CR	0.96	2,000	12.5	800.00	518.90	2,200.00
Osiama CR	1.06	1,800	11.25	720.00	467.01	1,980.00
Bomadi CR	1.95	2,650	16.56	1,060.00	687.54	2,915.00
Nikorogbo CR	1.22	2,000	12.5	800.00	518.90	2,200.00
Nun at Asamabiri	1.4	6,800	42.5	2,720.00	2,802.06	11,880.00
Kamborra CR	1.05	770	4.8125	308.00	199.78	847.00
Sengana CR	0.98	1,900	11.875	760.00	782.93	3,319.41
Ekole CR	1.18	1,480	9.25	592.00	609.86	2,585.65
Igeibiri CR	1	480	3	192.00	197.79	838.59
Bassa CR	1.18	1,540	9.625	616.00	634.58	2,690.47
Ikebiri CR	0.83	340	2.125	136.00	88.21	374.00

Due to progressive reduction in downstream flow, accompanied by siltation, the flood plains of the lower Niger River shrank, encouraging encroachments of various forms of physical development. As a result, relatively lower discharges cause water levels to easily exceed the channel capacity, creating flood conditions. The impacts of these floods are also made higher because of the developments that have now encroached the flood plains. Larger discharges create higher water levels or flood levels that are accompanied by longer standing period. The spread of these flood is determined largely by a combination of factors including, the water level, the topography and structural connectivity of the drainage basin. It is for this reason that the Niger River upon attainment of a certain water level flows into Orashi River. It is estimated that some 15% of Orashi River discharge is contributed by Niger River. These flow contributions are effected sometime late August to early September. In the same way, the Orashi River spills over to the Sombreiro River at a number of points including the Obrikom Bridge as experienced in September, 2012. The trajectory of the flood indicated that it approached the East-West Road almost at right angles (Fig. 5).The road with its limited through-flow significantly impeded downstream discharge of the flood water, thereby increasing upstream water level, flood standing time, erosivity and aggregate adverse impact on the socio-economic activities in the area.

Some major applications of discharge distribution are flood control and sedimentation management. A not so explicit application is pollution dispersion. As is well known, sediment load is directly correlated with discharge (Colby, 1956; Restrepo and Kjerfve, 2000). This direct correlation appears to be also true for the Niger Delta, where Wash load, suspended load and Bedload for some major rivers are directly correlated to various degrees (Fig. 6). The correlation of discharge with sediment load implies that sediment delivery to the coastline by rivers of known discharge can be predicted. The series of transgression and regression cycles in combination with currents (tidal, rip and longshore) and waves essentially redistributed fluvial sediments delivered to the area in the reconstruction of the Niger delta coastlines.

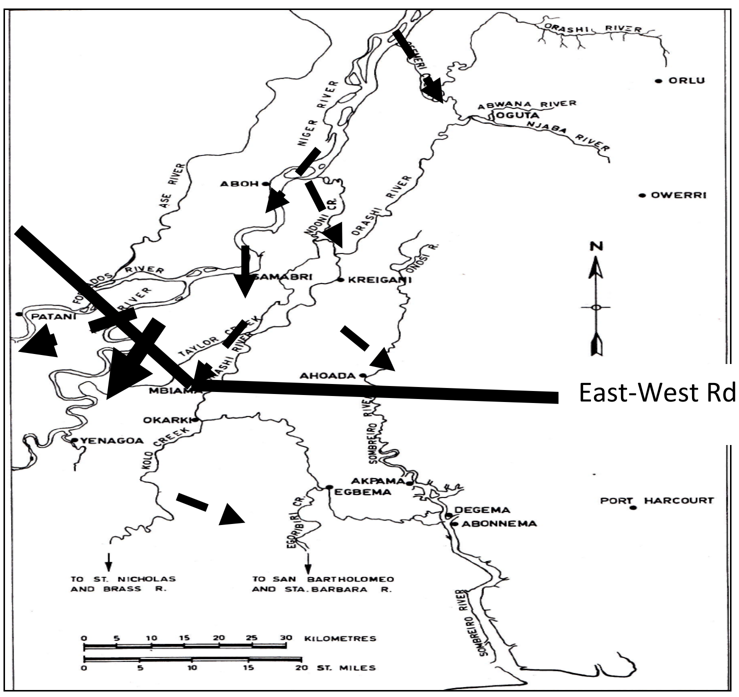

Fig. 5: The drainage system of Orashi River showing 2012 flood trajectory

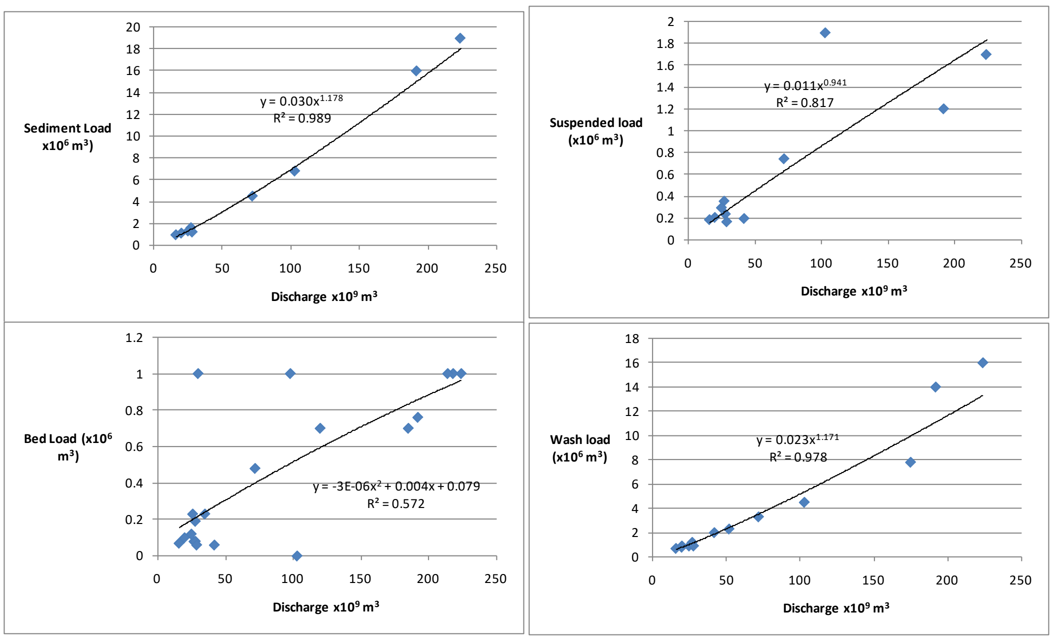

Fig. 6: Relationship between Discharge and Sediment load

The tidal estuaries of the Niger Delta are very dynamic due to the combined actions of continuous tidal and sediment fluxes, currents and waves in the area. In a region with a history of oil production and spillages, it is important to appreciate the potential role of tidal fluxes in the dispersion and disintegration of crude oil spills. Antia (2015) monitored tidal water bodies of three rivers in the eastern Niger delta for their flow velocity pattern to determine excursion lengths of a potential buoyant pollutant during a complete semi-diurnal cycle. While this approach may be appropriate for contingency planning for spill control, it may not adequately determine the potential for self cleansing which is better reflected by the river discharge that embraces not only velocity, but cross-sectional area and by extension total flow and turbulence. The ebb and flood tide discharge through the river estuaries across the Niger delta is shown in Fig. 7.

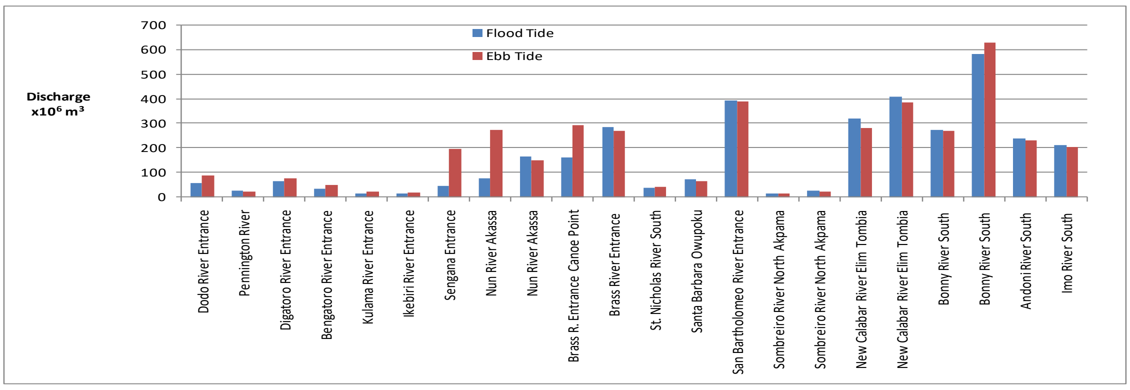

Fig.7: Variation of Discharge across the Niger Delta

Tidal excursion length and discharge varied in river estuaries across the coastline over time, because of differences in the intensity and magnitude of factors affecting flow in the estuaries. Ebb or flood tide discharge alone may not account for the efficiency with which a river is able to flux out pollutants. However, when both are compared and then normalized as a ratio, discharge can be used in a meaningful way as an index of flux efficiency. This index has been expressed by the relationship $(Q_{flood} - Q_{ebb})/Q_{flood}$. It is implicit from this relationship that negative sign of the ratio would imply a net outward flux into the ocean, while the intensity or efficiency of the flux is indicated by the magnitude of the index. This approach has been applied to the major river estuaries in the Niger Delta (Fig.8) using pre-dam discharge values and well as simulated post 1998 discharge values in order to determine possible changes in fluxing efficiency in the estuaries across the coastline of the Niger delta.

Fig. 8 shows a net ebb tide flux with the Nun River estuary being the most efficient. Most of the rivers to the west of Brass which are fed by Forcados River exhibited relatively stronger flux efficiencies prior to 1998. This may be directly attributed to the relatively higher proportion (59%) of Niger River waters transported through Forcados River during this period. The rivers to the east between New Calabar and Imo Rivers exhibited very weak ebb tide asymmetry or net upstream flow. Two reasons account for this trend; (i) firstly the fact that these rivers receive little or no freshwater influx from upstream sources, a matter made worse during the dry season with little rainfall, (ii) the flood tide flows are channelled to interconnected creek/rivers and discharged through other routes. After 1998, the flow through Nun River was increased, with corresponding increase in freshwater influx into the rivers between Sengana and St. Nicholas Rivers. The effect of this increase also impacted directly on the flux efficiencies of these rivers.

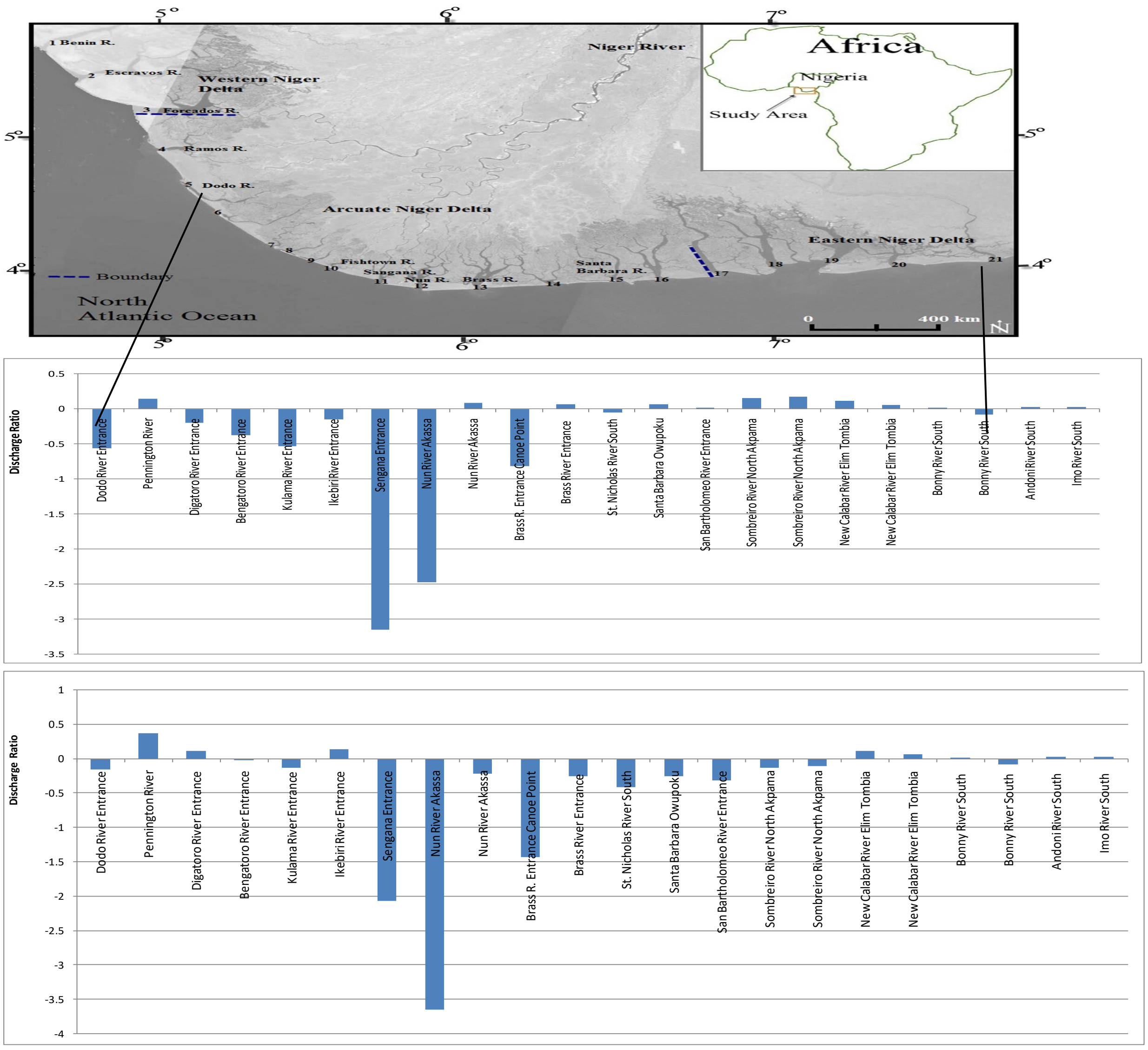

Fig. 8: Flux efficiency ratios for rivers in the Niger Delta, Pre-Dam (1961) and Post-1998

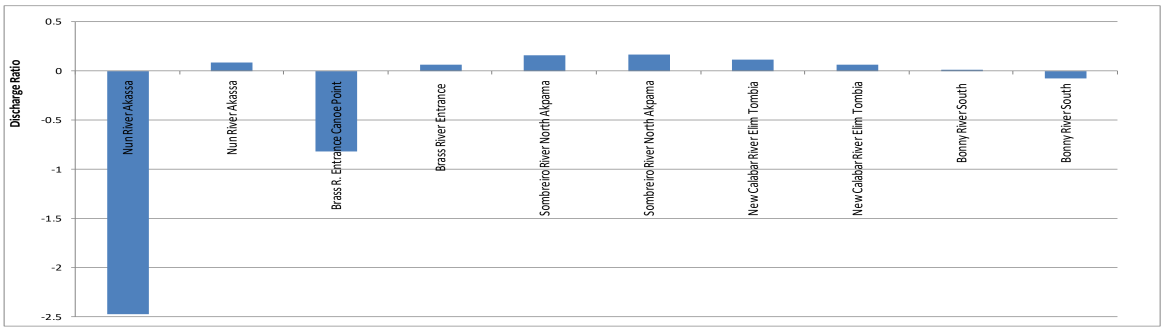

Fig. 9: Comparative Flux efficiency ratios for selected rivers in the Niger Delta, for Wet and Dry season flows

The effect of seasonal influence of discharge on the flux efficiency is captured in Fig. (9), where flux efficiencies for the same river cross section have been computed for wet and dry season discharges. With reduced freshwater influx during the dry season, there is a clear tendency for the flux efficiency to be positive, which will then support longer resident time of pollutants and by extension, low self cleansing competence. A similar situation was reported by Antia (2015) using essentially velocity data in which the estuaries and tidal river showed an ebb-asymmetry for the net tidal excursion length consistent with the prevailing net ebb velocity- and time –asymmetry. However, the creeks indicated no asymmetry in net tidal excursion length. This suggests that, unlike the creeks and rivers with little or no fresh inflows with a high tendency to retain pollutants, the estuaries and tidal river have the capacity to naturally self-cleanse themselves of influx of pollutants. This time-varying self-cleansing competency over a semi-diurnal tide reflects the maximum net ebb (ocean – ward) excursion length.

Conclusions

The Niger Delta receives a considerable amount of water and sediments from the Niger/Benue River discharges which exceed 26,000m^3/s during peak flows. The relative amount of water and sediments distributed to the distributary rivers is largely determined by the shape of the sand bars otherwise called morphormetrics at the Asamabiri bifurcation, where the Niger River splits into Forcados and Nun Rivers. The Nun River now receives 54% of the discharge (water and sediments) from the Niger River, which is 10% more than its historical share. The effects of this additional inflow is cascaded downstream to distributary rivers which experience changes in flood depth, water and sediment distribution, standing period of floods, changes in coastal erosion patterns, freshwater-saline water interfaces. The trajectory of flood water emanating from the Niger River through Orashi River to Sombreiro River at peak flow has now been determined with benefits in flood impact mitigations. Empirical relationship between sediment load and discharge for rivers in the Niger has been developed. Furthermore, a flux efficiency index which determined the efficiency of coastal rivers in disposing of pollutants has also been developed.

A net ebb tide flux has been observed in most rivers in the Niger delta with the Nun River estuary being the most efficient. Most of the rivers to the west of Brass which are fed by Forcados River exhibited relatively stronger flux efficiencies prior to 1998 by reason of receiving 59% of Niger River waters transported through Forcados River during this period. The rivers to the east between New Calabar and Imo Rivers exhibited very weak ebb tide asymmetry or net upstream flow largely because of the fact that these rivers receive little or no freshwater influx from upstream sources. After 1998, the flow through Nun River was increased, with corresponding increase in freshwater influx into the rivers between Sengana and St. Nicholas Rivers. The effect of this increase also impacted directly on the flux efficiencies of these rivers.

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An Overview of Flood Vulnerability Mapping: Strategy for Disaster Risk Reduction in the Niger Delta Region, Nigeria

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Abstract

Persistent flood disasters in the Niger Delta region continuously pose diverse challenges to the sustainable development of the region. Unfortunately, existing institutional policies on flood control has failed to adequately complement known structural measures with the relevant non-structural measures of flood risk management. The failure had been that the relevance of cartographic ingenuity in flood data collection and flood mapping are poorly understood, inappropriately underestimated, and so, are hardly ever reported. This review article provides deep understanding of flood vulnerability mapping as an often neglected non-structural measure in flood prone regions of developing countries, and showcases its applicability in the Niger Delta region of Nigeria for flood risk disaster reductions. To achieve this, an extensive systematic review was conducted on flood vulnerability mapping related peer-reviewed journal articles and documents domiciled in the Web of Science, Scopus and other relevant institutional databases. Lessons were drawn from some successful country-based experiences on the use of maps in modern-day management of flood risk disasters. The review further reveals the underlying potentials and procedure of flood vulnerability mapping as a robust non-structural strategy that is reliable and should precede structural measures in the management of flood risks and flood hazards in the Niger Delta region.

Keywords: Flood risk, flood vulnerability map, mitigation strategy and Niger Delta region

Introduction

Historically, flood disasters have been observed to be on the increase due to persistent regional environmental changes and global climatic uncertainties. For that reason, flood related risks currently ranks high among the major causes of devastations that constitute problematic issues to contend with at all levels of human society; such that, developmental processes in many countries are slowed down or brought to a standstill (Intergovernmental

Panel on Climate Change IPCC, 2013; United Nations Office for Disaster Risk Reduction-UNISDR, 2015, Li, *et al.,* 2016). As if that is not enough, the current escalations in human population growth, demanding for socio-economic spaces with respect to human occupancy and infrastructural development, continue to place more lives and properties at risk of future flood disasters (Komolafe *et al*., 2015; Kron, 2015; Li, *et al*., 2016). To that effect, the Executive Director of the United Nations Environment Programme – Achim Steiner, posits that "the invoice for our climate-changing emissions and 'other human impacts' will include more floods, droughts and other natural disasters. So, we need to 'climate proof' our farms, our infrastructure and our livelihoods in order to minimize our vulnerability to future disasters." In reality, such a call should appeal more to exposed regions of the world. Nevertheless, no nation is left out as all nations are exposed in a way, or is in danger of one form of natural disaster.

It is clear from previous studies (e.g. Abam, 1995; Ologunorisa and Adeyemo, 2005; Uyigue and Agho, 2007; Mmom and Aifesehi, 2013; Tawari-Fufeyin, Paul and Godleads, 2015) that the Niger Delta region of Nigeria is challenged by a myriad of disasters, including devastating extreme natural events, which continue to render most of its sections highly vulnerable to all sorts of ecological and environmental hazards (Aziagba 1991, Oyebande and Balogun, 1992, Abam, 1995, Ologunorisa, 2004, Ologunorisa and Adeyemo, 2005, Uyigue and Agho, 2007, Ishaya, *et al*., 2009, Tesi, *et al*., 2016). Particularly, the Niger Delta region is vulnerable to climate change impacts for reasons of its fragile ecosystem, oil and gas industrial – human activities such as gas flaring which seriously alter rainfall pattern, and heighten the susceptibility of climate change and its effects in the region (Nzeadibe, *et al*., 2012). As a result, flood risk reduction is a concern of critical consequence within and around the Niger delta region of Nigeria.

To that effect, some explanations to the peculiarity of flood type inundations and their consequences in the region have been proffered. Based on the general definition of flood – an overflow of water that submerges land or a covering by water of land that is not normally covered by water, Fubara (2014) identifies and distinguishes between three flood hazard types in the region (i) River overflow, (ii) Tidal overflow, and (iii) Meteorological flash floods. River overflow results to floods when the flowing water in the river exceeds the carrying capacity of the channel and the banks. Tidal run over occurs when gravitational pull by undersea mountains alters the local gravity field of the earth, and attractions by the sun and moon on the ocean, thereby causing water torrents to rise (flow) and fall in height. While meteorological flash floods occur in human settlements and affect infrastructure, due to high intensity rainfall, intense thunderstorms, dam break or intentional dam water release (eg Cameroon's release of water from its Lagdo dam in 2012) which accumulate waters over impermeable surface or saturated soil, especially, when the receiving end (River Benue in Nigeria) does not have the adequate drainage capacity (Aka and Yokoyama, 2013; Fubara, 2014; Agada and Nirupama, 2015). Despite existing awareness of the peculiarity of these flood types in the region, they yet seem to be less information of adequate mitigation strategies. This was evident by the magnitude of impacts recorded in Nigeria during and after the 2012 flood disaster – over two million people were internally displaced with about four hundred lives lost and N2.29 trillion worth of properties destroyed by the floods (National Emergency Management Agency NEMA, 2013 and Tawari-Fufeyin, *et al.,* 2015). Most states in the Niger Delta region – Bayelsa, Delta and Rivers which serves as the economic base of the nation were the most affected by the floods (Mmom and Aifesehi, 2013).

Unfortunately, the only known non-structural post-flood assessment after the 2012 event has been awareness creation for settlements to evacuate floodplains. But no specific location or emergency camp often called 'Internally Displaced Peoples' Camp – IDP have been provided for these vulnerable indigent populace in the Niger Delta Region. The idea of relocation may be fine, but yet remain incomplete where no clear cut provisions and directives are given. As such, this may not guarantee the people's safety from flood risk, nor give details of the expected magnitude, depth, height or direction of future floods. So, asking local inhabitants who understand less about current changes on regional and global climates, but are reliant on 'indigenous adaptive measures' to evacuate their ancestral settlements in floodplains to unknown destinations, may be ascribed to the ancient metaphor, of '*the blind leading the blind*'. Though, awareness creation is a non-structural strategy, nevertheless, it cannot assume a holistic position in flood disaster risk reduction.

This lacuna was resoundingly expressed and debated upon when delegates at the last National Conference in 2014, requested for the immediate review of the National Policy on Erosion and Flood Control in Nigeria (National Conference Report, NCR, 2014:207-208). The national policy had failed to address the regular mapping of shorelines and river banks that should have led to the production of maps of all vulnerable floodplains, dredging of shallow waters and the assessment of hydrographic features of all rivers, which is a prerequisite in predicting and averting impending flood disasters (NCR, 2014). However, it was observed that flood modeling and a lack of provision of flood data integration with other non-structural approaches to flood risk reduction have been largely ignored in the past (Nkwunonwo, *et al.*, 2015). Another key reason for the failure had been that the relevance of local or public participation which enhances cartographic resourcefulness in flood data collection and flood mapping are poorly understood, inappropriately underestimated, and so, is hardly ever reported. This is why the National Policy on Erosion and Flood Control failed, so it became an imperative issue of national discourse. Therefore, demystifying flood vulnerability mapping as an often neglected non-structural measure in coastal regions of developing countries, and showcasing its potentials and applicability in the Niger Delta region of Nigeria is the main focus of this paper.

To achieve this aim, we appraised the conceptualization of map production for the singular purpose of its application in flood risk management framework. This is done to provide deep understanding of flood vulnerability mapping as a key non-structural mechanism that is required in modern-day management of flood risk disasters (European Commission, 2007; APFM, 2013; Els and van Niekerk, 2013; United Nations office for Disaster Risk Reduction UNISDR, 2015). An extensive qualitative, but systematic review of relevant literature was conducted. We began by coining keywords that aided in the identification of empirical and conceptual studies domiciled in online repository and institutional research libraries (for example, Donald Ekong Library in the University of Port Harcourt, Online repository of the National Emergency Management Agency and the online repository of the United Nations office for Disaster Risk Reduction – http://www.preventionweb.net/organizations/3402).

Given that the growing body of flood risk-based studies (e.g., Kellens, *et al.,* 2013; Nkwunonwo, *et al.,* 2015; Rufat *et al.,* 2015; Aitsi-Selmi, *et al.,* 2016) have continued to lay credence to innovative web-based research tools and its dynamic contribution to populate the global flood disaster risk reduction domain. For instance, it has been observed that the Web of Science is a highly esteemed database, which—according to the database publisher—provides seamless access to multidisciplinary coverage of more than 10,000 high impact journals in the sciences, environment, social sciences, arts and humanities, as well as international proceedings coverage for more than 120,000 conferences. Scopus is a relatively new but rapidly expanding database, and claims to be the largest abstract and citation database, containing over 17,000 peer review journals (Kellens, *et al.,* 2013).

One hundred and ten (110) articles were collected and their respective abstracts and preambles were read with special focus on the application of maps or flood risk mapping strategy in flood mitigation and management. The search was holistic; however, emphasis was placed on flood events in Nigeria, with particular reference to the Niger delta region. This approach was used to synthesize 72 out of the 110 articles that centered on the aim of the paper, and so were analysed accordingly. In doing this, the indispensable relevance and vast information on flood vulnerability mapping in regional management of flood risk in flood prone areas were brought forth, for use in policy and decision making in the flood management sector. As such, lessons were drawn from some successful country-based experiences in modern-day management of flood risk disasters. The remainder of the article presents some prospects that flood vulnerability mapping upholds for the Niger Delta Region based on technical illustrations by Merz *et al.* (2007) and de Moel *et al.* (2009), which has proven successful in many European countries.

The article is structured in the following order: section 1 is an introduction that dwells on the background information for the need for flood mapping tools in the Niger Delta region and describes the systematic review method employed in the study. Section 2 describes the geography of the Niger Delta region. Section 3 illustrates how exposed and vulnerable the region is to flood risk. Section 4 presents theoretical and conceptual clarification on the connection between vulnerability, flood risk, risk elements and disaster reduction. Section 5 discusses some relevant flood mapping perspectives from different countries worthy of emulation. To this end, prospects of flood mapping, types, uses and benefits were explored; while the conclusions are provided in section 6.

Geography of the Niger Delta Region

Geographically, the Niger Delta region lies between Lat. 4^0 16``50`N; $9^0$ 20`` 10`N and Longitude 4^0 50`` 20`E; $7^0$ 50`` 00`E. Geopolitically, the region comprises of nine states – Abia, Akwa Ibon, Bayelsa, Cross River, Delta, Edo, Imo, Ondo and Rivers (Fig. 1), which was created in accordance with the Niger Delta Regional Development Master Plan (Federal Republic of Nigeria, 2004).

Fig. 1: Niger Delta Region of Nigeria

The region covers an area of 70,000 Km^2 of marshland, creeks, tributaries and lagoons that drain the Niger River into the Atlantic at the Bight of Biafra (World Bank, 1995). About one-third of this area is fragile mangrove forest, the second largest mangrove forest in the world. The biodiversity of the Niger Delta is very high with the area containing diverse plant and animal species, including many endangered, exotic and endemic animals and plants. It has an estimated population of about 30 million people, the bulk of which lives in rural fishing and farming communities (National Population Commission, 2009). The Niger Delta region is also the headquarters of Nigeria's oil and gas industry and currently the only oil and gas producing region in Nigeria (Nzeadibe *et al.,* 2012).

Flood Risk Exposure of the Niger Delta Region

The climatic impact from the complex atmospheric general circulations and influence of the South Atlantic Ocean dipole (SAOD) on summer precipitation over the Guinea Coast of West Africa has been linked to flood occurrences in the Niger Delta region (Nnamchi, *et al.,* 2012). It was reported that in its active years, the SAOD is a dominant mechanism that shapes the spatial character of summer precipitation at the entire Gulf of Guinea which is bounded by the Niger Delta region and other coastal settlements in West Africa. During this period, precipitation cascade tends to enlarge the sub-tropical arm of anomalous *Hadley-type* circulation and consequently large scale convection and mass flux convergence in the equatorial Gulf of Guinea region bordering the coastal fringes of West Africa where the Niger-Delta lies (Fontaine, Janicot and Moron, 1995; Nnamchi, *et al.,* 2012).

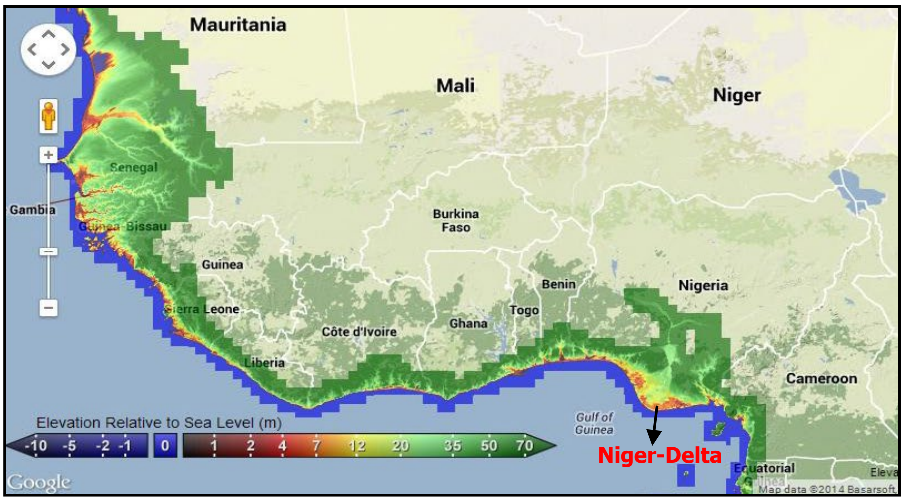

Fig. 2: Flood vulnerability with respect to coastal elevations and sea level rise in the Niger Delta Region. Source: Google, (2014).

Flood vulnerability level across the region is quite high given to the region's coastal elevations of < 4m in most sections, and <7m in others. The region's coastal elevation scenario is greatly impacted by continual *eustacy* (*see Fig. 2*). Meaning that floods can occur when sea level rises to encroach unto low relief coast lands during tidal surges and anomalous flood-producing rain, which then results to flood waters attaining heights approximately 3.2meters in most sections (Mmom and Aifesehi, 2013). Based on the dynamic physical forcings of the complex atmospheric general circulations and influence over the entire Gulf of Guinea (i.e. sea-land physical interactions, coupled with low elevations of the Niger Delta region), a hypothetical construct is modeled in the present study to show that coastal flood does prevail more in the region than other types of floods (Fig. 2).

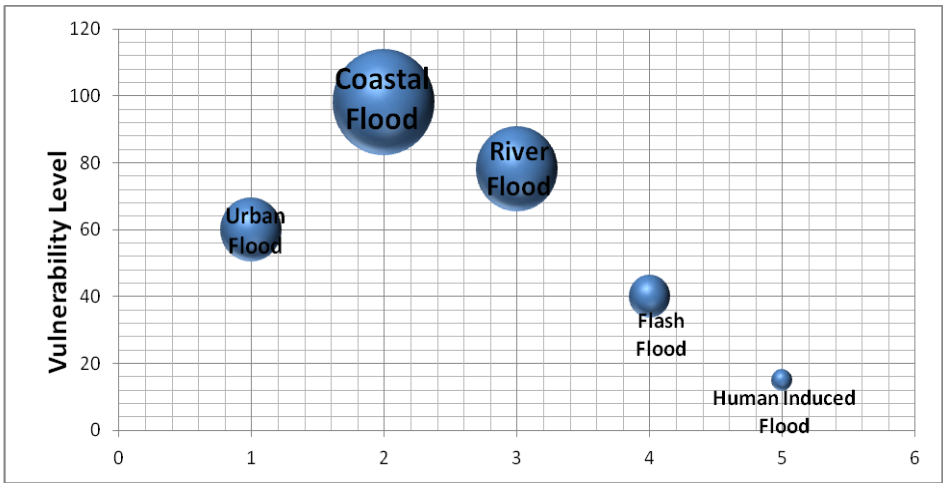

Fig. 2: A hypothetical construct of persistent flood types in the Niger Delta Region

In spite of the high disaster levels – huge losses of lives, properties and means of livelihood, reconnaissance survey of the region revealed that the dynamic movement of water during the 2012 flood event affected different ecological components by altering biophysical, physicochemical conditions of the region. This, however, increased the sensitivity and risk level of the regions' ecosystem health and biophysical environment, which comprises of biotic and abiotic habitats. Likewise, species populations are forced to migrate arbitrarily, while soil physicochemical contents are redistributed, to accidentally pollute downstream catchments. Till date, most communities in the region have not recovered from the impacts of the 2012 events, yet much greater floods are anticipated in the coming years, according to the recent awareness and sensitization campaign by the Nigeria Hydrological Services Agency - http://www.preventionweb.net/news/view/45017.

Additionally, the continuous uncensored oil seismic surveys, explorations and expansion in oil and gas activities (Ibe, 1988), unplanned settlement pattern, weak urban drainage facilities in the region culminates into poor urban design; and this, contributes a great deal to the increased impacts on livelihood and ecological degradation at the slightest chance of occurrence of the coastal and other types of floods. This is an indication of the regions high susceptibility to flood disasters, and therefore, suggests that the establishment of additional non-structural measures such as flood vulnerability mapping be given adequate consideration. This is possible only when policy and decision makers in the disaster risk reduction sector are armed with adequate information to provide them with the relevant understanding/information with respect to available non-structural measures.

Conceptual Elucidation

Flood risk assessment and flood vulnerability mapping

Consequent upon the geographic and socioeconomic attributes of the Niger Delta Region, the resultant effects of flood events in the region often appear multifaceted. So, assessing a flood hazard in such a scenario requires detailed consideration of elements of flood magnitude, such as flood type, depth, velocity and duration and other socioeconomic damages caused. As such, at the slightest occurrence of flood event, disaster risk managers, urban planners and flood risk experts and stakeholders are confronted with complexities often requiring multidisciplinary and interdisciplinary collaborations or institutional efforts to manage flood risk in the region. In this regard, a conceptual explanation is given to establish the connection between vulnerability, elements at risk, hazard and disaster as it concerns multi-integrated flood management by risk managers.

First, it is salient to understand that vulnerability and risk are highly interwoven and go hand in hand. Vulnerability is a condition that is determined by physical, social, economic, and environmental factors that increases the susceptibility of a community to the impact of hazard (Tingsanchali, 2012). When flood waters physically encroach on people and infrastructure – as it was the case in our region of interest in 2012, then the vulnerability of people and infrastructure becomes central, especially when they are unable to avert the impending disaster. According to the United Nations office for Disaster Risk Reduction UNISDR, (2015) such situation actually defines the risk factor in disaster management. In other words, risk is the probability of harmful consequences, or expected losses (i.e. lives lost, persons injured, damage to property and/or the environment, livelihoods lost, disruption of economic activity or social systems) due to the interaction between humans, hazards and vulnerable conditions (Ologunorisa, 2004; Olorunfemi and Adebimpe, 2008; Tesi, *et al.,* 2016).

Hazard conditions that represent risk may be natural – geological, hydro-meteorological and biological, and anthropogenic – human/technological induced environmental degradation, or both (Olorunfemi and Adebimpe, 2008). When these conditions are left unattended to, most times, disaster is the outcome of such unpreventable hazard conditions (Van Niekerk, 2015). Unfortunately, even with the abounding pre- and post-flood institutional warnings of Nigeria’s hydro-metrological conditions (Obeta, 2014), the current climatic variability yet exposes Niger Delta region to more flood risk conditions. In this paper, we follow the interpretation of vulnerability as being a function of a system's exposure to risk or stress, its sensitivity, and its adaptive capacity (IPCC, 2001).

$V = f(E, S, AC)$ (1)

where V is vulnerability, E is the exposure or element at risk, S is the sensitivity, and AC is the adaptive capacity.

Exploring, from the vulnerability standpoint, contributory factors of flood disasters are first determined. Components of vulnerability i.e. infrastructure at risk, level of sensitivity and perceived coping strategies are usually itemized and presented in quantitative terms (Liersch, *et al*., 2012). In some places, components of vulnerability are insured (Burby, 2001) to ensure accurate quantification and assessments in events of sudden flood disaster. In such cases, flood maps can aid in the interpretation of probable consequences of floods, help in the evacuation process and protection of infrastructure (Merz *et al.,* 2007; Maps, 2012).

To bring about clarity and precision, Liersch *et al.* (2012) illustrated the concept in their study by applying vulnerability theory to rice production in the management of water resources under climate variability and change. The quantitative values derived were used to explain better, and visualize (using flood maps) the change of the vulnerability components under different scenarios. Flood vulnerability mapping can be an effective flood risk communication strategy (either through maps, charts, simulations and/or by sensitization etc) which presents better understanding and conceptualization of the causal factors that influence flood disasters and how the risk of flooding is particularly perceived by the vulnerable people. Merz *et al.* (2007) further explains that it can aid the description of flood risk at different scales, ranging from the global to the local scale, and for different groups (de Moel, *et al.,* 2015). Case studies for strategies at the global scale are the analyses of Lehner and Döll, (2001) with maps relating to the flood circumstances in Europe under climate change, and the world map of natural hazards (Berz *et al.,* 2001; van Alphen, and Passchier, 2007), showing, among others, areas threatened by floods due to storm surges and severe rainfall.

Though, most flood risk mapping strategies are mainly designed for the local or regional scale concerns. Such maps also permit to evaluate flood condition of single land parcels and objects like buildings and other risk elements in communities. They are the basis for local flood defense measures (Merz *et al*., 2007). Usually, maps at the local scale have a scale of

1:2000 to 1:20,000, but regional peculiarity can detect risk elements and flood map design (de Moel *et al.,* 2009). This approach enhances the chances for identifying flood events caused by natural or anthropogenic factors or by a combination of both. Identifying a flood causative factor requires the understanding that risk is the probability of loss in the case of a disaster. The knowledge of prevailing flood types – river, coastal, flash, areal and urban, in addition to relevant multi-criteria approaches (Associated Programme on Flood Management APFM, 2013), which are capable of revealing similarities, characteristics and the disaster components (i.e. hazard, vulnerability and risk) associated with every flood event, remains a priority for the public, government, insurance companies and stakeholders in the flood risk management sector of every flood prone region or country.

In this regard, some notable international flood management debates have advocated for the integration of non-structural measures of flood vulnerability mapping into flood risk contingency plan, to be domesticated at the regional and local levels (European Commission, 2007; APFM, 2013; Els and van Niekerk, 2013). With respect to the peculiarity of regional and external influencing factors, non-structural measures ensures that flood hazard assessments maintain concerted proactive approach by the use of appropriate participatory engagements (Gaillard *et al.,* 2013) and instruments such as Geographic Information System, Remote Sensing and other relevant mapping tools for producing flood maps and flood decision support system (Marzocchi *et al.,* 2014; UNISDR, 2015).

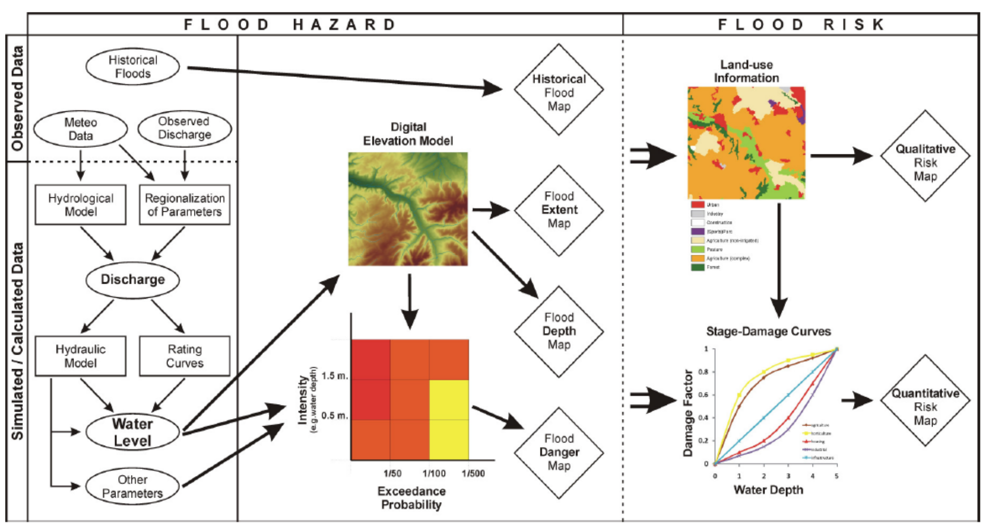

Fig. 3. Conceptual framework for flood hazard and flood risk mapping

*(The matrix and curves are purely illustrative and based on a hypothetical case. In the matrix the yellow colour signifies low danger, the orange colour moderate danger and the red colour high danger)(*de Moel, van Alphen and Aerts, 2009).

As an effective non-structural measure, flood vulnerability mapping typically stem from a functional geospatial capacity (Sanyal, and Lu, 2004; Seth, 2013), designed to guide the physical instrumentation and the implementation to completion of a flood management framework. It is a process in which the flood hazard/risk maps are made, through structured procedures (Fig. 3) like data collection and manipulation, flood data simulations and modeling to flood map production. Flood maps exist in many different forms, but in general it is possible to distinguish between flood hazard and flood risk maps. Flood hazard maps contain information about the probability and/or magnitude of an event whereas flood risk maps contain additional information about the consequences (e.g. economic damage, number of people affected). Within these two general types, however, there are different methods available to quantify hazards and risks resulting in different types of flood maps (Merz *et al.,* 2007; de Moel, 2009, Maps, 2012).

Given that disasters are inevitably the net product of the effects of severe natural events, huge losses of both lives and properties are frequently observed in the region, and this was evident during the 2012 flood disasters (Mmom and Aifesehi, 2013; National Emergency Management Agency NEMA, 2013 and Nkwunonwo *et al.,* 2015). We therefore classify flood as a localized hazard that is recurrent in the Niger Delta region. Sometimes it occurs with raging torrents, attaining heights of approximately 3.2meters within river drainage catchments – for instance, in the Orashi and Sombrairo basins, and less in the upper Emuoha axis of the New Calabar River (Mmom and Aifesehi, 2013). Identifying all risk components within and around the vulnerable basins is the ideal starting point in flood vulnerability mapping for the Niger Delta region. Having in place the right apparatus or standard framework for the purposes of combating and managing impending flood hazards is a *sine-qua-non* to the effective management of flood hazard worldover (United Nations office for Disaster Risk Reduction UNISDR, 2015) and so it ought to be for the Niger Delta region.

Flood Mapping Perspectives: Relevant lessons

The mapping of flood hazards is not new, as numerous governments, public and private institutions have already mapped and are still mapping flood hazards for different purposes.

Most regions and countries of the world have keyed into the integrated flood management joint initiative introduced by the Associated Programme on Flood Management, and have started rolling out detailed mechanisms that can operate under a functional flood control programme (European Commission, 2007; Els and van Niekerk, 2013; Getahun and Gebre, 2015). For instance, the Flood Directive of the European Union, enacted in November 2007, requires member states to create both flood hazard and flood risk maps of all floodplains (European Commission, 2007). Some of these established mechanisms largely involve detail mapping of vulnerability levels and risk zones in floodplains, basically for human occupancy; such that proper understanding can be obtained by way of visual interpretation.
In Europe, most large-scale flood mapping activities were initiated during the late 1990s, triggered by large flooding events (e.g. Høydal *et al.,* 2000). Currently, flood mapping is a very crucial requirement in order to meet with the European Union New Flood Directive in the effective management of flood disasters in the entire European Union (de Moel *et al.,* 2009). The USA and Canada have initiated several national flood management programs in which flood mapping is an important activity. In 1968 the National Flood Insurance Program (e.g. Burby, 2001) was launched in the USA and in 1976 the Flood Damage Reduction Program started in Canada (de Moel *et al.,* 2009). In Africa, South Africa, Zimbabwe, Ethiopia and Ghana – Nigeria's closest neighbour have equally followed in that direction by introducing flood risk mapping standards for their nations (e.g. van Alphen, 2007; Els and van Niekerk, 2013; Els, 2013; Getahun and Gebre, 2015). All these projects have prioritized and integrated flood mapping component into their flood control framework, and have encouraged the implementation of same in other places. No doubt, flood mapping is an essential element of flood risk management and flood risk communication. As a result, flood risk mapping is regulated by law. The Flood Directive of the European Union, enacted in November 2007, requires member states to create both flood hazard and flood risk maps (European Commission, 2007).

Although flood map production is frequently limited to mapping the flood hazard, however there is a lively discourse on flood risk mapping, including the potentially adverse effects on asset values, people and the environment – vulnerability (European Commission, 2007; de Moel *et al.,* 2009). In other words, flood risk mapping are necessary requirements for the effective understanding and efficient management of flood hazards. They constitute primary essentials and critical tools for providing dependable flood spatial information and localization – flood types, the probability of a particular flood event, the flood magnitude expressed, water depth or flow velocity, preparedness and emergency planning, land-use planning, land management, public perception and awareness raising etc. More recently, flood risk mapping provides clear directives in flood risk insurance, in that premiums can be collected through property tax or utility-like payment mechanisms (National Academies of Science NAS, 2015); meaning that flood risk maps are instruments used for prioritizing investments and as well, equipping authorities and people to prepare for disaster (Takeuchi, 2001; Merz and Thieken, 2004; Buchele *et al.,* 2006).

Contextually, the occurrence of a flood event with a potential likelihood can amount to a flood hazard, while the possible damages associated with such an event describes flood risk levels. Suggesting that, exposures to flood signify danger – a risk situation. It has been observed that flood risk situations occur due to the incompatibility between hazard and vulnerability levels operating in an area (Mileti, 1999; de Moel *et al., 2015*). In other words, flood risk is a function and a product of hazard and vulnerability (Ologunorisa and Abawua, 2004). Also, pertaining to flood reporting, risk accounting is needful *a priori* flood map productions. However, flood hazard statements do not always convey information about the consequences of such events on society, built environment or natural environment. Since these consequences depend, among others, on the intensity of the flood, hazard statements should extend beyond frequency rates, i.e. they should provide information about flood intensity, such as inundation depth or flow velocity etc, hence the need for flood map types (Merz and Thieken, 2004). This goes to explain that, hazard and risk quantification depends to a large extent on spatial specifications – area of interest, inclusive components and spatial resolution of data, and a detailed geovisual communication tool in the form of appropriate flood map.

In flood risk analysis, suitable scaled flood maps are very crucial for a risk assessment to be reliable. In that, maps give a direct and strong impression of the spatial distribution of the flood risk. Thus, maps are valuable for presenting and assessing a flood situation, providing information for several applications related to disaster management (Marzocchi *et al.,* 2014). In their work, Buchele *et al.,* (2006) noted that detailed spatial information on flood hazard and vulnerability is essential for the development of regional flood-management concepts, planning and cost-benefit analysis of flood-protection measures are extremely important, for the preparedness and prevention strategies of individual stakeholders (landlords, communities, companies etc.). In this wise, effectively mapped information of potentially vulnerable area can imply a direct legal and economic consequences for incompetencies on the part of public institutions and authorities in flood control for spatial planning, owner interests, insurance policies, etc (Buchele *et al.,* 2006; NAS, 2015). As such, enormous benefits abound in integrating flood mapping standards into the holistic management of flood disasters. This gives reasons for the unprecedented rise in the interest in flood vulnerability research especially now that global environmental change impacts are being observed at all scales, and so is driving policy makers to consider non-structural mechanisms of flood vulnerability mapping as a policy priority (European Commission, 2007; Els, 2013; Els and van Niekerk, 2013; Getahun and Gebre, 2015).

Being an affordable non-structural measure, and also that local knowledge is central in managing localized flood hazards, flood mapping functions are currently gaining unavoidable relevance globally in that they make local knowledge discernible by distinguishing between mixed qualitative stages of understanding – facts, data, information, knowledge and wisdom (Weichselgartner and Pigeon, 2015:109). More so, when integrated into a Geographic Information System GIS, it can effectively play the crucial role in identifying flood vulnerable elements that are interactively geovisualized for the effectual conceptualization and utilization by non-technical policy makers in the flood sub-sectors (Di Baldassarre *et al.*, 2010; Tran et al., 2009). Meaning that, flood mapping can be utilized to achieve several years of flood disaster mitigation and prevention which is essential in long term flood risk management.

Flood maps in disaster risk reduction: Prospects for the Niger Delta Region

Flood mapping is a non-structural measure that can complement structural measures in disaster risk reduction. The concept was introduced for the sustainable planning of land and urban areas, protection of lives, properties, human activities, and for the preservation of ecohydrological and coastal corridors (European Commission, 2007). Based on the successful implementation of flood mapping non-structural measure in different parts of the world as we have shown in the foregoing section, itemizing some useful illustrations of flood map types and their uses may be a relevant guide to non-technical policy makers in the flood management sector of the Niger Delta region.

Flood map types and their uses

Flood maps, though generated to manage flood disasters, come in various forms; they can be deployed for use at different stages of flood risk reduction. Given that flood events are peculiar, they expose lives and properties to different categories and levels of risks. The different types of flood maps are dependent on a number of factors such as the regional geographical identity – soil, topography, rainfall characteristics, infrastructure and urban development master plan, etc. In recent times, various agencies, public authorities and researchers have developed and classified flood maps based on the universal distinctiveness of flood risk around the world (Flood*site,* 2004; Merze and Thienken, 2007; Akukwe and Ogbodo, 2015). As such, six types of flood maps have been identified (Fig. 4).

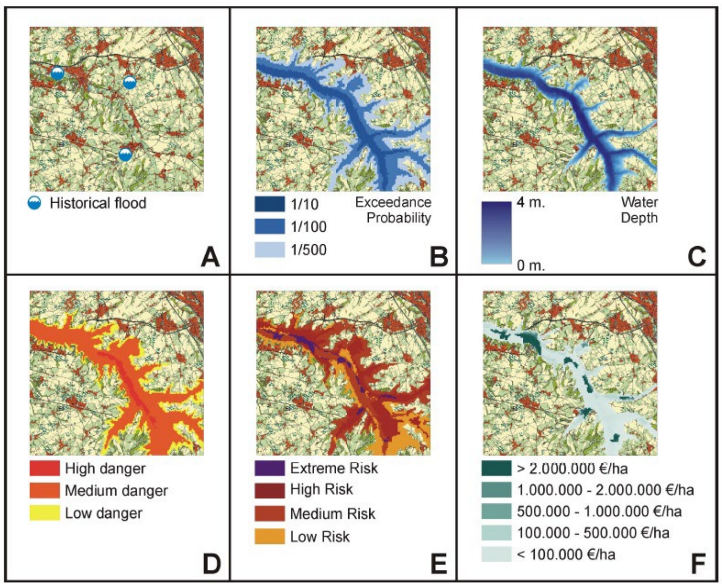

Figure 4. Types of flood maps:

(A) Historical flood map;

(B) Flood extent map;

(C) Flood depth map;

(D) Flood danger map;

(E) Qualitative flood risk map;

(F) Quantitative flood risk (damage) map.

Historical flood maps are used to show information of past flood occurrences of areas affected or exposed to flood risk. On this type of flood map, accurate locations of flood elements are depicted. Information displayed on flood maps is "particularly valuable", in that flood event information contained therein can be easily understood by the general public and not only for urban planning – eg, sitting of safe haven. ***Flood extent maps*** are broad-spectrum flood maps that displays in spatial extent areas inundated by a specific flood event. They are produced with the prime purpose of portraying flood return phases. Different hues, buffer lines or a combination of both can be used to depict flood return period on flood extent maps (de Moel *et al.,* 2009). ***Flood depth maps*** are used to show depth of water levels at different points during flood events. When it comes to damages recorded during flood disasters, water depth is a major consideration, hence the primary need for flood depth maps. This type of maps can be created after calculating flood return period during the creation of flood extent maps. ***Flood danger map*** uses matrix table to sketch or plot relationship between flood parameters. For instance, *intensity* against *exceedance probability* to relate or group flood parameters e.g. water depth, flow velocity, return period, into qualitative danger categories. In other words, to get an impression of the overall flood hazard in an area during flood event, parameters are aggregated into qualitative classes, and this is what describes a flood danger map (Fig. 4d). ***Qualitative risk map*** is similar to flood danger map, only that all exposed flood elements at risk (not parameters) and their "coping capacity" are qualitatively mapped. According to de Moel *et al*., (2009), the main quantifiable indicator for exposure is direct economic damage. This type of flood map is presented in a form of land use map (Fig. 3 and 4e), while in the case ***Quantitative risk (damage) map***, damages recorded are computed, quantified and displayed on a flood map to show differences in value of damage (Fig. 4f). Nevertheless, quantitative risk map is not yet well known or publicized like others (Figs 4a-4e).

To control floods and prevent flood disasters in the Niger Delta region, concerned authorities and stakeholders must as a matter of necessity develop sustainable framework and/or standard upon which strategies such as non-structural measures – flood risk maps, flood decision support can stem from. According to the United Nations Associated Programme on Flood Management APFM, "flood mapping involves both technical and administrative procedures; but the term flood mapping explicitly describes the development of flood maps which implicitly incorporates flood assessment that involves the analysis of various data and parameters representing flood conditions such as past floods, present floods and flood prediction" (APFM, 2013). Recent flood disasters and fatalities recorded in Niger Delta region – 2012 floods (NEMA, 2013), suggests that a well structured standard for flood mapping process and procedure such as those initiated by the United Nations Associated Programme on Flood Management be implemented right away for the region (See Fig. 5). This can be supported by a periodic multi-scaled and inclusive participatory mapping as described by Cadag and Gaillard (2012) and Padawangi *et al.* (2015).

With a standard framework in place, such as illustrated in Fig. 5, various detailed flood maps can be generated to populate a regional flood information database. The availability and accessibility of such comprehensive flood database certainly can provide useful and insightful geospatial data into the potential adverse consequences associated with floods at various stages and under numerous possibilities. This can numerically pinpoint actions so as to avoid unguided inferences. This will aid in the identification of inhabitants potentially at risk, as well as, economic means and installations which might cause accidental pollution or disease epidemic in cases of sudden flood event as was experienced in the region in 2012. In some geologically delicate countries like Japan, flood maps provide quick safety nets or guidance in the absence, or before the arrival of evacuation authorities and risk managers. Also, in France for instance, flood maps exits that show flood duration and flood history (Flood*site*, 2004).

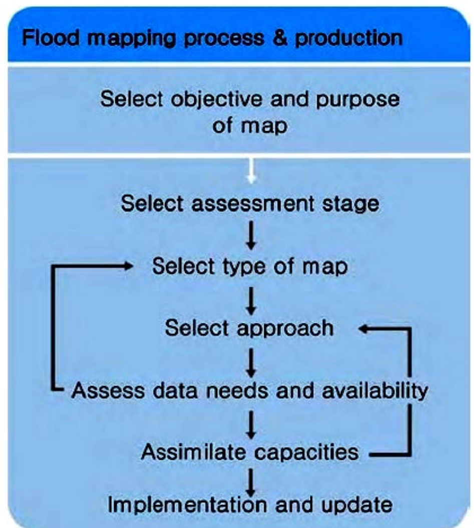

Fig. 5: A flood vulnerability mapping production process
Source: (APFM, 2013)

The role of flood maps in flood risk reduction in the Niger Delta region cannot be overemphasized. Accordingly, to control floods in the Niger Delta region, concerned authorities must as a matter of necessity begin or improve efforts towards developing detailed flood maps for the region which can make available flood spatial information for all and at all times. And this must be guided by appropriate flood mapping standards (European Commission, 2007) that is exclusive to the region. Flood risk maps, guided by established flood mapping standards offers reliable non-structural mechanism for assessing and preventing local and regional flood fatalities (Merze and Thieken, 2004). It can provide or guarantee the rapid mitigation response with respect to quick relocation to uplands or flood safe zones. If well planned for, flood vulnerability mapping can offer a hundred percent security against flood hazards and impact often experienced during flood disasters (Barroca *et al.,* 2006 and Blong, 2003).

Conclusion

The Niger Delta region is an environmentally sensitive area, thus, highly vulnerable to various ecological and environmental hazards. However, it is important to note the very important role played by climatic factors engineered by the general atmospheric circulation arising from the South Atlantic Ocean over the entire Gulf of Guinea which causes the region to experience anomalous flood producing rains. Due to the region's low lying topography, coastal floods rising up to 3.2m render the region recurrently inundated. And, various forms of flood disasters (e.g. 2012 flood incidence) have resulted in the loss of lives, properties and ecological disasters. Risk of species redistribution and struggle for survival are also the resultant effect of unpreventable flood disaster. The challenges posed by flood induced degradation can better be understood and appreciated when viewed against the backdrop of the benefits derivable from the wetlands and consumable freshwater water resources (Nwankwoala, 2012). So, the hydrological implication of future flood can sum up into uncertainties and unproductive effects on the region's ecological resilient capacity. Such that, if flood mapping is not well factored into vulnerability assessment, tendencies are that ecosystem chain breaks will continue to escalate. Such conditions are capable of impeding the relationship that maintains solid ecological and hydrological support for the effective provision of ecosystem goods and services needed in sustaining livelihood. In other words, there is need for the establishment of a functional flood vulnerability mapping framework to protect lives and the vast ecological potentials the region upholds for posterity.

Flood vulnerability mapping is a non-structural measure that complements structural measures in disaster risk reduction, and is here recommended for the Niger Delta region. The concept was introduced for the sustainable planning of land and urban areas, protection of lives, properties, human activities, and for the preservation of ecohydrological and coastal corridors (European Commission, 2007). Flood mapping measures has proven highly successful in many parts of the world that are at risk of persistent flood disasters. Intuitive mapping of disasters such as flood can go a long way to present a more direct and stronger idea of the spatial distribution of the flood risk than other forms of risk presentations e.g. verbal description (Merze, *et al.,* 2007); in that, maps are valuable for presenting and assessing flood situations and making available spatial data needed in a number of applications in relation to preventing or managing disasters (Marzocchi, *et al.,* 2014). The establishment of a flood risk management framework that is supported by multi-scaled participatory mapping can be a major breakthrough in managing flood risk. Flood maps can be very useful in presenting and assessing the local flood peculiarities of the region. They can also provide those needed detailed spatial information for various remedial strategies in flood protection, flood prevention and flood disaster management or flood disaster risk reduction.

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Rainfall Variability within and around Ogun and Komadugu-Yobe River Basins: Implications for Water Resources

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Abstract
This paper analysed variations in rainfall within and around Ogun River and Komadugu-Yobe River Basins in the South-western and North-eastern parts of Nigeria, respectively. Variability analyses were based on Normalised Rainfall Anomaly, Rainfall Variability Index, and Coefficient of Variation for a thirty-year period from 1981 to 2010 using monthly data. Non-parametric Wilcoxon Signed Rank Test and its parametric equivalent, the Paired Sample T-Test was used to determine if significant differences exists between pairs of decadal rainfall series. Results of the spatio-temporal variance for Ogun River Basin (1.21) and Komadugu-Yobe River Basin (1.08) indicate that differences between yearly fluctuations in each basin are not significant at 1percent level. The determination of yearly climatic regime through the Rainfall Variability Index revealed that most of the years fell within the ± 0.5 *range indicating that most of the years were normal years while the generally lower values of coefficient of variation within the Ogun River Basin implies higher rainfall reliability, low variability and more dependable rainfall distribution. Differences between pairs of decades at Abeokuta and Ikeja (Ogun River Basin) were not significant while the difference between the rainfall series of the 1980s and 2000s at Ijebu-Ode was significant. Potiskum was the only location within the Komadugu-Yobe River Basin where no significant difference existed between pairs of decadal rainfall series. Also, differences between pairs of decades were not significant at Abeokuta and Potiskum. Conclusively, climatic variability should be given high consideration in the planning, development and management of water resources at the river basin level.*
Keywords: Decade, Rainfall, River Basin, Variability, Water Resources

Introduction
Variability is an integral part of rainfall characteristics (amount, duration and intensity) worldwide and this is inextricably linked to the natural global spatio-temporal dynamics of rainfall. A number of factors are responsible for long term rainfall variability in Nigeria. These include the Inter-tropical discontinuity mechanism (ITD), the Tropical Easterly Jet

(TEJ), Sea Surface Temperature Anomaly (SSTA), biogeophysical feedback mechanism and the El-Nino Southern Oscillation (ENSO), (Olaniran, 2002).

The immense benefits of derivable information to other disciplines such as hydrology and water resources management have prompted many studies on the spatial and temporal variability of rainfall. For example, Turkes (1996) analysed the spatial and temporal variations of annual rainfall in Turkey using a number of methods including Analysis of Variance (ANOVA), F-Test and the Normalised Annual Rainfall Anomaly. The results of the study showed that most of the locations exhibited significant low-frequency fluctuations in annual rainfall. The study also attributed some of the difficulties of freshwater supply in major cities such as Istanbul to high level of negative rainfall anomaly. Nsubuga *et al*. (2014) analysed the nature of rainfall including its variability, in the main drainage sub-basins of Uganda using several methods including the Normalised Rainfall Anomaly, Precipitation Concentration Index, Trend Analysis, ANOVA and Drought Severity Index. The results of the rainfall variability analyses revealed low variation in annual rainfall. In spite of the low annual rainfall variability and relative abundance of water resources in the country, the authors advocated efficient water policy and rational water use based on pessimistic climate change predictions for the country. Oguntunde *et al*. (2006), utilised Rainfall Variability Index amongst other methods to analyse the trend and variability in the hydroclimatology of Volta River Basin of Ghana between 1901 and 2002. The study showed 1968 and 1983 as the wettest and dry years, respectively. The study also revealed that the basin has undergone a general desiccation in the last 3 decades of the 20th century. Hydroclimatic elements such as rainfall and evaporation, and land use – land cover changes were identified as drivers of observed trends in climate and runoff in the basin since the 1970s.

The study conducted by Odekunle *et al*. (2007), using Z-distribution anomalies showed that rainfall exhibits a higher level of variability in the Northern Guinea Savannah Zone of Nigeria than in the Southern Guinea Savannah Zone of the country. The study showed that rainfall variability affects water availability, leading to a reduction in the length of growing season, consequently affecting the yield of maize. The study also revealed that inter-annual variability of rainfall is responsible for observed differences in the rates of maize yield in the Guinea Savannah Zone of the country.

In recognition of the usefulness of rainfall variability information in providing deeper insights into the water balance dynamics on different spatial and temporal scales for water resources planning and management, this study is aimed at analysing rainfall variability and implications for water resources in two river basins of Nigeria.

Study Area

Ogun River Basin is located in southwestern Nigeria between latitudes 6^0 26´N and 9^0 10´N and longitudes 2^0 28´E and 4^0 08´E. It occupies an area extent of about 23,000km^2. The headwaters of the river is at Igaran Hills from where it flows southwards before finally discharging into the Lagos Lagoon. Dry season within the Basin is between the months of November and March, while the rainy season commences in April and lasts till October. Mean Annual Rainfall varies between 900 and 2,000mm, while annual evapotranspiration is between 1,600 and 1,900 mm (Bhattacharya and Bolaji, 2010). Several communities in Lagos, Ogun and Oyo State are located within the drainage basin (Okeyode, 2012).

Komadugu-Yobe River Basin is a transboundary basin located between latitudes 9.79^0 N and13.85 ^{0}N and longitudes 7.63^0E and 13.57^0E. It occupies an area extent of about 148,000 km^2, with 85,470 km^2 located within Nigeria. Although the basin is a transboundary, the study covers only the Nigeria section that includes five states in Northern Nigeria; Bauchi, Borno, Jigawa, Kano and Yobe States. The Komadugu-Yobe River system is made up of three major rivers, the Hadejia, Jama'are and Misau. The Hadejia River is formed by the confluence of the Rivers Challawa and Kano, while the source of Jama'are is in the Jos Plateau. Annual rainfall varies from less than 400mm in the northern part of the basin to over 1,200 mm in the southern part of the Basin (Oyebande, 2001; Oyebande *et al*. 2008). The Ogun and Komadugu-Yobe River Basins are as shown in Fig. 1.

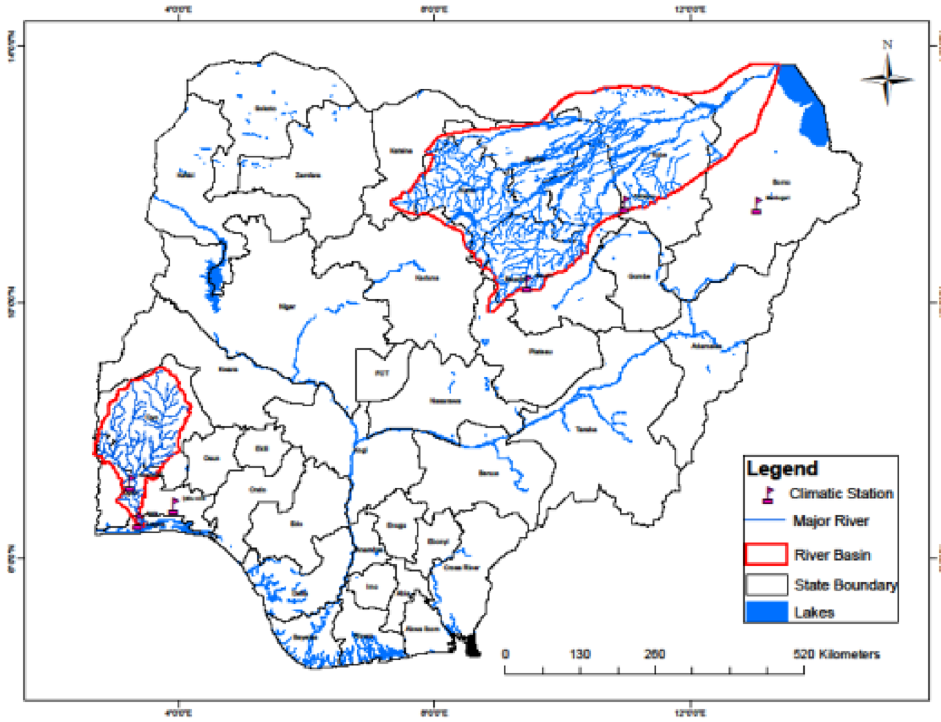

Fig.1: Ogun and Komadugu Yobe River Basin within Nigeria

Methodology

Thirty-year monthly rainfall data for the period 1981 to 2010 was obtained from the archive of the Nigerian Meteorological Agency (NIMET). Locations for which rainfall data were collected were Abeokuta, Ijebu-Ode and Ikeja, for Ogun River Basin, and Bauchi, Maiduguri and Potiskum for Komadugu-Yobe River Basin. The stations are all within and around the river basins. Methods used in analysing the variability of rainfall at the two river basins are the Coefficient of Variation, Rainfall Variability Index, Normalised Rainfall Anomaly, Non-parametric Wilcoxon Signed Rank Test and its parametric equivalent the Paired Sample T-Test. Shapiro-Wilk Test was used to determine the normality of the rainfall distribution prior to the application of the Paired Sample T-Test. Normality, parametric and non-parametric tests were run using the Statistical Package for the Social Sciences (SPSS) version 17.0. The Coefficient of Variation (CV) which was used to determine the inter-annual variability and reliability of the rainfall is defined as:

$CV = \sigma_{S}/R_{S}$ (1)

where $\bar{R}_s$ is the long term mean annual rainfall and σ_s is the standard deviation of annual rainfall totals for station s.

Rainfall Variability Index was used to categorise the rainfall time series into 5 different climatic regimes; the very wet climatic year, the wet climatic year, the very dry climatic year, the dry climatic year and the normal climatic year (Oguntunde, 2012). The Rainfall Variability Index is expressed as:

$\delta_i = (P_i - \mu)/\sigma$ (2)

where δ_i is Rainfall Variability Index for year I, P_i is annual rainfall for year i, and μ and σ are the mean and standard deviation of the annual rainfalls for the study period. When the value of δ is within± 0.5, the year is characterised as a normal year, when the value of δ is between the range of +0.5 and +1, it is categorised as a wet year, when $\delta > +1$, it is categorised as a very wet year. Values of δ between -0.5 and -1 is characterised as a dry year, while δ value < -1 is characterised as a very dry year (Oguntunde 2006; Oguntunde, 2012).

Normalised Rainfall Anomaly as presented by Kraus' (1977) was used to determine the temporal and spatial variance of rainfall (year –to- year fluctuations). The Normalised annual rainfall anomaly for a given station or location is expressed as:

$A_{sy} = (R_{sy} - R_s)/\sigma_s$ (3)

where R_{sy} is the annual total rainfall for station s during year j; R_s and σ_s are the mean and standard deviation of the annual rainfall for station s, respectively. The area average (River basin mean) normalised rainfall anomaly (A_{ry}) for each region is defined as:

$A_{ry} = (1/N_i)\sum_{s=1}^{N_s} A_{sy}$ (4)

where N_j is the number of regional stations operating in the year j. The variance in time is estimated as:

$$v(time) = \frac{\Sigma N_j A_{ry^2}}{J-1} \quad (5)$$

where N is the number of stations operative in the year j and J is the number of years of record for the series A_{ry}. The mean spatial variance between rainfall anomalies in the river basins are expressed as:

$$v(area) = \frac{n-\Sigma N_j A_{ry^2}}{n-j} \quad (6)$$

where n, the total number of station years, is computed as:

$n = \Sigma N_j = \Sigma J_i$ (7)

The statistical significance of the ratio of variance estimates (variance in time/variance in area) was determined by F-Test (Krauss, 1977; Turkes, 1996).

Non-parametric Wilcoxon Signed Rank Test and its parametric equivalent the Paired Sample T-Test were used to determine the existence of significant differences between pairs of decadal rainfall series. Wilcoxon Signed Rank Test is defined as:

$$W = \sum_{i=1}^{N_r} \left[Sgn\left(X_{2,i} - X_{1,i}\right) * R_i\right] \qquad (8)$$

where $x_{1,I}$ and $x_{2,I}$ are the time series of rainfall (i = 1,2……n), Sgn is the sign function and R_i is the rank.

The Paired Sample T-Test was computed using:

$$t_s = (x_t - \mu)\sqrt{N-1}\ / \sigma \qquad (9)$$

where $\overline{x_t}$ is the mean of the subseries of rainfall, μ is the mean of the series, σ is the standard deviation and N is the number of the subseries.

The Shapiro-Wilk Test for normality was computed based on the formula:

$$W = \left[\sum_{i=1}^{n} a_i\, x_{(i)}\right]^2 \Big/ \sum_{i=1}^{n} (xi - x)^2 \qquad (10)$$

Normality of annual rainfall distribution was checked to ensure the reliability of the results of the parametric Paired Sample T-test. The uses of parametric tests are based on the assumption that the sample data being used follow the normal distribution (Madansky, 1988; USEPA, 1996; Thode, 2002; Machiwal and Jha, 2012).

Results and Discussion

Inter-Annual Variability

Annual rainfall CV for Abeokuta, Ijebu-ode and Ikeja in the Ogun River Basin varied between 4.6% and 11%, 4.4% and 10.7%, and 5.1% and 11.4%, respectively. In the Komadugu-Yobe River Basin, the coefficient of variation ranged from 6.6%to 15.6% at Bauchi, 5.8%to 22.9% at Maiduguri, and 6.1%to 25% at Potiskum. The lower values and the lower range of annual rainfall CV exhibited in the Ogun River Basin is an indication of higher rainfall reliability when compared with the Komadugu-Yobe River Basin. According to Nsubuga *et al.* (2013), low values of coefficients are indicative of higher rainfall reliability and more dependable rainfall distribution. The higher level of rainfall reliability in the Ogun River Basin is attributed to its latitudinal position and the residence time of the predominant Tropical Maritime air mass (mT). Over Nigeria, the rainfall producing southwesterly airstream decreases with distance from the coast or increase in latitude. In the coastal area, the mT air mass predominates for about 7 months of the year, while in the sahelian part of the country mT air mass is resident for about 3 to 5 months (Olaniran, 1988; Olaniran 1990).Similarly, the dynamics of rainfall in the country, and by extension, the two river basins, are subject to the seasonal migration of the Intertropical discontinuity (ITD) on the northward and southward migration across the country. The double maixima rainfall experienced in the southern part of the country is attributed to the northward advance and southward retreat of the ITD when the zone D weather traverses the country. The zone D weather is also responsible for the peak rainfall of the months of July/ August in northern Nigeria (Olaniran, 1987).

Annual Climatic Regime

Rainfall Variability Index for the two river basins is presented in Table 1. As shown in the table, the rainfall time series is mainly characterised by a succession of alternating dry, very dry, wet, very wet, and normal years. Within the study period, the climatic regime at Abeokuta was predominantly normal, with 12 out of the 30 years categorised as normal periods. At Ijebu-Ode, the climatic regime was also mainly normal with 11 out of the 30 years exhibiting this characteristic. The situation at Ijebu-Ode however differs from Abeokuta because the area experienced uninterrupted succession of normal years between 1987 and 1995. At Ikeja equal number of normal years and wet years was experienced.

In the Komadugu-Yobe River Basin, the period 1981 to 2010 was predominantly normal, with 10, 12, and 12 years characterised as normal years at Bauchi, Maiduguri and Potiskum respectively. From the results of the Rainfall Variability Index, it was noted that dry and very dry conditions prevailed at both river basins in 1982, 1983, and 1985. This condition is a reflection of the widespread drought of the early-mid 1980s in West Africa.

A number of reasons have been hypothesised as being responsible for the occurrence of drought in Nigeria and Subtropical West Africa. These include a reduction in the residence times of the rainiest parts of the ITD due to its southward displacement, inhibition of rainfall behind the ITD, and the weakening of the rainy season intensity in certain years. This weakening is due to the weakening upward motions in the monsoons at the peak of the rainy season due to stronger inversions and / or large scale subsidence (Kidson, 1977; Nicholson, 1981; Acheampong 1982; Acheampong 1987; Olaniran, 1991). Wet years are however attributed to the significant northward incursion of the ITD during such periods (Lamb, 1977; Nicholson, 1981; Olaniran, 1991).

Table 1: Results of Rainfall Variability for Ogun and Komadugu-Yobe River Basins

Climatic	Ogun River Basin			Komadugu-Yobe River Basin		
Regime	Abeokuta	Ijebu-Ode	Ikeja	Bauchi	Maiduguri	Potiskum
Wet Year	4	7	9	4	4	6
Dry Year	2	5	4	8	7	5
Vey Wet Year	6	3	3	4	3	3
Vey Dry Year	6	4	5	4	4	4
Normal Year	12	11	9	10	12	12

Temporal and Spatial Variance of Rainfall at the Basins

The results of the area-averaged (basin-averaged) normalised annual rainfall anomaly and the spatio-temporal variance for the two river basins are presented in Table 2. The ratio of variance estimate for Ogun River Basin (1.21) and Komadugu-Yobe River Basin (1.08) are both less than the table values of 1.696 and 1.860 respectively. This implies that the differences between the year-to-year fluctuations in the individual catchments are not significant at 1 percent level of significance. Furthermore, the variance ratios (1.21 for Ogun River Basin, and 1.08 for Komadugu-Yobe River Basin) are below the limiting value of 1.50 or less for F0.01 or 1 percent probability level. This also suggests that differences in annual rainfall fluctuations at both basins are not significant at 1 percent level.

Table 2: Spatio-Temporal Variance of Annual Rainfall at Ogun and Komadugu-Yobe River Basins

Variables	Ogun River Basin	Komadugu-Yobe River Basin
v (Time)	1.17	1.07
Degrees of Freedom (J-1)	29	29
V (Area)	0.967	0.994
Degrees of Freedom (N-J)	120	150
Ratio of Variance (F-Test)	1.21	1.08
v1= 29, v2 = 150, $F_{0.01}$		
at 1% level of significance	1.696	1.860

Normality Analysis of Rainfall Distribution

Results of the Shapiro-Wilk Test to check the normality annual rainfall at the two river basins are presented in Tables 3. As shown in Table 3, W(30) = 0.961, P > 0.05 for Abeokuta, W(30) = 0.985, P > 0.05 for Ijebu-Ode, and W(30) = 0.975, P > 0.05 all indicate that annual rainfall was not significant at P > 0.05. Because P > 0.05, it is therefore concluded that annual rainfall distribution is not significantly different from a normal distribution. In the Komadugu-Yobe River Basin annual rainfall is also not significantly different from a normal distribution for Bauchi, W(30) = 0.948, P > 0.05, Maiduguri, W(30) = 0.957, P > 0.05 and Potiskum, W(30) = 0.969, P > 0.05.

Table 3: Result of Shapiro-Wilk Test for Rainfall Normality at Ogun River Basin

Ogun River Basin	Abeokuta	Ijebu-Ode	Ikeja
Test Statistic	0.961	0.985	0.975
df	30	30	30
Sig (P Value)	0.330	0.944	0.694
Komadugu-Yobe River Basin	Bauchi	Maiduguri	Potiskum
Test Statistic	0.984	0.957	0.969
df	30	30	30
Sig (P Value)	0.154	0.257	0.506

*df - Degrees of Freedom,
* Sig- Significance

Differences in Decadal Rainfall

The results of the Wilcoxon Signed Rank Test and Paired Sample T-Test for Ogun River Basin (Table 4) shows that except for the rainfall pair of decade 1 and Decade 3 at Ijebu-Ode and Ikeja, there were no significant differences between pairs of decadal rainfall at 5 percent level of significance. Based on the results presented in Table 5 (Decadal Mean Rainfall), it can be concluded that there was no significant increase in the decadal mean rainfall from the first decade to the third decade having established that there were no significant differences between pairs of decadal rainfall. It is however concluded that the increase in mean rainfall received between decade 1 and decade 3 at Ijebu-Ode and Ikeja are statistically significant having established that there were significant differences between the pair of decadal rainfall.

Table 4: Results of Wilcoxon Signed Rank Test and Paired Sample T-Test for Ogun River Basin

Wilcoxon Signed Rank Test

Decadal Pair	Abeokuta P Value (2 tailed)	Ijebu-Ode P Value (2 tailed)	Ikeja P Value (2 tailed)
Decade 1 and 2 (1981- 1990) and (1991 – 2000)	0.45^{NS}	0.09^{NS}	0.24^{NS}
Decade 1 and 3 (1981- 1990) and (2001 – 2010)	0.29^{NS}	0.03^{S}	0.05^{S}
Decade 2 and 3 (1991-2000) and (2001 2010)	0.68^{NS}	0.39^{NS}	0.39^{NS}

Paired Sample T-Test

Decadal Pair	Abeokuta P Value (2 tailed)	Ijebu-Ode P Value (2 tailed)	Ikeja P Value (2 tailed)
Decade 1 and 2 (1981- 1990) and (1991 – 2000)	0.55^{NS}	0.11^{NS}	0.39^{NS}
Decade 1 and 3 (1981- 1990) and (2001 – 2010)	0.37^{NS}	0.02^{S}	0.03^{S}
Decade 2 and 3 (1991-2000) and (2001 2010)	0.66^{NS}	0.29^{NS}	0.27^{NS}

^{NS} Not Significant at 5% Level of Significance; P value >0.054

^{S} Significant at 5% Level of Significance; P value ≤ 0.05

Table 5: Decadal Mean Rainfall for Ogun River Basin

Decadal Mean	Abeokuta (mm)	Ijebu-Ode (mm)	Ikeja (mm)
Decade 1 (1981-1990)	1151.9	1418.2	1334.2
Decade 2 (1991- 2000)	1218.4	1640.0	1467.9
Decade 3 (2001- 2010)	1257.8	1743.5	1608.1

The results of Wilcoxon Signed Rank Test and the Paired Sample T-Test for Komadugu-Yobe River Basin are presented in Table 6. As shown in the Table the differences between pairs of decadal rainfall for Bauchi and Maiduguri were significant for the pairs of decade 1 and 2, and decade 1 and 3. The difference between decade 2 and 3 were however not significant at both locations. At Potiskum differences between all pairs of decadal rainfall were not significant at 5 percent level of significance. Based on these results and the decadal mean rainfall presented in Table 7, it can be concluded that the increase in mean rainfall received between decade 1 and 2 at Bauchi and Maiduguri was significant, while the increase between decade 2 and 3 was not significant. For Potiskum the increase in mean rainfall received between decade 1 and 2, and the decrease in mean rainfall between decade 2 and 3 were not statistically significant.

Table 6: Results of Wilcoxon Signed Rank Test and Paired Sample T-Test for Komadugu-Yobe River Basin

Wilcoxon Signed Rank Test			
	Bauchi	Maiduguri	Potiskum
Decadal Pair	P Value (2 tailed)	P Value (2 tailed)	P Value (2 tailed)
Decade 1 and 2 (1981- 1990) and (1991 – 2000)	0.04^{S}	0.01^{S}	0.20^{NS}
Decade 1 and 3 (1981- 1990) and (2001 – 2010)	0.03^{S}	0.02^{S}	0.24^{NS}
Decade 2 and 3 (1991-2000) and (2001 2010)	0.89^{NS}	0.33^{NS}	0.45^{NS}
Paired Sample T-Test			
	Bauchi	Maiduguri	Potiskum
	P Value (2 tailed)	P Value (2 tailed)	P Value (2 tailed)
Decade 1 and 2 (1981- 1990) and (1991 – 2000)	0.52^{S}	0.00^{S}	0.15^{NS}
Decade 1 and 3 (1981- 1990) and (2001 – 2010)	0.03^{S}	0.01^{S}	0.34^{NS}
Decade 2 and 3 (1991-2000) and (2001 2010)	0.85^{NS}	0.15^{NS}	0.42^{NS}

^{NS} Not Significant at 5% Level of Significance; P value >0.05

^{S} Significant at 5% Level of Significance; P value ≤ 0.05

Table 7: Decadal Mean Rainfall for Komadugu-Yobe River Basin

	Bauchi	Maiduguri	Potiskum
Decadal Mean	(mm)	(mm)	(mm)

Decade 1 (1981-1990)	918.8	445.3	594.5
Decade 2 (1991- 2000)	1119.9	608.6	684.6
Decade 3 (2001- 2010)	1137.6	689.8	655.3

Implications for Water Resources

As a main driver of observed variability in surface and groundwater, water resources within a drainage basin are subject to rainfall variability and the prevailing climatic regime. An in-depth understanding of the pattern of inter-annual variability of rainfall in the river basins is therefore required. This is because inter-annual variability of rainfall poses a challenge to water resources, especially in the area of availability of water for agricultural production and water supply for domestic and industrial use, as well as the occurrence of extreme conditions such as floods and droughts.

In the wet to very wet climatic regime of 2007 and 2010 for example, increased inflows into the Oyan Dam from high rainfalls within Ogun River Basin resulted into high streamflows and high water level of the dam. This necessitated the release of excess water from the dam that resulted in massive flooding of downstream communities within its floodplain. During the said periods, rainfall variability was very low with coefficients of variation in the range of 8.4 and 11.3 in 2007, and 6.6 and 9.5 in 2010. These characteristics are typical of humid tropical region with high rainfall reliability which at times leads to excess runoff.

In the Komadugu-Yobe River Basin, the high level of rainfall seasonality, drought recurrence and low rainfall reliability as revealed by the high values of coefficient of variation has necessitated the construction of various hydraulic structures. For example the sustained succession of dry and very dry years in the early to mid 1980s (Bauchi: 1982 to 1987; Maiduguri, 1981 to 1985, and Potiskum: 1982 to 1985) resulted in the construction of more hydraulic structures, including Challawa and Hadejia Barrage both of which were completed in 1992.To further ensure water security many individuals and communities have resorted to digging of deep wells to meet their domestic and agricultural water needs. Similarly, the number of dry and very dry years (40 % in Bauchi, 37 % at Maidugri, and 30 % at Potiskum) experienced in the basin during the study period has also contributed to farmers- pastoralists conflicts over water access and utilization. The high level of rainfall seasonality, drought recurrence and low rainfall reliability as revealed by the high values of coefficient of variation has often resulted in water stress. To further ensure water security, many individuals and communities have resorted to digging of deep wells to meet their domestic and agricultural water needs. Similarly, the number of dry and very dry years (40 % in Bauchi, 37 % at Maidugri, and 30 % at Potiskum) experienced in the basin during the study period has also contributed to farmers- pastoralists conflicts over water access and utilization.Due to the water resources challenges posed by the rainfall regime of the sahelian region in general and the Komadugu-Yobe River Basin in particular, a number of initiatives aimed at sustainable management of water resources have been established.These include the World Bank agricultural development projects in the 1980s, national fadama development programme in the 1990s, the establishment of river basin development authorities, Hadejia-Nguru wetland conservation project, North-East arid zone development programme, Department of International Development (DFID) Joint Wetlands Project (JWL), International Union for Conservation of Nature (IUCN)/Water and Nature Initiative (WANI), and the Lake Chad Commission/ Global Environment Facility Projects (Chiroma, et al., 2005).

Based on the significant changes between decadal pairs of rainfall at different locations within the two river basins, long term water resources planning and management could become difficult, especially if changes lead to major changes in the distribution of water resources. This therefore calls for more secured plans that would ensure the sustainable management of water resources under different prevailing conditions.

Conclusions and Recommendations

This paper has profiled the variability of rainfall in Ogun and Komadugu-Yobe River Basins and discussed the implications of the observed patterns on water resources developments**.** Three decadal patterns of variability on which future planning could be based has been presented. From the results obtained, the higher reliability of rainfall in the Ogun River Basin when compared with lower reliability of the Komadugu-Yobe River Basin may be due to the longer residence time of the rainiest parts of the ITD (Zones C and D) in the southern part of the country during its southward displacement. Furthermore, the twice a year (northward advance and southward retreat) movement of the Zone D weather which is responsible for the double maxima rainfall over the Ogun River Basin contributes to the higher rainfall reliability experienced when compared with the single maxima of the Komadugu-Yobe River Basin.

Although, some of the issues raised are being addressed through the on-going water resources master plan being prepared by Japan International Cooperation Agency for the eight hydrological areas of the Nigeria, It is, however, recommended that, water resources developments in Ogun River Basin should be on long term basis due to its higher rainfall reliability, low variability and more dependable rainfall distribution. The occasional very wet and very dry years especially in the Komadugu-Yobe River Basin should be catered for through development of potential reservoir sites to ensure further water security and optimal operations of existing reservoirs that is based on sound knowledge of rainfall variability within the region.

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Spatio-temporal Analysis of Meteorological Drought in the Sudano Sahelian Region of Nigeria

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Abstract
This study analyzes the spatial and temporal extent of meteorological drought occurrences in the Sudano-Sahelian Region of Nigeria (SSRN) from 1965 to 2010. It employed the Standardized Precipitation Index (SPI) to analyze the 46 years precipitation data of selected meteorological stations in the study area. The result of the study indicates that SSRN had received below average rainfall for 22 years during the period under investigation. It also reveals occurrences of three extreme drought situations in 1973, 1983 and 1987, and that the droughts of the 1980s had more devastating effect due to the duration and severity. Spatially, Maiduguri had the worst dose of drought categories below -0.99, and that the prominent droughts of the 1970s and 1980s mostly hit Maiduguri. Also, Maiduguri was declared a disaster prone area as major drought episodes are mostly first noticed there before the other parts of the study area. During the period of the study, Bauchi had the highest rainfall mean, followed by Yelwa and Kano. Nguru had the lowest standard deviation while Kano had the highest for Period 1. Yelwa showed the lowest coefficient of variation (CV) of rainfall which by implication has the most consistent rainfall pattern while Kano has the most inconsistent rainfall pattern with high CV. Period 1965 to 1989 shows decreasing trend while other period shows increasing trend of rainfall. All the stations showed clear drought situation for the drought episodes in 1973 and 1983, while most of the recent years show mostly near normal and wet situations. The analysis revealed many drought situations without a clear pattern.
Keywords: Drought, Rainfall, Episodes, Standardized Precipitation Index

Introduction
Drought is defined as a period in which a region has a deficit in its precipitation and, consequently, water supply. Precipitation deficit is a normal feature of the climate which usually occurs in every climatic region from time to time with different intensities. It is generally defined as a persistent and abnormal moisture deficiency (Palmer, 1965), and it has a negative impact on vegetation, animals, and people. Drought occurrence and severity do not strictly adhere to consequences of climatic fluctuations as its other causes include a sudden

increase in water demand due to socio-economic growth and development over space and time, which is beyond the water supply capacity (Oyebande and Balogun, 1990).

West African Sahel has been prone to prolonged and severe drought, usually aggravated by its increasing population (FGN, 2005). The underlying cause of most droughts can be related to changing weather patterns such as low rainfall, reduced cloud cover and greater evaporation rates which are exacerbated by human activities such as deforestation, bush burning, overgrazing and poor cropping methods that reduce water retention of the soil (Abubakar and Yamusa, 2013). One of the earliest and most influential explanations of the cause of drought in the Sahel was that of Charney *et al*. (1977), which suggested that low or lack of rainfall triggered by human activities such as deforestation and overgrazing is the cause of drought in the Sahel. In what has become known as Charney's model, decrease in vegetation cover caused by over-grazing and deforestation lead to an increase in the reflectivity or albedo of the land surface which result into a reduction in the convection that is necessary for the formation of rainfall-generating clouds (Charney *et al*., 1977). Also, drought in the region used to be attributed to a simple southward displacement of the Inter-Tropical Convergence Zone (ITCZ). This rather simplistic explanation has been rejected because it failed to explain many important characteristics of rainfall such as late onset or early cessation (Nicholson, 1993). Also, Nicholson (1993), Foland *et al*. (1986), Ekpoh (1991) and Akonga (2001), have all reported that the Sahelian drought has tele-connections with El Nino Southern Oscillation (ENSO), a phenomenon associated with periodic fluctuation in the intensity of the inter-tropical atmospheric and oceanic circulations, and this is usually coincident with an anomalous warming of the Eastern Tropical Pacific Ocean. Indeed, the persistent droughts, in a number of times, have resulted in famine in the Sudano-Sahelian region of Nigeria. For instance the drought of 1972-1973 dropped farm yields by up to 60% (Okorie, 2003).

The frequent occurrences of drought in the region have been principally responsible for the social and economic retrogression and poor quality of life mostly among the less privileged ones in the society (Yeates, 1964). On many occasions, local citizens were forced to leave their natural habitats and had even resulted into the sale of children during the severe drought of 1902-1904 which covered the whole region (Apeldoorn, 1981). In the southern parts of Nigeria, the occurrence of armed robbery was believed to be related to the insurgence of migration from the Sahel to the coastal areas of Lagos and Niger Delta in the early seventies (Adefolalu, 1983). Therefore, it is very imperative to conduct an in depth study of droughts in the SSRN in other to work out plans to mitigate its impact. This paper presents the results of the analysis of the spatial and temporal extent of the prominent drought episodes in the Sudano-Sahelian region of Nigeria by applying the standardized precipitation index (SPI) using 46 years precipitation (1965 to 2010).

Material and Methods

Location and description of study area

The study area lies within the Sudano-Sahelian Region of Nigeria (Fig. 1) represented by Sokoto, Kebbi, Zamfara, Katsina, Kano, Jigawa, Bauchi, Yobe, Borno, Gombe and Adamawa states and north at latitude 10ºN and extends to about latitude 14º N. This ecological zone houses 25% of the Nigerian population and supports three-quarter of cattle population, about 75% of the goats and sheep, and almost all the donkeys, camels and horses found in the country (Ifabiyi and Ojoye, 2013). Major cereals such as millet, sorghum and rice and crops such as cowpeas, groundnut and cotton are the main crops grown in the region (Odekunle *et al*., 2008). The climate of the zone is dominated by the influence of three major meteorological features, namely; the Tropical Maritime (Mt) air-mass, the Tropical Continental (CT) air-mass, and the equatorial easterlies (Ifabiyi and Ojoye, 2013). The two air-masses (MT and CT) meet along a slanting surface called the inter-tropical discontinuity (ITD); the equatorial easterlies are rather erratic and relatively cool winds from the east in the upper troposphere along the ITD (Ifabiyi and Ojoye, 2013). The movement of the ITD northwards across the country between January and August, and its retreat from the southern fringe of the Sahara desert, after August, causes much of Nigeria to experience seasonal rainfall (Ojoye, 2012). The MT air mass encloses a number of rainfall producing systems such as the disturbance lines (particularly the easterly waves), squall lines and the two tropospheric jet streams (i.e. African Easterly Jet and Tropical Easterly Jet). The mean annual rainfall in SSRN is between 1016 mm in the wettest part and less than 508 mm in the driest part and the mean annual temperature is between 26 and 28°C in the SSRN of Nigeria (Ojanuga, 1987). The dry season is from October to April/May, while the highly variable seasonal rainfall is concentrated in a short wet season which runs from May to September.

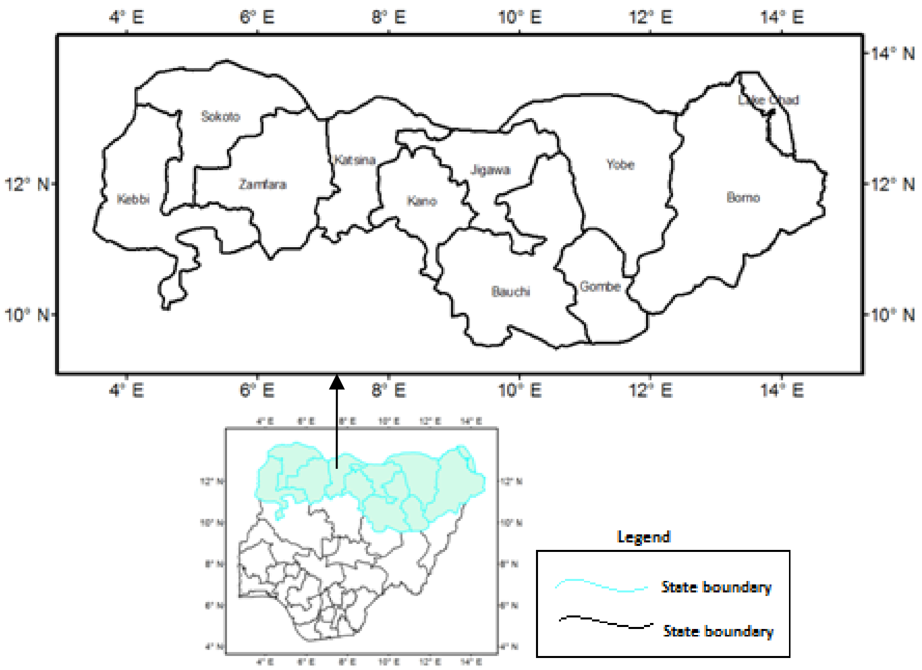


Fig. 1: Map of Nigeria showing the Study Area.

Data

The stations include Sokoto (13.01^{0}N, 05.15^{0}E), Yelwa (10.53^{0}N, 04.45^{0}E), Gusau (12.01^{0}N, 06.42^{0}E), Katsina (13.01^{0}N, 07.41^{0}E), Kano (12.03^{0}N, 08.32^{0}E), Nguru (12.53^{0}N, 10.28^{0}E), Potiskum (11.42^{0}N, 11.02^{0}E), Bauchi 10.17^{0}E, 09.49^{0}N), and Maiduguri (11.51^{0}N, 13.05^{0}E). Accordingly, rainfall data from 1965-2010 (46 years) for the stations were obtained from the Nigerian Meteorological Agency.

Methods of analysis

The standardized precipitation index (SPI) was used in this research because of its versatility and that it uses only precipitation data as its input data. Also, it is less complex than many other indices. It can provide early warning of drought and help in the assessment of drought severity (WMO, 2012). The SPI was computed for each year of study for the whole area and for each station using the monthly precipitation data through the equation below;

$$SPI = \frac{X_{ij} - \bar{X}_i}{\sigma_i} \qquad 1$$

where X_{ij} is the rainfall for the ith station and jth observation, $\bar{X}_i$ is the mean rainfall for the ith station and σ_i is the standard deviation for the ith station. The results were classified into different drought categories as in Mckee *et al*. (1993) (Table 1). The result of the SPI calculation were represented graphically with microsoft excel and also spatially with ARCGIS software through the use of the inverse distance weighted (IDW) interpolator.The IDW interpolation method was used in this study because its principle is simply understandable, it lacks turnable parameters and has the ability to work in N dimensional space. The IDW algorithm is not as complicated as the Kriging method and it produces reasonable results for many type of data set. It has ability to interpolate scattered data and to work on any grid. The algorithm can work even when all points lie in a low-dimensional subspace.

Table 1 shows a classification system linking SPI with drought intensities. A drought event comes about any time the SPI is continuously negative. The event comes to an end when the SPI become positive.
The most frequently used measure of relative dispersion is the coefficient of variation (CV). The CV is used to describe the variability of rainfall that occurs in time. The higher the CV of a particular station, the more variable or inconsistent the rainfall of that locality is in time. This is calculated by dividing the standard deviation (δ) by the mean ($\bar{X}$) and multiplying the result by 100 and is given as;

$$CV = \frac{\delta}{\bar{X}} * 100 \qquad 2$$

Trend analysis was performed on the rainfall series using the IBM SPSS 20 in other to determine the presence or otherwise of trend. The Spearman test (R_s) was used to identify trends and also determine the significance. The statistical significance was assessed on two levels: statistically significant level 0.01 and 0.05 representing a very strong and a strong trend, respectively.

Table 1: Drought classification using SPI values (McKee et. al., 1993).

SPI values	Description
2.0 or more	Extremely wet
1.5 to 1.99	Very wet
-1.0 to -1.49	Moderately wet
-0.99 to 0.99	Near Normal
-1.0 to -1.49	Moderately dry
-1.5 to -1.99	Severely dry
-2.0 and less	Extremely dry

Results and Discussion

The period under consideration were sub-divided into eight decadal period of 11years growing seasons of 3 months (July-September) and 6 months (May – October) in other to have eight complete series of 1965-1975, 1970-1980, 1975-1985, 1980-1990, 1985-1995, 1990-2000, 1995-2005, 2000-2010 from the entire period. The amount of rainfall for both 3 and 6 months growing seasons of 1980-1990 was found to be the lowest. The bulk of the rainfall recorded within the period of study occurred between 1990 and 2010, as shown in Fig. 2. The analysis indicates that there was a more serious decline of rainfall amount within 1980–1990 decade. This is also an indication that the area experienced below long-term average rainfall in the growing season of 1980-1990 decade. Past studies like Ekpoh and Ekpenyong, (2011) and Odjugo, (2010) have also reported a decline in rainfall amount in this period.

From Fig. 3, most of the early years (1965-1995) were years of drought while the recent years (1996-2010) revealed a recovery from past droughts. The area generally experienced about 22 years of below average rainfall or drought situation (i.e. negative SPI index value) between 1965 and 2010. Specifically, the period 1966 to 1995 shows series of drought years with few wet years for the study area. On the other hand, from 1998 to 2010, the area has generally experienced wet years just as reported by Fabeku and Okogbue (2014). Also, Table 2 illustrates further the SPI classification as categorized into moderate drought (MD), severe drought (SD), extreme drought (ED), above normal drought (AN) (i.e. the total number of MD, SD and ED) and below average rainfall (BA) (i.e. SPI value less than zero).

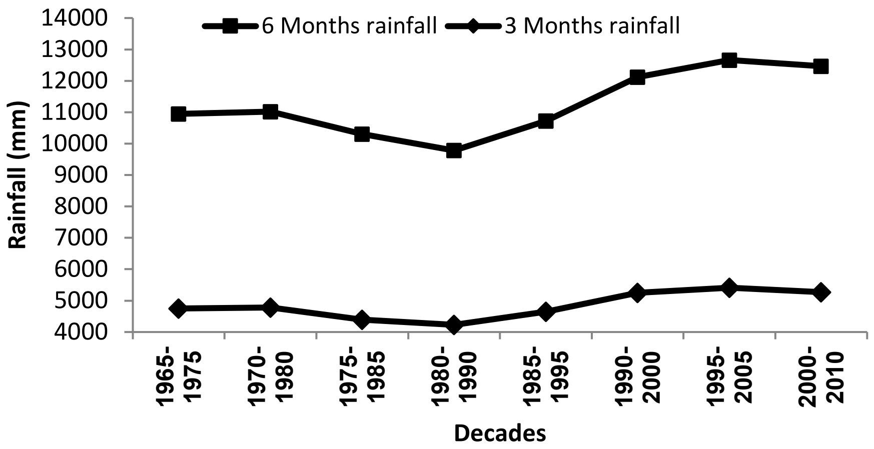


Fig. 2. Decadal 3 and 6 months rainfall amount in the study area between 1965 and 2010

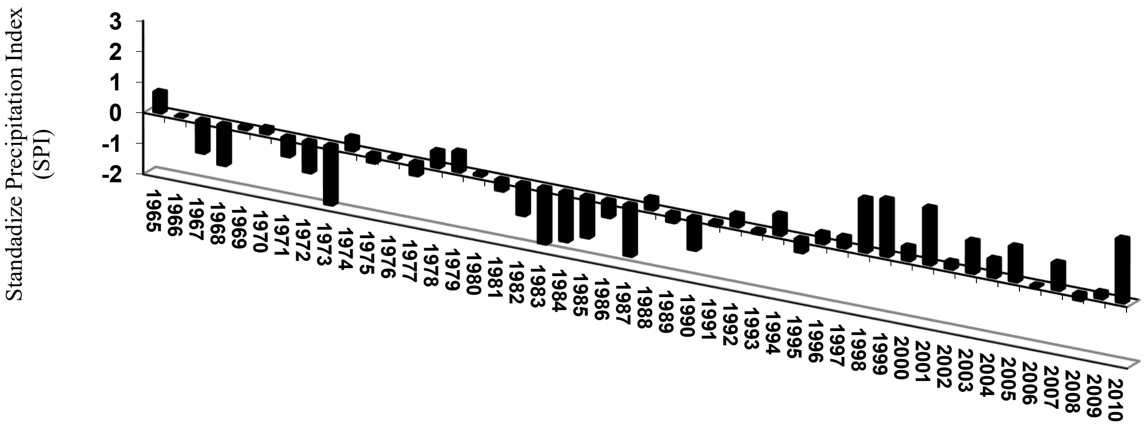


Fig. 3: SPI values against each year of study averaged over the entire study area for 1965-2010

The area experienced 3 extreme drought situations (i.e. SPI index value of -2 and less) within the study period in 1973, 1983 and 1987. There was also a severe case of drought in 1984, while the entire area generally experienced four moderate drought situations in 1972, 1982, 1985 and 1990. The remaining years showed years of near normal, moderately wet and very wet situations as noted in 1998, 1999, 2001 and 2010. The longest drought run throughout the entire area within the study period is the period 1981-1991, with a marked rainfall deficit. The most intense multiple-year drought event within the study period was 1981-1987; a run of 7 years followed by three 3-year event in 1971-1973, 1966 -1968 and 1988 – 1990. The lowest drought index was found in 1973 and 1983 (-1.9 and – 1.8 respectively). The series of drought condition as revealed in the analysis is in line with the findings of Adeaga (2002) and Obi (2012). The extreme drought of 1983 started in 1981 as a normal dry year, then became moderate drought in 1982 and later escalated into extreme drought in 1983. It shared similarity with the one that happened from 1971 to 1973 (Adeaga, 2002; Oladipo, 1993). However, this study found that the 80s drought was more devastating as it progressed into severe and moderate drought conditions in 1984 and 1985, respectively and later end up into an extreme case in 1987. Okorie *et al*. (2010) also reported that there are many years of drought incidence between 1975 and 2004. During the study period, drought years occurred about 48% of the time. However, the recent years in the area generally experienced wet situations as also earlier reported by Abaje *et al*. (2012b) and Abaje *et al*. (2013). Analysis was further undertaken for each station (Fig. 6 and Fig. 7) in order to know the situation in each station. Generally, the graphs show that all the stations experienced drought situation during the 1970's and 1980's drought episodes, while few stations experience drought situation during the 1990's and 2000's. The worst drought situation within the study period in Sokoto was recorded in 1987 while 2010 was the year with the highest positive value which implies wet condition. The result from Katsina is in line with the findings of NIMET (2001) that the area survived 13 years of below average rainfall between 1982 and 1999.

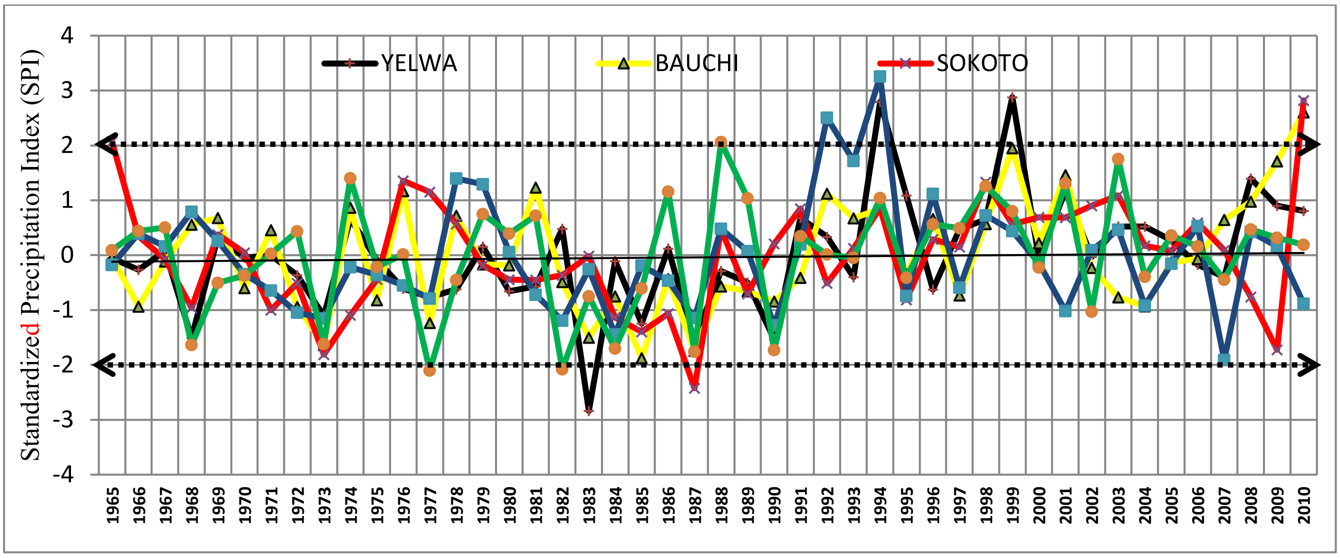


Fig. 4: Standardized Precipitation Index (SPI) values over each station in the study area. (The dashed line marks the point of extremely dry and extremely wet situation).

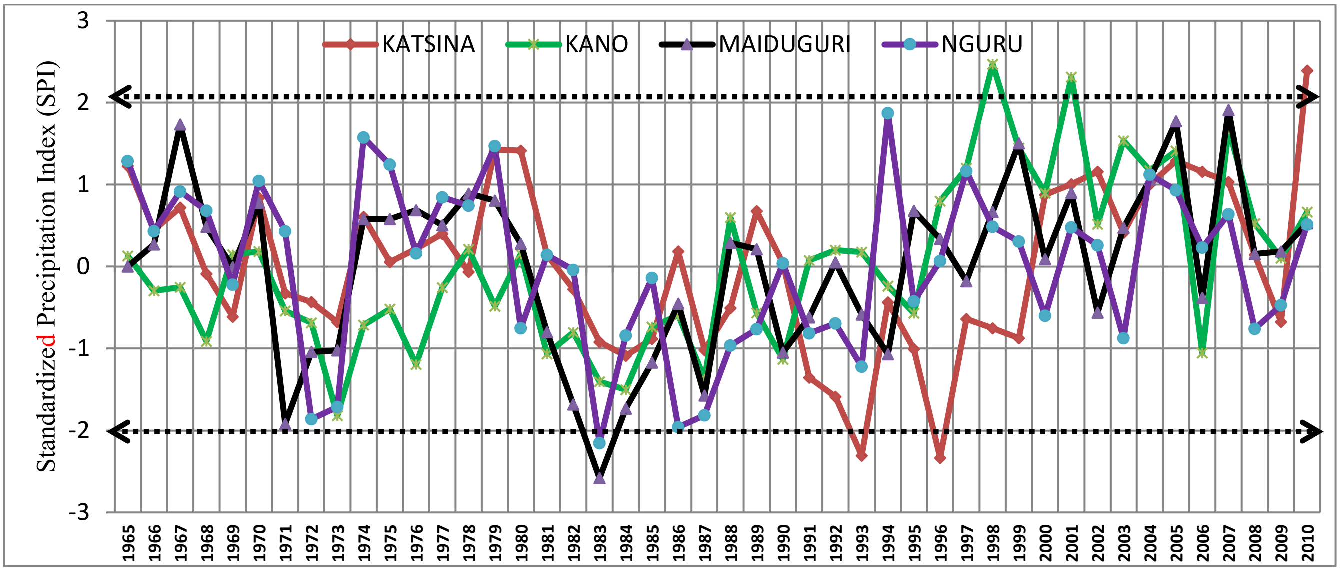


Fig. 5. Standardized Precipitation Index (SPI) values over each station in the study area. (The dashed line marks the point of extremely dry and extremely wet situation).

The number of Above Normal (AN) drought situation experienced in Maiduguri within the study period shows that Maiduguri is the worst hit by unbearable drought as it has the highest number of above normal drought occurrences. This implies that the area is highly prone to severe drought situation. Yelwa and Bauchi mostly show near normal situation. However, there were more near normal situation in all the stations than both drought and wet situation. From Table 2, the result for Sokoto reveals several years of drought between 1967 and 1996 whereas 1997-2010 were wet years except for 2008 and 2009. Sokoto had about 21 years of below average rainfall with3 years of severe drought situation in 1973, 1987 and 2009, and 5 years of moderate drought in 1971, 1974, 1984, 1985, and 1986. Katsina had about 22 years of below average rainfall with 3 severe cases in 1992, 1993, 1996 and 4 years of moderate drought condition in 1984, 1987, 1991, and 1995. In Nguru, there were 20 years of below average rainfall within the study period with 5 severe cases in 1983, 1972, 1973, 1986, 1987, and one moderate drought situation in 1993. Gusua had about 25 years of below average yearly rainfall with one year of severe drought situation in 2007 and six years of moderate drought in 1972, 1973, 1982, 1987, 1990, and 2001. Kano had about 22 years of below average rainfall within the period. It experienced 2 years of severe drought situation in 1973 and 1984, 6 years of moderate drought situation in 1976, 1981, 1983, 1987, 1990 and 2006. Potiskum had about 19 years of below average rainfall with two years of extreme drought situation in 1977 and 1982, five years of severe drought in 1968, 1973, 1984, 1987, 1990 and 2 years of moderate drought in 1974 and 2002. It was also evident that Potiskum was next to Maiduguri in terms of above normal drought situation. Maiduguri had about 18 years of below average rainfall with 5 severe drought situations in 1982, 1983, 1984, 1987, 1971 and 5 moderate drought situations in 1972, 1973, 1985, 1990 and 1994 within the study period. Yelwa had about 25 years of below average rainfall situation within the study period with 3 years of severe drought situation in 1983, 1968, 1987, and 3 years of moderate drought situation in 1973, 1985 and 1990. Bauchi had about 27 years of below average rainfall within the study period with 4 severe cases of drought in 1973, 1983, 1985 and 1987, and 1 year of moderate drought in 1977.

Table 2: Summary of Number of Drought Occurrences and the Corresponding Years of Occurrence

Stations	ED	Years	SD	Years	MD	Years	AN	BA
Study area	3	1973,1983, 1987	1	1984	4	1972, 1982, 1985, 1990	8	22
Sokoto	1	1987	2	1973, 2009	5	1971, 1974, 1984, 1985, 1986	8	21
Katsina	2	1993,1996	1	1992	4	1984, 1987, 1991, 1995	7	22
Nguru	1	1983	4	1972, 1973, 1986, 1987	1	1993	6	20
Gusua	-	-	1	2007	6	1972, 1973, 1982, 1987, 1990, 2001	7	25
Kano	-	-	2	1973, 1984	6	1976, 1981, 1983, 1987, 1990, 2006	8	22
Potiskum	2	1977,1982	5	1968, 1973, 1984, 1987, 1990	2	1974, 2002.	9	19
Maiduguri	1	1983	4	1971, 1982, 1984, 1987	5	1972, 1973, 1985, 1990, 1994	10	18
Yelwa	1	1983	2	1968, 1987	3	1973, 1985, 1990	6	25
Bauchi	-	-	4	1973, 1983, 1985, 1987	1	1977	5	27

In order to examine the type of climatic variations that have occurred within the period under consideration, rainfall data for 46 years was divided into three periods (1965-2010), (1965-1989) and (1990-2010) and analyzed using the mean, the standard deviation, and the coefficient of variability. The results are presented in Table 3. Nguru showed the lowest mean rainfall, followed by Katsina and Maiduguri, a situation which continued for the remaining periods.

Table 4: Temporal rainfall variation for each station

	Period 1 (1965 – 2010)			**Period 2 (1965 – 1989)**			**Period 3 (1990 – 2010)**		
	Mean	**Std.dev**	**CV(%)**	**Mean**	**Std.dev**	**CV(%)**	**Mean**	**Std.dev**	**CV(%)**
Sokoto	634.9	156.26	24.6	589	148.7	25.2	668.5	150.5	21.8
Katsina	550	150.4	27.3	553	114.8	20.8	546.4	187.2	34.1
Nguru	422.5	104	24.6	415.7	117.4	28.2	430.5	87.7	20.4
Gusau	894.5	170.43	19.1	853.7	117	13.7	943.1	210.7	22.3
Kano	900.4	337.9	37.5	711.2	164.1	23.1	1125.7	355.7	31.6
Potiskum	636	140.8	22.1	611.8	156.9	25.7	664.9	116	17.5
Maiduguri	590.5	152.9	26	556.5	156.5	28.1	630.9	141.7	22.5
Yelwa	998	174	17.4	918.8	111.2	12.1	1092.3	190	17.4
Bauchi	1029.8	181.36	17.7	965.7	153	15.8	1106.1	186.2	16.8

Generally, the mean, standard deviation and coefficient of variation vary from each station to the other. Ekpoh and Ekpenyong (2011) stated that the larger the change in the standard deviation the higher the risk of both deficient as well as excessive rainfall. Sumner (1988) noted that the mean is the measure generally used to represent the "normal" rainfall condition of a place. Climatologically, any climatic variation that involves a shift in both the mean and standard deviation implies extreme climatic condition (Fukui, 1979). Stations with high CV have low consistency of rainfall in time, while stations with low CV have higher consistency in rainfall. Yelwa showed the lowest coefficient of variation which means that Yelwa had the lowest range of variation in relation to the mean for the first period and hence. This shows that by implication, Yelwa has the most consistent rainfall among the stations understudy. Within periods 2 and 3, there was an increase in deviation from the mean value for Sokoto, Katsina, Gusau, Kano, Yelwa, Bauchi. Bauchi has the highest rainfall mean, followed by Yelwa and Kano throughout the entire periods. Nguru had the lowest standard deviation while Kano had the highest for period 1, and this reveals that there is a wide gap between the average rainfall amount and the observed rainfall in Kano within the period. Katsina and Maiduguri also show a high percentage of variation for the first period. In period 2, Yelwa had the lowest standard deviation, while Kano has the highest, but Nguru and Maiduguri have the highest coefficient of variation with Yelwa and Gusau having the least. However, Kano and Gusua has the highest standard deviation for period 3, and Kano has the highest coefficient of variation. Within period 2 and 3, there was an increase in the standard deviation value for Sokoto, Katsina, Gusau, Kano, Yelwa, Bauchi. This can be attributed the sudden increase in the rainfall over the entire region in the period. However, Nguru, Potiskum and Maiduguri showed more stability for near normal situation in the third period.

Table 5: Trends on annual rainfall over each station

	1965-2010	1965-1989	1990-2010
Maiduguri	0.150	-0.325	0.358
Nguru	-0.107	-0.555**	0.144
Kano	0.534**	-0.268	0.235
Katsina	0.028	-0.398*	0.621**
Potiskum	0.112	-0.113	0.140
Gusau	0.152	-0.205	-0.266
Sokoto	0.220	-0.333	0.019
Bauchi	0.332*	-0.184	-0.044
Yelwa	0.429**	-0.292	0.289

**Significant at the 0.01 level, *Significant at the 0.05 level, the painted values are the negative trend.

From Table 5, the trend analysis for each station reveals that there was a non significant decreasing rainfall trend only in Nguru, whereas, every other station showed an increasing trend when analyzed for the entire study period. Kano, Bauchi and Yelwa showed a significant increasing trend which means that the rainfall in the stations improved looking at the trend from 1965-2010. Also, period 1965-1989 showed a negative trend which signifies decreasing rainfall with the decrease being significant in Nguru and Katsina. It also shows that this period marks the beginning and the end of major drought events in the region. The last period (1990-2010) marked a period of positive rainfall trend (sake for Gusau and Bauchi) which implies that rainfall in these stations improved in this period and significantly in Katsina.

Figure 6 shows the SPI spatial map of the study area for the specified period. The red colour shows the most affected area and also area with the least and unstable rainfall within a particular year, while the green colour shows the area least affected. The years for the spatial map were selected as they were among the years with notable drought in the region. From Fig. 8, the drought of the 1970s started from 1971 as shown in the SPI map for 1971 and was more pronounced in the north-eastern part which was seen to continue till 1972 as its severity moved towards the north western part and later established into more severe drought in 1973 as it concentrated around the north central and later moved back to the eastern part of the study area as it cuts some part of the central area. Spatially, the 1980's drought that started mildly in 1981 and became pronounced in 1982 at the north eastern part of the study area was seen to move towards the central part of the area (around Kano $12^0$03'N, $08^0$12'E) in 1984 but still very much prominent at the eastern part. This continued to spread to almost the entire area in 1985 (and also was still very much prominent at the eastern part of the study area) except Yelwa ($10^0$53'N, $04^0$45'E) where it was prominent in 1983. The drought episodes of the 1980s were also mild in 1986 but ended their occurrence finally in 1987 at the north western part of the study area (Sokoto $13^0$01'N, $05^0$15'E) in an extreme situation.

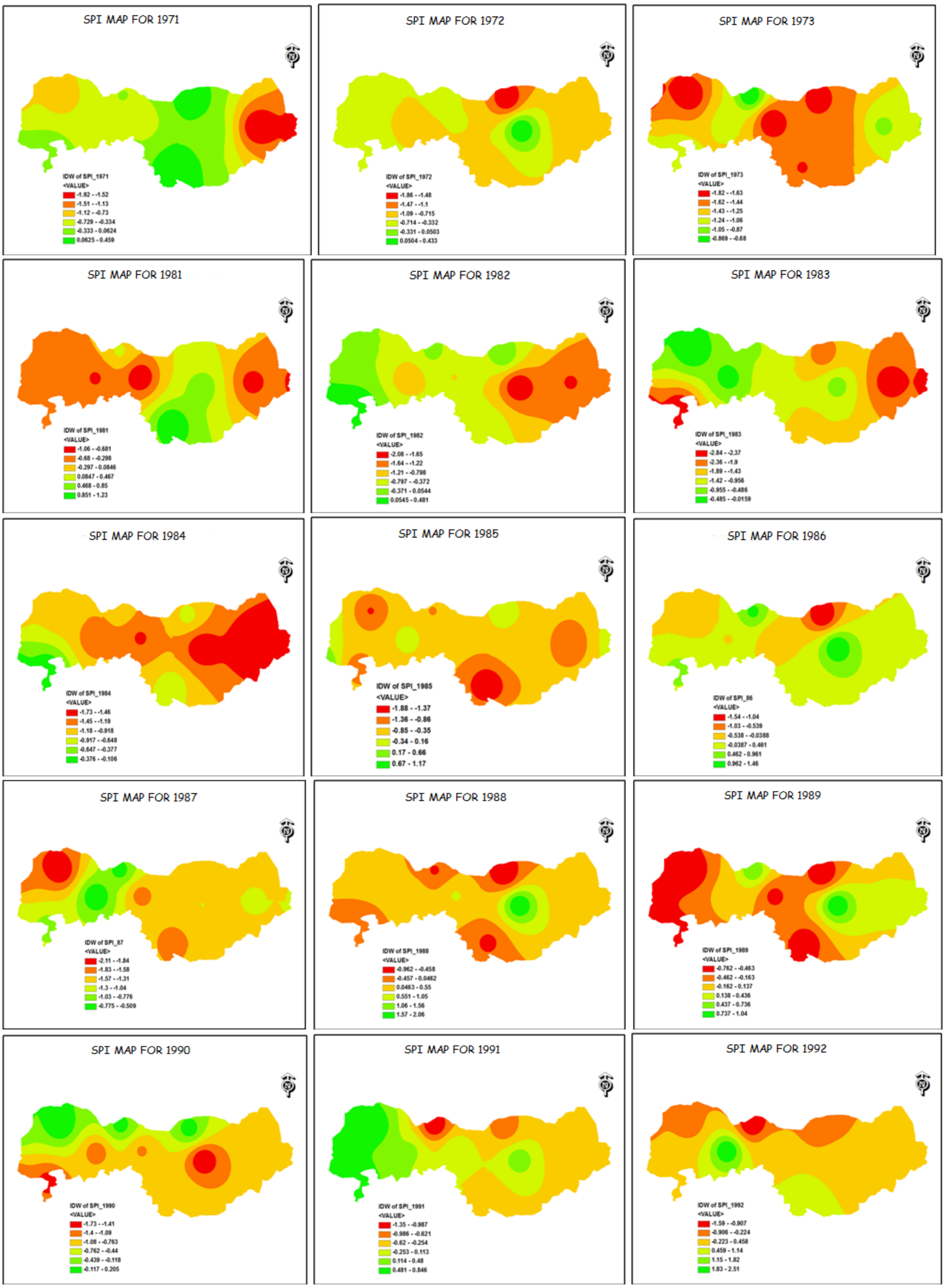
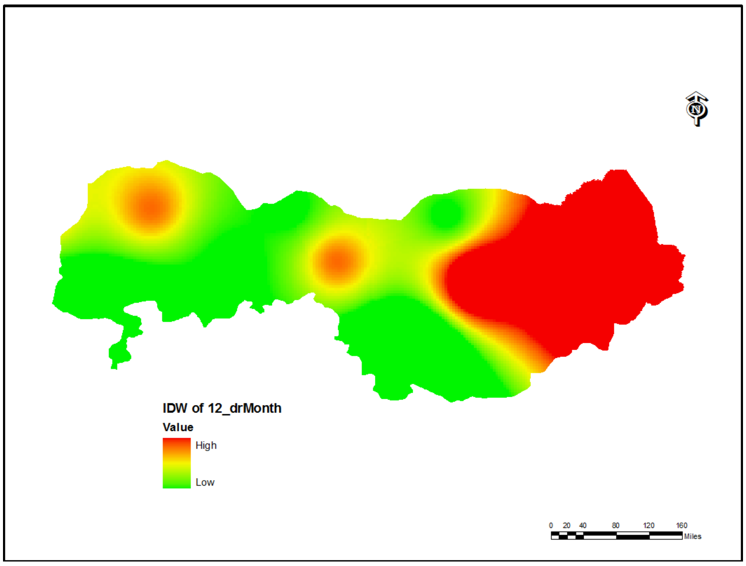


Fig. 6: SPI spatial map of the study area for 1971-1973 and 1981-1992

The droughts of the early 1990s, as recorded in this research were the mildest of all. It started insignificantly in 1989 from the western and central part of the study area and became severe as they moved to the eastern part of the study area in 1990 where Maiduguri and Potiskum lie. The drought pattern and movement from the spatial interpolation also coincide with the earlier findings of Abaje *et al*. (2013). The remaining years of the late1990s to 2010 show no defined drought episode as most of the years were wet and moderate.



Fug. 7: Drought Frequency Risk for the study Area

The overall drought frequency risk for the study area, based on the findings of this study, is illustrated in Fig. 7, which shows the frequency of the above near normal drought situation occurrences in the area in which the northeastern part shows high risk of such situation than the others. Therefore, more attention should be given to the area in terms of all the necessary drought mitigation plans. The haphazardly spatial representation of the result can be attributed to the systems that bring about instabilities in West Africa.

Conclusions and Recommendations

The SPI analysis has shown that several drought years occurred in the study area within the study period, but unfortunately, there was no clear pattern as a severely wet year can be supplanted by a dry year. As the prominent droughts of the 1970s and 1980s mostly affected Maiduguri and thus was declared a disaster prone area, effort should be made by the necessary agency and stakeholders to put down necessary modalities to contain the menace as it will surely come again in the future. Due to the specific climate conditions and the resulting precipitation patterns in this area, a more populated meteorological network with the inclusion of the existing stations would have improved the quality of the results of the study. Also, the growing season's rainfall was found to be below average in the early decade of study, despite the later improvement in the last decade, effort should be put in place in other to be on watch because drought is a natural hazard that cannot be stopped.

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Comparative Evaluation of Different Time Scale Vegetation Index Anomalies for Drought Analysis in the Sudano-Sahelian Region of Nigeria

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Abstract
Satellite imageries provide real-time information and great potentials for drought analysis. This paper is aimed at investigating the application of Normalized Difference Vegetation Index (NDVI) at different time scale for drought analysis in the Nigerian Sudano Sahelian Region. Thirty one years records of Vegetation indices were obtained from the National Aeronautics and Space Administration and SPOT – Vegetation Programme of Vision on Technology and processed into time series at different time scales of percent decadal, monthly and annual NDVI anomalies. It was discovered that the percent decadal NDVI anomalies and percent monthly NDVI anomalies reflected droughts at all level of severity while percent annual NDVI anomalies undermined and masked drought occurrences especially, near normal and moderate ones. As a result, percent decadal NDVI anomaly and percent monthly anomaly were recommended for drought monitoring and real-time drought analysis in the region, to prevent and manage drought-induced environmental disaster.
Keywords: Satellite Imageries, Vegetation Index, Normalized Different Vegetation Index, decadal anomalies, time scales.

Introduction
Drought is one of the most important weather –related natural disaster and is often aggravated by human activities. Since it affects large areas for months and years. It has serious adverse impacts on regional food production, human life expectancy, and the economic performance of regions or countries. According to Fidelis (2003), Borno State is one of the most affected land areas of Nigeria that has suffered a fifteen-year drought during the period between 1960 and 1999. The persistent drought has indeed, a number of times caused famine in Northern Nigeria, especially the drought episode of 1972-1973, during which thousands of animals died and farm yields dropped by up to 60% (Adeogun, 2013; Fidelis, 2003). It is pertinent that drought management systems should utilize and rely on real-time information sources to aid early preparedness. According to FAO (1999), satellite

images are often the only information available in near real-time for arid and semi –arid regions of Africa, which are often subject to drought and poor crop conditions, and where timely and reliable ground information is often difficult to obtain. Normalized Difference Vegetation Index (NDVI) images are used to know the areal extent of healthy vegetation (NDVI values range from +1.0 to -1.0), and areas of barren rock, sand, or snow usually show very low NDVI values (for example, 0.1 or less). Sparse vegetation such as shrubs and grasslands or senescing crops may result in moderate NDVI values (approximately 0.2 to 0.5) and high NDVI values (approximately 0.6 to 0.9) correspond to dense vegetation such as that found in temperate and tropical forests or crops at their peak growth stage (USGS, 2011).
The use of NDVI for drought analysis is relatively new and its application might be used erroneously by researchers as noted by Jayasuriya (2011) For instance, Standardized Precipitation Index at different time scales had been misused for different types of drought investigation. The use of NDVI to drought investigation might be misused like the previous indices in the past. Hence, this study aimed at evaluating different time scale NDVI anomalies for drought analysis in the Nigeria Sudano-Sahelian Region

Materials and Methods

Study Area

The Sudano-Sahelian region of Nigeria (SSRN) lies between Latitudes 11^0 and 13^0N and Longitudes 4^0 and 15^0E (Maduakor, 1991) and, constitutes most of Borno, Kano, Sokoto, Adamawa, Bauchi, Gombe, Jigawa, Katsina, Kebbi, Yobe and Zamfara States in Nigeria as shown in Fig. 1. The climate of this region results from the influence of two main wind systems: the moist, relatively cool, monsoon wind which blows from the Atlantic Ocean towards the country and brings rainfall; and the hot, dry, dust-laden Harmattan wind which blows from the north-east across the Sahara desert. The mean annual precipitation in the region is generally less than 1000 mm. The Sahel at the northern tip of Yobe and Borno states, receives less than 500 mm of rain annually in about 3-4 months. These areas often experience chronic water shortages during the dry season when rain-fed springs and streams dry up (Apeldoon, 1981, Oladipo and Kwaghsa, 1994).

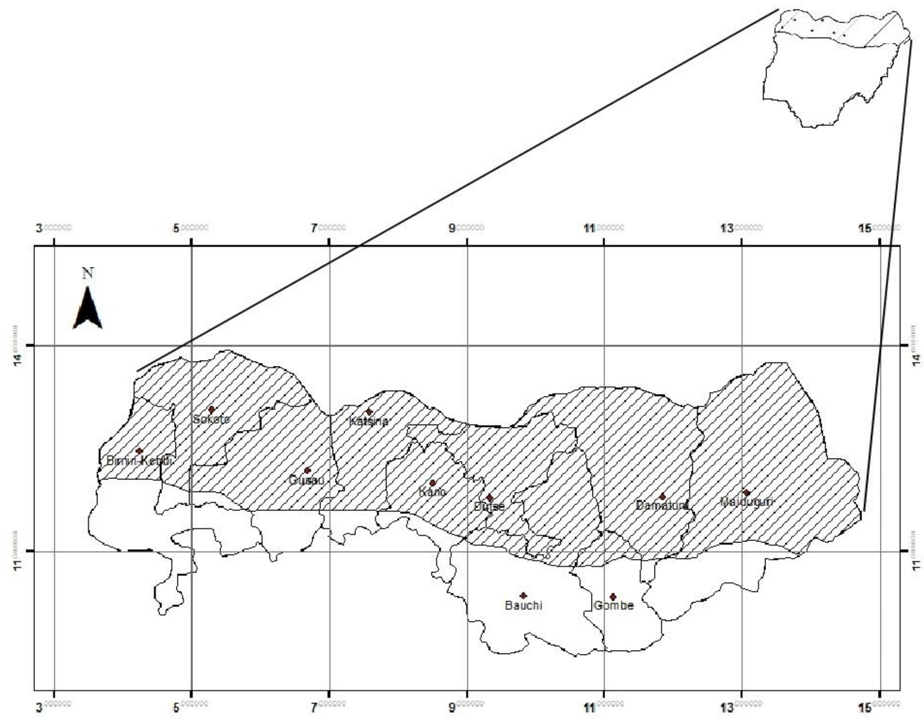

Fig. 1: Study Area: Nigerian Sudano-Sahelian Region

Data acquisition

The imageries covering the study area were downloaded from the websites of National Aeronautics and Space Administration (NASA) and SPOT-Vegetation Programme of Vision on Technology (VITO) at www.earlywarning.usgs.gov and [www.free.vgt.vito.be,](www.free.vgt.vito.be) respectively. The image data i.e., Normalized Difference Vegetation Index (NDVI), provided by NASA consists of imageries from 1981 to 2008 while the imageries available from VITO covers the period 1989-2012. This implies that the two sets of data consist of 27 and 10 years of records respectively. However, in other to have a robust hydrologic analysis, a record length of not less than 30 years is required (WMO, 1988). As a result, imageries covering the study area and spanning 31 years were extracted from the two sets to form a continuous record from 1981 to 2011.

Preparation of Map of the Study Area

The study area, Sudano-Sahelian Region of Nigeria (SSRN), was digitized from an existing grid map of Nigeria which served as a background map for the digitization process. The background map was uploaded into an ArcGIS 9.2 environment, a Geographic Information System (GIS) application software, and then georeferenced using four identified points on the map with respect to their latitude and longitude. Point and polygon shapefiles prepared in the Arc Catalog component of the software were also uploaded into the ArcGIS environment and used together with the map to digitize the study area. The prepared map of the study area was processed further by applying symbology and labeling functions in ArcGIS.

Data Extraction and Processing

The remotely sensed data were extracted and processed using Imagery Display and Analysis (IDA) software after which the imageries were validated.

Extraction and processing of imageries: The imageries were extracted and processed with the Imagery Display and Analysis (IDA) GIS application software known as Windisp 5.1. The NASA imageries can be displayed, extracted, processed and analyzed with this software but the VITO imageries have to be processed to IDA formats readable by Windisp 5.1. Hence, application software called VGT Extract was used to extract the imageries from VITO imagery files and imported into Windisp 5.1 for further processing and analysis.

The WinDisp 5.1 software was used to open each of the imageries (containing decadal data) and then the prepared map of SSRN (Fig. 1) was super imposed on the imagery so as to extract the NDVI for the region alone. The extracted NDVI data were then imported into Excel Spreadsheet. for further analysis. The data extracted were yearly decadal NDVI and 31 year NDVI average. The extraction was done for the 7 synoptic stations in the study area after which the data were averaged to obtain the yearly representative values for the region (SSRN).

Moreover, the NASA image data comprises of dimensionless NDVI datasets stored as pixels. But the VITO image data were stored as eight bits per pixel (or Bytes) values between 0 and 255 that have to be converted to pixel values (PV) using the equation (1) developed by Jacob *et al*. (2010):

$$PV = (DNx0.004) - 0.1 \quad (1)$$

That is, scale = 0.004 and offset = 0.1. Hence, the pixel values (PV) which were the real dimensionless values of NDVI were derived from the equation. This conversion was done for all the VITO data set after extraction.

Validation of imageries: Image validation was achieved by using phonological metric approach. The approach involves plotting an annual NDVI and observing if the rising part and point of inflexion for falling part of the curve correspond with the beginning of rainy season/growing season and end of rainy season respectively, in the region. This is in accordance with the expectation that the NDVI, a measure of vegetative surface reflectance, values increase during the beginning of rainy season and also, reduce during the end of the rainy season.

The data sets have been temporarily smoothed to remove noise as a result of aerosols and cloud. The SPOT Vegetation data are gathered by Landsat 7's Enhanced Thematic Mapper Plus (ETM+) Sensors. The other set are obtained from Moderate Resolution Imaging Spectroradiometer (MODIS) carried aboard NASA Terra and Aqua Satellite and hence, they are known as Global MODIS data

Computation of Different percent NDVI Anomalies for Drought Analysis in the SSRN
The NDVI were analyzed at different time scales using the percent NDVI anomaly. The percent NDVI anomaly for a particular decade, *i,* as expressed in equation (2)

$$Percent\ NDVI\ Anomaly = \frac{NDVI_I - NDVI_{mean}}{NDVI_{mean}} x100\% \quad (2)$$

The percent NDVI anomaly was processed for each of the decade in the yearly data extracted and plotted with respect to decade ranging from the first decade to the last decade of the study period. The graph obtained was analyzed with respect to drought occurrence in the region. The drought events in the region were classified based on Table 1.

Table 1: Drought Risk Classification Using NDVI Anomalies

Percent NDVI Anomalies	Drought Class
Above 0%	No Drought
0% to -10%	Slight Drought
-10% to -20%	Moderate Drought
-20% to -30%	Severe drought
Above -30%	Very Severe Drought

Apart from the decadal time scale, other time scales considered are monthly, wet season, dry season and annual time scales. The monthly percent NDVI anomaly was obtained by adding the three decades in a month and divide by 3. In the same way, the annual percent NDVI anomalies were obtained for all the stations by adding and averaging the total monthly percent NDVI anomalies. Table 1 was used to classify drought in the region using NDVI anomalies at different time scale NDVI anomalies. The NDVI anomalies at different time scales were compared to choose one that reliably represents the Nigerian Sudano-Sahelian Region drought situation.

Results and Discussion

Data Extraction and Processing

The imageries of Nigerian Sudano-Sahelian Region were extracted and validated. Fig. 2 presents the result of imageries validation using phonological metrics. The figure indicates that the rise in NDVI average graph corresponds to the beginning of raining season, which is May, and the fall in NDVI average occurs during the end of the raining season, September in the region. These observations validate the two data sets and hence could be used for the study.

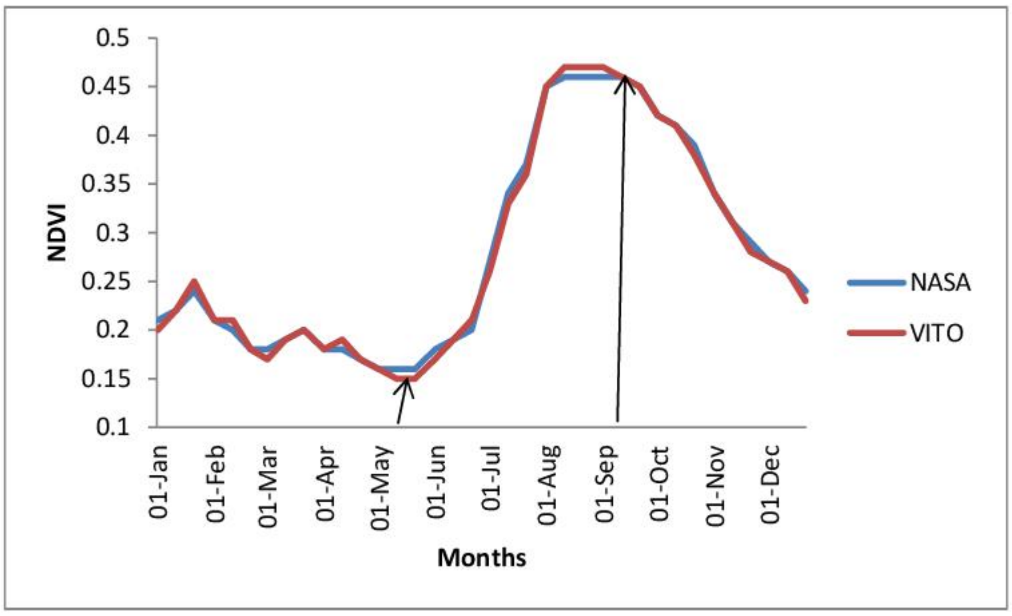

Fig. 2: Validation of imageries using phonological metric

Percent decadal NDVI anomalies

Figure 3 shows the percent decadal NDVI anomalies for the seven stations. Drought variations were observed in the seven stations in the Nigeria Sudano-Sahelian Region (NSSR). The figures reflected that the seven stations had experienced a lot of drought events of different magnitude and intensities from 1981 to 2011. The figure showed that the period of worst drought in the region was from first decade of July, 1983 to last decade of March 1985, that is from 91st decade to 153rd decade, with the peak in the last decade of October 1984 (around 138th decade). This observation is well documented in the literature as stated by Medugu (2007). The observed drought episode of 1983 to 1985 is another lengthy drought in NSSR after those of 1911-1914 and 1951-1954 reported in the literature. Another set of drought events observed in the region were recorded in 1987 to 1988, from 252nd decade to 288th decade, and in 1993 to 1994, from 468th decade to 504th decade. The various droughts were classified as severe drought (-20 to -30% percent NDVI anomalies) and very severe drought (percent NDVI anomalies greater than 30%) in all the seven stations as seen in Fig. 3.

The very severe droughts of 1983-1985, 1987-1988 and 1993-1994 were mostly succeeded by slight droughts (0 to -10% percent anomalies) to moderate droughts (-10 to -20% percent

NDVI anomalies) at different time and duration in the seven stations as shown in Fig 3. However, very severe and severe droughts were experienced in Sokoto Station in 2003 and 2005, respectively. This is in agreement with the investigation by Adegboyega *et al*. (2016) who observed that 90% of the state experienced severely dry conditions between 2002 and 2011 using Standardized Precipitation Index. Also, notable drought events were observed in Maiduguri and Kano in 2009, from 1008th decade to 1044th decade. The results indicated that though, the NSSR was generally being threatened by drought but, its severity, magnitude and intensity varied from one location to another.

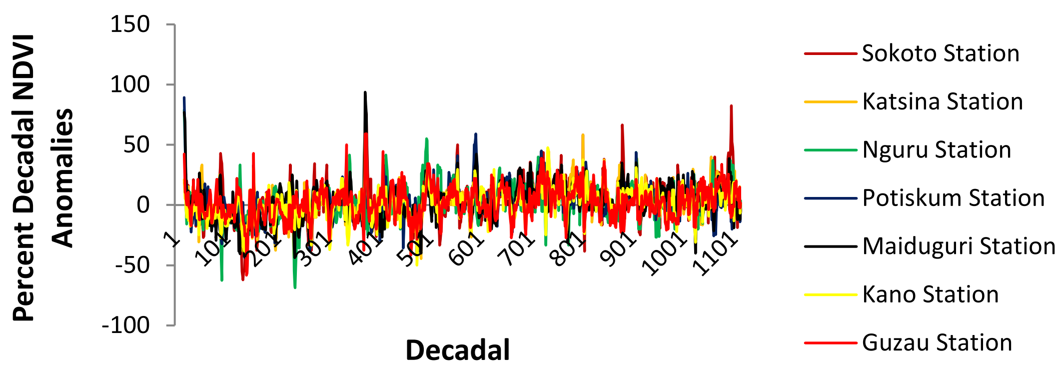

Fig. 3: Percent Decadal NDVI Anomaly Trend at NSSR Stations

Percent monthly NDVI anomalies

Figure 4 shows percent monthly NDVI anomalies for the seven synoptic stations. Comparing the graphs of percent decadal NDVI anomalies with the percent monthly NDVI anomalies for each station, the drought trend observed in the former were similar to that observed in the latter for each station.

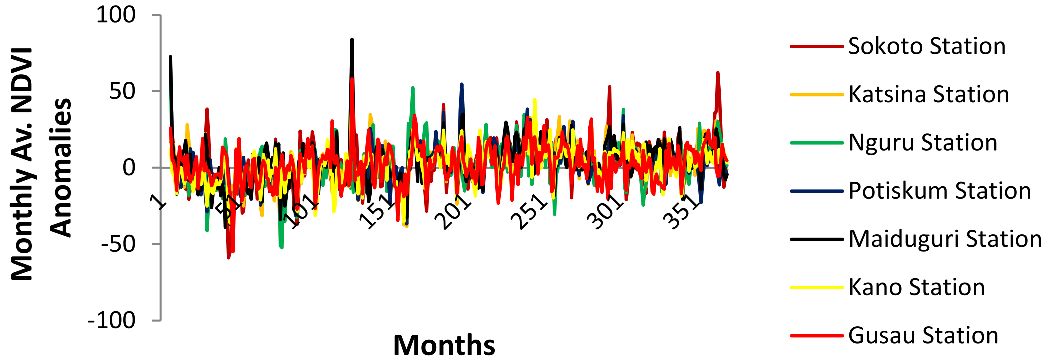

Fig. 4: Percent monthly NDVI anomalies for NSSR stations

Percent annual NDVI anomalies

Percent annual NDVI anomalies for the seven stations are presented in Fig. 5. Notably, the percent annual NDVI anomalies values were positive from 1994 to 2011 at nearly all the stations which implied that there were no droughts during the period. This is in contrary to the two other NDVI anomaly time scales investigated. Although the results supported Chima *et al.,* (2011) in which highest maximum positive NDVI value was reported in the year 2000 out of the four years – 1972, 1980, 1990 and 2000 – investigated. Moreover, Fabeku and Okogbue (2014) noted dramatic reduction in drought occurrence from 1990 towards 2005, the end of their study period, but not complete absence of drought as indicated in Sokoto Station, Katsina Station, Maiduguri Station and Kano Station, from 1994 or 1997 to 2011 as shown in Fig. 5. Fabeku and Okogbue (2014) and the results of percent decadal NDVI anomalies and percent monthly NDVI anomalies in the this study agreed and indicated that the region had witnessed intense drought events in the past but reduced drought episodes in the recent years probably as a result of an increase in rainfall due to climate variability.

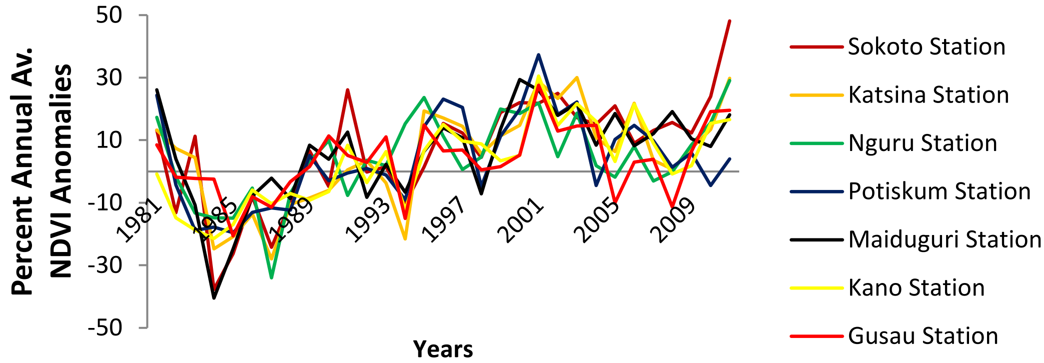

Fig. 5: Percent annual NDVI anomalies for NSSR stations

By comparing the three percent NDVI anomalies investigated, it is obvious that percent decadal NDVI anomalies and percent monthly NDVI anomalies reflected drought occurrence at all level of severity and magnitude. However, percent annual NDVI anomaly time scale undermined and concealed slight and moderate droughts in the recent years for the seven stations. This observation reflects that for real-time drought forecasting, percent decadal and percent monthly NDVI anomalies are adequate because drought occur gradually at low severity which the percent annual NDVI decadal might masked.

Conclusions and Recommendations

The study has shown that the SSRN had witnessed many drought episodes ranging from very severe to near normal drought conditions and the notable ones that cut across the investigated stations were: 1983-1985, 1987-1988 and 1993-1994 drought events. The percent decadal NDVI anomaly and percent monthly NDVI anomaly time scales reveal droughts at all level of severity and hence, they are suitable for drought monitoring and real-time forecasting because drought, regarded as a creeping phenomenon, occurs gradually as slight drought, which the percent annual NDVI decadal might mask. The results indicate that though, the NSSR is generally being threatened by drought but, its severity, magnitude and intensity vary from one location to another. The application of NDVI anomalies to drought monitoring and forecasting should be limited to percent decadal anomalies and percent monthly anomalies because percent annual anomalies undermine and mask slight drought episodes especially, during the incident stage of drought occurrence.

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Analysis of the Stochastic Characteristics and Modelling of Monthly Rainfall Time Series of Abeokuta, Nigeria

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Abstract

This study attempts to analyse the stochastic characteristics of rainfall for Abeokuta, Nigeria and its probable simulation. To this end, rainfall time series data of Abeokuta was obtained from the Nigerian Meteorological Agency (NIMET) for a period of 28 years. The analysis of the stochastic characteristics entails the assessment of temporal trend and periodicity while modeling of the time series was done by employing the seasonal multiplicative Autoregressive Moving Average (ARIMA) modeling technique. Results obtained indicate that there was no discernible trend in the annual series though spectral analyses show that there is high periodicity of fluctuating frequency in the monthly time series. Based on the extent of periodicity and degree of randomness, a multiplicative seasonally differenced ARIMA model was found appropriate for the simulation of the monthly rainfall regime; model choice was on the basis of Akaike Information Criterion (AIC) and Autocorrelation functions. On the basis of these two criteria, $ARIMA(0,0,1) \times (0,1,1)_{12}$ *and* $ARIMA(1,0,1) \times (1,1,1)_{12}$*, respectively were adjudged probable candidate models for simulation studies. However considering the fact that rainfall phenomenon exhibits high spatio-temporal variability, the seasonal persistence can only be explained relatively by the autoregressive component rather than solely the moving average component; thus, the second model is preferable. Despite this though, for effective generalization of simulation results, Artificial Neural Network and Wavelet models are recommended and in this regard too, conditional probability of rainfall occurrence should be considered.*

Keywords: *Stochastic characteristic, seasonality, trend, ARIMA, Simulation*

Introduction

Weather has generally been considered as the state of the atmosphere at a given time at any given location. It may also be referred to as the aspects of the atmospheric state which is visible, experienced and affects human activities (Ogolo and Adeyemi, 2009). Weather and climate science is founded on observing and understanding our complex and evolving environment. It is therefore an inherent requirement that climate scientists make available the best possible information on the current state of the climate, and on its historical context. This draws on globally distributed observations and monitoring systems and networks. This is also dependent on robust data processing and analysis to synthesis vast amounts of data, properly taking into account observational uncertainty resulting from both measurement limitations and sampling (Morice *et al*., 2012).The weather conditions of any given location is often described in terms of the meteorological elements which include the state of the sky, temperature, winds, pressure, precipitation, and humidity. These factors initiate and influence the atmospheric processes (Ayoade, 1993).

According to Williams (2008), among all the climatic elements, rainfall is the most variable, both temporally and spatially and such variations can have significant impacts on economic activity. Rainfall is one of the most important components of hydrologic cycle which begins with change in temperature and relative humidity (Tsoho, 2008).Theoretically, an increase in heavy rainfall events can be expected in response to global warming. Satellite observation and related history indicates that the amount of perceptible water in the vertical column over the ocean increases non-linearly with increasing sea surface temperature. Thus, the amount of water vapor available for rainfall is greater for higher base temperature typically of the tropics or warmer temperature due to enhanced greenhouse condition (Whetton *et al*., 2001). There is general agreement that many areas of currently high precipitation is expected to experience precipitation increases, whereas many of the areas at present with low precipitation and high evaporation, now suffering water scarcity, are expected to have rain decreases in the future (IPCC, 2007).

The hydrologic effects of climate change will have an important influence on all types of basins and many areas will likely follow predicted changes in precipitation (Melkamu, 2013). In the Mediterranean region, continental precipitation is increased by 5–10% over the 20th century in the northern hemisphere and decreased in other regions (for example, North and west Africa and parts of the Mediterranean), increases in the east African basins (IPCC, 2007). Hayileyesus (2011) presented a thesis on evaluation of climate change impacts on hydrology on selected catchments of upper Blue Nile basin based on the precipitation scenarios generated. He indicated that, change of precipitation in percent for the first future time series: 2031-2040 with respect to the base period.

To enhance an understanding of the dynamics of hydroclimatic processes, hydrological modeling becomes an undeniable fact, as models are now major tools in the study of hydrological processes, mainly used for different purposes such as water management or flood forecasting. The estimation of hydrological model parameters is a difficult task. Reasons for these are the highly non-linear nature of hydrological processes. This means that changes of some parameters might be compensated by others. Unfortunately traditional manual calibration of models with reasonable parameter values often leads to weak results. Hence, nowadays automatic procedures based on numerical methods are used (Bardossy and Singh, 2008). Against this backdrop, the central theme of this study is the assessment of the stochastic characteristics of rainfall time series of Abeokuta.

Materials and Method

Study Area

The entire study area is bounded by Oyo state to the north and Lagos State to the South. It is located in southern Nigeria, bordered geographically by latitudes 6.26^0 N and 9.10^0N and longitudes 2.28^0E and 4.8^0 E. The land area is about 23,000km^2 with a generally low relief and gradient in the North-South direction. The two major vegetation zones that can be identified the area are the high forest vegetation in the north and central parts, and the swamp/mangrove forests that cover the southern coastal and floodplains, next to the lagoon. It has two distinct seasons throughout the year. The monthly rainfall distribution in the study area shows a distinct dry season extending from November through March and a rainy season spanning April to October.

Data Collection

The rainfall data of Abeokuta, Ogun State was obtained from the Nigerian Meteorological Agency (NIMET). The data obtained covered a period of twenty eight years (1982-2009).
(iii) Analysis of Stochastic Characteristics
For this study, stochastic characteristics examined were limited to temporal trend, serial dependence and periodicity.

Trend Analysis

The Mann-Kendall non-parametric test was considered for trend detection in the annual time series data because of its robustness and unique advantages over other methods. Trend examination according to the Mann-Kendall approach was done by employing equations (1) – (4) in terms of the overall Z test statistic; in this regard, at 5 % significance level.

$$S = \sum_{k=1}^{n-1} \sum_{j=k+1}^{n} sgn(X_j - X_k) \quad 1$$

Where, X_j and X_k are the annual values in years j and k, j > k, respectively, and

$$sgn(X_j - X_k) = \begin{cases} 1 & if\ X_j - X_K \quad > 0 \\ 0 & if\ X_j - X_k \quad = 0 \\ -1 & if\ X_j - X_k \quad < 0 \end{cases} \quad 2$$

$$VAR(S) = \frac{1}{18}\left[n(n-1)(2n+5) - \sum_{p=1}^{q} t_p(t_p - 1)(2t_p + 5)\right] \quad 3$$

Source: Musa *et al. (2016);* Besaw *et al. (2010);* and Ghanbarpour *et al. (2007)*

where, q is the number of tied groups and t_p is the number of data values in the p^{th} group. The values of S and VAR(S) were used to compute the test statistic Z as follows

$$Z = \begin{cases} (S-1)/Var(S)^{1/2} & S > 0 \\ 0 & S = 0 \\ (S+1)/Var(S)^{1/2} & S < 0 \end{cases} \quad 4$$

Source: Longobardi and Villan *(2009)* and Tesfaye *et al. (2006)*

The Mann-Kendall test was carried out in accordance with the works of Otache *et al*. (2011); Ahaneku and Otache (2014) and Chatfield (2004), with the aid of the excel template of ‘MAKESEN’s version 1.

Serial dependence and Periodicity

The Durbin-Watson test was considered in order to check for serial correlation; i.e., over time rather than over realizations. The analysis of periodicity was done by evaluating the spectral density using the Fast Fourier transforms with Tukey lag window.

Model development

The development of stochastic models for simulation studies requires that the data series should be near second order stationarity. To this end, both seasonal and non-seasonal differencing was considered and corresponding models were developed accordingly. The choice of a particular candidate model was based on Akaike Information Criterion and Autocorrelation functions.

Results and Discussion

Model development and Analysis of Stochastic Characteristics

The time series is treated as trend free since the Mann-Kendall test result showed no significance in the trend with a Z-value of 0.45. However, a clear seasonal pattern is observed in the ACF plot of the raw rainfall data with discernible periodicity of order six as shown in Fig. 1. A single seasonal differencing was found out to be suitable in achieving near stationarity in accordance with the work of Kumar and Vanajakshi (2015). Using Box, *et al.* (2008) methodology and considering the ACF and PACF of the differenced data, seasonal autoregressive integrated moving average models of orders $(0,0,1) \times (0,1,1)_{12}$ and $(0,0,1) \times (0, 1, 2)_{12}$ and ARIMA$(1,0,1) \times (1, 1, 1)_{12}$ were identified. Model diagnostic check was in accordance with the works of Williams and Hoel (2003) and Burnham and Anderson (2004), and the Corrected Akaike Information Criterion (AICc) computed for the two models were 1296.36 and 1297.11 , respectively (see Table 1). Model $(0,0,1) \times (0,1,1)_{12}$ has the least AICc value as shown in high-lighted row of Table 1 and thus, taken as a better model in this regard. Table 2 shows another model characteristics on the basis of the behaviour of the ACF and PACF of the seasonally differenced monthly series (see Figs 3 and 4).

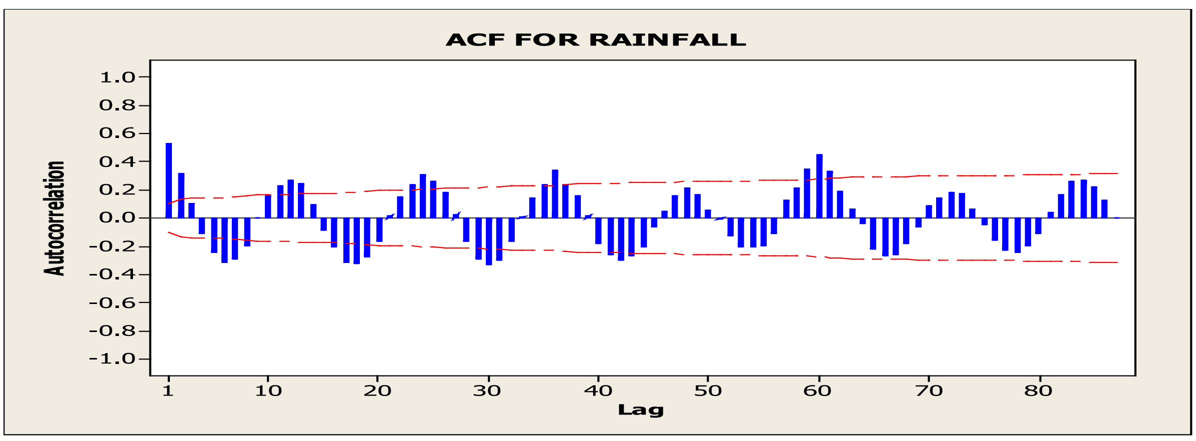

Fig. 1: Correlogram showing seasonal pattern in monthly rainfall of Abeokuta, Nigeria

Table 1: SARIMA - Model order selection for rainfall

Non-Seasonal model order (p, d, q)	Seasonal model order (P, D, Q)s	Sum of squares	AICc - value
(0, 0, 1)	$(0, 1, 1)_{12}$	1799603	1296.36
(0, 0, 1)	$(0, 1, 2)_{12}$	1784306	1297.11

Table 2: SARIMA (1, 0, 1) x $(1, 1, 1)_{12}$ and estimated values

Model Type	Model Order	Parameter Estimated	P- Value	Constant
NSMA (θ)	1	-0.3047	0.000	0.7801
SMA (Θ)	12	0.9661	0.000	,, ,,

NSMA: Non-seasonal moving average; SMA: seasonal moving average

Figure 2 shows the ARIMA (0,0,1) x $(0,1,1)_{12}$ model prediction capability. It is glaringly evident that there is a good correlation between the observed and simulated values. This implies that the model has the capability of reproducing the rainfall regime over time. Table 3 shows the analysis of the simulations. Here, the Mean Absolute Percentage Error (MAPE) was considered in accordance with Lewi's error scaling system (i.e. MAPE value < 10 %). Both the ACF and PACF diagrams (Figs 3 and 4) show spikes at lags one and 12; this connotes the implications of seasonal persistence requiring models that can account for this dependence structure in the overall. It is on this basis that a seasonal multiplicative ARIMA model that embodies complete representation of the characteristics of the autocorrelation structure becomes desirable since it may be able to reproduce the random error variations.

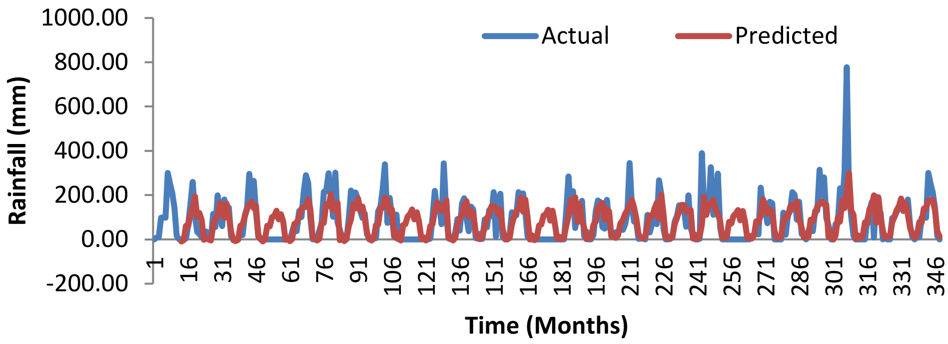

Fig. 2: Monthly rainfall Plot for SARIMA (0, 0, 1) x (0, 1, 1)$_{12}$ Model.

Table 3: Summery of Error Values for Observed and Predicted Rainfall

Model Type	Model Order	Forecast Err.	MSE	RMSE	MAPE (%)
SARIMA	$(0,0,2)x(0,1,1)_{12}$	3.09	58.01	26.68	7.62
SARIMA	$(0,0,1)x(0,1,1)_{12}$	0.21	53.61	21.61	2.29

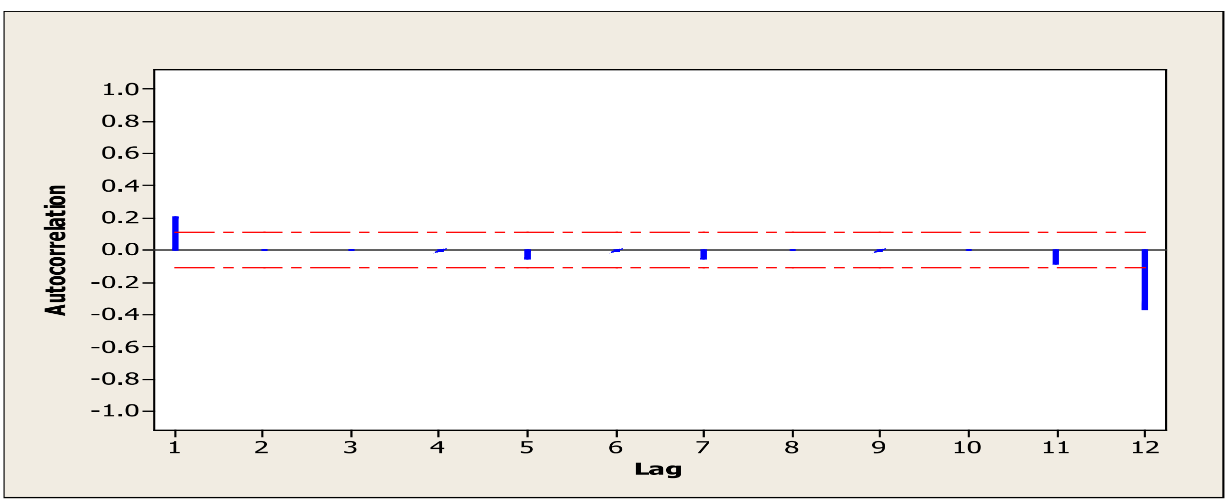

Fig. 3: Autocorrelation plot for seasonally differenced rainfall series

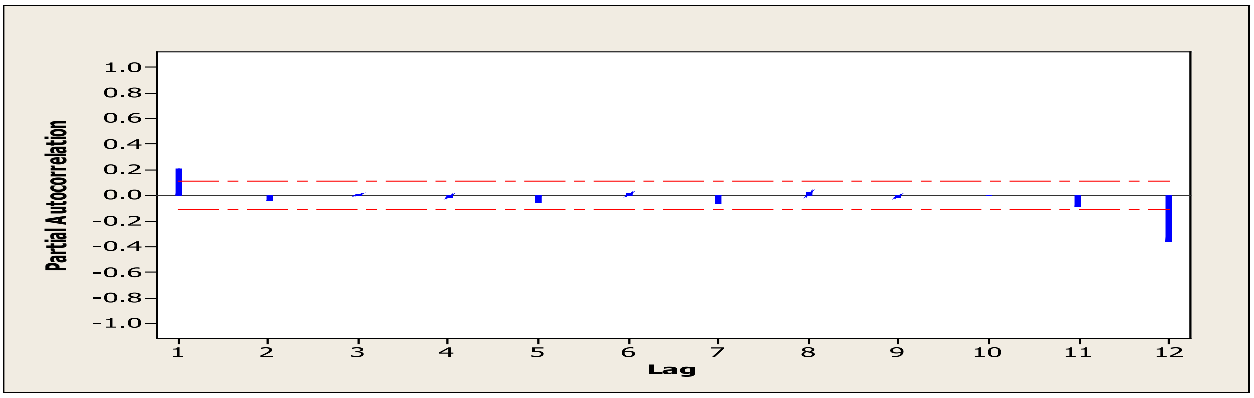

Fig. 4: Partial Autocorrelation plot for the seasonally differenced rainfall series

From the spectral density diagram, it can be seen that the higher the frequency, the lower the density. This indicates a positive autocorrelation in the time series which agrees with the Durbin-Watson test carried out for serial dependence. This is presented in Figs (5) and (6), respectively. From Fig. (5), the periodic nature of the time series is evident; here, low frequencies of high density dominate indicating a probable rainfall regime of short wavelength. In addition, Fig. (6) shows the fluctuations of the frequency pattern; the non-regularity here basically connotes seasonal non-coherence of the rainfall regime resulting from temporal variability.

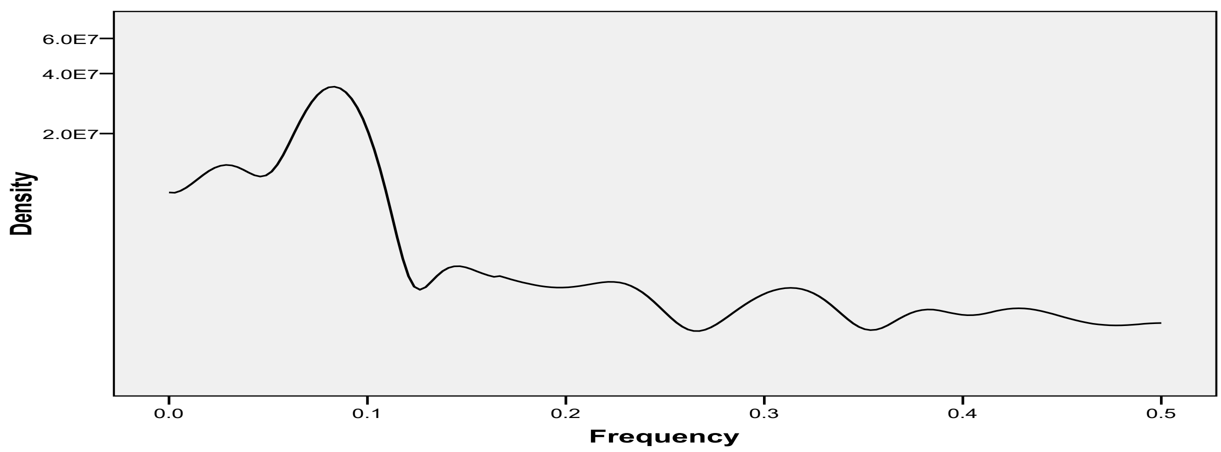

Fig. 5: Spectral Density Plot for Monthly Rainfall

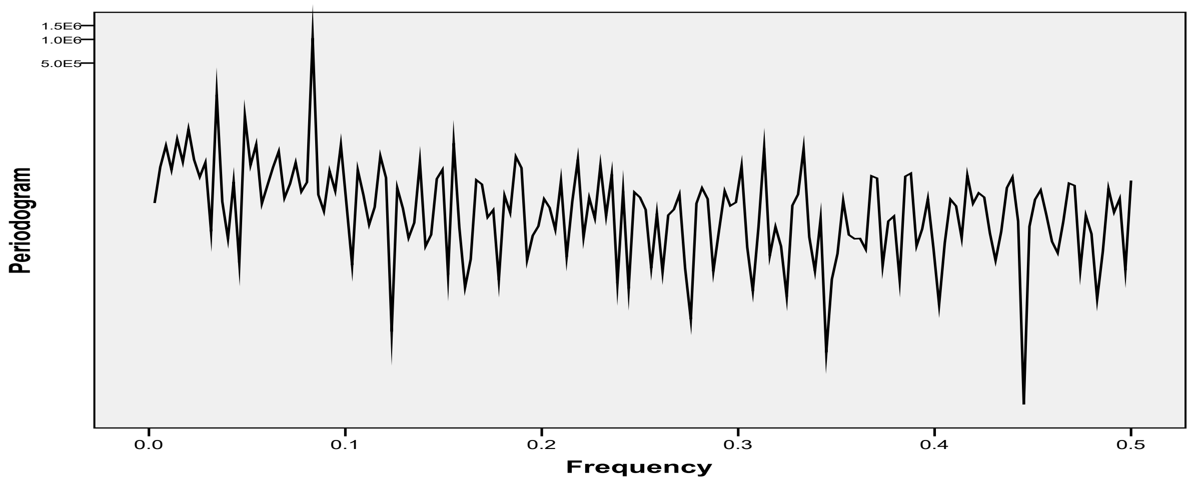

Fig. 6: Periodogram of Monthly Rainfall by Frequency

Conclusions

The accessibility to records of hydrological processes in which rainfall is a major determinant is imperative for proper guide and timely preparation against extreme events. Several methods have been used to predict hydrological behaviors, but have shown some weaknesses due to their stochastic nature. The results obtained in this study demonstrate that there was no trend in the annual series of the rainfall regime though with seeming discernible seasonal periodicity of order six (6) and seasonal non-coherence in frequency. It suffices to note that autoregressive models of low orders can be used for preliminary prediction of the rainfall series. However, considering the stationarity requirement in stochastic modeling technique of this kind, the adequacy of the models so developed should be accepted with cautious optimism. This is against the backdrop of the fact that data pre-processing which is required to achieve second order stationarity distorts the entire spectrum of the original time series and thus limits the possibility for real-time generalizations. To complement the application of stochastic modeling approach as employed, it is recommended that Wavelet Analysis and Soft Computing Techniques should be explored for real-time simulations.

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Evaluation of Hydropower Potentials of Selected Rivers in Kwara and Kogi States, Nigeria

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Abstract

This paper presents the findings from the evaluation of hydropower potentials of selected Rivers in Kwara and Kogi States, Nigeria for rural electrification. The catchment parameters of the Rivers such as length, areas and slope were determined for use in Soil Conservation Services (SCS) method to estimate the ordinates of the synthetic unit hydrographs required in the estimation of runoff discharge. The historical stream flow was extended using Markov model, while the stream flows for the ungagged Rivers were estimated based on Loucks method. The stream flows were adopted to develop flow duration curve from which the 50% dependable flow for generating power was determined. The 50% dependable flows obtained were 0.12 m^3/s, 0.26 m^3/s, 0.30m^3/s, 0.51m^3/s, 0.70 m^3/s, 2.00 m^3/s, 2.15 m^3/s, 2.25m^3/s, 4.00 m^3/s, 5.00 m^3/s, and 5.53m^3/s for Mopa, Duku, Swashi, Osse, Kiyhomi, Moro, Ndaffa, Oyun, Asa, Oshin and Oyi respectively with corresponding hydropower potential of 13.42 kW, 29.08 kW, 33.55 kW, 57.04 kW, 78.28 kW, 224.00 kW , 240.44 kW, 252.00 kW, 805.20 kW, 559.17 kW and 618.44 kW, respectively which summed up to a total hydropower potential of about 3.0 MW. The limitation of this study is that most of the rivers are not gauged, it is thus recommended that gauging stations should be established along the rivers to ensure accurate stream flow reading.

Keywords: Rivers, runoff, flow duration, hydropower and rural electrification

Introduction

Power is a very important component of infrastructure in the overall development of a nation, there is therefore, an ever increasing need for more power generation in all countries of the world. In true global perspective of power demand, most countries of the world are formulating methods and devices to explore the various possibilities of energy generation. The Nigerian Energy Policy Report of 2003 as cited in Bilewu *et al.* (2010), revealed that less than 40% of the country population is connected to the national grid system with over 60% of the time without power supply (Kennedy – Darling *et al*., 2008). The estimated long term power demand of Nigeria was put at 25 GW for the year 2010 to sustain industrial growth (Okpanefe and Owolabi, 2001). The Power Holding Company of Nigeria (PHCN) has an installed capacity of 6 GW, but actual available output is less than 2.5 GW with thermal plants providing 61%, while hydropower generation is about 31% and the remaining 8% by other sources (Olivia, 2008). The overall potential of hydropower generation of Nigeria is in excess of 11 GW as reported by Zarma (2006). This means that less than 20% of the hydropower potential of the country has been realized. The development of a mini hydro scheme at the selected sites is thus a small step in this realization. Small hydropower can adequately contribute to meet the electricity needs of the country with availability of seasonal and perennial rivers and streams which provide excellent opportunities for hydropower development. Sule (2003) stated that Nigeria is blessed with a number of rivers and streams which are either seasonal or perennial; the Rivers Niger and Benue with several tributaries constitute the Nigerian river system which offers some potential renewable source of energy for economically viable large hydropower development while other major rivers include Kaduna, Sokoto, Hadejia, Yobe, Gongola, Ogun, Osun, Imo, Cross River.

In this study, the discharge and hydropower potentials of the selected Rivers in Kwara and Kogi States, Nigeria were evaluated. The Rivers considered were Mopa, Duku, Swashi, Osse, Kiyhomi, Moro, Ndaffa, Oyun, Asa, Oshin and Oyi.

Material and Methods

Study area

River Moro catchment is about 581.5 km^2 with a length of 46.8 km and is a left-hand tributary of Asa River. The catchment of Asa River is between latitudes $8^0$15’ and $8^0$45’ North and longitudes $4^0$24’ and $4^0$34’ East, its total area is 962.0 km^2 with river length of 57.5 km. Asa river runs from south to north of Ilorin to join with Oyun river. The catchment of Oyun River is between latitudes $8^0$30’ and $8^0$45’ North with longitudes $4^0$15’and $4^0$30’ East. Its total area is 652.95 km^2 with a length of about 33 km. Other rivers considered are Duku, Kampe (Mopa), Ndaffa, Kiyhomi, Oshin, Oyi, Osse and Swashi. Map of Nigeria showing the locations of the river watershed is presented in Fig. 1, while the characteristics of the River watersheds are presented in Table 1

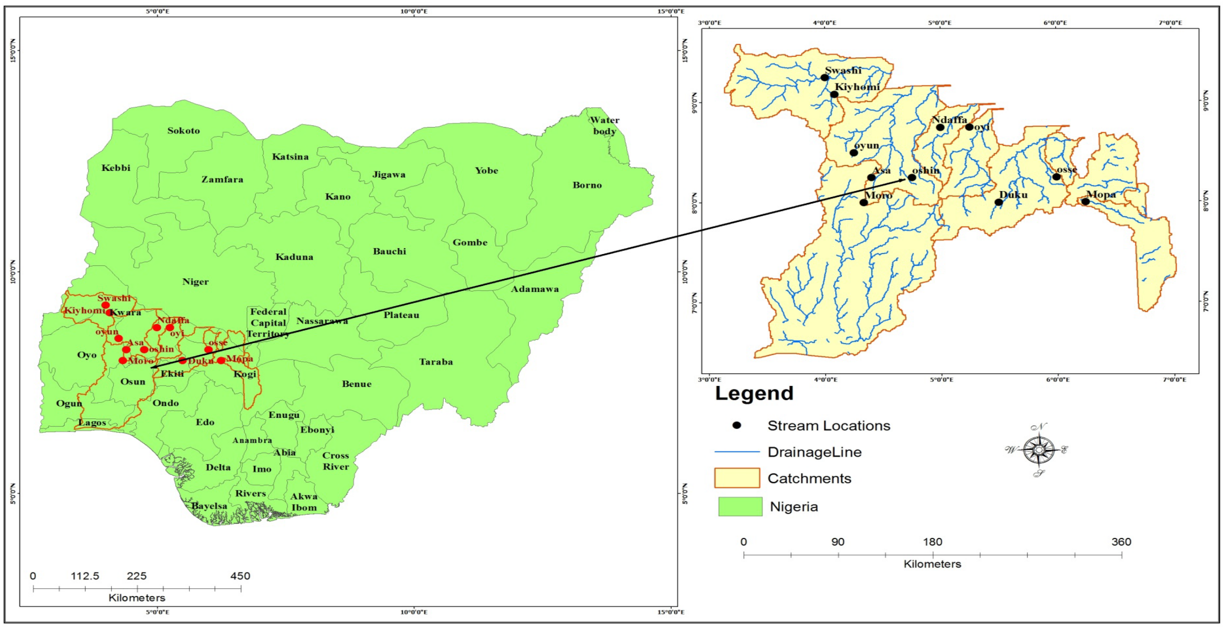

Fig. 1: Map of Nigeria showing location of the river watersheds

Table 1: Watershed characteristics and peak unit hydrograph ordinates for rivers

No	River Watershed	L (km)	L_c (km)	A (km^2)	Sc	Coordinate of the River Catchment	Peak unit hydrograph ordinates ($m^3/s/cm$)
1	Oyun	33.01	21.82	652.95	0.0108	4° 15'- 4° 30'E; 8° 30'- 8° 45'N	152.63
2	Asa	47.86	25.98	962.90	0.0116	4° 24'- 4° 34'E; 8° 15'- 8° 45'N	173.8
3	Moro	46.80	16.00	581.50	0.0280	4° 20'- 4° 30'E; 8° 00'- 8° 45'N	149.92
4	Duku	8.63	5.95	77.29	0.0285	5° 30'- 5° 45'E; 8° 00'- 8° 45'N	74.24
5	Mopa	6.86	3.51	27.38	0.0666	6° 15'- 6° 45'E; 8° 00'- 8° 42'N	43.06
6	Ndaffa	27.16	18.05	619.41	0.0146	5° 00'- 5° 15'E; 8° 45'- 9° 00'N	188.96
7	Kiyhomi	14.29	6.42	175.77	0.0123	4° 05'- 4° 15'E; 9° 05'- 9° 15'N	82.30
8	Oshin	81.95	54.54	1425.12	0.0260	4° 45'- 4° 48'E; 8° 15'- 9° 00'N	231.97
9	Oyi	65.47	37.15	1708.02	0.0328	5° 15'- 5° 30'E; 8° 45'- 8° 52'N	361.40
10	Osse	11.50	6.98	125.01	0.0142	6° 00'- 6° 09'E; 8° 15'- 8° 30'N	73.12
11	Swashi	8.54	6.61	89.96	0.0148	4° 00'- 4° 30'E; 9° 15'- 9° 30'N	67.30

Source: (Sule and Salami 2015).

where L is the length of the river Channel (km), L_c is the length of the river from the outlet to a point near the centroid (km), A is thewatershed area (km^2) and Sc is the slope of river channel (m/m).

River flow

The monthly flow data of Oyun River at Oyun Dam Offa available from 1972 to 1981 (Salami and Ajenifuja, 2009) was used in modeling the river flow. Thomas – Fierring model based on a first order Markov model was adopted and the synthetic flow series were calculated using observed historical flow sequences (Salami and Sule, 2012), the model developed was used to extend the flow up to the year 2014. The summary of the monthly flow statistics is presented in Table 2. Similarly, Asa river flows were available from 1966 to 1985 and extended to year 2014 based on Thomas – Fierring. The summary of the monthly flow statistics of the predicted flow is presented in Table 3.

However, in the case of ungauged Moro River where there was no streams flow data, the stream flow data was estimated using equation (1) (Loucks *et al*., 1981). The method was based on the fact that the characteristics of the watershed of a river in humid regions (as the case in the region under study) watersheds are generally homogeneous and the spatial distribution of seasonal rainfall does not significantly vary from one part of the river basin to another. In these situations, estimated flows Q_t^s at any site s can be based on the watershed A^s above those sites, and the stream flow $Q_t^{s'}$ and watershed area $A^{s'}$ above the nearest or most representative gage site s'. The equation is given as in Eq. (1), (Loucks *et al*., 1981).

$$Q_t^s = Q_t^{s'} \left(\frac{A^s}{A^{s'}} \right) \tag{1}$$

Where Q_t^s = stream flow at ungauged site downstream (m^3/s)

$Q_t^{s'}$ = stream flow at gauged site upstream (m^3/s)

A^s = watershed area contributing to ungauged site (km^2)

$A^{s'}$ = watershed area contributing to gauge site (km^2)

The summary of the monthly predicted flow statistics for Moro River is presented in Table 4. Similar procedure was adopted for other ungagged rivers such as Duku, Mopa, Ndaffa, Kiyhomi, Oshin, Oyi, Osse and Swashi with the summary of their monthly flow statistics presented in Tables 4 – 12, respectively.

Estimation of Flow for Power Generation and Hydropower Potential

It is not economically feasible to harness the entire runoff of a river during flood as this will require a huge storage. In this case, the storage is defined and fixed and the firm yield for power generation is dependent on overflow and storage available in the reservoir. In this study, flow duration curve was adopted to determine 50% dependable flow for power generation.

Flow duration curve for the selected River flow

In developing the flow duration curve for the case study, method established by Oregon State University in 2002 to 2005, (http://water.oregonstate.edu/streamflow/) as reported by Olukanni and Salami (2012) was adopted. The method involves establishment of relationship between discharge and percent of time that the indicated discharge is equaled or exceeded (exceedence probability). The flow duration curve obtained for rivers Oyun, Asa, Moro, Duku, Mopa, Ndaffa, Kiyhomi, Oshin, Oyi, Osse and Swashi is presented in Figs 2 to 12, respectively and the 50% dependable flow of 2.25 m^3/s , 4.00 m^3/s , 2.00 m^3/s , 0.26 m^3/s , 0.12 m^3/s , 2.15 m^3/s, 0.70 m^3/s, 5.0 m^3/s, 5.53 m^3/s, 0.51 m^3/s and 0.30 m^3/s was also obtained for the rivers, respectively.

Hydropower Potential of the Selected Rivers

The hydropower potential of the Rivers were estimated based on equation (2) as adopted by Sule *et al*. (2011).

$$P = 9.81 \times Q \times H \times E_t \times E_g \qquad (2)$$

where P is the power (KW), Q is the discharge for power generation; H is the net head (m), E_t is the turbine efficiency = 80% and E_g is the generator Efficiency = 95%

According to Pumia (1990), a hydroelectric work comprises of the following components: Forebay, Intake Structure, Surge Tank, Penstocks, Power House, Turbines and Governors, Generators, Transformers and Transmission Lines. Water is taken from the forebay through the intake structure, surge tank and penstock and delivered into the power house which houses the turbines and the generators. The generated power is stepped up with the aid of transformers and distributed through the transmission lines. It is important to note that the water resource and the available head at the forebay are the key factors in hydropower generation.

It was suggested that the power house be located at some distance downstream in order to acquire enough net head for energy generation. This arrangement makes a head of 27.0 m for Asa and 15.0 m for other locations. The appropriate location to achieve the net head would be subject to detailed topography.

Based on the net head at which the turbine will operate, a medium head turbine is required. For this purpose, a Kaplan Turbine is suitable for use in accordance to Rajput (2006) as cited in Bilewu *et al*. (2010). The efficiency of the Turbine and the Generator used is assumed at 98% for large units and 95 to 96% for units smaller than 5 MW. Mays and Tung (1992) and Mays (2005) revealed that Turbine efficiency varies with the discharge head. In this study, the recommended turbine has an efficiency of 80%.

Results and Discussion

The summary statistics of the estimated monthly flow for all the rivers are presented in Tables 2 to 12 and the estimated energy potential for 50% dependable flows for the Rivers are in Table 13. However, the flow duration curves developed for the selected rivers are as in Figs 2 to 12, respectively. The downward trend of the FDC's curves as presented in Figs 2 – 12 is an indication that low flow has a high frequency of re-occurrence, while higher flow has a low frequency of re-occurrence. In order words, low flow has high reliability than high flow since their frequency of occurrence is very high.

The potential estimated hydropower energy obtained varies from the smallest value of 13.42 kW for Mopa River to the highest value of 805.20 kW for Asa River. The values obtained for other rivers were 618.44 kW, 559.17 kW, 251.63 kW, 240.44 kW, 223.67 kW, 78.28 kW, 57.04 kW, 33.55 kW and 29.08 kW for Oyi, Oshin, Oyun, Ndaffa, Moro, Kiyhomi, Osse, Swashi and Duku Rivers, respectively with a total potential estimated hydropower energy of about 3.0 MW.

Table 2: Statistics of monthly flow ($x10^6$ m^3) for Oyun River (1972-2014)

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Mean	0.19	0.56	1.30	1.38	1.10	1.33	1.19	1.08	2.69	1.44	1.06	0.83
Median	0.04	0.28	0.99	1.12	0.91	1.04	0.79	0.83	2.54	1.25	0.56	0.30
S.D	0.34	0.64	0.84	0.73	0.76	0.92	1.20	1.08	1.10	0.82	1.12	1.12
C.V	1.81	1.13	0.65	0.53	0.69	0.70	1.01	1.00	0.41	0.57	1.05	1.36
Min	0.00	0.01	0.29	0.43	0.23	0.42	0.35	0.09	0.89	0.44	0.02	0.00
Max	1.54	2.48	4.17	3.49	3.69	4.84	6.27	5.45	6.29	4.88	4.82	5.22
Skew	2.72	1.77	1.51	1.08	1.99	2.53	2.88	2.14	1.35	2.17	1.78	2.26

C.V = Coefficient of Variation, S.D = Standard deviation

Table 3: Statistics of monthly flow ($x10^6$ m^3) for Asa River (1966-2014)

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Mean	1.65	1.18	1.45	3.75	12.20	16.07	30.30	54.19	69.52	55.93	23.15	3.00
Median	1.78	1.17	1.42	3.11	12.93	13.82	23.35	42.76	68.17	53.31	20.80	2.78
S.D	0.76	0.62	0.86	3.21	6.81	10.15	21.49	38.11	42.77	25.01	15.18	1.96
C.V	0.46	0.53	0.59	0.86	0.56	0.63	0.71	0.70	0.62	0.45	0.66	0.65
Min	0.16	0.07	0.04	0.25	0.21	0.36	1.00	6.10	6.04	2.99	0.41	0.16
Max	3.15	3.28	3.46	14.02	23.73	35.52	79.56	156.7	156.5	100.7	73.80	7.93
Skew	-0.3	0.96	0.45	1.54	-0.07	0.35	0.72	1.26	0.29	-0.01	0.97	0.69

Table 4: Statistics of estimated monthly flow (x10^6 m^3) for Moro River (1966-2014)

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Mean	1.00	0.71	0.88	2.26	7.37	9.70	18.30	32.72	41.98	33.77	13.98	1.81
S.D	0.46	0.37	0.52	1.94	4.11	6.13	12.97	23.02	25.83	15.10	9.17	1.18
C.V	0.46	0.53	0.59	0.86	0.56	0.63	0.71	0.70	0.62	0.45	0.66	0.65
Min	0.10	0.04	0.03	0.15	0.13	0.22	0.61	3.68	3.65	1.81	0.25	0.10
Max	1.90	1.98	2.09	8.47	14.33	21.45	48.04	94.64	94.48	60.77	44.56	4.79
Skew	-0.3	0.96	0.45	1.54	-0.07	0.35	0.72	1.26	0.29	-0.01	0.97	0.69

Table 5: Statistics of estimated monthly flow (x10^6 m^3) for Duku River (1966-2014)

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Mean	0.13	0.10	0.12	0.30	0.99	1.30	2.45	4.39	5.63	4.53	1.88	0.24
S.D	0.06	0.05	0.07	0.26	0.55	0.82	1.74	3.09	3.46	2.03	1.23	0.16
C.V	0.46	0.53	0.59	0.86	0.56	0.63	0.71	0.70	0.62	0.45	0.66	0.65
Min	0.01	0.01	0.00	0.02	0.02	0.03	0.08	0.49	0.49	0.24	0.03	0.01
Max	0.25	0.27	0.28	1.14	1.92	2.88	6.44	12.69	12.67	8.15	5.98	0.64
Skew	-0.3	0.96	0.45	1.54	-0.07	0.35	0.72	1.26	0.29	-0.01	0.97	0.69

Table 6: Statistics of estimated monthly flow (x10^6 m^3) for Mopa River (1966-2014)

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Mean	0.05	0.03	0.04	0.11	0.35	0.46	0.86	1.54	1.98	1.59	0.66	0.09
S.D	0.02	0.02	0.02	0.09	0.19	0.29	0.61	1.08	1.22	0.71	0.43	0.06
C.V	0.46	0.53	0.59	0.86	0.56	0.63	0.71	0.70	0.62	0.45	0.66	0.65
Min	0.00	0.00	0.00	0.01	0.01	0.01	0.03	0.17	0.17	0.09	0.01	0.00
Max	0.09	0.09	0.10	0.40	0.67	1.01	2.26	4.46	4.45	2.86	2.10	0.23
Skew	-0.3	0.96	0.45	1.54	-0.07	0.35	0.72	1.26	0.29	-0.01	0.97	0.69

Table 7: Statistics of estimated monthly flow (x10^6 m^3) for Ndaffa River (1966-2014)

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Mean	1.06	0.76	0.93	2.41	7.85	10.33	19.49	34.85	44.71	35.97	14.89	1.93
S.D	0.49	0.40	0.55	2.06	4.38	6.53	13.82	24.52	27.51	16.08	9.77	1.26
C.V	0.46	0.53	0.59	0.86	0.56	0.63	0.71	0.70	0.62	0.45	0.66	0.65
Min	0.10	0.05	0.03	0.16	0.13	0.23	0.64	3.92	3.89	1.92	0.26	0.10
Max	2.02	2.11	2.22	9.02	15.27	22.85	51.17	100.8	100.7	64.73	47.47	5.10
Skew	-0.3	0.96	0.45	1.54	-0.07	0.35	0.72	1.26	0.29	-0.01	0.97	0.69

Table 8: Statistics of estimated monthly flow (x10^6 m^3) for Kiyhom River (1966-2014)

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Mean	0.30	0.21	0.26	0.68	2.23	2.93	5.53	9.89	12.69	10.21	4.23	0.55
S.D	0.14	0.11	0.16	0.59	1.24	1.85	3.92	6.96	7.81	4.56	2.77	0.36
C.V	0.46	0.53	0.59	0.86	0.56	0.63	0.71	0.70	0.62	0.45	0.66	0.65
Min	0.03	0.01	0.01	0.05	0.04	0.07	0.18	1.11	1.10	0.55	0.07	0.03
Max	0.57	0.60	0.63	2.56	4.33	6.48	14.52	28.61	28.56	18.37	13.47	1.45
Skew	-0.3	0.96	0.45	1.54	-0.07	0.35	0.72	1.26	0.29	-0.01	0.97	0.69

Table 9: Statistics of estimated monthly flow (x10^6 m^3) for Oshin River (1966-2014)

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Mean	2.44	1.74	2.15	5.55	18.06	23.77	44.84	80.19	102.9	82.77	34.26	4.44
S.D	1.12	0.91	1.27	4.75	10.08	15.02	31.80	56.41	63.30	37.00	22.47	2.90
C.V	0.46	0.53	0.59	0.86	0.56	0.63	0.71	0.70	0.62	0.45	0.66	0.65
Min	0.24	0.11	0.06	0.37	0.31	0.54	1.48	9.03	8.94	4.43	0.60	0.24
Max	4.66	4.86	5.11	20.75	35.12	52.57	117.8	232.0	231.6	149.0	109.2	11.73
Skew	-0.3	0.96	0.45	1.54	-0.07	0.35	0.72	1.26	0.29	-0.01	0.97	0.69

Table 10: Statistics of estimated monthly flow (x10^6 m^3) for Oyi River (1966-2014)

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Mean	2.93	2.09	2.57	6.65	21.64	28.49	53.74	96.11	123.3	99.20	41.06	5.32
S.D	1.34	1.10	1.52	5.69	12.08	18.00	38.11	67.60	75.86	44.35	26.93	3,48
C.V	0.46	0.53	0.59	0.86	0.56	0.63	0.71	0.70	0.62	0.45	0.66	0.60
Min	0.28	0.13	0.08	0.44	0.37	0.65	1.78	10.82	10.71	5.31	0.72	0.28
Max	5.58	5.83	6.13	24.87	42.10	63.00	141.1	278.0	277.5	178.5	130.9	14.1
Skew	-0.3	0.96	0.45	1.54	-0.07	0.35	.72	1.26	0.29	-0.01	0.97	0.69

Table 11: Statistics of estimated monthly flow (x10^6 m^3) for Osse River (1966-2014)

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Mean	0.21	0.15	0.19	0.49	1.58	2.09	3.93	7.03	9.02	7.26	3.01	0.39
S.D	0.10	0.08	0.11	0.42	0.88	1.32	2.79	4.95	5.55	3.25	1.97	0.25
C.V	0.46	0.53	0.59	0.86	0.56	0.63	0.71	0.70	0.62	0.45	0.66	0.65
Min	0.02	0.01	0.01	0.03	0.03	0.05	0.13	0.79	0.78	0.39	0.05	0.02
Max	0.41	0.43	0.45	1.82	3.08	4.61	10.33	20.35	20.31	13.06	9.58	1.03
Skew	-0.3	0.96	0.45	1.54	-0.07	0.35	0.72	1.26	0.29	-0.01	0.97	0.69

Table 12: Statistics of estimated monthly flow (x10^6 m^3) for Swashi River (1966-2014)

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Mean	0.15	0.11	0.14	0.35	1.14	1.50	2.83	5.06	6.49	5.22	2.16	0.28
S.D	0.07	0.06	0.08	0.30	0.64	0.95	2.01	3.56	4.00	2.34	1.42	0.18
C.V	0.46	0.53	0.59	0.86	0.56	0.63	0.71	0.70	0.62	0.45	0.66	0.65
Min	0.01	0.01	0.00	0.02	0.02	0.03	0.09	0.57	0.56	0.28	0.04	0.01
Max	0.29	0.31	0.32	1.31	2.22	3.32	7.43	14.64	14.62	9.40	6.89	0.74
Skew	-0.3	0.96	0.45	1.54	-0.07	0.35	0.72	1.26	0.29	-0.01	0.97	0,69

Table 13: Estimated energy potential for 50% dependable flows for the Rivers

River	50% dependable Flow (m^3/s)	Net head (m)	Turbine efficiency (%)	Generator efficiency (%)	Power (KW)
Oyun	2.25	15	80	95	251.63
Asa	4.00	27	80	95	805.20
Moro	2.00	15	80	95	223.67
Duku	0.26	15	80	95	29.08
Mopa	0.12	15	80	95	13.42
Ndaffa	2.15	15	80	95	240.44
Kiyhomi	0.70	15	80	95	78.28
Oshin	5.00	15	80	95	559.17
Oyi	5.53	15	80	95	618.44
Osse	0.51	15	80	95	57.04
Swashi	0.30	15	80	95	33.55

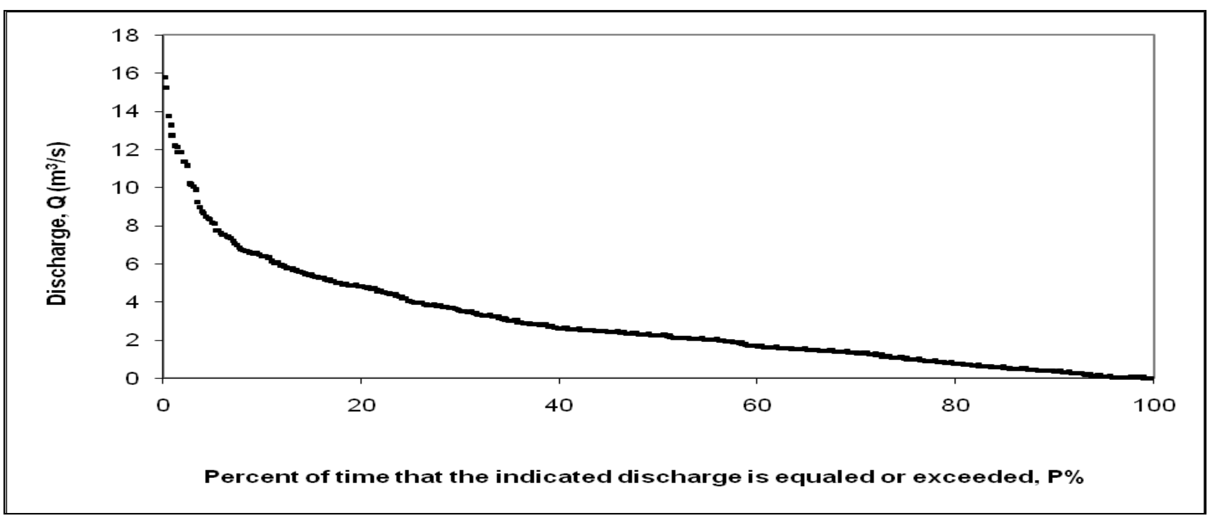

Fig. 2: Flow duration curve for Oyun River

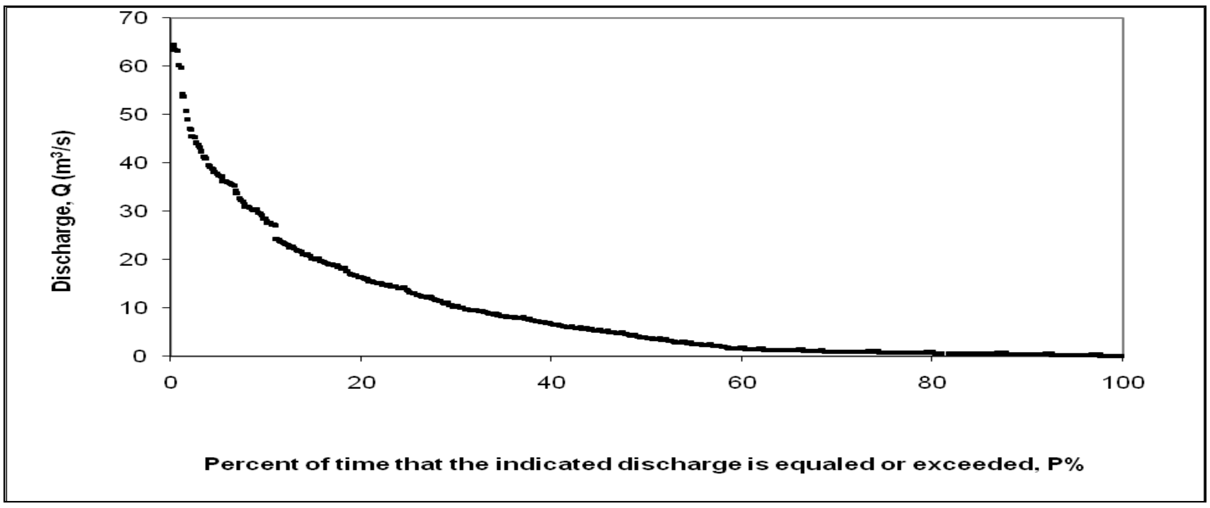

Fig. 3: Flow Duration curve for Asa River

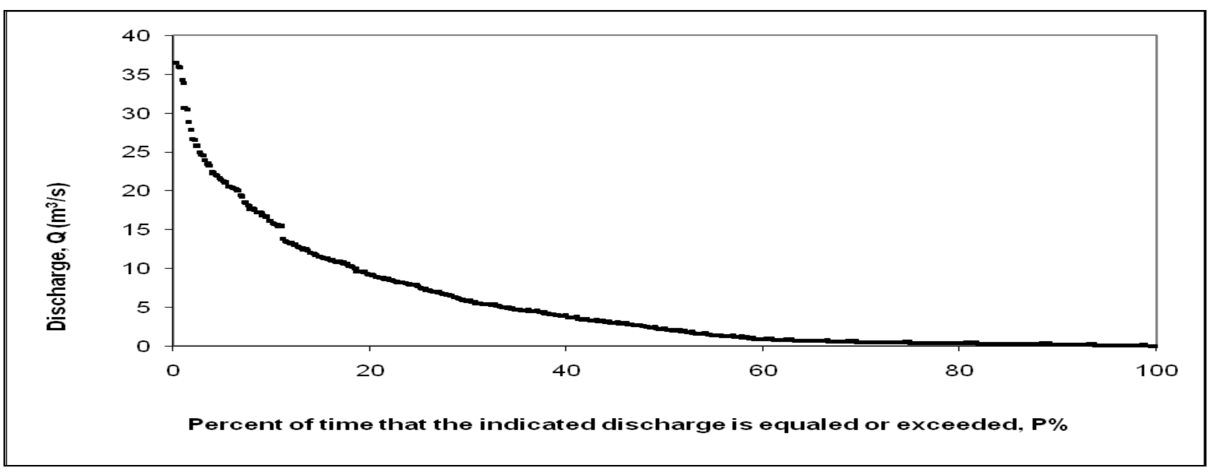

Fig. 4: Flow Duration curve for Moro River

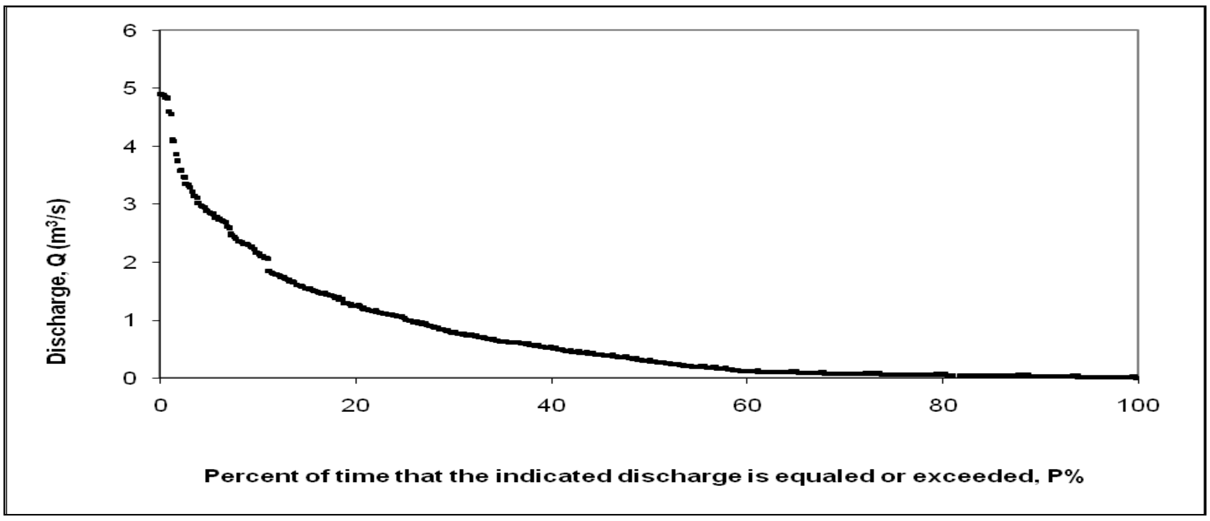

Fig. 5: Flow Duration curve for Duku River

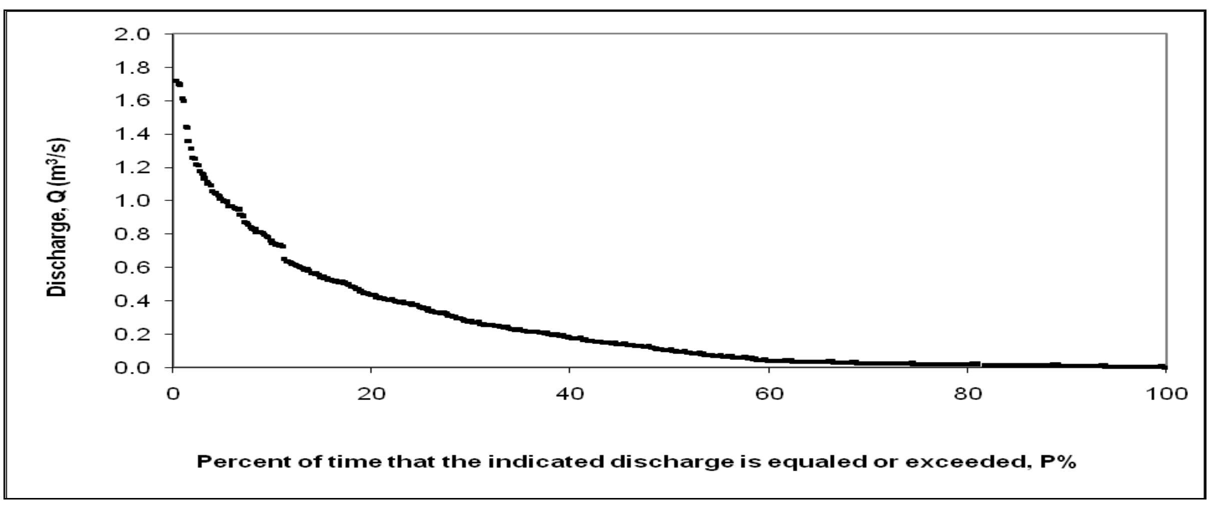

Fig. 6: Flow Duration curve for Kampe River

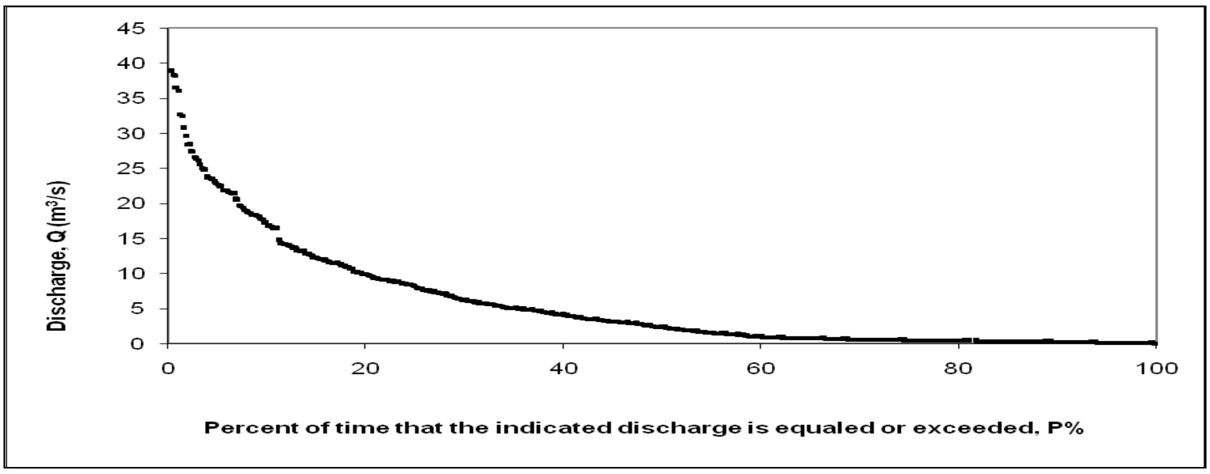

Fig. 7: Flow Duration curve for Ndaffa River

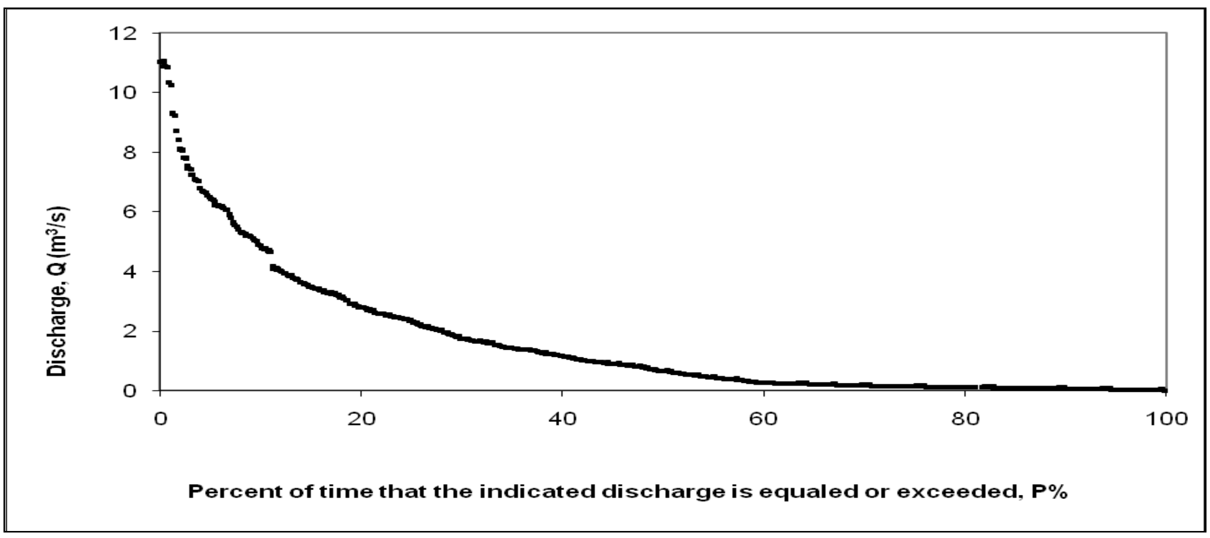

Fig. 8: Flow Duration curve for Kiyhomi River

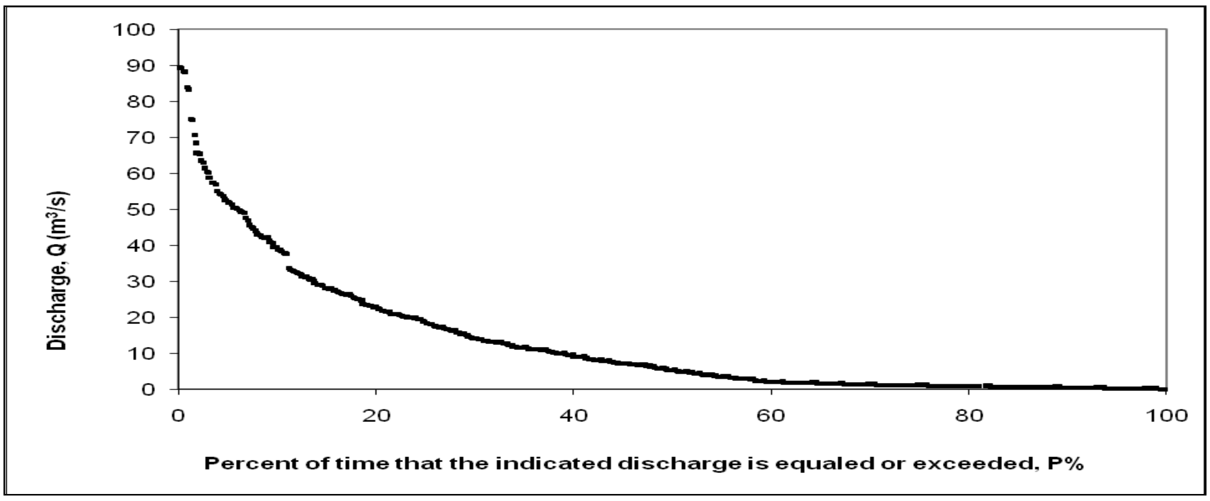

Fig. 9: Flow Duration curve for Oshin River

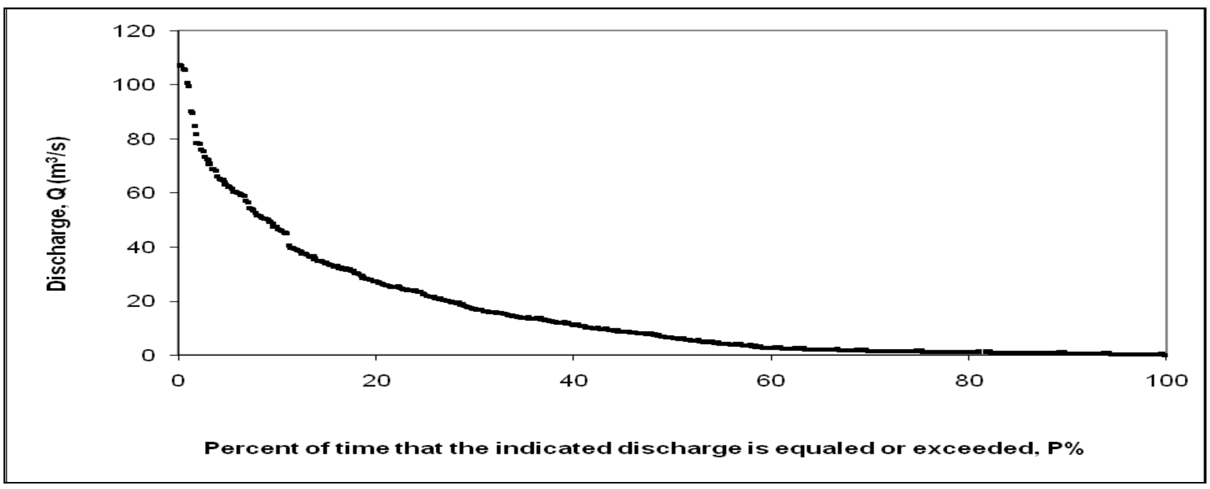

Fig. 10: Flow Duration curve for Oyi River

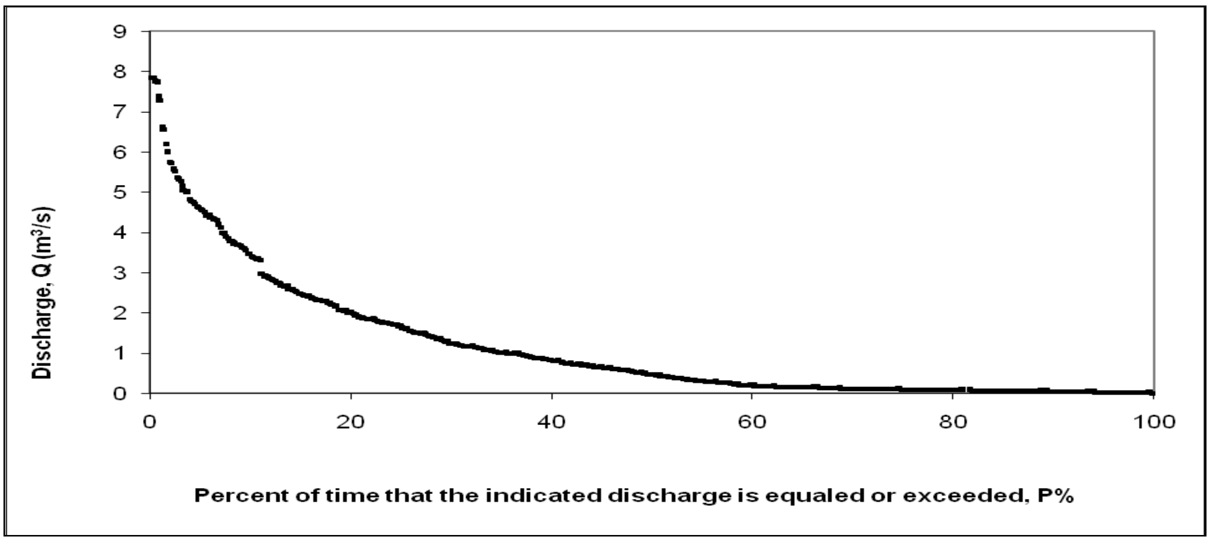

Fig. 11: Flow Duration curve for Osse River

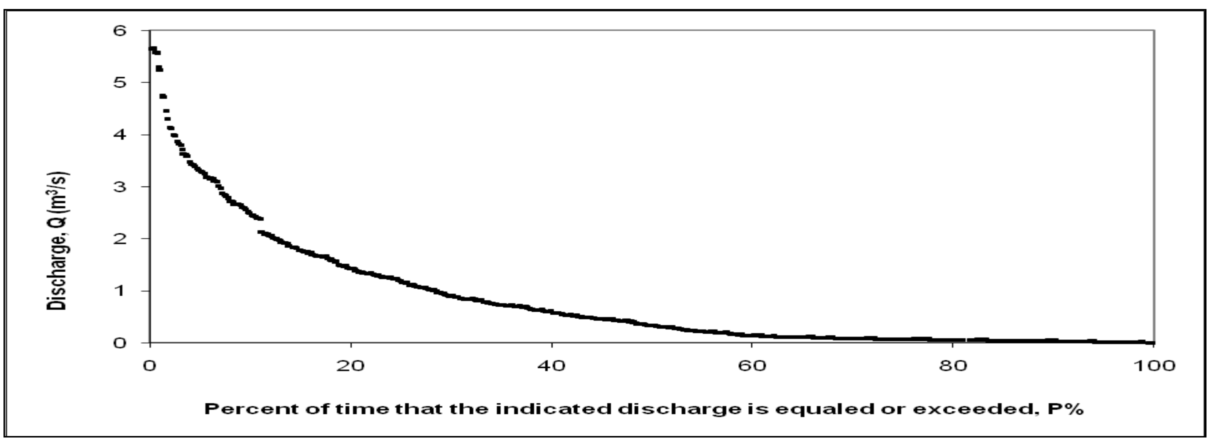

Fig. 12: Flow Duration curve for Swashi River

Conclusion

The estimated potential energy for Mopa, Duku, Swashi, Osse, Kiyhomi, Moro, Ndaffa, Oyun, Asa, Oshin and Oyi River is 13.42 kW, 29.08 kW, 33.55 kW, 57.04 kW, 78.28 kW, 224.00 kW , 240.44 kW, 252.00 kW, 805.20 kW, 559.17 kW and 618.44 kW, respectively. with a total value of hydropower potential of about 3.0 MW. The installed capacity also depends on the capacity factor which has been established to vary from 0.25 to 0.75. It is believed that the estimated Hydro-electric power potential will supplement the energy demand at the various locations to support the electricity utilization of rural household.

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Effect of Population Growth on Water supply and sanitation facilities in Nigeria

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Abstract
This paper evaluated population pattern and effect of population growth in Nigeria on the potentials for improving water supply and sanitation practices. Information on population, water supply and sanitation practices in Nigeria between 2006 and 2014 were collected from archives. The pattern of population growth in Nigeria, relationships between percentage of households' distribution and percentage of the population, and the number of people per household were appraised. Effects of the population growth on access to improve water supply and sanitation practices were assessed using analysis of variance (ANOVA). The study revealed that from a population of 16.05 million people in 1911, 18.72 million in 1921, 20.06 million in 1931 and 30.42 million in 1952, the country's population rose to 88. 58 million in 1991, the population was more than twice of the 1952 population in 39 years. In 2006, the country recorded a total population figure of 139.98 million. There were four growth patterns in the population demographics. The first growth period was for 1911and 1931, the second was between 1931 and 1973, the third is between 1973 and 1991 and fourth was between 1991 and 2012. A percent of household distribution is equivalent to 0.9865 of percentage population. The relationship between the number of people per household ranges from 3.6441 (Southwest geopolitical zone) to 5.6555 (Northwest geopolitical zone). The number of people per household was in the order of South West less than (<) South- South < South East < North Central < North East < North West. The study revealed that population growth had effects on access to sanitation facility ($F_{2,4}$ = 7.220 and p = 0.047), on access to piped water ($F_{2,4}$ = 1.622 and p = 0.305) and on access to other improved water sources ($F_{2,4}$ = 0.263 and p = 0.781). The study concluded that there is the need to review maintenance of sanitation facilities and safe water systems to enhance access to improve sanitation facilities and safe water in Nigeria

Keywords: Population; Safe Water, Geopolitical Zones, Population Growth

Introduction

The initial concept of the population was formerly used as a view of a universe of phenomenon comprising recognizable selected elements and concerned with highly general aspect of the distribution, trend, and change. In environmental science and engineering, the term population refers to the total number of people resident in a particular area at specials time. It refers to addition to or subtraction from the existing population through the interaction of the three elements of population change (birth, death, and migration; Sajini, 2011). It impacts primarily on the environment through the use of natural resources (water, air, and land) and production of waste (air, solid and liquid). The population is associated with environmental stress such as reduction of ecosystem complexity, loss of biodiversity and the alteration of the all-important biogeochemical cycle (Asthana and Asthana, 2006; Sajini, 2011). It is a major source of environmental pollution and degradation. Environmental pollution and degradation in Nigeria result from deforestation and domestic activities, transportation and industrial activities, economic development, population progression, urbanization, intensification of agriculture, rising energy use and transportation, the dynamic interplay of socio-economic, foundation and technological activities (Alo, 2008; Sule, 1995; Sajini, 2011). Various factors are affecting the population and environmental issues (Fig. 1). Figure 2 presents relationship between population and environmental health. Human health and wellbeing are appreciably affected by the environment. Asthana and Asthana (2006) and Sajini (2011) reported that environmental health, malnutrition, and diseases are caused by contaminated and polluted environment, human wastes and air pollution form the diseases in the developing countries. Potable water (quality and quantity) is an essential ingredient to life. Improved access to safe drinking water, waste disposal, and sanitation issues are the major parts of Millennium Development Goals (MDG- JMP, 2014). The global MDGs on drinking water target a coverage of 88% was met in 2010. It was reported that 76% of the world's population had access to an improved drinking water source in 1990. About 89% of the world's population had access in 2012, an increase of 2.3 billion people. Fifty-six per cent of the global's population (four billion people) are now enjoying the highest level of access to piped water (Fig. 3). Even though progress towards the MDGs target represents important gains the progress has been uneven. Sharp geographic, sociocultural and economic inequalities in access persist and sometimes have increased (JMP, 2014). JMP (2014) presents examples of unequal progress among marginalized and vulnerable groups (Figs 4 and 5). These figures display the status of and trends in access to an improved drinking water sources and sanitation. From these figures, it was discovered that sub-Sahara Africa and Southern Asia were the two regions with the lowest changes in the access to potable water and improve sanitation facilities. These two regions are among the highest populated regions in the world, which indicates that attention to the effect of population and population growth would help in reducing uneven progress in access to potable water and improve sanitation facilities. In Nigeria (a country in sub- Sahara Africa) impacts of population growth on access to drinking water and improve sanitation facilities are rare. Hence this study focuses on population growth in Nigeria and impact on access to clean water and improves sanitation facilities.

Materials and Method

Information on population, access to improve water supply and sanitation practices in Nigeria between 2006 and 2014 were collected from archives (NPC, 2010; Umoh, 2001; Ojo *et al.,* 2006; NBS, 2010 and 2012; JMP, 2013 Asani and Oke, 2014; Oke *et al*., 2014; 2015; Ismail *et al.*, 2015). The pattern of population growth, the relationship between percentage household distribution and percentage population, the number of people per household in the national and the six geopolitical zones were assessed. Effect of the population on access to improve water supply and sanitation practices were evaluated employing analysis of variance (ANOVA). Computations of the effects and ANOVA were conducted as follows:

$$E_{HAs} = \frac{\sum_{i=1}^{N} X_{ai}}{N_s} \tag{1}$$

where; E_{HAs} is the effect of population on access to safe water in Nigeria in the selected year; N_s is the number of total number of the people in Nigeria at the particular year, and X_{ai} is the total percentage of access to safe water in Nigeria in the selected year

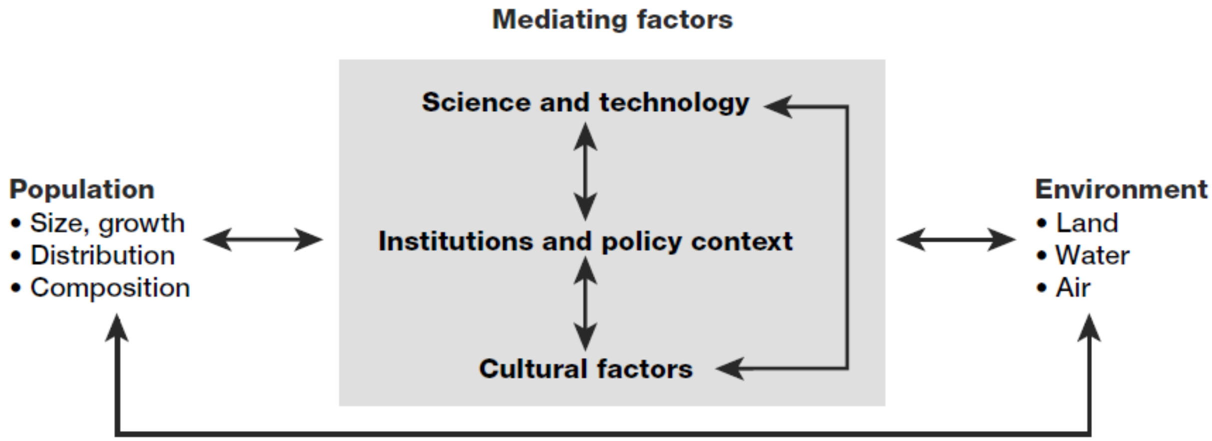


Fig. 1: Factors Affecting the Population and Environment Relationship (Source: Orians and Skumanich, 1995; De Souza *et al.,* 2003)

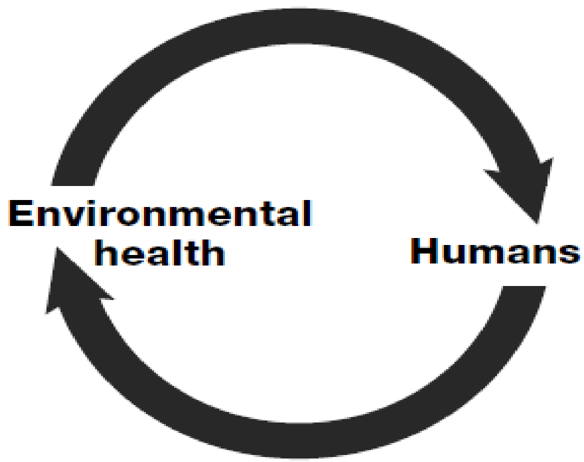


Fig. 2: The Population, Health, and Environment Cycle (Source: McMichael, 2001; De Souza *et al.,* 2003)

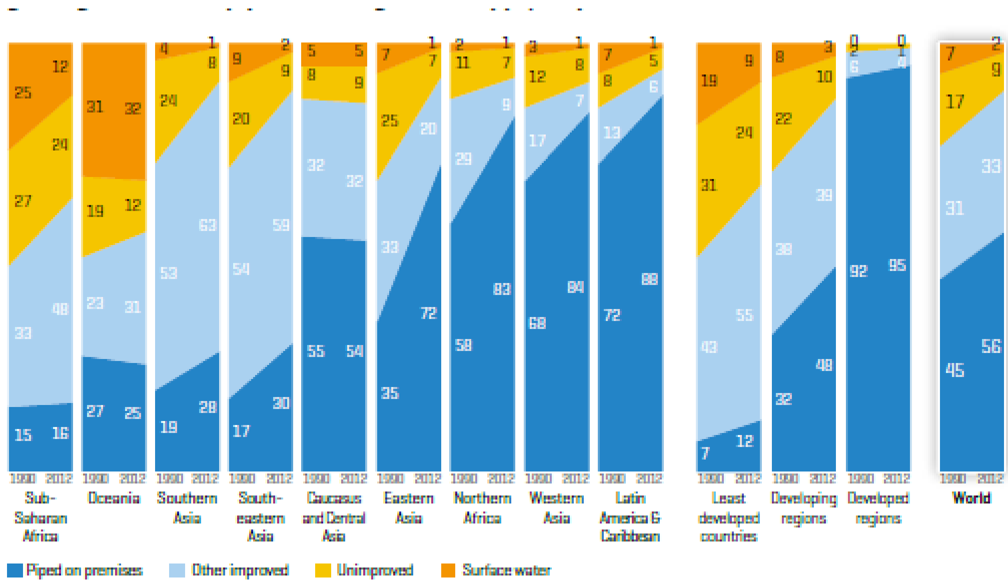


Fig. 3: Trends in Potable Water Coverage (%) by Developing Region between 1990 and 2012(Source: JMP, 2014)

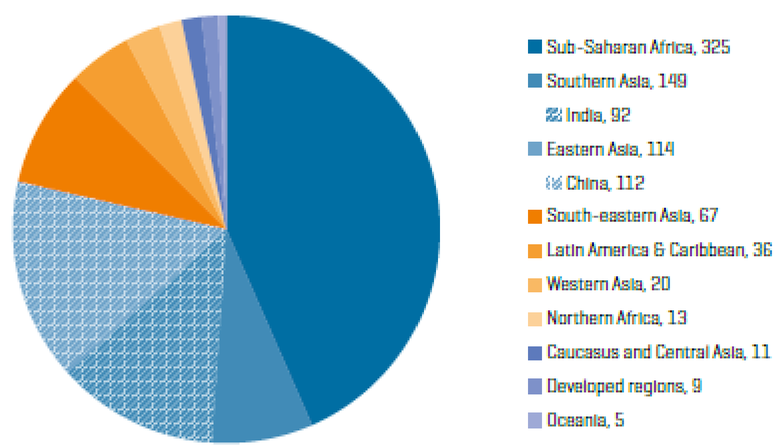


Fig. 4: Number of People (in Millions) without access to an improved Potable Water in 2012 (Source: JMP, 2014)

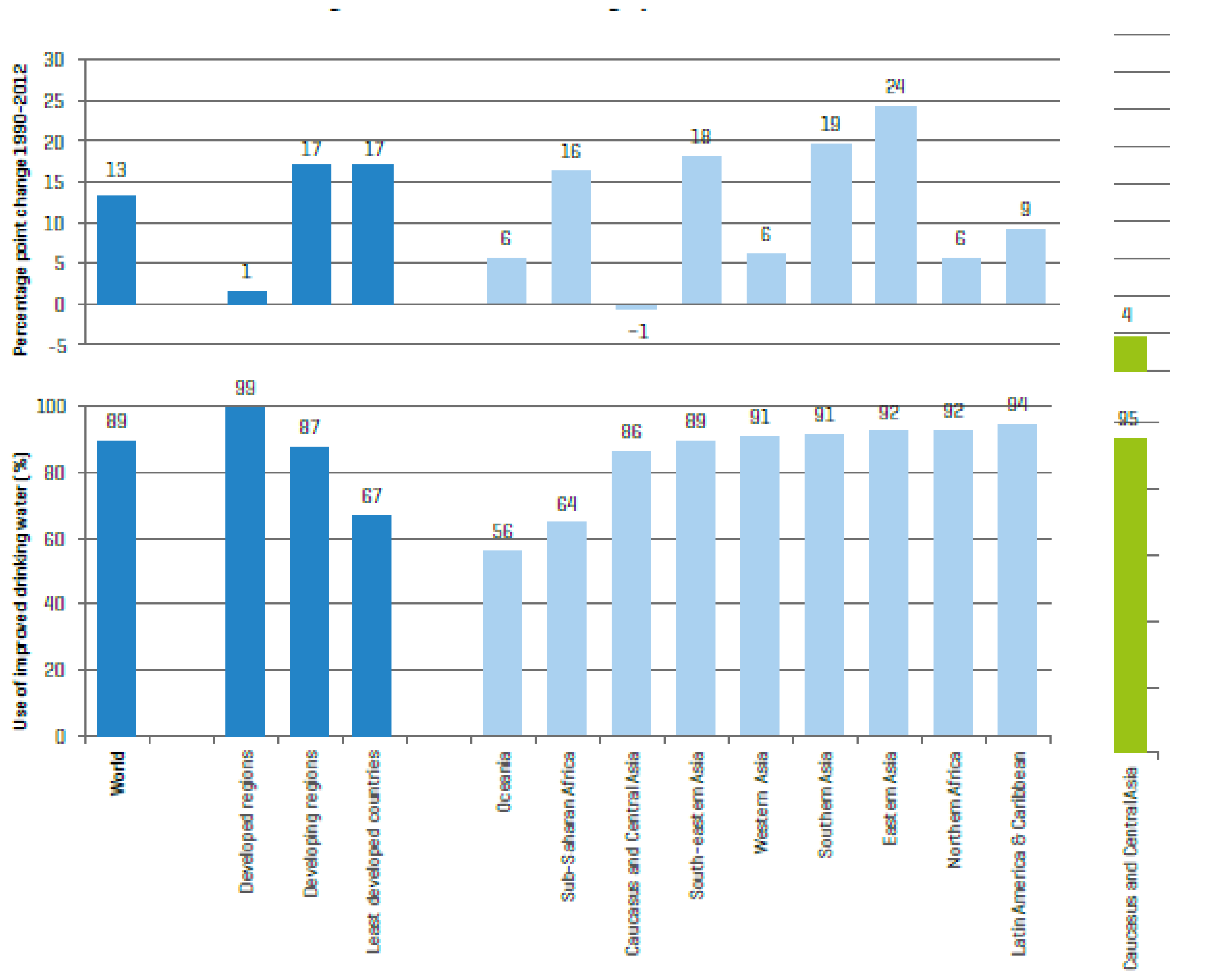


Fig. 5b: Use of Improved Potable Water Sources in 2012 and Percentage Point Change between 1990 and 2012 (Source: JMP, 2014)

Fig. 5a: Use of Improved Sanitation Facilities in 2012 and Percentage Point Change Between 1990 and 2012 (Source: JMP, 2014)

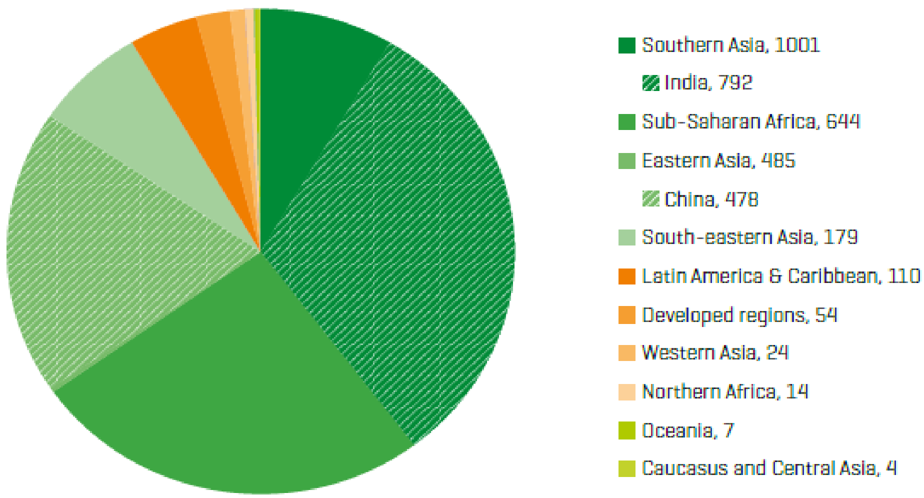


Fig. 5c: Number of people (in Millions) without access to an improved sanitation facility (Source: JMP 2014)

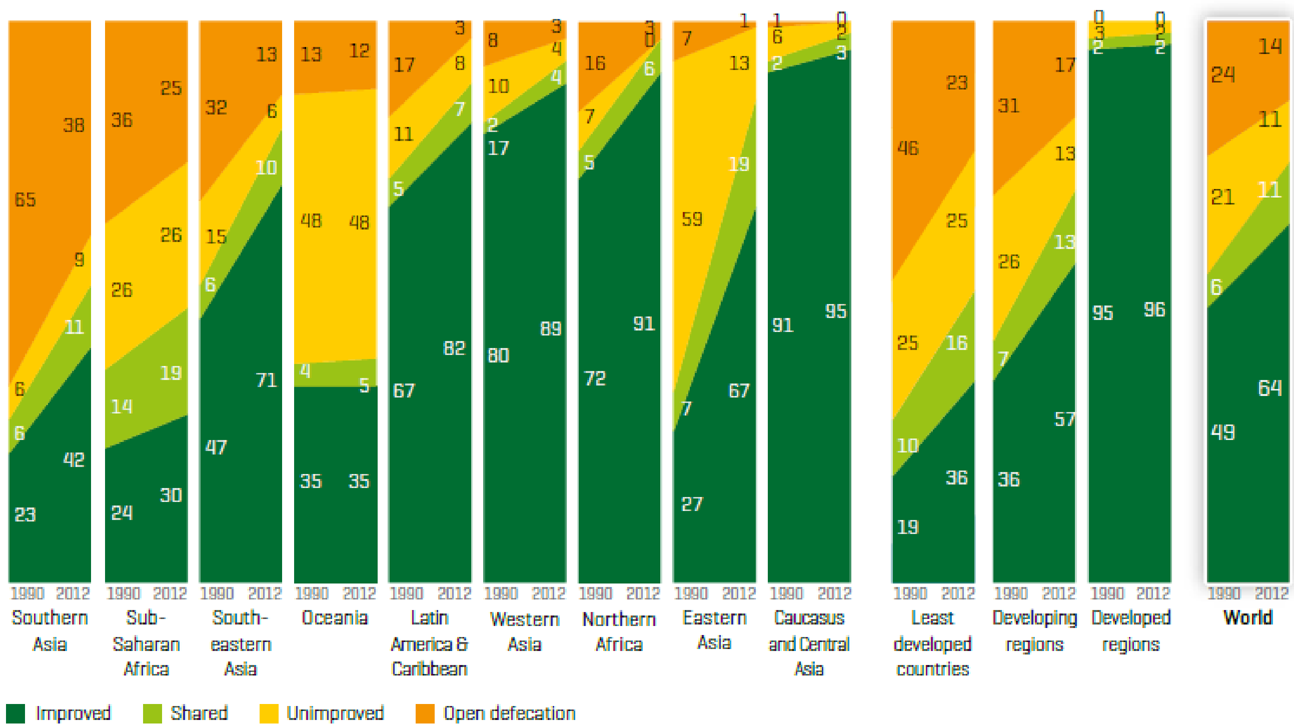


Fig. 5d: Sanitation Coverage Trend (%) between 1990 and 2012 by MDGs Regions (Source: JMP, 2014)

$$E_{Las} = \frac{\sum_{i=1}^{N} X_{lai}}{N_{las}} \qquad (2)$$

where; E_{Las} is the effect of population on access to improve sanitation facilities in Nigeria in the selected year; N_{las} is the number of total population of people in Nigeria in the selected year, and X_{lai} is the total percentage of access to improve sanitation facilities in the selected year.

$$E_{Geo} = \frac{\sum_{i=1}^{N} X_{gi}}{N_{gs}} \qquad (3)$$

where; E_{Geo} is the effect of population on access to solid waste disposal methods in Nigeria in the selected year; N_{gs} is the number of a total number of population in Nigeria in the selected year, and X_{gi} is the total percentage of access to solid waste disposal methods in Nigeria in the selected year. Sum of Squares (SS), Mean Square (MS) and F-Value were computed as follows (Gardiner and Gettinby, 1998; Guttman *et al.,* 1971):

$$\mathrm{SSA} = \left(\mathrm{E}_{\mathrm{HAs}}\right)^2 r\left(2^{k-2}\right) \qquad (4)$$

Where: SSA is the sum of square of factor A; r is the replication of the data (= 1) and k is the level of the factor (= 2)

$$MSA = \frac{SSA}{a-1} \qquad (5)$$

Where: MSA is the mean square of the factor and a-1 is the degree of freedom of the factor.

$$F = \frac{MSA}{MSE} \qquad (7)$$

where: MSE is the mean square of the error and F is the F-value

Results and Discussion

Population Growth in Nigeria

Figure 6 presents information on the population of Nigeria between 1911 and 2006. The census in Nigeria can be grouped into three as decade census (1911-1921- 1931; 1952 – 1962 and 1963- 1973); yearly census (1962-1963) and irregular period census (1931- 1952; 1973 – 1991 and 1991 – 2006). Nigeria's demographic history revealed that from a population of 16.05 million people in 1911, 18.72 million in 1921, 20.06 million in 1931 and 30.42 million in 1952, the country's population rose to 88. 58 million in 1991, the population is more than twice of the 1952 population in 39 years. In 2006, the country recorded a total population figure 139.98 million. This population growth translates to an annual geometrical growth rate of 3.2% over 1991 census figure (Oke *et al.,* 2015). This population growth indicates that base on this geometrical growth rate of the population will double itself in 22 years. The sustained geometrical population increase raised challenges which should be taken seriously given the challenging environment and decaying water supply facilities provided for the growing population number (Fig. 3). From the figure, there was four growth pattern in Nigeria's population demographics. The first growth model was between 1911and 1931, the second was between 1931 and 1973, the third is between 1973 and 1991 and fourth was between 1991 and 2012. There was rapid growth in the second growth pattern compared to the other two growth patterns. This increase in the growth pattern in the second phase (between 1931 and 1973) could be ascribed to an inter play of many factors over the years and the death has been declining. Umoh (2001) and Sajini (2011) reported that the death rate of 13.9 per 1000 people as against a regularly high birth rate of 44.5 per 1000 people contributed to an increase in the growth rate pattern. Some of the factors advance to explain that contributed to the rapid growth rate were the low mortality rate, enriched agriculture and higher food security, healthier nutrition, improvement in general sanitation of the people and better therapeutic care and the scientific breakthrough in techniques for controlling infectious diseases. Other important factors that responsible for the rapid growth rate within this period were avaliability of vaccination, regular immunization and the usage of insecticides to calm mosquitoes and other insect vectors. The disastrous effect of wars, famines, and other natural disasters have been significantly regulated due to international co-operation, the discovery of oil, better-quality transportation and information technology, attached with the impact of industrialization that has increased the range of consumable and capital goods available for use. From the figure, the third growth pattern was a decline in population growth rate which could be accredited to the key economic recession in the 1980s, socio-economic and political factors. Figure 7 presents the relationship between population and percentage people in the urban areas of the country. From the figure, it was revealed that population growth contributed critically to increase in urban population. Growing rate of population in the municipal area increased from 35 % in 1990 to 42 % in 2000 and 50 % in the year 2012, which indicates that there was an increase in the urban area population at a rate of 7 % per decade in 2000 and 6.67% in 2012. The growing could be attributed to job and education opportunities in the urban areas than rural and availabilities of social amenities in the cities than in the countryside areas.

Relationship between Percentage Household and Population Percentage

Figures 8 (a to b) show the relationship between percentage of household distribution and population rate. Figure 8a presents relationship at the national level. Figure 8b displays the relationship at geopolitical zones. From the figure, it can be appreciated that there is a real affiliation between these two parameters at the national and geopolitical levels. The Coefficient of Determination (CD) ranges from 0.9698 (South West geopolitical zone) to 0.9926 (Northwest geopolitical zone). The relationship factor varieties from 0.9865 (national level) to 1.1135 (Southwest geopolitical zone). At National level (Fig. 8a) the correlation influence was 0.9865 which indicates that a percent of household distribution is equivalent to 0.9865 of percentage population. At geopolitical levels the relationship dynamics were 1.0548 (North Central); 1.1021 (North East); 1.0567 (North West); 1.0316 (South East); 1.1005 (South- South) and 1.1135 (South West), which indicates that percentage household distribution is a function of the geopolitical zone. These values revealed that the features of the percentage of household distribution were in the order of South West greater than (>) North East > South- South > North West > North Central > South East, which indicates that fewer people were living per house in the South West than any other geopolitical zone. This relationship could be attributed to compound systems in the Northern part compared to flat (bungalow) systems in the South West. This result indicates that housing system and some people that had access to improve sanitation facilities is a function of the location, geopolitical zones, and many other factors. Figure 8a shows existing relationship between the percentage of household distribution and population percentage in the urban and rural areas respectively. From the figure, the percentage of household distribution and percentage population for rural and built-up areas were similar.

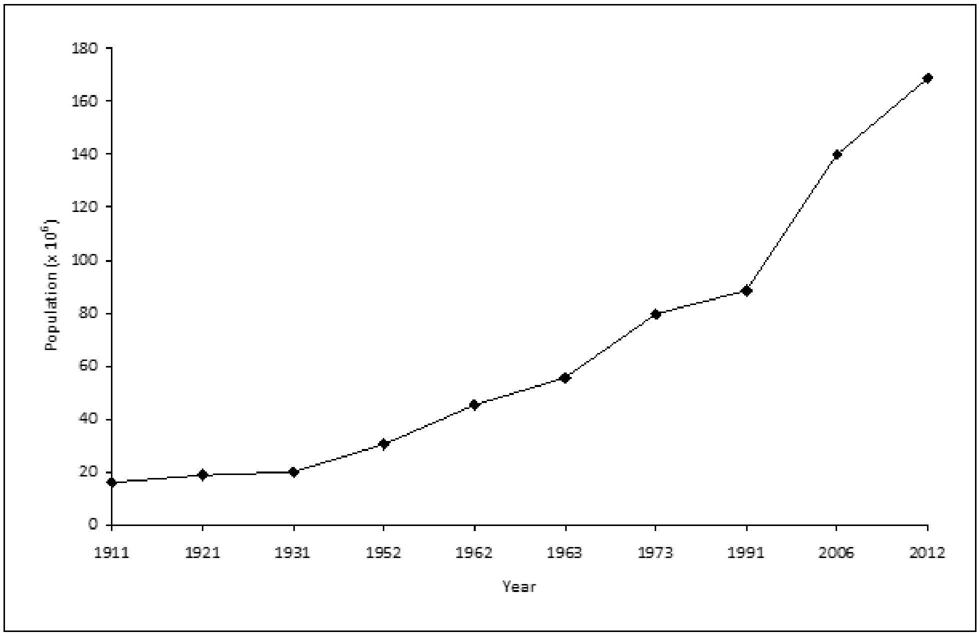


Fig. 6: The Pattern of Population Growth In Nigeria between 1911 and 2012

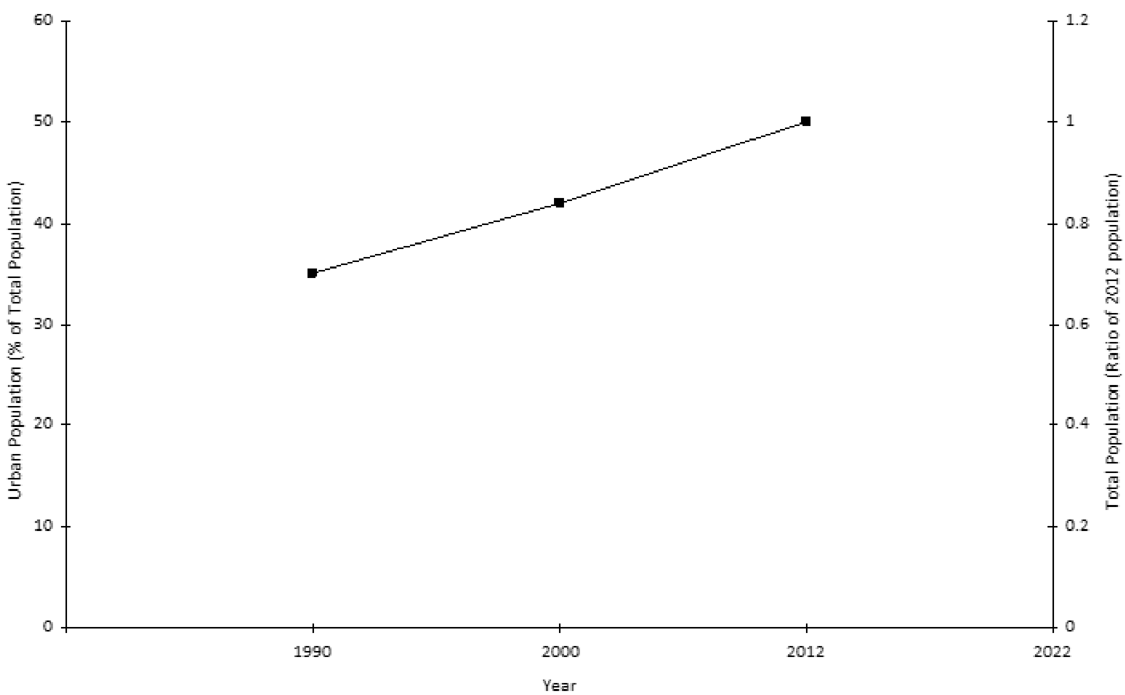


Fig. 7: The Relationship between Urban population, Ratio of Total population and the year (Developed from JMP, 2014)

The Relationship between Number of Household and Number of People

Figure 9 (a to b) shows the relationship between people in the household and number of household. Figure 9a presents relationship at the national level. Figure 9b illustrates the affiliation at six geopolitical zones. From the figure, it can be seen that there is a real connection between these two parameters at the national and geopolitical levels. The CD) ranges from 0.9901 (Northeast geopolitical zone) to 0.9982 (Southwest geopolitical zone). The relationship between the number of people per household arrays from 3.6441 (Southwest geopolitical zone) to 5.6555 (Northwest geopolitical zone). At National level (Fig. 9a) the correlation influence (the number of people per household was 4.614) was 0.9865. At the geopolitical level, the relationship features (number of people per household) were 4.6177 (North Central); 5.2189 (North East); 5.6555 (North West); 4.007 (South East); 3.7748 (South- South) and 3.6441 (South West). This correlation influnce indicates that number of people per household is a function of the geopolitical zone. These values revealed that the number of people per household were in the order of South West less than (<) South- South < South East < North Central < North East < North West. The result indicates that fewer people were living per house in the South West than any other geopolitical zone. These figures revealed that the average number of people per household in these six geopolitical zones were South West (4) South- South (5), South East (5), North Central (5), North East (6); and North West (6). This value indicates that fewer people were living per house in the South West (lower than National average) than any other geopolitical zone. This result could be attributed to compound systems in the Northern part compared to flat (bungalow) systems in the South West. This result indicates that number of people per household that had access to improve sanitation facilities is a function of the location, geopolitical zones, and many other factors.

The Effect of Population Growth on Access to Safe Water and Improve Sanitation Facility

Figure 10 shows the trends of access to improve water supply (safe water) between 1990 and 2012. From the figure, there was a disparity in the access to drinking water in Nigeria between rural and urban areas. Figure 11 shows the trends of access to improve water supply (nontoxic water) between 1990 and 2013 by State in Nigeria. From the figure, there was a disparity in the access to clean water in Nigeria between the States. Figure 12 shows the trends of access to improve sanitation facility between 1990 and 2012. From the figure, there was a disparity in the access to sanitation facility in Nigeria between rural and urban areas. From the numbers, 72% of urban dwellers to 47% of the rural population have access to improve water sources; while the ratio of water access to sanitation is only 2: 1-that is 58% water supply access to 26% sanitation (WHO and UNICEF, 2010). Based on the geopolitical region, the NC, NE, and NW zones of the country had improved drinking water access of 52.2%, 27.3%, 42.5% respectively compared to 72.7% and 54.1% in the SW and SE zones respectively. On the other hand, 29%, 34.4%, 34.1% representing the NC, NE, NW respectively used improved sanitation in comparison to 55.5% and 55.0% in SE and SW zones respectively. These results revealed that access to improve water supply and sanitation facility in Nigeria was vulnerable by geographical, socio-economic and institutional factors (such as population). There was a significant regional and local disparity between the north and south as well as urban and rural areas in access to safe water and improved sanitation. These observations were similar to observation made by NBS (2007), Amakom (2009); WHO and UNICEF (2010), Akpabio (2012) and Onabolu *et al.* (2011) that access to safe water and improve sanitation in Nigeria governed by many factors.

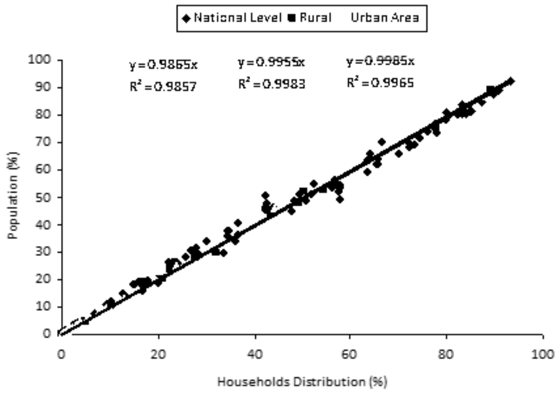


Fig. 8a: Relationship Between percentage Household and Population in the Six Geopolitical zones

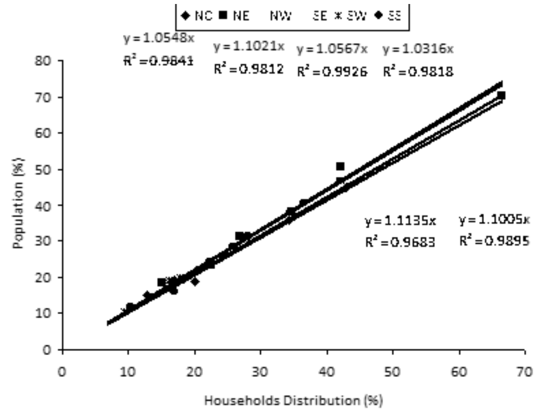


Fig. 8b: Relationship Between percentage Household and Population at National level

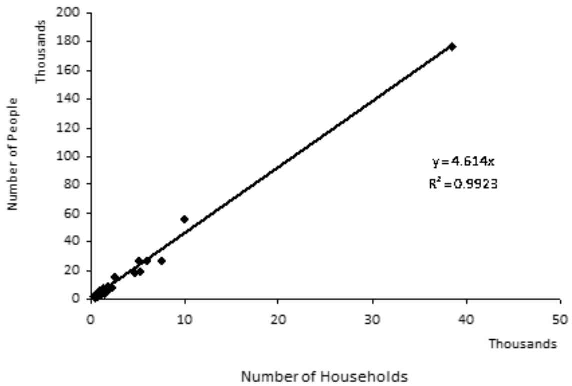


Fig. 9a: Relationship between Household and Population in Nigeria

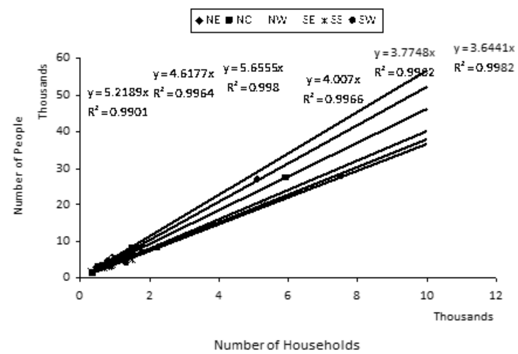


Fig. 9a: Relationship between Household and Population in six Geopolitical Zones of Nigeria

Statistical Evaluation of the Effect of Population Growth on Access to Safe Water and Improve Sanitation facility

Tables 1 to 4 show the statistical evaluation of the effect of population growth on access to sanitation facility, safe water, piped water and other improved water sources. From Table 1, it can be seen that population growth had effects on access to sanitation facility ($F_{2,4} = 7.220$ and $p = 0.047$). The table also revealed that the effect was significant at 95 % confidence level ($p < 0.050$). This observation could be attributed to the cost of setting up an improved sanitation facility. Also, there was a significant difference between the descriptions (National level, rural and urban areas) at 95 % confidence level. The effect of population growth on access to sanitation facility within rural and urban areas ($F_{2,4} = 7.986$ and $p = 0.040$) could be attributed to the disparity in the population growth within the rural and urban areas as well as at the national level. Table 2 presents the the effect of population growth on access to safe water. The study revealed that population growth had an impact on access to drinking water ($F_{2,4} = 0.916$ and $p = 0.470$), which was not significant at 95 % confidence level. Also, from the table, there was a significant difference between the descriptions (National level, rural and urban areas) at 95 % confidence level. The effect ($F_{2,4} = 7. 292$ and $p = 0.046$) could be attributed to the disparity in the population growth within the rural and urban areas as well as at the national level. Table 3 presents a statistical evaluation of effects of population growth on access to piped water. The assessment revealed that population growth had an impact on access to piped water ($F_{2,4} = 1.622$ and $p = 0.305$). The effect was found not to be significant at 95 % confidence level ($p > 0.50$). There was no significant difference between the descriptions (National level, rural and urban areas) at 95 % confidence level on access to piped water. The effect ($F_{2,4} = 3.009$ and $p = 0.159$) could be attributed to the disparity in the population growth and piped water projects within the rural and urban areas as well as at the national level. Table 4 presents the statistical evaluation of the effects of population growth on access to other improved water sources. The assessment revealed that population growth had an impact on access to other improved water sources ($F_{2,4} = 0.263$ and $p = 0.781$). The effect was found not to be significant at 95 % confidence level ($p > 0.50$). There was a significant difference between the descriptions (National level, rural and urban areas) at 95 % confidence level. The effect ($F_{2,4} = 17. 038$ and $p = 0.011$) could be attributed to the disparity in the population growth within the rural and urban areas as well as at the national level.

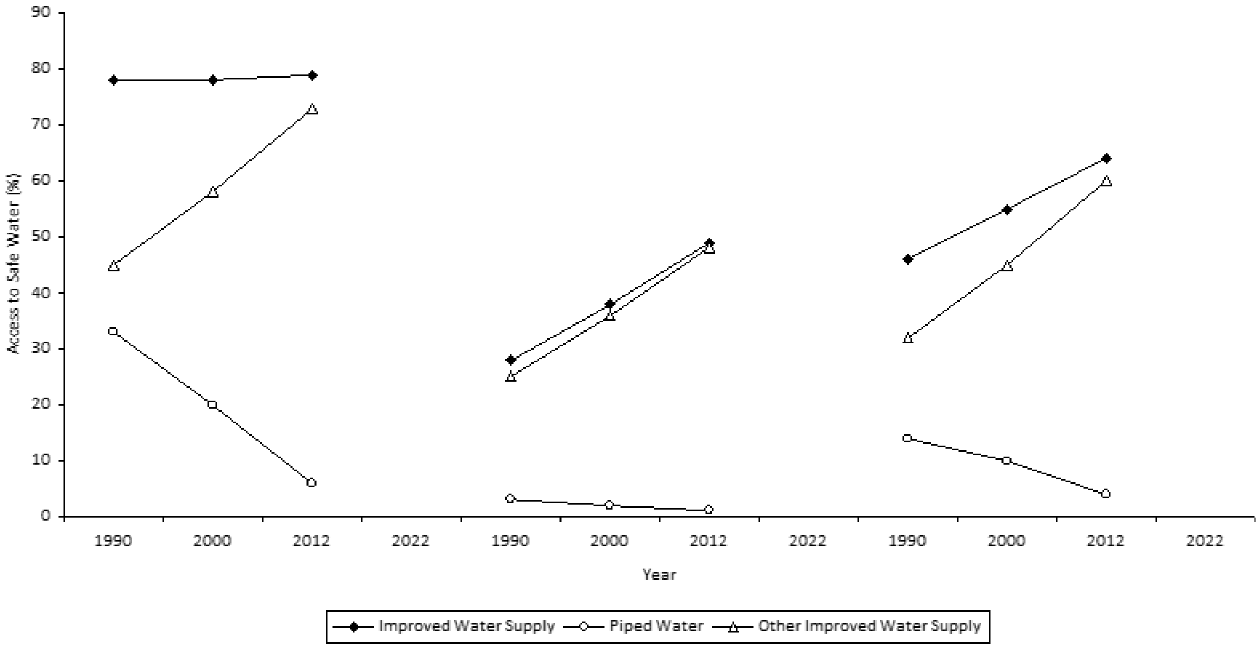
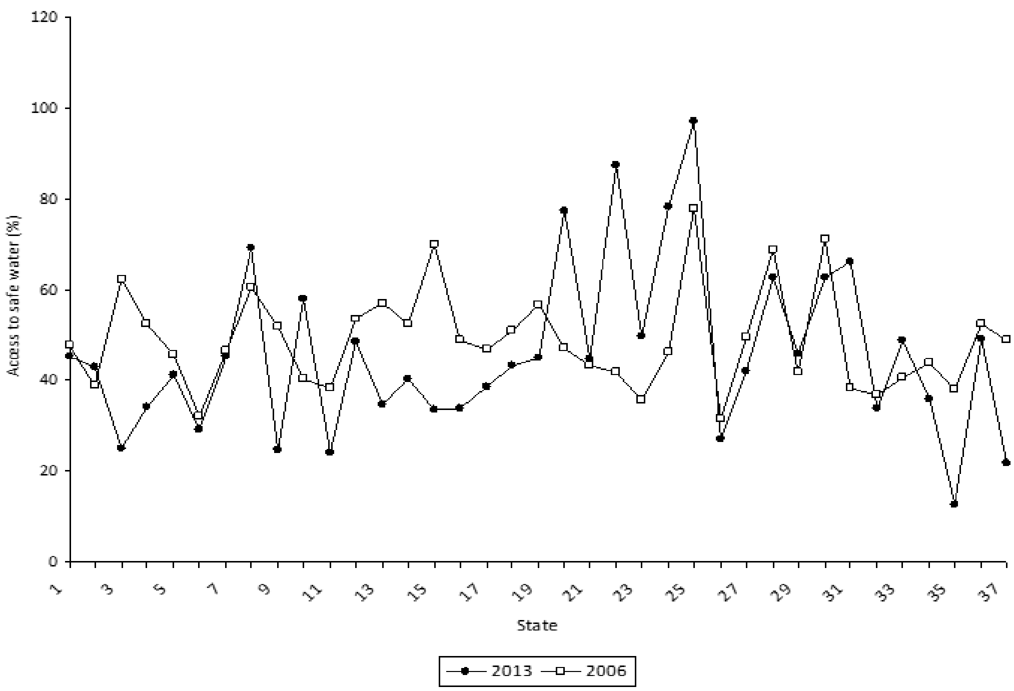


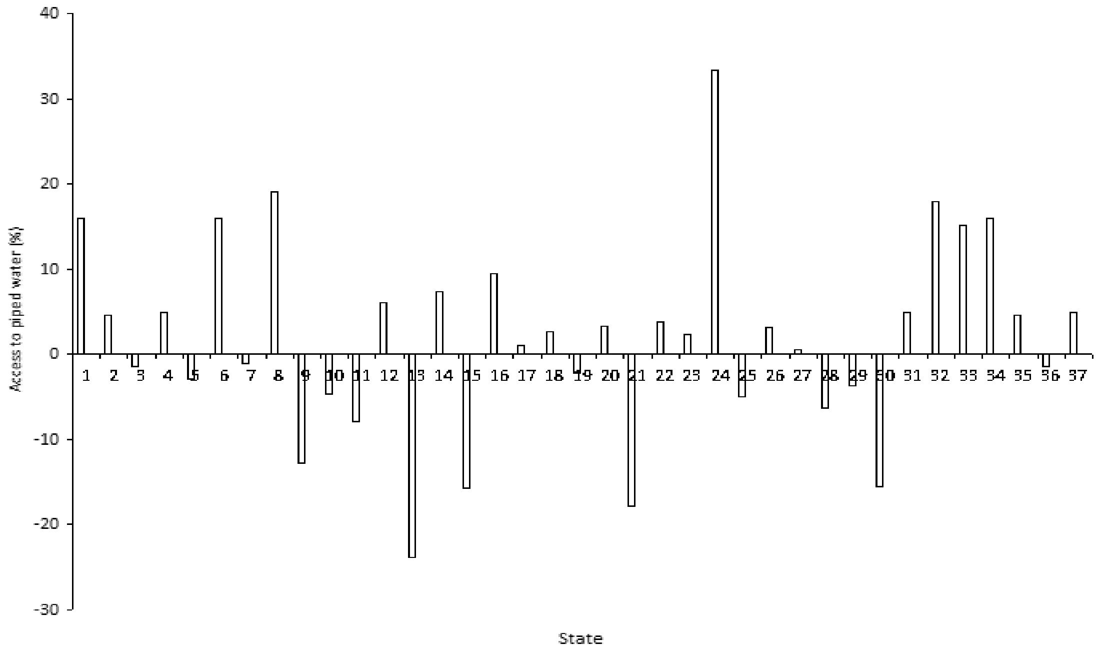
Fig. 10: The Trend of Access to safe Water in Nigeria between 1990 and 2012 (Developed from JMP, 2014)



SN	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
STATES	Abia	Adamawa	Akwa Ibom	Anambra	Bauchi	Bayelsa	Benue	Borno	Cross River	Delta	Ebonyi	Edo	Ekiti	Enugu	FCT	Gombe	Imo	Jigawa	Kaduna	Kano	Katsina	Kebbi

SN	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37
STATES	Kogi	Kwara	Lagos	Nasarawa	Niger	Ogun	Ondo	Osun	Oyo	Plateau	Rivers	Sokoto	Taraba	Yobe	Zamfara

Fig. 11a: The Pattern of Access to Safe Water Between 2006 and 2013 In Nigeria by States



SN	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
STATES	Abia	Adamawa	Akwa Ibom	Anambra	Bauchi	Bayelsa	Benue	Borno	Cross River	Delta	Ebonyi	Edo	Ekiti	Enugu	FCT	Gombe	Imo	Jigawa	Kaduna	Kano	Katsina	Kebbi

SN	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37
STATES	Kogi	Kwara	Lagos	Nasarawa	Niger	Ogun	Ondo	Osun	Oyo	Plateau	Rivers	Sokoto	Taraba	Yobe	Zamfara

Fig. 11b: The Trend of Access to Piped Water Source in Nigeria Between 2006 and 2013 as Related to the States and Federal Capital Territory in Nigeria.

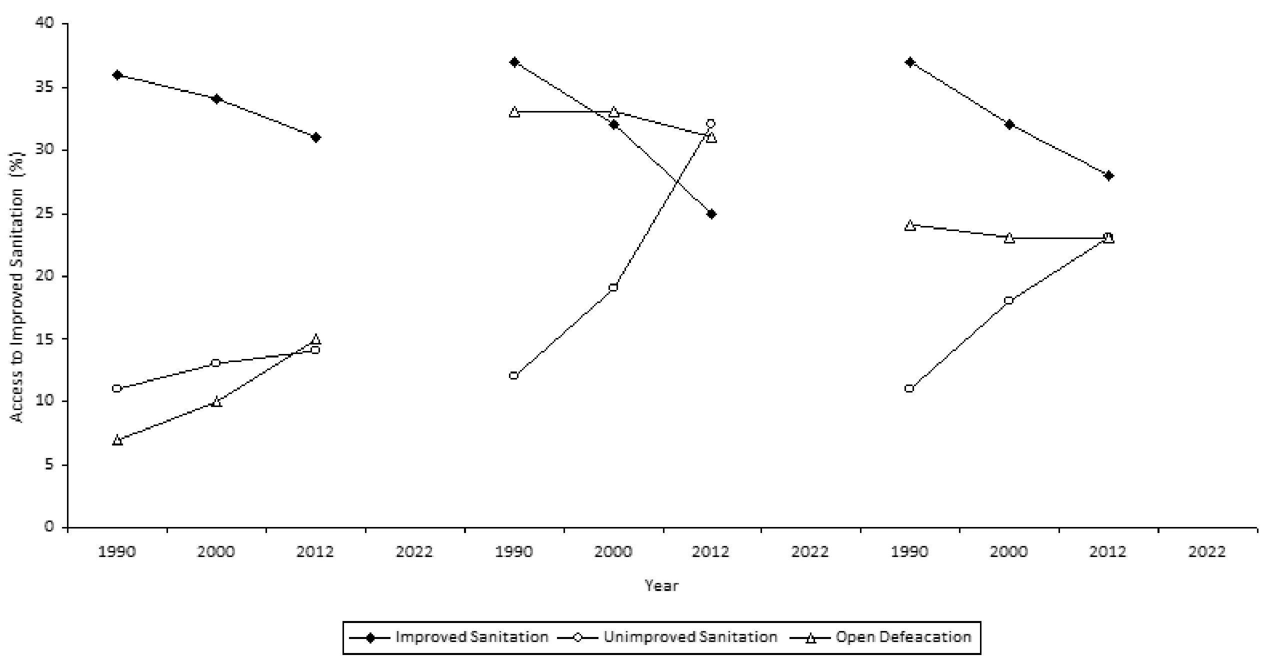


Fig. 12: The Trend of Access to Improve sanitation Facility in Nigeria between 1990 and 2013 (Developed from JMP, 2014)

Table 1: The Effect of Population Growth on Access to Sanitation Facilities

Source of Variation	Sum of Squares	Degree of freedom	Mean Square	F- Value	P-value
Within the Population growth	0.2529157	2	0.1264578	7.2197937	0.0470563
Between Descriptions	0.2797593	2	0.1398796	7.986077	0.0401116
Error	0.0700618	4	0.0175154		
Total	0.6027367	8			

Table 2: The Effect of Population Growth on Access to Safe Water

Source of Variation	Sum of Squares	Degree of freedom	Mean Square	F- Value	P-value
Within the Population growth	0.313106	2	0.156553	0.9158799	0.470457
Between Descriptions	2.4929216	2	1.2464608	7.2921527	0.046326
Error	0.6837272	4	0.1709318		
Total	3.4897549	8			

Table 3: The Effect of Population Growth on Access to Piped Water

Source of Variation	Sum of Squares	Degree of freedom	Mean Square	F- Value	P-value
Within the Population growth	0.1970828	2	0.0985414	1.6220917	0.3048886
Between Descriptions	0.3656113	2	0.1828057	3.0091665	0.159415
Error	0.2429984	4	0.0607496		
Total	0.8056926	8			

Table 4: The Effect of Population Growth on Access to Other Improved Water Sources

Source of Variation	Sum of Squares	Degree of freedom	Mean Square	F- Value	P-value
Within the Population growth	0.0150924	2	0.0075462	0.2626764	0.7812951
Between Descriptions	0.9789212	2	0.4894606	17.037674	0.0110365
Error	0.1149125	4	0.0287281		
Total	1.1089262	8			

Conclusion

This study investigated the effect of population growth on access to improve sanitation facilities and safe water. The study revealed that access to safe water in Nigeria is a function of many factors. Based on the findings, the following specific conclusions were drawn:

1) The population growth had an effect on access to improve sanitation facility, piped water, safe water and other improved water sources in Nigeria;
2) The impact of population growth on access to an improved sanitation facility in Nigeria was significant;
3) The effect on access to other improved water sources was significant at 95 % confidence level; and
4) There is the need to review access to improve sanitation facilities and safe water supply to enhance access to improve sanitation facilities and drinking water in Nigeria

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Performance Evaluation of Subsurface Horizontal Flow Constructed Wetland for the Treatment of Organic Pollutants of Wastewater from Ahmadu Bello University, Zaria, Nigeria.

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Abstract
Constructed wetlands have gained much importance for treating domestic, industrial and agricultural wastes and are considered as an effective secondary or tertiary treatment method. The treatment of organic pollutants in wastewater of Ahmadu Bello University (ABU), Zaria, by sub-surface horizontal flow constructed wetland was assessed. A wetland was designed and constructed with dimensions 14m x 3.5m x 0.45m, lined with geomembrane of polyethylene and filled with gravel 10-15mm size to a depth of 0.2m at the bottom, followed by sand (0.3-0.5mm size) to a depth of 0.20m and local soil layer of 0.05m. Influent wastewater was provided from elevated storage tank of 3,000 litres to the constructed wetland through pipes. Samples were collected at the inlet and outlet of the constructed wetland every seven (7) days for ten weeks and analyzed for TSS, FC, BOD, COD, PO_4-, NO_3- and NH_4-. The results showed that the maximum removal efficiencies by the constructed wetland for TSS, FC, BOD, COD, PO_4-, NO_3- and NH_4- by 89.2%, 94.3%, 93%, 80.5%, 67.5%, 80.5% and 32.92%, respectively. The constructed wetland removed considerable amounts of the organic pollutants from wastewater of ABU that otherwise would have been discharged into the drains and subsequently emptied into Kubanni River at the downstream of the University dam.
Key words: Constructed wetland, Organic pollutants, Wastewater, Hydraulic resident time.

Introduction
Industrialization and urbanization in developing countries like Nigeria have brought about pollution of water bodies in urban cities with inherent consequences including compromised sanitation, public health, poor nutrient recovery in the ecosystems and pollution of freshwater resources (Home *et al.,* 2010). Unfortunately, the developing countries lack the required capital layout and experienced and skilled manpower to operate and maintain conventional

wastewater treatment plants. This has been the major contributor to poor wastewater treatment and disposal in developing countries (Ciria *et al*., 2005). The frequent outbreaks of diseases such as diarrhea, cholera, and typhoid in developing countries have been partly attributed to these depressing factors (Adagbada *et al*., 2012). Also haphazard disposal of untreated wastewater from industries, households, and institutions such as Ahmadu Bello University (ABU), Zaria has caused severe deterioration of water bodies in many developing countries.

According to Lukman (2009), the effluent from waste stabilization ponds in Ahmadu Bello University, Zaria is found to be rich in organic nutrients, and consequently, discharges into the drains which subsequently empty into Kubanni River at the downstream of the University dam which is the main source of water supply in the university. The need therefore, to develop a low-cost wastewater treatment technology that will effectively eliminate or drastically reduce the quantities of organic pollutants in the wastewater becomes imperative.
Researchers have shown that wetland systems have great potential in controlling water pollution from domestic, industrial and non-point source contaminants (Vymazal, 2005; Rai *et al.,* 2013). Wetland systems use aquatic plants, soils and their associated micro-organisms to remove contaminants from wastewater (Sohair, *et al.,* 2013; Rai *et al.,* 2015). Constructed wetlands (CWs) proved to be a good alternative for such wastewater treatment. They offer low operation and maintenance costs since no mechanical components or external energy supply is required.

Constructed wetlands are an engineered eco-technological system, designed with ecological principles to exploit the natural processes involving wetland vegetation, soils and associated microbial assemblages for treating wastewaters for the removal of nitrogen, phosphorus, total solids, and trace elements (Soda *et al.,* 2012; Madera-Parra et al., 2013; Rai *et al.,* 2013; Nivala *et al*., 2013; Guittonny-Philippe *et al.,* 2014). The purpose of this study is to evaluate the efficiency of subsurface horizontal flow constructed wetland system in the removal of physico-chemical parameters such as chemical oxygen demand, biochemical oxygen demand, total solids, suspended solid, phosphates, ammonia, and nitrates in the wastewater of Ahmadu Bello University, Zaria.

Materials and Methods

Study Area

The study area is located within Ahmadu Bello University, Zaria, Kaduna State, Nigeria and lies between latitude 11° 01'N, longitude 7^0 04'E and altitude 685m (Fig. 1). Zaria is a very large, heterogeneous city and one of the most important cities in Northern Nigeria (Uba *et al.*, 2013). It has a stream known as Kubanni River which flows in a Southeast direction through the premises of Ahmadu Bello University. The Zaria region is characterized by two seasons- rainy season from May to September and dry season from October - April.

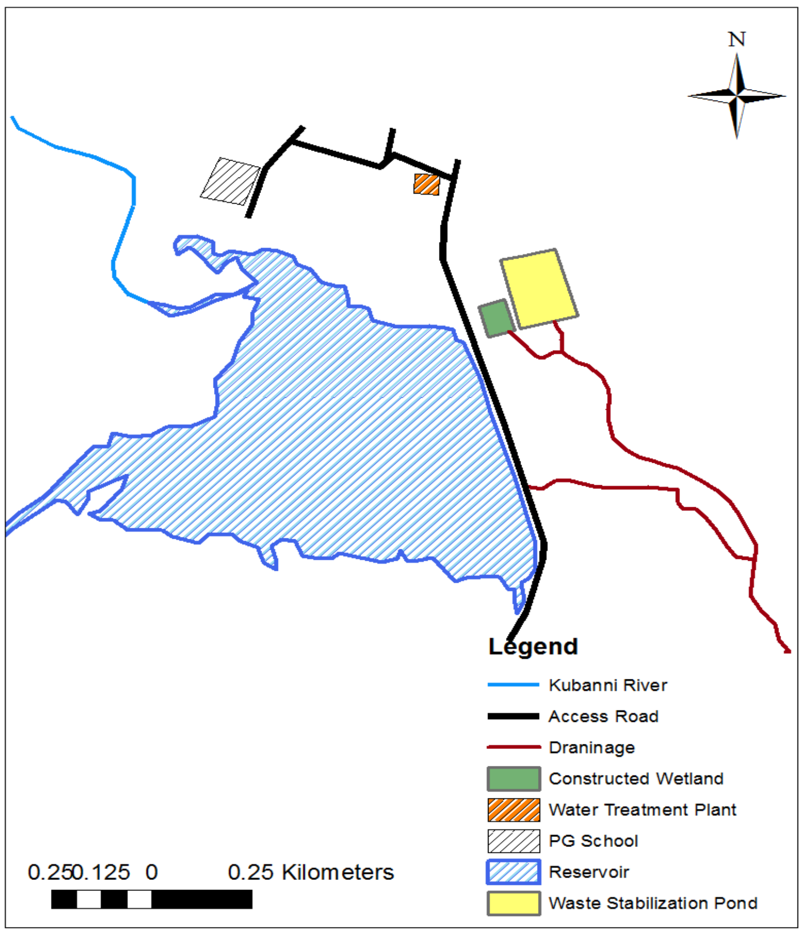

Fig. 1: Ahmadu Bello University Wastewater Treatment Plant Location

Experimental site Set-up

A pilot scale wetland was designed and constructed adjacent to the Ahmadu Bello University waste stabilization pond. The dimensions of the constructed wetland were 14 m x 3.5 m x 0.45 m with the bottom slope of 1% based on design calculation in accordance with Crites and Tchobanoglous (1998) recommendation for length/width ratio which falls between 2:1 and 4:1. The excavated wetland was lined with a geo-membrane of polyethylene, to prevent percolation of wastewater into the groundwater. The base of the wetland was filled with gravel (10-15 mm size) to 0.2 m depth, followed by sand (0.3-0.5 mm size) to 0.20 m depth and then covered with local soil 0.05 m depth (Fig. 2).

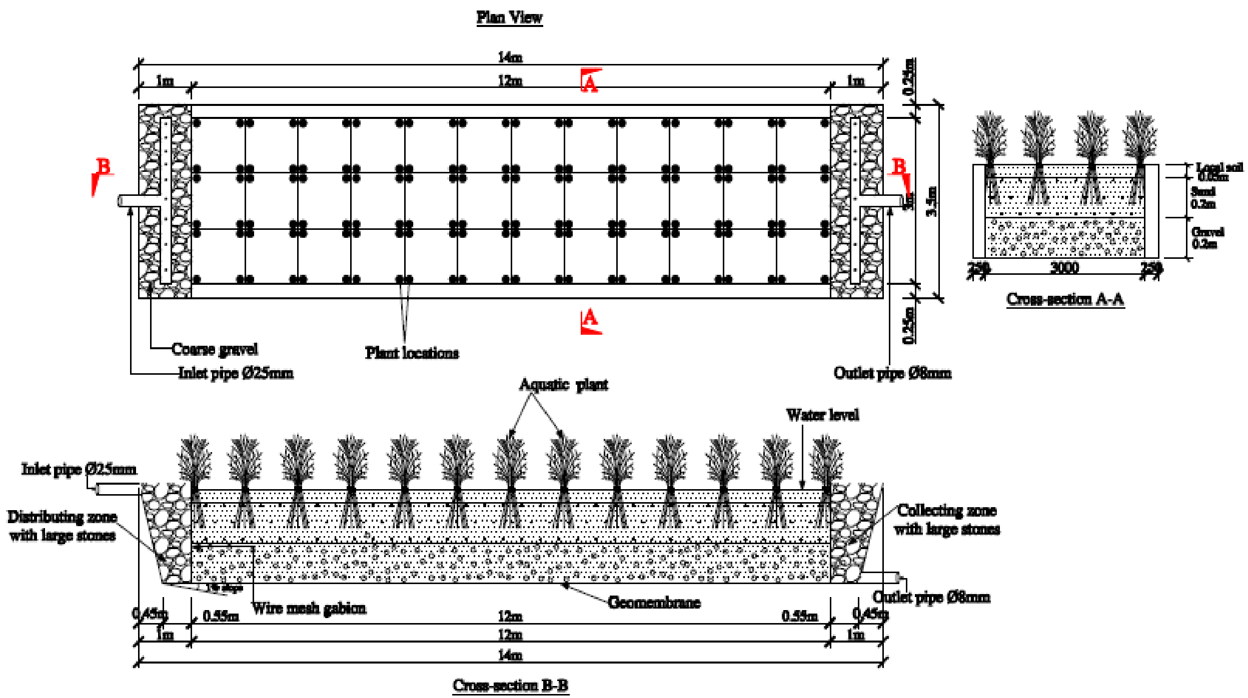

Fig. 2: Constructed wetland plan and cross-section

Coarse gravels (50-100 cm size) were placed at the inlet and outlet of the cell, to help prevent clogging, to facilitate relatively even water distribution throughout the cell, and the smooth collection of treated wastewater at the outlet. The constructed wetland cell was divided into three equal parts by planting clumps of three different macrophytes- Poaceae *(Phragmites Karka)*), Typhaceae (*Typha australis*) and Cannaceae (*Canna indica*), at approximately 4 plants/m^2. A moist soil condition was maintained after planting the plants and the water level in the constructed wetland cell was slowly increased until the new shoots developed. Tap water was used to irrigate the constructed wetland continuously for one month. Thereafter, tap water and wastewater were weekly introduced into the constructed wetland cell in a formulated percentage ratio of (80:20), (60:40), (40:60), (20:80) and (0:100), respectively for five weeks to reduce shock to the plants. According to USEPA (1993) plants should be allowed to become well established before the wastewater is introduced into the system since the plants need an opportunity to overcome the stress of planting before other stresses are introduced. The high oxygen demand of the waste water could inhibit initial plant growth. The wastewater from the waste stabilization pond system at Ahmadu Bello University was pumped (using a 5Hp surface pump) into an elevated storage tank of 3000 litres capacity. The wastewater was gradually released into the constructed wetland cell through pipe network by gravity (Fig.3).

The storage tank also serves as a sedimentation and equalization chamber to the constructed wetland. To reduce suspended solids from the wastewater entering the constructed wetland, a strainer was installed at the end of the suction hoist of the pump and a screen installed at the outlet of storage tank leading to the constructed wetland cell via the pipe network. The wastewater from the storage tank into the wetland is controlled by a gate valve and distributed to the constructed wetland through a polyvinylchloride (PVC) pipe ɸ25mm with control gate-valves. The average rate of inflow was 6,000 l/d and the outflow 4,500 l/d. The calculated wastewater hydraulic retention time was seven days, based on Darcy's law at 35.6% porosity.

Sample Collection and Analyses

Collection of samples started after three months of the construction and stabilization of wetland to allow sufficient time for establishment of vegetation and biofilm. Samples were taken every 7 days (hydraulic retention time calculated based on the ratio of the volume of the constructed wetland and the flow rate). One litre wastewater sample was collected from influent and another one litre wastewater sample from effluent of the constructed wetland using clean dried plastic bottles and then analyzed. The sampling protocols were in line with the APHA, (1998) standards. Samples were analysed for pH, Temperature (T), Total Suspended solids (TSS), Biological Oxygen Demand (BOD_5), Chemical Oxygen Demand (COD), Phosphate (PO_4^-), Ammonia (NH_4^-), Nitrate (NO_3^-) and Total Coliforms was determined using most probable number (MPN) technique. The pH and temperature of the influent and effluent of the system were measured by means of a pH meter and thermometer, respectively.

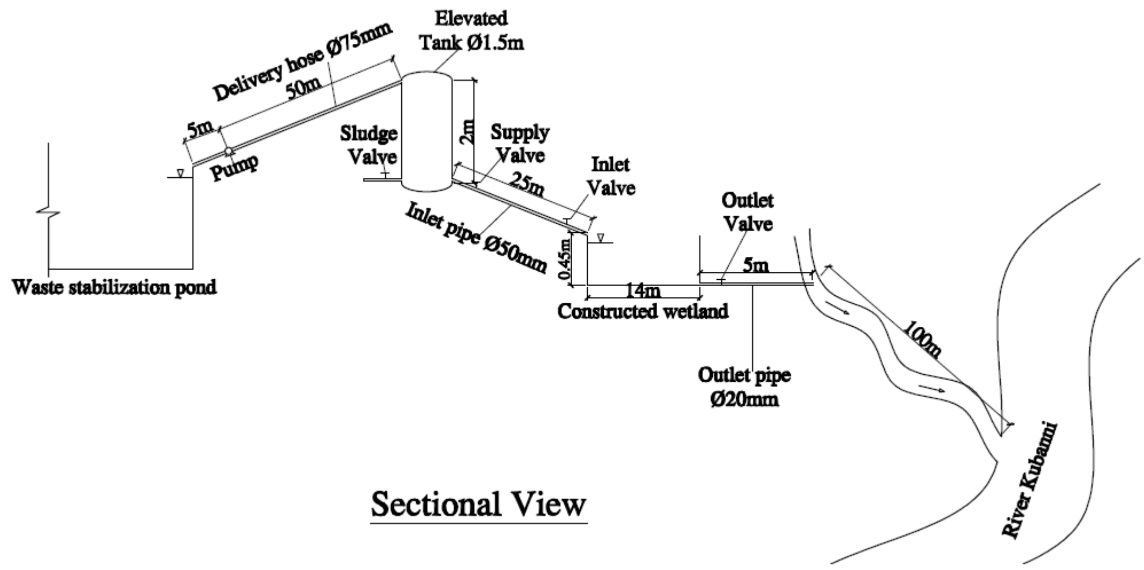

Fig. 3: Diagrammatic sketch of Experimental design

Results and Discussion

The concentrations of parameters studied at the inlet and outlet are presented in Table 1. The pH of influent wastewater of the constructed wetland varied from 6.24 to 6.80 with an average of 6.57 while that of the effluents was between 6.84 and 7.4 with average 7.16. The pH of the influents wastewater had no significant variation in comparison with that of the effluents. They are circum-neutral which suggests a slightly acidic to slightly alkaline conditions. Water with high salinity is toxic to plants and poses a salinity hazard. Generally, wetland waters have pH varying from 6-8 (Kadlec and Knight, 1996) and the pH of effluent of the constructed wetland falls within this range. Also it falls within the permissible limits of good water quality for irrigation (pH 6.0 – 8.5) of the (WHO, 1994) and (FAO, 1994). The observed difference between the pH of the influent of wastewater of constructed wetland and that of effluent probably would have been caused by plant photosynthesis that occurred during the day (Sawyer and McCarty, 1978).

The temperature readings of inlet and outlet wastewater of the constructed wetland are shown in Table 1. The temperature of influent wastewater ranged from 27.82 to 28.01^{0}C with a mean value of 27.96^{0}C, while that of effluent was between 27.89 and 28.11 ^{0}C with an average of 28.03^{0}C. The temperature of effluent wastewater from the constructed wetland was slightly higher than that of the influent as a result of retention of heat from the sun during the day time until the early hours of the morning, by the filter media of the sub-surface horizontal flow constructed wetland. The above range of temperatures fall within the optimum temperature for bacterial activity, as stated by Metcalf and Eddy (1995), that the optimum temperature for bacterial activity ranges from 25^{o}C to 35^{o}C, while the nitrifying bacteria and some aerobic bacteria stop action at 50^{o}C.

The results of removal efficiencies of Total Suspended Solids by the constructed wetland are shown in Table 1. The TSS removal efficiency by constructed wetland ranged from 84 – 89.2% during the ten (10) weeks retention time. Similar to this study, Rai *et al*. (2013) found constructed wetland to remove more than 65% of TSS from inlet wastewater after 36 h retention time under fully established condition, while Zhang *et al.* (2012) reported 79.93% of TSS removal efficiency from constructed wetland. The FC removal efficiency by constructed wetland ranged from 87- 94.3% during ten (10) weeks retention time. It was observed that the FC removal efficiency increases as the hydraulic resident time increases. A high reduction in faecal coliforms and high pathogen removal in constructed wetlands could be attributed to the damage of their cytoplasmic contents caused by sunlight penetration Awuah *et al.* (2002) and Davies-Colley *et al.* (1997). The DO of influent wastewater of the constructed wetland varied from 1.76 – 1.80mg/l, while that of the effluents was 2.70 - 4.70mg/l. It is observed that the DO increases as the hydraulic resident time increases. A similar study by Rai *et al*. (2013) reported that DO increased from 0 - 4.71 mg/l at 36 h in a fully established constructed wetland. This is probably as a result of oxygen release by exudation into the root zone around sediments, a phenomenon similar to what UNEP (2011) attributed to hollow stem features of wetland plants for passage of oxygen to root tissues. The BOD removal efficiency of the constructed wetland is shown in Table 1. The BOD removal efficiency by constructed wetland ranged from 78 – 93% during the ten (10) weeks study period. It was observed that the BOD removal efficiency increased as the hydraulic resident time increased. This agrees with the results of other researchers like Vymazal (2010); Zhang *et al*. (2010); Baskar *et al.* (2014) and Karathanasis *et al*. (2003). According to Zhang *et al*. (2009), the high removal rates of BOD are caused by sedimentation of suspended solids and by rapid decomposition processes in the water and upper soil layers.

The COD removal efficiency by constructed wetland ranged from 68 – 80.5% during ten (10) weeks retention time. It was observed that COD removal efficiency increased as the hydraulic resident time increased. Zhang *et al* (2014) and Golda et al. (2014) in similar research works reported COD maximum removal efficiency of 82% and 77.8%, respectively. The phosphate removal efficiency by constructed wetland ranged from 34.70 – 67.50% during the study period. These results are in conformity with the ones of similar studies carried out by Martinez-Guerra *et al*. (2015), Vymazal (2004), Klomjek *et al*. (2005) and Rai *et al.* (2015) with removal efficiency of phosphate 60%, 60%, 36% and 71.1%, respectively. The nitrate removal efficiency by constructed wetland ranged from 68 – 80.5% during ten (10) weeks retention time. Truu *et al.* (2009) in a similar study reported 89.6% of NO_3^- removal. It was observed that NO_3^- removal efficiency increased as the hydraulic resident time increased. This may probably be attributed to the dense plant root system in the constructed wetland which might have improved filtration and stimulated microbial activities especially nitrifying bacteria, leading to increased nutrient uptake (N, P) and biomass production (Korboulewsky *et al.,* 2012). The Ammonia (NH_4^-) removal efficiencies by constructed wetland range from 16.83 - 32.92% during ten (10) weeks period. It was observed that the Ammonia (NH_4^-) removal efficiency increases as the hydraulic resident time increases. The low percentage removal of ammonia from the constructed wetland is similar to the result obtained by Young *et al*. (2000) and this could probably be as a result of limited uptake of ammonia by plants.

Conclusion

The constructed wetland removed considerable amounts of organic pollutants in wastewater of ABU that otherwise would have been discharged into the drains and subsequently empty into Kubani River at the downstream of the University dam. The maximum removal efficiencies by the constructed wetland for TSS, FC, BOD_5, COD, PO_4-, NO_3- and NH_4- by 89.2%, 94.3%, 93%, 80.5%, 67.5%, 80.5% and 32.92% respectively. The increased of DO levels from 2.70 to 4.70 mg/l during the ten (10) weeks monitoring period at 7days hydraulic residence time, indicates that constructed wetland may be ecosystem friendly. The widened root zone and vast biofilm surface area of the aquatic plants during the period might have brought about the significant amount of organic pollutants removal. The operation and maintenance costs of the constructed wetland were much lower compared to conventional treatment systems.

Table 1: Inlet and Outlet Concentrations and Removal Efficiencies of the Measured Parameters from Constructed Wetland

Parameters	Hydraulic resident time	Weeks									
		1	2	3	4	5	6	7	8	9	10
pH	Inlet readings	6.8	6.55	6.73	6.52	6.24	6.55	6.61	6.31	6.62	6.72
	Outlet readings	7.4	7.15	7.33	7.12	6.84	7.15	7.21	6.9	7.22	7.3
Temp	Inlet readings (T^0C)	27.82	27.91	27.98	27.86	28.01	27.98	27.96	28.06	28.02	7.99
	Outlet readings (T^0C)	27.89	27.95	28.03	27.93	28.08	28.05	28.04	28.11	28.09	8.08
TSS	Inlet Conc.(mg/l)	165	211	156	182	173	169	178	186.4	164	168
	Outlet Conc.(mg/l)	26.4	27.43	18.72	20.02	18.68	17.75	26.7	26.84	22.8	2.85
	Removal Efficiency (%)	84	87	88	89	89.2	89.5	85	85.6	86.1	6.4
FC	Inlet Conc. $x10^4$ (mg/l)	3.8	3.4	2.9	3.5	3.1	2.8	3.6	2.6	2.61	3.66
	Outlet Conc. $x10^4$ (mg/l)	4.56	3.74	3.19	4.2	3.41	3.02	2.84	1.9	1.8	2.08
	Removal Efficiency (%)	88	87	88	88	89	89.2	92.1	92.7	93.1	94.3
DO	Inlet Conc.(mg/l)	1.8	1.84	1.76	1.78	1.76	1.79	1.78	1.82	1.78	1.76
	Outlet Conc.(mg/l)	2.7	3.15	3.64	4.1	4.26	4.38	4.48	4.6	4.69	4.7
	Removal Efficiency (%)	33.58	41.59	51.65	56.59	58.69	59.13	60.27	60.43	62.05	62.55
BOD_5	Inlet Conc.(mg/l)	156	190	185	276	198	176.5	172.6	176.8	189	210
	Outlet Conc.(mg/l)	34.3	30.4	24.05	30.36	18.61	15.53	14.15	14.14	13.61	14.7
	Removal Efficiency (%)	78	84	87	89	90.6	91.2	91.8	92	92.8	93
COD	Inlet Conc.(mg/l)	410	430	402	595	451	352	389	392	348	418
	Outlet Conc.(mg/l)	131.2	124.7	96 48	136.85	94.71	76.74	83.25	81.93	69.25	81.51
	Removal Efficiency (%)	68	71	76	77	79	78.2	78.6	79.1	80.1	80.5
PO_4-	Inlet Conc.(mg/l)	6.2	6.41	5.98	6.85	5.94	5.97	5.94	6.29	6.15	6.2
	Outlet Conc.(mg/l)	4.05	4.11	3.7	3.97	3.25	2.99	2.77	2.52	2.21	2.02
	Removal Efficiency (%)	34.7	35.86	38.08	42.02	45.3	49.8	53.4	60	64	67.5
NO_3-	Inlet Conc.(mg/l)	8.92	8.47	8.74	7.88	7.25	7.82	8.63	7.28	7.98	8.16
	Outlet Conc.(mg/l)	2.5	2.2	2.10	1.5	1.16	1.14	1.09	0.83	0.86	0.85
	Removal Efficiency (%)	72	74	77	81	84	85.4	87.4	88.6	89.2	89.6
NH_4-	Inlet Conc.(mg/l)	18	16	17.2	16.8	16.1	17	14 .6	16.3	17.3	15.8
	Outlet Conc.(mg/l)	14.97	13.04	13.76	13.3	12.55	12.91	10.89	11.68	12.04	10.6
	Removal Efficiency (%)	16.83	18.48	20.02	20.84	22.08	24.04	25 43	28.37	30.4	32.92

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Assessment of Heavy Metal Concentration in Borehole Water of Sango Ward, Ilorin, Kwara State

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Abstract
Borehole is a major source of potable water for some people in Ilorin to meet domestic water requirement. Water from borehole is usually free from disease–causing microorganisms but chemical contents may above the permissible limits that can cause disease to man. This study was conducted to determine the concentration of heavy metals in the borehole water of Sango Ward in Ilorin East Local Government Area, Ilorin, Kwara State, Nigeria. Water samples were collected from 8 boreholes from different locations in Sango Ward, Ilorin and concentration of heavy metals in the water were determined. All the heavy metals mainly Arsenic, Cadmium, Chromium, Copper, Lead, Manganese, Mercury and Nickel were determined using the Standard Methods for the Examination of Water and Wastewater by American Public Health Association (APHA, 2005). The concentrations of Arsenic, Cadmium, Chromium, Copper, Lead, Manganese, Mercury, Nickel and other chemicals like Calcium, Carbonate, Electrical conductivity, Total alkalinity, Total dissolved solid and pH in the water for 8 locations were respectively varied from 0.01 – 0.08 mg/l, 0.02 – 0. 09 mg/l (6 locations not detected/negligible), 0.01 – 0.04 mg/l (4 locations not detected), 0.02 – 0.03mg/l (6 locations not detected), 0.01 – 0.18 mg/l, 0.1 – 11.6 mg/l, 0.003 – 0.14 mg/l, 0.01 – 0.08 mg/l, 4 – 17 mg/l, 14 – 49 mg/l, 803 – 1319 µmho/cm, 24 – 68 mg/l, 520 – 857 mg/l and 6.9 – 7.9. The results indicated that the concentration of Arsenic, Cadmium, Copper, Lead, Manganese, Mercury and Nickel of the borehole water above the permissible limits of World Health Organisation (WHO) for drinking water in some areas of Sango Ward, Ilorin. Drinking this water over a long period of time in the area where the heavy metals above the permissible limits can cause diseases like cancer, neurological disorder, gastrointestinal disorder and kidney problem to man.

Keywords: Borehole, groundwater, heavy metals, water quality, potable water

Introduction

Water is an essential resource for survival of all living things. Two major sources of water for domestic uses are surface and groundwater water. Groundwater includes borehole, spring water and open well while surface water includes river, stream and lake. Groundwater provides potable water to an estimated 1.5 billion people worldwide daily and a reliable resource for meeting rural water demand in Sub-Saharan Africa (Iyasele and Idiata, 2011). Potable water is a colourless, odourless water that is free from pathogens and the chemical contents are within allowable limits and safe for drinking without causing any disease to man. Borehole water is usually free from pathogen but the quality may be affected by chemicals which can affect the health of man (Yusuf *et al*., 2012). Groundwater quality depends on the quality of recharge water, atmospheric precipitation, in-land surface water and sub-surface geochemical processes (Olatunji, 2015). High concentration of heavy metals in drinking water can causing certain diseases like cancer, neurological disorder and kidney problem to man. Pollution of groundwater has become a major environmental issue, particularly where groundwater represents the main source of drinking water (Kravitz *et al*., 1999 and Maitera *et al*., 2011 and Nwankwoala, *et al*., 2011).

Heavy metals are metallic elements that have relatively high density and are toxic at low concentrations. Heavy metals include Arsenic (As), Chromium (Cr), Cadmium (Cd), copper (Cu), Lead (Pb), Manganese (Mn), Mercury (Hg) and Nickel (Ni). Actually, trace amount of some heavy metals are required by living organisms, any excess amount of these metals can be detrimental to life (Akhilesh *et al*., 2009 and Berti and Jacobs, 1996). The solubility of heavy metals in soils and groundwater are controlled by pH, amount of metal and cation exchange capacity (Martinez and Motto, 2000).The presence of Aluminium, Arsenic, Cadmium, Chromium, Cobalt, Copper, Iron, Lead, Manganese, Nickel and Zinc in high concentrations of groundwater can cause an adverse effect on human health and make that water unsuitable for consumption (SON, 2007). Chromium in water supplies is generally found in the hexavalent form which is highly toxic and in higher concentration to be carcinogenic. High concentrations of nickel (now considered to be a human carcinogen) as both soluble and sparingly soluble compounds may cause changes in muscle, brain, lungs, liver, kidney along with causing cancer (WHO, 2004).

Heavy metals contamination of groundwater is a worldwide environmental problem affecting water resources because of their strong toxicity even at low concentrations (Bernard and Ayeni, 2012 and Fidelis *et al*., 2012). Heavy metals are natural components of the earth's crust, and they can enter the water and food cycles through a variety of chemical and geological processes (Nkansah and Ephraim, 2009 and Obi and George, 2011). Heavy metals are natural components of the environment; they are present in rocks, soil, plants and animals, bond in organic and inorganic molecules or bound to particles in air (Tan and Wong, 2000). Exposure to unsafe levels of heavy metals can cause serious health effects with varying symptoms depending on the nature and quantity of the metal ingested (Adeyemi *et al*., 2007 and Uffia *et al*., 2013). Heavy metal toxicity can result in damaged or reduced mental and central nervous function, lower energy levels, and damage to blood composition, lungs, kidneys, liver, and other vital organs (Jarup,2003). Long-term exposure may result in slow and progressive physical, muscular, and neurological degenerative processes such as muscular dystrophy and multiple sclerosis (Momodu and Anyakora, 2010). Cadmium intoxication can lead to kidney, bone and pulmonary damages (SON, 2007 and WHO, 2011). The maximum permissible limits and health impact of some heavy metals according to Standard Organisation of Nigeria (SON) Act 2007 for drinking water quality was shown in Table 1. Thus, the specific of objectives of this study were to determine the concentration of heavy metals in some selected boreholes in Sango Ward, Ilorin and the suitability of the borehole water for consumption without causing any disease to man.

Table 1: Heavy metals and health impact

Heavy metals	SON Act 2007 Water Standards (mg/l)	Health impact
Arsenic	0.01	Cancer
Cadmium	0.003	Toxic to kidney
Chromium	0.05	Cancer
Copper	1.0	Gastrointestinal disorder
Lead	0.01	Cancer, interference with vitamin D metabolism, affect mental development in infants, toxic to the central and peripheral nervous systems
Manganese	0.2	Neurological disorder
Mercury	0.001	Affects the kidney and central nervous system
Nickel	0.02	Possible carcinogenic

Source: Standard Organisation of Nigeria (SON) for drinking water quality Act, 2007

Materials and Methods

Ilorin lies on the latitude 8º30¹N and longitude 4º35¹E at an elevation of about 340 m above sea level (Ejieji and Adeniran, 2009). Ilorin is in the Southern Guinea Savannah Ecological zone of Nigeria with annual rainfall of about 1300 mm. The wet season begins towards the end of March and ends in October while the dry season starts in November and ends in March (Ogunlela, 2001). The geology of the study area (Sango Ward, Ilorin) is composed of the weathered, partly weathered and fresh crystalline basements rocks. The oldest rocks comprises gneiss complex which is biotite-hornblende gneiss with intercalated amphibolites. This underlies over half of the study area other rocks types are the older granites mainly porphiritic granite, gneiss and granite-gneiss and quartz-schist (Olatunji, 2012). Adekeye (2001) also pointed out that over 80 % of Kwara State in which Ilorin is the state capital is underlain by crystalline precambrian basement rocks while the remaining part is underlain by cretaceous and younger sediments. The rocks of the basement complex include granites, amphibolites, granites gneiss, biotite gneiss, migmatites while the younger sediments comprises the alternating beds of sand stones, shales and clays (Adekeye, 2001). The main river in the study area is Asa river and its tributaries are Oyun and Alalubosa.

The study was conducted between November 2015 and March 2016 during the dry season when the water quality (chemicals) of the borehole is due to inherent geological formation of the area, and minimum contribution from pollution by seepage and percolating (recharging) water is expected. Water samples were collected from 8 boreholes located in different areas (Table 2) in Sango Ward of Ilorin, Ilorin East Local Government Area, Ilorin, Kwara State, Nigeria. The boreholes sampled were at least 300 m away from each other.

Table 2: Selected boreholes in Sango Ward, Ilorin

S/No	Borehole ID No	Location	Type of pump
1	BH 1	Onisana House, Okesuna	Hand
2	BH 2	Kannike/Soro (kannike I), Ojagboro	Hand
3	BH 3	Kannike/Oniyo (Kannike II), Ojagboro	Submersible (motorized)
4	BH 4	Ita Ajia (Ajia House),	Hand
5	BH 5	Sarkin Gambari House. Gambari	Hand
6	BH 6	Oju-koto, Isale koko	Submersible (motorized)
7	BH 7	Alangua Sango House, Ipata	Hand
8	BH 8	Togun House, Dumo	Hand

BH = borehole, ID No = identification number,

Chemical analysis of the water

Water samples were collected in cleaned plastic bottles washed with a detergent, rinsed with tap water, 1:1 nitric acid solution and then rinsed with distilled water (cadmium – free de-mineralized water). Water samples were digested within 6 hours by addition of 5 mL concentrated nitric acid to preserve the water for a longer period against any decomposition by bacteria before chemical analysis of the heavy metals was determined. All the heavy metals mainly Arsenic, Cadmium, Chromium, Copper, Lead, Manganese, Mercury and Nickel were determined using the Standard Methods for the Examination of Water and Wastewater by American Public Health Association (APHA, 2005). The instruments used during the determination of heavy metals and other chemicals analysis were Water Engineering Kit by Hach (DREL/5), multi-parameter bench-photometer by Hanna (HI83200), pH meter and conductivity meter.

Results and Discussion

The results of concentration of some selected heavy metals Arsenic, Cadmium, Chromium, Copper, Lead, Manganese, Mercury and Nickel in the borehole water obtained from 8 locations in Sango Ward, Ilorin were shown in Table 3. The concentration of Arsenic (which can cause cancer to man) in the water in 7 locations (BH 2 to BH 8) varied from 0.02 to 0.08 mg/l and this above the permissible limits of 0.01 mg/l given by World Health Organisation (WHO, 2011) Guidelines for drinking water quality while only BH 1 is within the permissible limits. The concentration of Cadmium in the borehole water in 6 locations were not detected (ND) or negligible, concentration of Cadmium in BH 5 was 0.002 mg/l which was below the permissible limits of WHO (2011) while the value in BH 4 was 0.009 mg/l that above the limits which is toxic to kidney over. The concentrations of Chromium and Copper in the 8 locations were below the permissible limits and some locations, these two heavy metals were not detected. Lead is another heavy metal that cause cancer and affect mental development of a baby, the concentration of Lead (0.20 – 0.18 mg/l) above WHO permissible limits (0.01 mg/l) in 6 locations while only BH 2 and BH 7 were below the permissible limits as shown in Table 3.

The borehole water had high concentration of Manganese (Mn) that can cause neurological disorder to man. The values of Manganese obtained by Okoro *et al*. (2012) for underground water in Ilorin in 8 locations varied from 0.08 to 0.48 mg/l and values of Mn from 0.21–48 mg/l have exceeded the permissible limits of SON (2007) while only 048 mg/l above

WHO (2011) limits. The concentration of Mn in groundwater of University of Ilorin, Ilorin at the main campus by Okoro *et al*. (2014) varied from 0.20 - 0.31 mg/l which above SON (2007) limits. This indicated that groundwater in some parts of Ilorin have high concentration of Mn. This high contents of manganese, Lead and Arsenic might be due to geological composition of the area that actually responsible for the high content of this heavy metal. In 5 locations, the concentrations of Manganese varied from 0.6 – 11.6 mg/l while the values in BH 2, BH 5 and BH 7 were 0.2, 0.4 and 0.7 mg/l, respectively but WHO limits (2011) was 0.4 mg/l. The concentration of Manganese in some selected underground water in Ilorin by Okhoro *et al.* (2012) also varied from 0.08 to 0.48 mg/l which indicated that the underground water of some areas in Ilorin above WHO limits (2011). The concentrations of mercury were also higher in 5 locations while only 3 locations were below the permissible limits given by WHO (2011). Drinking of water with high concentration of Mercury that above the permissible limits over a long period of time can cause kidney problem and this heavy metal can affect central nervous system. The concentrations of Nickel in 7 locations were below the permissible standards which varied from 0.01 – 0.06 mg/l the value was higher in BH 5 (0.8 mg/l) while WHO Standards is 0.07 mg/l. The pH of the borehole waters in all the 8 locations were below the permissible limits (SON, 2007 and WHO, 2011).

The high contents of heavy metals in the groundwater of Sango Ward, Ilorin might be due to the quality of water recharging the groundwater of Sango Ward, Ilorin. Again, the groundwater might be polluted by some heavy metals which might be from leaching of heavy metals from the soils (polluted or contaminated soil) around the study area in which domestic wastewater and refuse are dumped at the bank of Asa river which may infiltrate and recharge the groundwater. Sholadoye and Nwoye (2015) found out that the soil of dumpsites at Sango, Ilorin has high concentration of Cd, Mn and Pb and these were 230.17±0.015, 720.03±0.010 and 40.87±0.21 µg/L respectively which can pollute the groundwater. Other chemical properties of water determined were Calcium, Carbonate, Electrical Conductivity and Total Alkalinity and these were below the permissible limits of WHO (2011) and SON (2007). These chemicals can not cause disease to man. The values of Electrical Conductivity in BH 4 and BH 5 were higher than the permissible limits but cannot affect health of man. Total dissolved solid (TDS) were all higher than the permissible limits by WHO (2011) and SON (2007) in all the 8 locations but TDS has no health implication on man.

From the chemical analysis of the borehole water, BH 1 and BH 2 have better quality than the other borehole water from the 6 locations. Generally, based on WHO (2011) Guidelines for drinking water quality and SON Act (2007) for water drinking quality, all the water from the 8 locations are not suitable for consumption for a long period of time because the water can cause certain diseases to man.

Table 3 Heavy metals in the borehole water from 8 locations in Sango Ward, Ilorin

Parameter	WHO	SON	BH 1	BH 2	BH 3	BH 4	BH 5	BH 6	BH 7	BH 8
Arsenic (mg/l)	0.01	0.01	0.01	0.04	0.08	0.02	0.03	0.05	0.07	0.06
Cadmium (mg/l)	0.003	0.003	ND	ND	ND	0.009	0.002	ND	ND	ND
Chromium (mg/l)	0.05	0.05	0.01	ND	ND	0.03	0.02	ND	ND	0.04
Copper (mg/l)	2.0	1.0	ND	ND	0.03	0.02	ND	ND	ND	ND
Lead (mg/l)	0.01	0.01	0.02	0.01	0.06	0.16	0.18	0.03	0.01	0.09
Manganese (mg/l)	0.4	0.2	0.2	0.6	2.4	11.6	0.4	5.5	0.1	10.9
Mercury (mg/l)	0.006	0.001	0.001	0.003	0.06	0.011	0.003	0.14	0.10	0.016
Nickel (mg/l)	0.07	0.02	0.03	0.01	0.04	0.06	0.08	0.04	0.02	0.05
Calcium (mg/l)	150	200	04	08	06	17	15	12	09	17
Carbonate (mg/l)	200	150	16	14	22	49	42	38	15	40
EC (µS/cm)	1000	1000	824	803	884	1319	1174	974	854	968
Total Alkalinity (mg/l)	200	-	30	24	30	68	58	52	26	56
TDS (mg/l)	500	500	536	520	574	857	763	633	555	629
pH	6.5-8.5	6.5-8.5	7.1	7.2	7.2	7.3	6.9	7.0	7.2	7.9

ND = Not Detected (negligible), WHO = World Health Organisation (2011) Guidelines for drinking water quality and SON = Standard Organisation of Nigeria (2007) Act for Drinking Water quality.

Conclusion

Borehole is a good source of water for domestic uses but the water may have high concentration of heavy metals such as Arsenic, Cadmium, Chromium, Copper, Lead, Manganese, Mercury and Nickel based on the mineral contents of area (geological formation of the area and pollution by the contaminated soil) which may have health implication on man. The concentrations of Arsenic, Cadmium, Chromium, Copper, Lead, Manganese, Mercury, Nickel and pH in the water for 8 locations in Sango Ward, Ilorin were respectively varied from 0.01 – 0.08 mg/l, 0.02 – 0.09 mg/l (6 locations not detected/negligible), 0.01 – 0.04 mg/l (4 locations not detected), 0.02 – 0.03mg/l (6 locations not detected), 0.01 – 0.18 mg/l, 0.1 – 11.6 mg/l, 0.003 – 0.14 mg/l and 6.9 – 7.9. The concentrations of some heavy metals (such as Arsenic, Lead, Manganese Mercury and Nickel) in borehole water sampled in Sango Ward, Ilorin were higher than the permissible limits of WHO (2011) and this can cause certain diseases to man in the community.

Recommendation

Government at Federal, state and local government levels should ensured that necessary water tests are carried out on borehole water to know if the concentration of heavy metals is within the permissible limits by WHO (2011) or SON Act (2007). Water quality tests should be carried out for every month of the year for borehole water in Sango Ward of Ilorin for about three years consecutively to have a real conclusion about the heavy metals composition of the groundwater of Sango Ward, Ilorin. Any borehole that has high concentration of heavy metals should be treated to prevent disease like cancer, neurological disorder and kidney problem otherwise the borehole should not be used for consumption but may be used for other purpose like car wash, washing of cloth and irrigating some crops.

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Quality Assessment of Groundwater in Abuja, Nigeria for Domestic and Irrigation Purposes

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Abstract

Evaluation of the groundwater characteristics in Abuja for household and irrigation purposes was carried out in this study for both rainy and dry seasons for three consecutive years. The groundwater in the region is alkaline with bicarbonate dominating the major ions. The values of electrical conductivity (EC), total dissolved solids (TDS) and total hardness (TH) were higher in wet season than dry season and it can be attributed to rock-water interaction, dilution, dissolution and chemical weathering. The value of SAR ranged between 0.05 to 0.44 with a mean value of 0.22 for the rainy season and 0.07 to 4.20 with an average value of 1.24 for the rainy season. The mean value of SSP, MAR, RSBC, PI and KR are 37. 95%, 32.21%, 0.31meq/l, 119.31% and 1.11 meg/l, respectively for the dry season and 39.49%, 33.46%, 0.06meq/l, 72.67% and 0.62meq/l, respectively for the rainy season. The average concentration of TDS, EC and TH in the dry season are 123.50 mg/l, 191.28 µs/cm and 62.57 mg/l while their corresponding values in the rainy season are 224.33 mg/l, 300.50 µs/cm and 82.32 mg/l. Considering on the outcome of the analyses and interpretation of water quality parameters (WQI, SAR, SSP, MAR, RSBC, PI, KR, TH, TDS and EC), the appropriateness of groundwater in Abuja for irrigation purposes is in the order of good to excellent and poor for domestic use due to high nitrate content, which is due to urban pollution. The plotting of the salinity diagram falls within the low salinity zone, which is an indication of low sodic water and further confirms the appropriateness of the groundwater system for irrigation purposes. The variation in the yearly results obtained during the three consecutive years of this study was insignificant which implies that the groundwater chemistry in the locale is fairly constant, characteristic of slightly contaminated groundwater system. Based on the findings, the groundwater in Abuja is suitable for irrigation purposes and poor for domestic purposes.

Keywords: Quality Assessment, Groundwater, Irrigation Purposes, Domestic Use, Abuja

Introduction

The availability of clean fresh water is one of the greatest challenges facing mankind today as millions of people especially in rural areas still lack access to potable water (Amadi *et al*., 2015). The developmental programmes since the oil boom era in Nigeria and the steadily growing population in the last four decades have put tremendous pressure on the nation's available resources (Adelana and Olasehinde, 2003). In the same vein, the projected water supply to the Federal Capital Territory, Abuja, Nigeria, has become grossly inadequate. Public water supply from Lower Usuma Dam Water Works, with a production capacity of 8000 m^3/hour of treated water and designed to serve a population of 500,000 people about 25 years ago has failed to meet the growing demand for water as a consequence of population increase and urbanization (DanHassan *et al*., 2012; Okunlola *et al*., 2015).

Within the last decade, therefore, there is erstwhile significant rise in groundwater demand and utilization in the Federal Capital Territory, Abuja, Nigeria, especially for institutional, domestic and irrigational purposes. This is further manifest in the peripheral communities where greater part of the population live (Olasehinde and Adelana, 2004). Over the years, there has been an unprecedented influx of people to the Federal Capital Territory for economic reasons and for seeking safe havens, away from the crisis-ridden towns in the neighbouring states. With an unprecedented growth rate of 13% and a population of over 6.7million people living on a territory of about 8,000 square kilometers, Abuja is the fastest growing city in Africa ((Adelana *et al*., 2001; Olasehinde *et al*., 2001).

It is therefore important to explore for groundwater sources to supplement the limited surface water sources to meet the irrigation needs of the populace. Both the quantity and quality aspects are essential for resource evaluation. Consequently to meet the increasing demand for water for irrigational, domestic and industrial purposes, there has been heavy dependence on groundwater especially in the rural communities where groundwater seems to be the only option for the provision of potable water. The weathered/fractured basement and sandstone formation in the study area form significant aquifer systems supporting the provision of drinking water to the populace and small-scale industries.

Natural water either surface or ground sources, contains dissolved solids and gases as well as suspended matter. The quantity and quality of these constituents depend on geologic and ecological factors, and they are endlessly varying as a consequence of the action of water with the contact media and activities of man (Amadi *et al.,* 2014). The present study aims at looking into the synergy between quality and quantity of available groundwater in the study area for irrigation purposes in order to meet their food demand. The protracted utilization of certain water for irrigation purposes accounted for the reduced harvests resulting from the worsening in the soil physical properties. The unfavorable effects of irrigation water quality on soil physical properties is related to the buildup of sodium ion on the soil exchange complex, which imparts unsteadiness to the soil aggregates and whose interruption followed by spreading of clay particles results in blockage of soil pores. The water quality utilized for irrigation is consequently indispensable for the yield and quantity of crops, preservation of soil productivity and protection of the environment. Simultaneously, the quality of irrigation water is vastly influenced by the land constituents of the water source.

According to Nag and Shreya (2014), several chemical constituents influence the appropriateness of water for irrigation and the factors include:

1. The total concentration of soluble salts (which is largely interrelated to the definite conductance of water)
2. The relative quantity of sodium to calcium and magnesium
3. The concentration of boron
4. The virtual amount of bicarbonate to calcium and magnesium

The study, therefore, evaluates the suitability of groundwater from shallow aquifers in Abuja for domestic and irrigation purposes. It is believed that the baseline information provided in the study will help in solving the problem of acute food and water shortage in the Federal Capital Territory, Abuja.

Materials and Methods

Description of the study area

In 1978, Abuja, the Nigerian Federal Capital Territory was created, following the resolution to move the nation's capital away from Lagos in the southern coastal area to a more central place inside Nigeria, devoid of domination by any of the major ethnic groups. The factors considered for the location of the "new" capital were justified by the Federal Government in Decree No. 6 of 1976. It lies approximately between longitudes $6^0$46' and $7^0$37'E and latitudes $8^0$21' and $9^0$18'N (Figure 1). The study area covers an area of about 5,000 km^2 of the 8000 km^2 of the territory. The Federal Capital Territory is bordered by Kaduna State to the north, Kogi State to the south, Niger State to the west and Nasarawa State to the east.

Relief and Drainage

The topography of the FCT is diverse with the lowest elevations in the Territory within the farthest south-west at the floodplains of the River Gurara (76 m above sea level). From here, the land rises unevenly northwards, eastwards and northwestwards. The peak part of the territory is found in the northeast where there are many peaks above 760 metres beyond sea level. Hills crop up as clusters and long ranges all over the Territory.

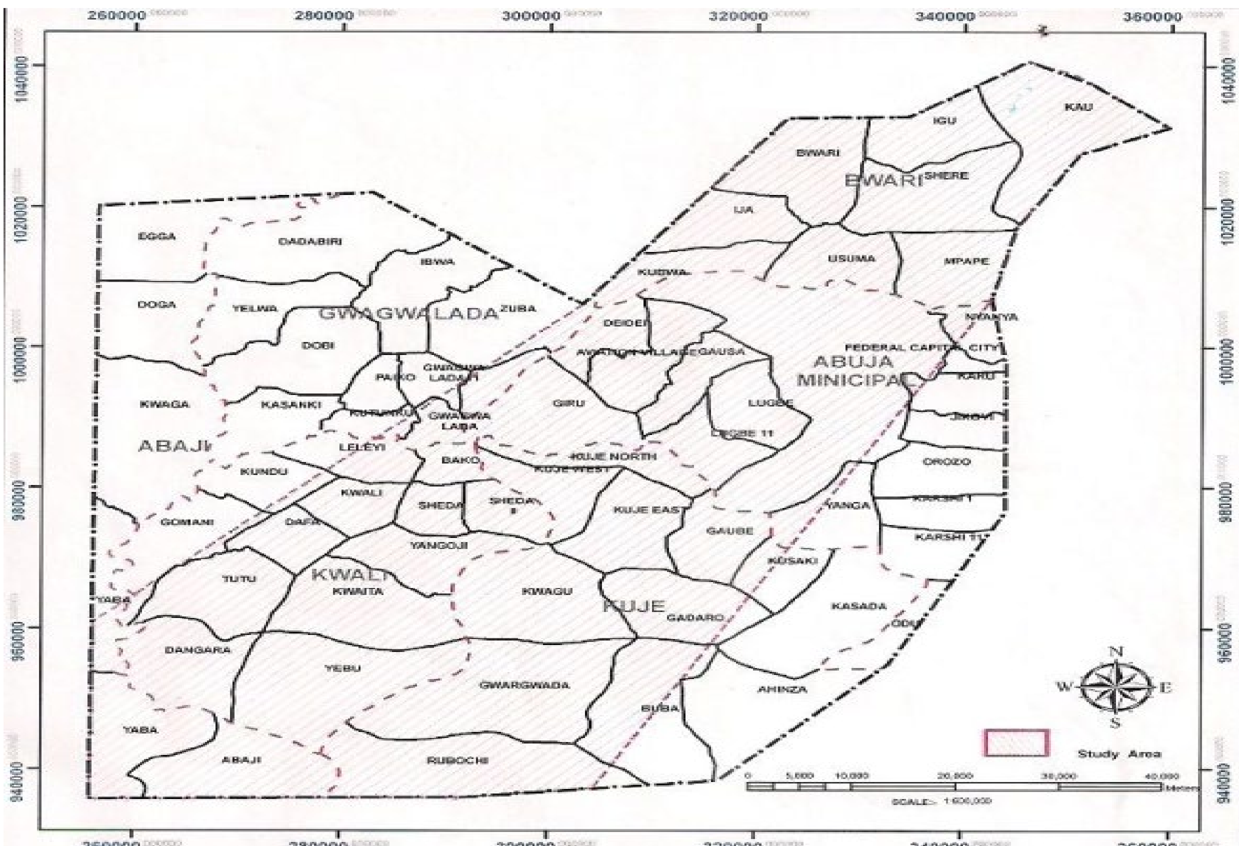

Fig. 1: Map of Abuja, Nigerian’s Federal Capital

The most well-known of these comprise the Gawu range in the northwest, the Bwari-Aso range in the northeast, Idon Kasa to the northwest of Kuje, Wuna range in the north of Gwagwalada and the Wasa-Sukuku range running across the centre of the Territory from Wasa in the east to Kwali in the west. The topography of Abuja is diverse with the lowest elevations in the farthest southwest with numerous hills occurring in the northeastern portion.

The rivers take their cause from the hills in the northeast and flows to the southwestern. The two main rivers are the River Gurara and River Usman, which come together at Nyimbo village to form an offshoot of River Niger in the south.

Geology of the Study Area

Abuja is underlain by Precambrian rocks belonging to the Nigerian Basement Complex, which envelop about 85% of the surface of the land while the remaining 15% are covered by Cretaceous rocks of sedimentary origin from the Bida Basin (Figure 2).

The main lithologic units associated are:

(a) The Older granites
(b) The Metasediments (schist, phyllite and quartzite)
(c) The Migmatite-Gneiss Complex
(d) The Nupe Sandstones of the Bida Basin

The Older Granites are understood to be pre-, syn- and post tectonic rocks, which intrude and intersect equally the migmatite-gneiss-quartzite complex and the schist belts (Rahaman, 1988; Obaje, 2009). They have a broad variety in both age (750 – 450 Ma) and composition and exhibit diverse and longer magmatic cycles related to the Pan African orogeny (Mc Donald, 2008). The Older granites consist of Biotite Granite (coarse porphyritic), large intrusive masses generally oblique in nature forming dissected zones of the Zuma/Bwari – Aso hills and outcrops of the Gwagwa Plains, Biotite Granite (fine to medium grained) forms ridge row trending northeast – southwaest throughout the territory; Ryolite, forming small round intrusives bounded by porphyritic gneiss in the Usuma Valley in the northeastern part of the study area.

Sampling

A total of 65 groundwater samples were collected from boreholes and hand-dug wells yearly, covering two seasons: dry and rainy seasons, for three consecutive years, from October, 2011 to September, 2014. The sampling was carried out for the same site. The container was entirely filled with water taking care that no air bubble was trapped inside the water sample. The bottles were sealed with double plastic caps in order to prevent evaporation and instantly conveyed to the laboratory for the relevant physico-chemical analyses.

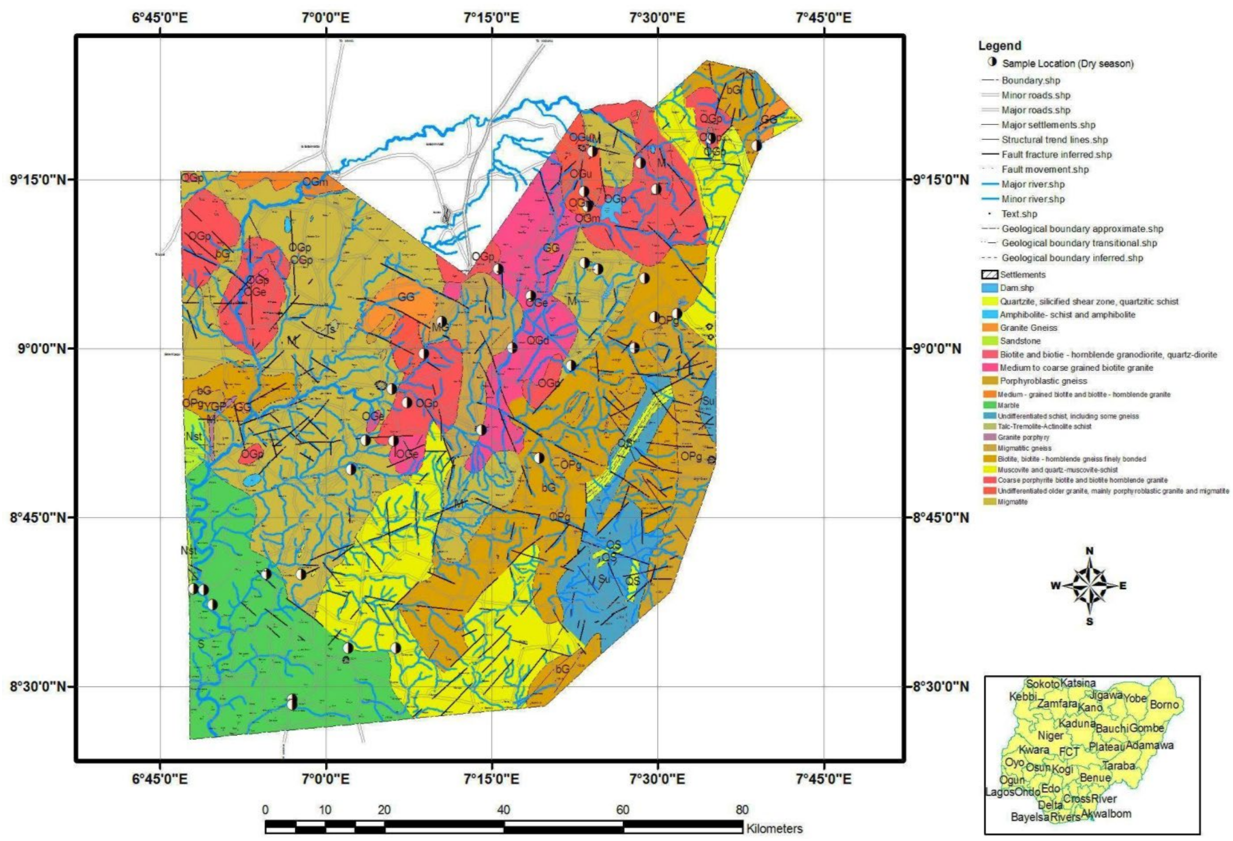

Fig. 2: Geological map of Abuja showing sample locations

Laboratory Analysis

The groundwater samples were analyzed in the laboratory for major ionic concentrations using standard methods (APHA, 2008). Calcium and magnesium were determined titrimetrically using standard EDTA, chloride by normal $AgNO_3$ titration, bicarbonate by titration with HCl, sodium and potassium by flame photometry. The pH, total dissolved solids and electrical conductivity were determined in the field using pHTestr 2, ECTestr+ by Eutech Instruments and DIST 3 by Hanna Instruments respectively. The sulphate and phosphate were determined by Spectrophotometer CL 22D.

Data Treatment and Classification Model

The essential parameters affecting the aptness of water for irrigation purposes are as follows: electrical conductivity (EC), soluble sodium percentage (SSP), total dissolved solids (TDS), magnesium adsorption ratio (MAR), sodium adsorption ratio (SAR), permeability index (PI), residual sodium bicarbonate (RSBC) and Kelly's ratio (KR). The results of the analyses were further explained using graphical representations like United States Salinity Hazard Chart and the Doneen plots.

Results and Discussion

Electrical Conductivity (EC)

The mainly significant water quality guideline on crop yield is the water salinity vulnerability as determined by electrical conductivity (EC). The principal outcome of water with high EC on crop productivity is the failure of the plant to vie with ions in the soil solution for water (physiological drought). The higher the EC, the less water is obtainable to plants nonetheless the soil may look as if wet. In view of the fact that plants can merely transpire water (pure water), utilizable plant water in the soil solution reduces dramatically as EC increases (Amadi *et al.,* 2013).

On the basis of electrical conductivity, irrigation indices categorization is given in Table 3. For the water samples taken in the dry and rainy seasons, the electrical conductivity values vary from 10 µs/cm – 800 µs/cm and 10 µs/cm – 1420 µs/cm respectively (Tables 1 and 2). They fall within the irrigation water categories as excellent category (47.5%), good category (50%) and fair category (2.5%) for dry season samples while rainy season samples are classified as excellent category (35%), good category (40%) and fair category (25%) as shown Table 3; Figures 3, 4, 5 and 6.

Soluble Sodium Percentage (SSP)

Sodium percent is an essential aspect for investigating sodium hazard. It is as well used for adjudging the quality of water for agricultural objectives. High percent sodium water for irrigation purposes may stunt plant growth and reduces soil permeability (Joshi *et al*, 2009). The soluble sodium percent values for the dry season sampling campaign range from 9.99% – 59.06% (average 37.95%) while for the rainy season sampling period the sodium percent vary between 17.2% and 67.90% (average 39.48%). This indicates low alkali hazards and reasonable to excellent irrigation quality (Wilcox, 1950).

Total Dissolved Solids (TDS)

Salts of calcium, magnesium, sodium and potassium existing in the irrigation water may be injurious to plants. When present in severe quantities, they diminish the osmotic actions of the plants and could avert sufficient aeration. The TDS values vary from 10 – 520 mg/l (average 123.5 mg/l) and 10 – 923 mg/l (average 224 mg/l), for both the dry season and rainy season sampling periods respectively. The water can be categorized as exceptional irrigation water according to the determined values in Tables 1 and 2.

Sodium Adsorption Ratio (SAR)

The Sodium adsorption ratio provides a comprehensible indication about the adsorption of sodium by soil. It is the quantity of sodium to magnesium and calcium which have an effect on the availability of the water to the plants. The sodium adsorption ratio of water samples from the dry and rainy season samples ranged from 0.05 – 0.44 (average 0.22) and 0.07 – 4.20 (average 1.23) respectively (Tables 1 and 2). The samples drop under the group of C1-S1 and C1-S2, signifying little alkali hazards and superb irrigation water (Figures 3, 4, 5 and 6), except one sample in the dry season and two samples in the rainy season that showed high salinity hazard. The observed wide range and high deviation as contained in Tables 1 and 2 is an indication that the groundwater quality in the area is skewed by many factors. The TDS, EC and TH display reasonable variation which suggests that the contaminants are from different sources.

Table 1: Statistical summary of concentration of different indices for rating water for irrigation Purposes (Dry Season)

Parameters	Minimum	Maximum	Mean	Stand. Deviation
SAR	0.054	0.437	0.222	0.104
SSP (%)	9.990	59.058	37.947	9.994
RSBC (meq/l)	-1.569	1.142	0.313	0.557
PI (%)	44.525	371.411	119.310	59.831
TH (mg/l)	2.583	253.167	62.567	57.111
MAR (%)	6.722	60.161	32.210	12.175
KR (meq/l)	0.327	2.359	1.106	0.418
TDS (mg/l)	10.000	520.000	123.500	117.440
EC (μS/cm)	10.000	800.000	191.280	0.182

Table 2: Statistical summary of concentration of different indices for rating water for irrigation Purposes (Rainy Season)

Parameters	Minimum	Maximum	Mean	Stand. Deviation
SAR	0.070	4.201	1.238	1.128
SSP (%)	17.219	67.900	39.485	15.368
RSBC (meq/l)	-2.034	1.136	0.058	0.728
PI (%)	14.717	208.847	72.674	58.428
TH (mg/l)	4.250	439.583	82.320	101.029
MAR (%)	9.708	49.918	33.462	11.518
KR (meq/l)	0.095	1.795	0.616	0.478
TDS (mg/l)	6.500	923.000	224.325	39.706
EC (µS/cm)	10.000	1420.000	300.500	351.395

Table 3: Categorization and Suitability of water for Irrigation

Category	EC (µS/m)	RSBC (meq/l)	SAR	SSP (%)	Suitability for irrigation
I	< 117.5	<1.25	<10	<20	Excellent
II	117.5 – 503.61	1.25 – 2.5	10 – 18	20 – 40	Good
III	>503.61	>2.5	18 – 26	40 – 80	Fair
IV	Nil	Nil	>26	>80	Poor

Source: Ayers and Wescot, 1985; Wilcox, 1950

Table 4: Classification of water for irrigation based on TDS

Classification	Total Dissolved Solids (mg/l)	Remark
Non-saline	< 1000	All the Samples
Slightly saline	1000 – 3000	None
Moderately saline	3000 – 10,000	None
Very saline	>10,000	None

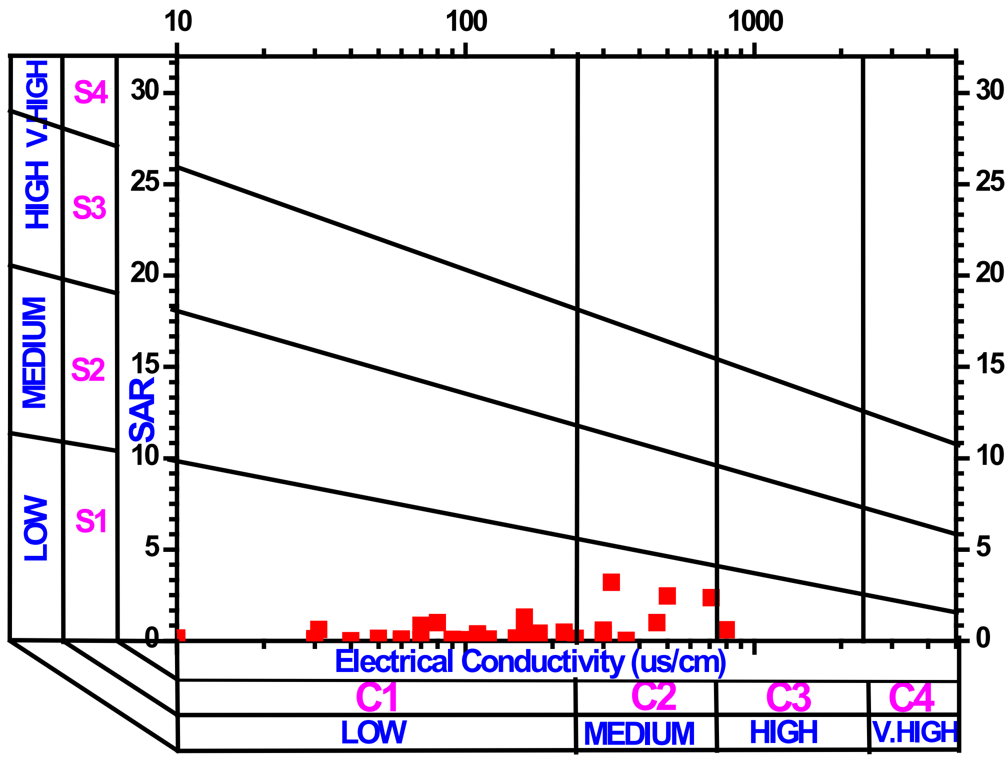

Fig. 3: Salinity hazard diagram for dry season

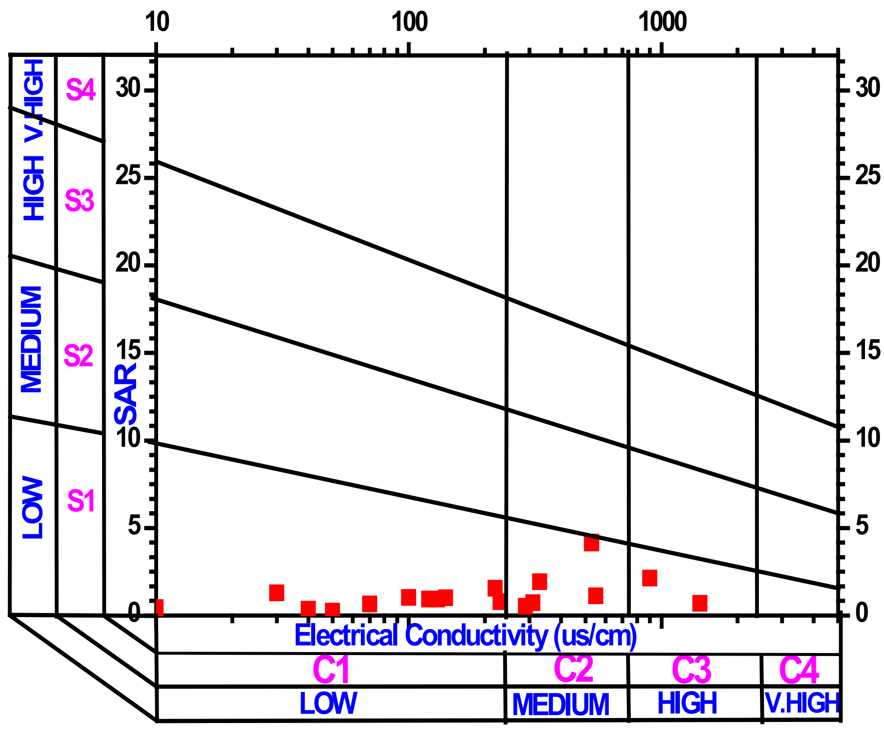

Fig. 4: Salinity hazard diagram for rainy season

From the salinity hazard diagram: S1, S2, S3 and S4 represent low, medium, high and very high sodium (alkali) hazard while C1, C2, C3 and C4 implies low, medium, high and very high salinity hazard. The logical data delineated on the EC versus SAR exemplify that most of the groundwater samples fall mainly in the field of C1-S1 and C2-S1 (Figure 3) for the dry season sampling, indicating low to medium salinity and low sodium water, which may be utilized for irrigation on nearly all kinds of soil with no risk of moveable sodium (Karanth, 1989). Similar trend was observed in figure 4 (rainy season sampling) except a few samples, about 10.5% of the total samples analyzed falls in the C3 field, which implies that the groundwater in these locations can be utilized for irrigation on virtually all kinds of soil with lesser risk of exchangeable sodium (Okiongbo and Dauglas, 2013). None of the samples fall in the area of uncertain (C4-S3) and unsuitable (C4-S4) region for irrigation.

Magnesium Adsorption Ratio

Magnesium concentration in water is regarded as one of the most significant qualitative condition in determining the quality of water for irrigation. In general, calcium and magnesium retain a state of steadiness in nearly all waters. Additional magnesium in water will unfavorably have an effect on crop produced as the soils happen to be more saline (Joshi *et al*., 2009). The magnesium adsorption ratio calculated for water samples collected in the dry season were within the range of 6.72 % to 60.16 % (average 32.21 %) while the values for water samples collected in the rainy season vary between 9.71 % and 49.91 % (average 33.46 %), with only 3 (average 7.5 %) of the dry season samples having values beyond the conventional limit of 50% (Ayers and Westcot, 1985). The high magnesium adsorption ratio triggers damaging effects to soil when the value is higher than the permissible limit of 50%.

Residual Sodium Bicarbonate (RSBC)

The concentration of bicarbonate and carbonate affects the appropriateness of water for the purpose of irrigation. The water with high RSBC has high pH. Hence, land irrigated with such water happens to be unproductive owing to deposition of sodium carbonate (Eaton, 1950). The remaining sodium carbonate values for water samples collected in the dry and rainy seasons range from -1.57 – 1.14 meq/l (average 0.31 meq/l) and -2.03 – 1.14 meq/l (average 0.058 meq/l) respectively (Tables 1 and 2). The remaining sodium bicarbonate usefulness are less than 2.5meq/l and the water is adjudged safe for irrigation purposes (Figs 5 and 6).

Permeability Index (PI)

The soil permeability is influenced by the long-standing use of irrigated water and the influencing components are the total dissolved solids, sodium bicarbonate and the soil type. For water samples collected in the dry and rainy seasons, the permeability index values range from 44.53 – 371.41% (average 119.31%) and 14.72 – 208.84% (average 72.67%) respectively as contained in Tables 1 and 2. The results therefore indicate that most of the water samples fall in the region of Class I and Class II, and can be classified as good irrigation water (Doneen, 1964)

Kelly's Ratio (KR)

The Kelly's Ratio (KR) values of water samples for the dry season sampling campaign vary between 0.33 and 2.36% (average 1.12%) while those for the rainy season period range from 0.095 - 1.79% (average 0.61%) and shown in Tables 1 and 2 respectively. A quarter of the samples collected in the dry season have KR values above but close to the permissible limit while two samples (Gaduwa and Rubochi) collected in the rainy season have KR values above but close to the permissible limit. Most of the groundwater samples fall in the region of the tolerable limit of 1.0% and are therefore deemed appropriate for irrigation purposes (Table 3). The chemical wear down of rock-forming minerals is the major determinant in the development of chemical constituent of groundwater in the study area.

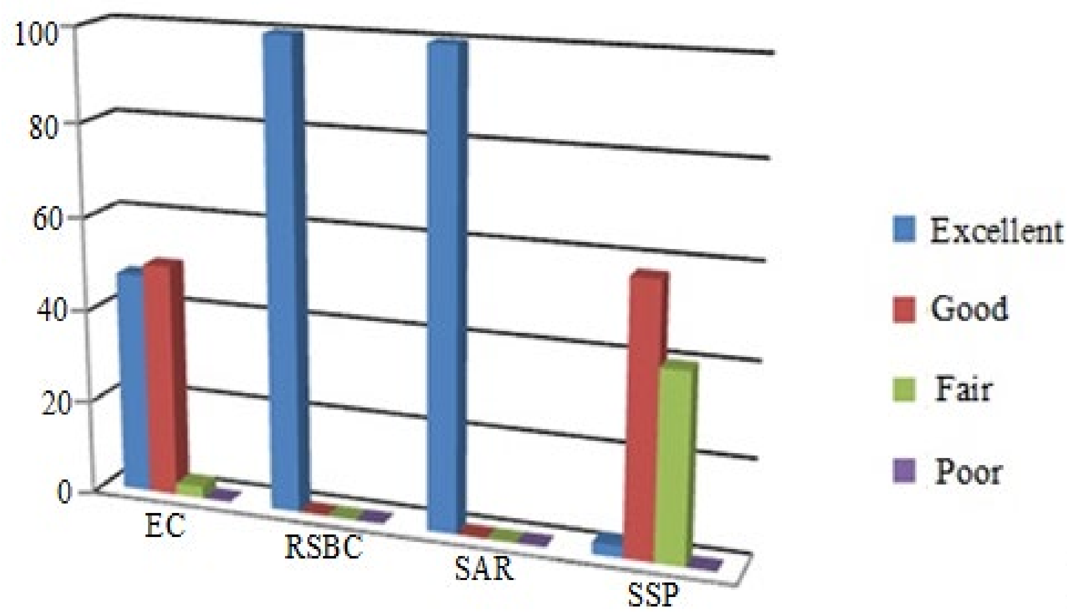

Fig. 5: Irrigation Index Rating for Dry Season

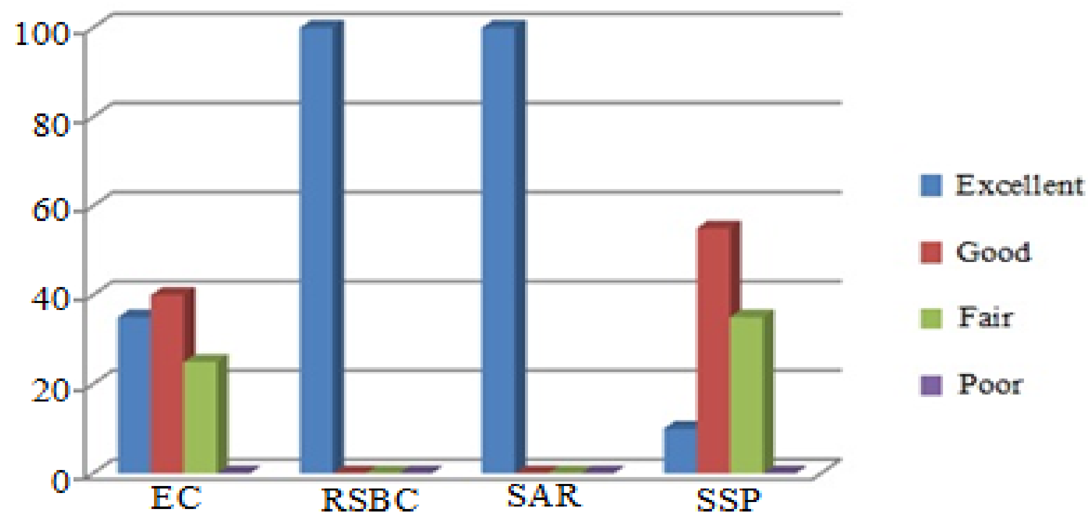

Fig. 6: irrigation Rating for rainy season

Nitrate

The concentrations of the major ions were detected to be lower than their respective maximum permissible limits put forward by World Health Organization and Nigerian Standard for Drinking Water Quality except nitrate whose concentration in some locations exceeds the recommended 50 mg/l. High nitrate content in water for domestic uses causes infant methaemoglobinaemia , also known as blue-baby syndrome, in addition to gastric cancer, metabolic malady and livestock poisoning. The high nitrate content in the shallow groundwater from the area may be credited to the intense metropolitan overflow and high speed of permeation of leachate through the overburden into the perched superficial aquifers in the area that are recorded for the period of the rainy season. The average concentration of total dissolved solids (TDS) and electrical conductivity (EC) were also higher in rainy season equated to the dry season as experienced previously, which is also credited to metropolitan overflow and or dissolution of rock layer in the course of groundwater movement.

Conclusion

The quality of groundwater from Abuja has been assessed for irrigational purposes in this study. The facies analyses indicate that the groundwater in the area is of alkaline (bicarbonate-type). The electrical conductivity values and the total dissolved solids values of the groundwater samples were within the acceptable limit during the dry season sampling but with higher values during the rainy season sampling. This can be attributed to rock-water interaction resulting in chemical weathering and dissolution, triggered by rain-water, as more ions were dissolved in the course of infiltration and groundwater movement thereby enriching the groundwater composition. On the basis of the quality parameters examined such as SAR, SSP, MAR, RSBC, PI and KR, the appropriateness of groundwater samples for irrigation is in the ratio of good to excellent (93%) and poor to fair (7%). About 93% of the plotting in the salinity charts falls within the low salinity zone, indicating low sodic water and thus suitable for irrigation purposes, with a very few isolated exceptions (7%). The yearly variation in the results obtained during the three years of investigation was insignificant. This is an indication that the chemistry of the groundwater system in the area is almost constant and the implication is that the groundwater it is free from urban pollution and suitable for irrigation purposes as at the time of the present study.

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Application of Geosciences Techniques for the Assessment of Dumpsite Leachates and Groundwater Pollution in Regolith Aquifers

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Abstract

Groundwater in regolith aquifer around Awan-Nepa dumpsite in Keffi (north-central Nigeria) was assessed for contamination attributable to heavy metal leachates. The assessment was conducted by mapping elevation of static water table, geo-elecrtic sounding, determining concentrations of heavy metal ions in filtrate created using the dumpsite soil colloid, and in water samples obtained from twenty wells dug manually into the regolith within the dumpsite vicinity. Contamination extent was evaluated using contamination factor (CF), index of pollution load (PLI), index of metal pollution (MPI), and index of geo-accumulation (I_{geo}). Groundwater convergence zones were revealed at 2.5 Km SW and 4 Km NW of the dumpsite. Topsoil at the dumpsite was found to be thin (0.8-1 m) and characterised with moderate resistivity (140-240 Ωm) and transverse unit resistance (120-150 Ωm^2). These values indicate high permeability and hydraulic conductivity within the topsoil. Low resistivity (35-45 Ωm) characterised the regolith at the dumpsite, indicating the presence of a contaminant plume. Surface runoff from rainfall dissolved some metal components of the dumpsite waste. Part of the dissolved metals infiltrated the regolith, and built up a contaminant plume. Concentrations of arsenic, chromium, manganese, nickel and lead is higher than 0.7 mg/l in water samples obtained from the regolith wells. This concentration value exceeds World Health Organisation prescribed limit for potable water. Values of CF indicate moderate level contamination from arsenic and moderate to very high contamination level from cadmium and copper at the dumpsite. Less than 0.024 PLI value reveals that the area is free from heavy metals aggregate effects. Approximately 0.6 MPI value shows the dumpsite's vicinity is free from anthropogenic pollution attributable to heavy metals, in spite of some contamination at the dumpsite. The spatial concentration maps reveal a contamination plume at the dumpsite, and a gradual attenuation in contamination level outward from the dumpsite. The maps also show that the concentration of barium, chromium, arsenic and lead within the convergence is lower than 5% of the concentration in

filtrate from the dumpsite's soil colloid. Water in the groundwater convergence zones is fit for drinking.
Keywords: Regolith aquifer, permeability, Hydraulic conductivity, Dumpsite, Groundwater covergence

Introduction

Common diseases within the environs of such dumpsites include hypertension, skin cancer, kidney failure, liver dysfunction, osteomalacia, osteoporosis, deafness and neurological diseases. Such diseases have been associated with ingestion of heavy metals (Deming, 2002; Adegoke *et al.*, 2009; Ayolabi *et al.,* 2013; Singh *et al.,* 2015). It is this association that necessitates the assessment of groundwater contamination that is connected with heavy metals leached into the regolith aquifer in the environs of Agwa-Nepa dumpsite. Low electrical resistivity values generated from geo-electrical sounding are traditionally employed to identify areas with unusually high amount of ions related to groundwater contaminant plumes (MacFarlane *et al.,* 1983; Becker, 2002; Rosquit *et al.,* 2003; Jegede *et al.,* 2011; Carpenter and Reddy, 2011; Omolayo and Tope, 2014).The issue with the approach is that highly clayey interval within the regolith could simulate similar low resistivity values and misguide interpretation. Pollution status is also sometimes qualitatively categorised using concentration of ions obtained from chemical analysis of samples of groundwater (Adegoke *et al.*2009; Alile *et al.*, 2013; Ayolabi *et al.*, 2013; Omolayo *et al.*, 2014). Such qualitative categories could be subjective, blurred and do fail to quantitatively specify contamination extent. Besides this, few published works exist on the use of numerical indices developed from geo-electric resistivity measurements to ascertain transportation direction of contaminant ions from dumpsites into groundwater contained in regolith. This work deploys numerical indices such as CF, PLI, MPI, and I_{geo} to evaluate ionic concentrations of heavy metals determined in groundwater by Inductively Coupled Plasma- Mass Spectrometry (ICP-MS) method of chemical analysis. Furthermore, the work strives to infer migration direction of contaminant ions from dumpsite leachate into groundwater from hydraulic conductivity criteria developed from geo-electrical resistivity data.

Methodology

Agwan-Nepa dumpsite is located in Keffi, north-central Nigeria, within Latitudes 8°49′00″N, 8° 53′00″N and Longitudes 7° 51′ 00″ E, 7° 55′00″E (Fig.1). The dumpsite is massive and many inhabitants within its environs drink water fetched from hand-dug wells tapping its regolith aquifer.

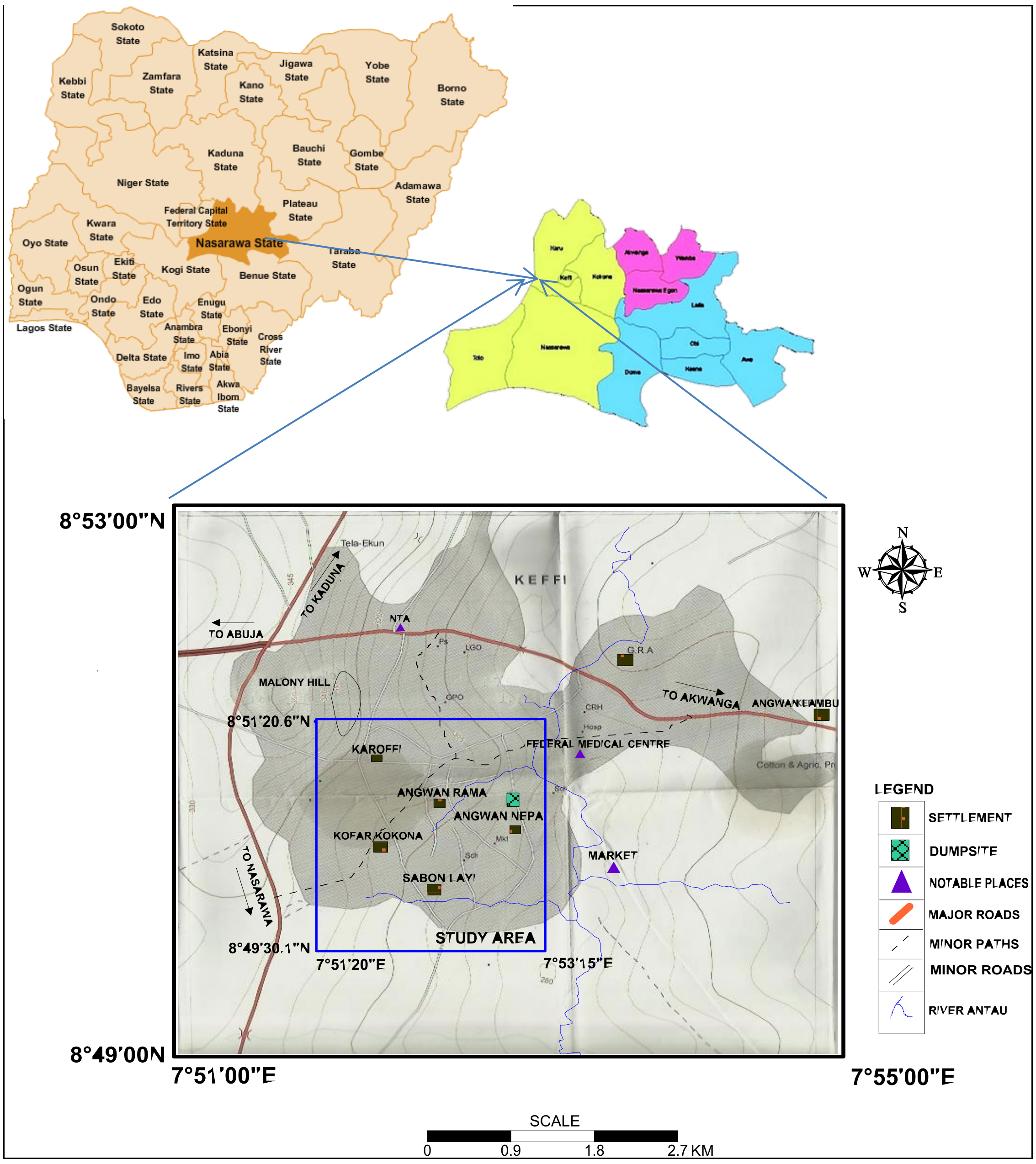

Fig.1: Location map of Agwan-Nepa dumpsite

Detailed lithological mapping of the area was carried out. Static water table elevation was determined by subtracting depth to static water table from the elevation of the top of each well's concrete protection, obtained using a Geographic Positioning System(GPS) device. Soil sample was taken from depth of 0.8m at the dumpsite because exposed geological sections in the area revealed that the soil thickness is generally less than 1.0m. The sample was soaked in a clean plastic bottle containing one litre of distilled water and the resulting colloid was shaken vigorously and left to settle for one week. This was then filtered and the filtrate labelled L0. Water table elevation map was generated with Suffer 11 contouring software. Samples of groundwater were taken from twenty wells dug manually into the regolith (locally called hand-dug wells). These samples were labelled L1-L20. Ionic concentrations of heavy metals comprising arsenic (As), barium (Ba), cadmium (Cd), chromium (Cr), copper (Cu), iron (Fe), manganese (Mn), nickel (Ni), and zinc (Zn) were determined in the twenty groundwater samples (L1 to L20) and filtrate (L0) using ICP-MS method, at Acme Laboratory in Vancouver BC, Canada. The laboratory was chosen for the analysis because it employs state-of-the-art equipment and software for generating chemical data with accuracy level required for making inferences concerning human health. Maps illustrating the spatial variations of each heavy metal's concentration were produced using Suffer 11. The method of Tijani *et al.*(2004), Sarala *et al.*(2013), Singh *et al.*(2013), and Onwuka *et al.* (2014) was used to calculate CF:

$$\mathrm{CF} = \frac{\mathrm{C_s}}{\mathrm{B_n}} \qquad (1)$$

In Equation 1, C_s represents the measured concentration of each heavy metal in a sample, and B_n is the average crustal abundance of the corresponding metal (obtained from Mason, 1966). Calculation of PLI was carried out using the method of Sarala and Uma (2013), and Onwuka *et al*. (2014) :

$$\mathrm{PLI} = (\mathrm{CF_1} \times \mathrm{CF_2} \times \mathrm{CF_3} \times \mathrm{CF_4} \times \ldots\ldots \mathrm{CF_{n-1}} \times \mathrm{CF_n})^{\frac{1}{n}} \qquad (2)$$

In Equation 2, CF_i represents each heavy metal's Contamination Factor in a sample while 'n' represents the whole number of heavy metals utilised in the computation for each sample.

Sarala and Uma (2013) method was employed to calculate MPI:

$$\mathrm{MPI} = \mathrm{Log}\sum_{n=1}^{10}\left(\frac{\mathrm{X}}{\mathrm{B_n}}\right) \qquad (3)$$

'X' in Equation 3 represents average concentration value for each metal in all regolith groundwater sample and B_n represents a standardiser, which is of each corresponding metal's average crustal concentration.

Calculated of I_{geo} was made with the method of Sarala *et al.* (2013) and Onwuka *et al.* (2014):

$$I_{geo} = \log_2 \frac{C_n}{1.5B_n} \quad (4)$$

where the concentration of each metal in a sample is represented by C_n while the mean crustal abundance for the corresponding metal is represented by B_n (obtained from Manson, 1966). Table 1 was employed in categorising the groundwater contamination status: after Hakanson, (1980); Sarala *et al.* (2013) and Singh *et al.* (2014) .

Table 1: Contamination factor (Cf) and Geoaccumulation Index (Igeo) categorisation

CF/Igeo	Category
<1	Neglible contamination factor
1-3	Mild contamination factor
3-6	Substantial contamination factor
>6	Very high contamination factor

Contamination is implied when PLI or MPI or Igeo is greater than 1, while values lower than 1 indicates a clean status (Sarala *et al.*, 2013). Vertical Electrical Sounding (VES) was carried out at twenty locations, using the Schlumberger field geometry in which maximum electrode spacing (AB) was 100m. Such electrode spacing guarantees that the electrical current generated from an external source (a battery) would investigate the entire regolith interval. Values of apparent resistivity (ρ_a) were calculated using Unuevho *et al. (*2012)

$$\rho_a = \left(\frac{(AB)^2-(MN)^2}{MN}\right)\frac{\pi}{4}\frac{\Delta V}{I} \quad (5)$$

where 'AB' and 'MN' are respectively current electrodes spacing and potential electrodes spacing, ΔV is the potential difference between the potential electrodes and I is the current passing between the current electrodes. Win Resist interpretation software was used to generate geoelectric sections from the apparent resistivity data.

Longitudinal unit conductance (S) and transverse unit resistance (T) values were obtained for topsoil and weathered basement intervals, using the methods of Mailet (1974):

$$S = \sum_{i-n}^{n} \frac{hi}{\rho i} \quad (6)$$

$$T = \sum_{i-n}^{n} hi\rho i \quad (7)$$

The thickness and true resistivity value of each unit in a geoelectric section are represented respectively by h_i and ρ_i in Equations 6 and 7. Maps representing areal values of S, T and true resistivity ρ were created using Surfer 11 contouring software. Elevation data on static water table was integrated with ionic concentration data for heavy metals, as well as S, T and resistivity data. The integrated data was used to validate the presence of leachate contaminant plume at the dumpsite, to decipher the plume movement direction, as well as to ascertain the status of contamination of groundwater within the regolith.

Results and Discussion

Flow pattern and its implication

Static water table elevation map (Fig. 2) revealed a groundwater divide that trends NNW-SSE. The divide terminates about 0.7Km SE of Karoffi. The groundwater flow direction is NNE and SSW northwards and southwards of the divide respectively. The position of the dumpsite on the SE of the divide, and the opposing groundwater flow directions on either side of the divide creates a geomorphologic setting that protects groundwater on the north of the divide from the dumpsite leachates. Converging groundwater flow system at 2.5 Km SW of the dumpsite suggests that distant areas beyond the convergence zone are free from influence of the dumpsite leachate. Another groundwater convergence zone exists at about 1 Km SW of Karoffi, which is about 4 Km NW of the dumpsite. This indicates that groundwater flow system from the dumpsite does not extend beyond 4Km NW of the dumpsite. The rapid change in static water table elevation, east of Sabon Layi (around L13) and around south of Karoffi (around L16) implies poor hydraulic conductivity, low permeability and transmissivity of regolith (combined topsoil and weathered layers) in these places. Apart from the vicinities of L13 and L6, static water table elevation changes slowly.

The resistivity sounding data revealed that H-type geo-electrical resistivity curve dominantly characterise the study area (Fig. 3). This indicates three geo-electric layers: top soil, weathered basement and fresh basement. The top soil is very thin (0.8-1 m) at the dumpsite and its immediate vicinity (Fig. 4). The weathered basement is slightly thin (4.5-6.5 m) around the dumpsite (Fig. 5). Moderate resistivity values (140-240Ωm) and transverse unit resistance (T) values (120-150 Ωm^2) indicate high permeability and hydraulic conductivity within the top soil at the dumpsite (Figs. 6 and 7 respectively). Figure 8 reveals that the weathered basement's T value is moderate to high (150-350 Ωm^2) within the dumpsite vicinity. The T value is very high (750-1250 Ωm^2) in the southern areas and high in the central portions (350-550 Ωm^2). The weathered basement's S value (Fig. 9) is low (0.06-

0.19 Ω) at the dumpsite, and moderate (0.19-0.29 Ω) in the central portion and the on the SW of the dumpsite.

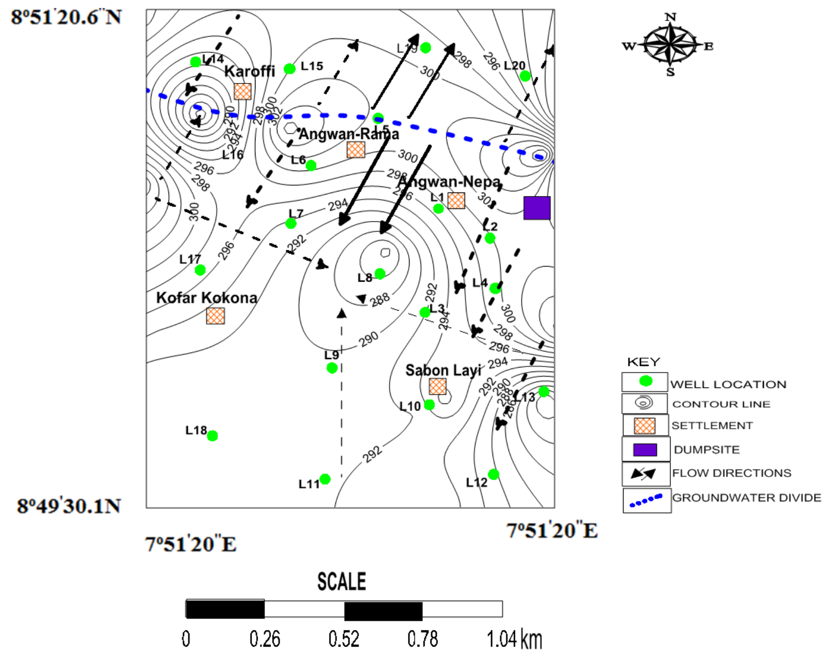

Fig. 2: Static water table elevation Contour map of Angwan-Nepa dumpsite and its environs

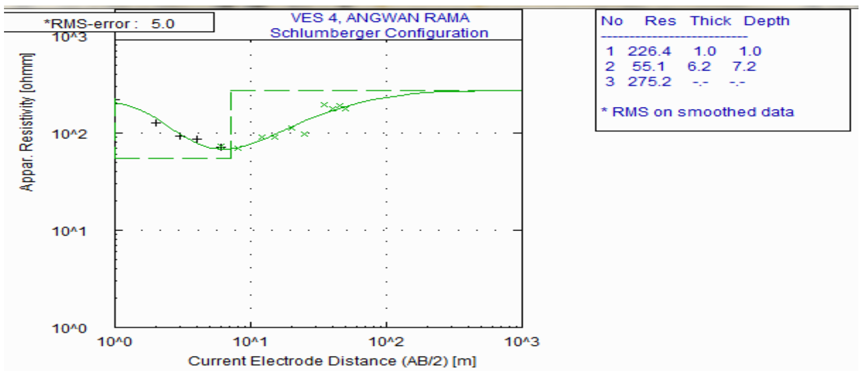

Fig. 3: Representative H-type curve for Agwan-Nepa

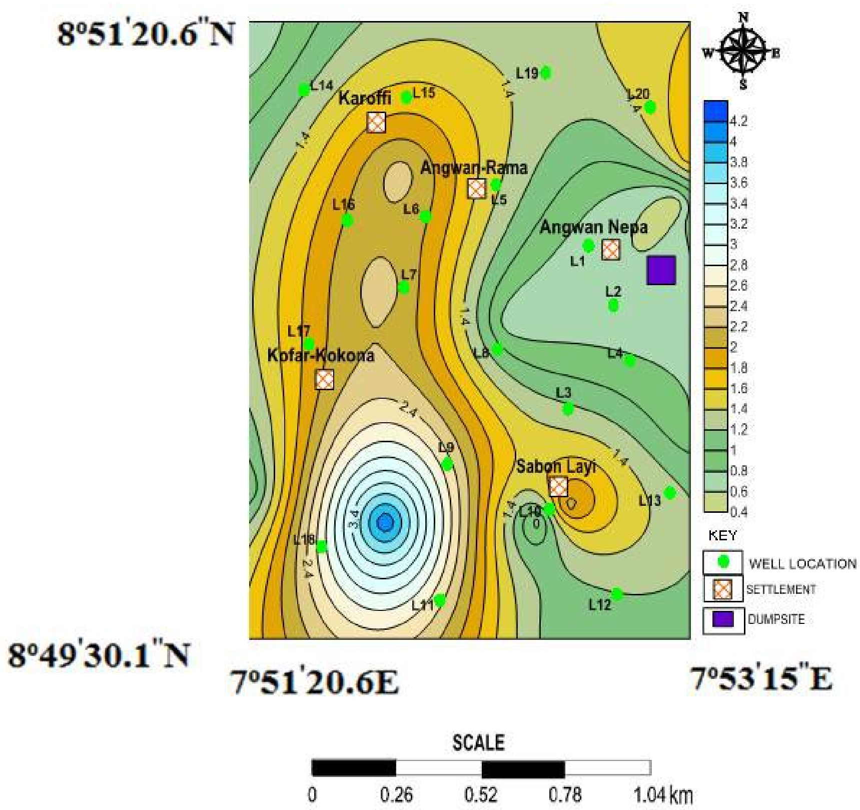

Fig.4: Topsoil thickness map

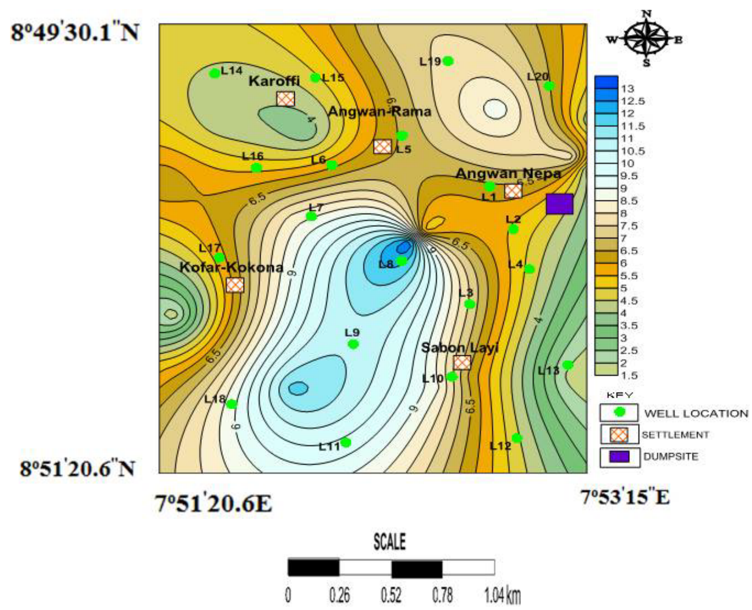

Fig.5: Weathered basement thickness map

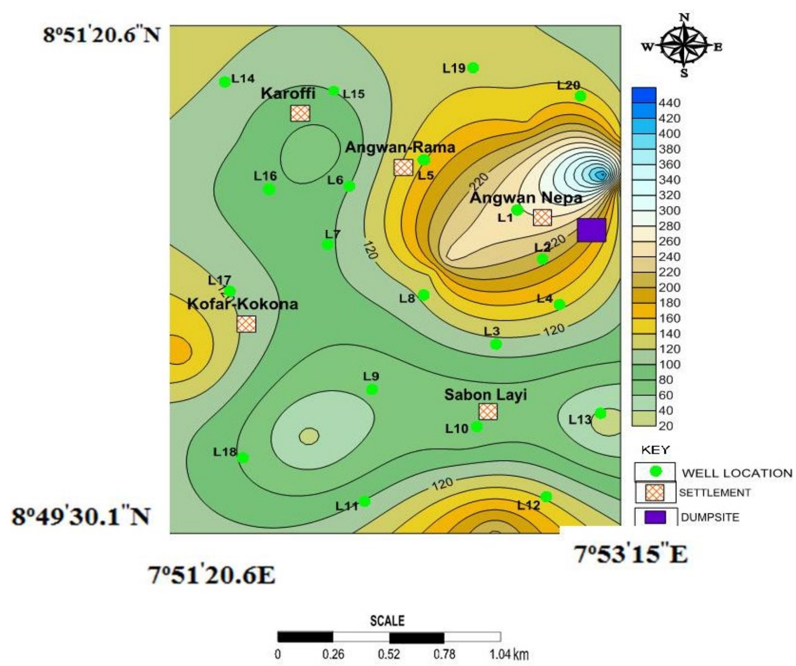

Fig.6: Topsoil's isoresistivity map

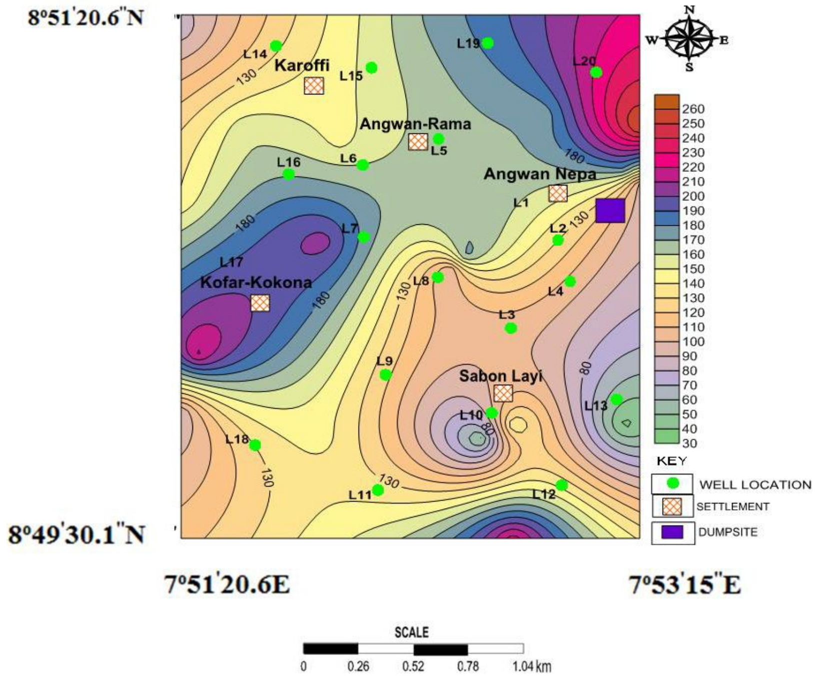

Fig.7: Topsoil's T map

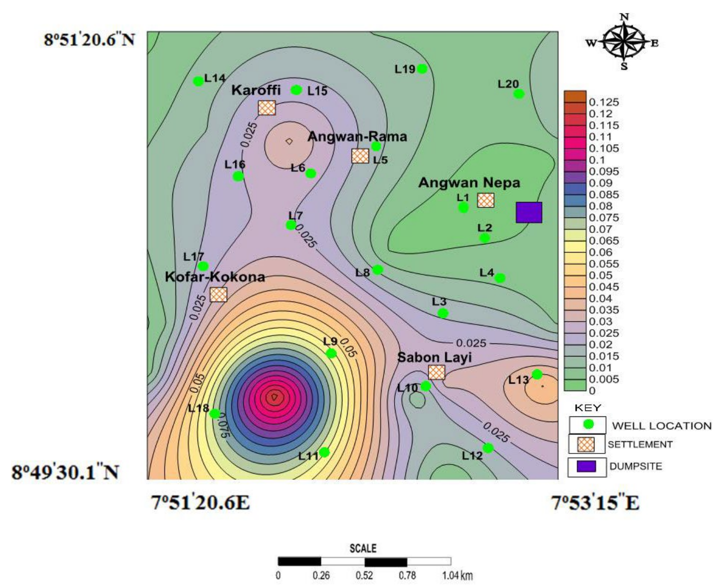

Fig.8: Weathered basement's T map

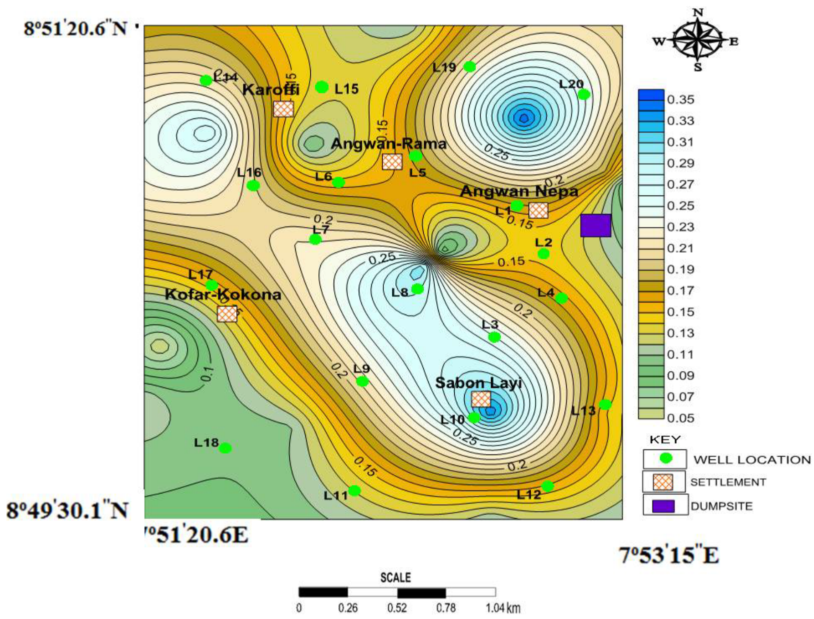

Fig. 9: Weathered basement's S map

The pattern of T and S values, as well as slowly changing static water table elevation, indicates widespread high permeability and hydraulic conductivity in the area. Weathered basement isoresistivity map (Fig.10) reveals lowest resistivity values (10-15 Ωm) on east of Sabon Layi. This reflects high clay content already indicated by rapid changes in water table elevation in the area. The map also reveals very low resistivity values (35-45 Ωm) at the dumpsite. This suggests the presence of a contaminant plume associated with groundwater at the dumpsite. Slightly acidic rain water falling upon the miscellaneous waste at the dumpsite possesses capacity to dissolve some portion of the metal components in the waste. The dissolved metals would travel in percolating solution through the thin soil interval into the weathered basement, where it is intercepted by groundwater within the regolith, and then gradually build up a contaminant plume.

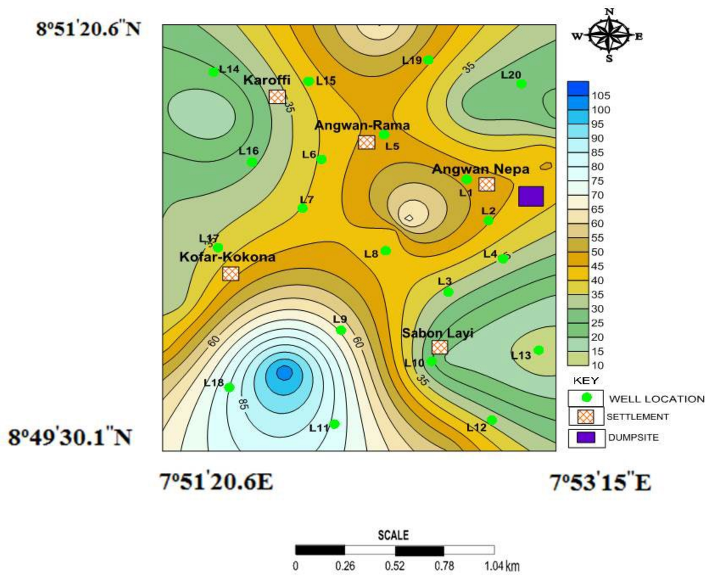

Fig.10: Weathered basement's isoresistivity map

Heavy metal concentration and its spatial distribution

Concentration of each heavy metal in the filtrate from dumpsite's soil sample colloid (L0) and water samples from the hand-dug wells is given in Tables 2 and 3. Mean concentration of As, Ba, Cd, Cr and Cu is respectively 0.29, 0.32, 0.27, 0.41and 2.22 mg/l. Their respective range is 0.05 – 0.8, 0.02 – 0.7, 0.05 – 0.66, 0.17 – 0.75 and 0.1 – 5.4 mg/l. Fe, Mn, Ni, Pb and Zn have respective average concentrations of 1.25, 0.76, 0.81, 0.34, and 2.63 mg/l. Their respective concentration range is 0.3 -6.9, 0.05 – 1.65, 0.21 – 0.18, 0.01 – 1.04 and 0.5 – 5.7 mg/l. The graphical illustration of each of the metal's mean concentration in comparison with WHO (2011) prescribed standard for potable water is given in Fig.11. The mean concentration of each of these metals (with the exception of Zn) exceeds the maximum limit prescribed by WHO (2011) for potable water. This is because higher concentration of zinc is required by the human body for metabolic functions. This is the reason why medical practitioners commonly prescribe zinc to be taken as a dietary supplement to body metabolic patients.

Table 2: Concentration of each heavy metal in filtrate from dumpsite soil's colloid (L0) and water samples from hand-dug wells (L1-L10)

Sample	**Parameter (mg/l)**									
No.	**As**	**Ba**	**Cd**	**Cr**	**Cu**	**Fe**	**Mn**	**Ni**	**Pb**	**Zn**
L0	**3.0**	**5.8**	**0.7**	**3.0**	**8.0**	**10**	**5.5**	**3.0**	**4.0**	**30**
L1	0.12	0.02	0.40	0.36	1.70	1.1	0.40	1.38	0.14	3.14
L2	0.12	0.04	0.20	0.26	4.90	0.6	0.20	0.47	0.88	1.30
L3	0.80	0.09	0.16	0.22	2.80	0.4	0.20	0.38	0.78	3.25
L4	0.18	0.4	0.51	0.31	1.53	0.9	0.50	1.08	0.11	5.67
L5	0.25	0.3	0.19	0.33	1.03	0.5	0.60	0.39	0.75	1.89
L6	0.11	0.3	0.18	0.34	4.30	0.7	0.20	0.43	0.76	1.55
L7	0.10	0.2	0.25	0.34	2.76	0.4	0.07	0.58	0.72	2.38
L8	0.05	0.2	0.17	0.36	1.24	0.9	0.09	1.50	0.82	2.12
L9	0.12	0.2	0.51	0.17	5.41	0.3	1.41	0.43	0.56	2.10
L10	0.23	0.3	0.38	0.35	1.72	0.6	0.12	0.56	1.04	2.43

Table 3: Heavy metals' concentration in water samples from hand-dug wells (L11-L20), heavy metals' concentration range and mean concentration

Sample	**Parameter (mg/l)**									
No.	**As**	**Ba**	**Cd**	**Cr**	**Cu**	**Fe**	**Mn**	**Ni**	**Pb**	**Zn**
L11	0.10	0.3	0.21	0.39	1.90	0.52	0.30	0.50	0.10	3.67
L12	0.12	0.2	0.66	0.75	2.59	1.96	0.51	1.29	0.22	5.70
L13	0.52	0.6	0.37	0.32	1.24	3.2	1.65	0.68	0.87	3.68
L14	0.21	0.3	0.59	0.44	3.40	6.9	0.61	1.17	0.86	2.16
L15	0.38	0.4	0.05	0.75	0.80	1.0	0.98	0.80	0.10	0.50
L16	0.21	0.4	0.05	0.62	0.70	1.0	0.23	0.70	0.30	1.80
L17	0.32	0.4	0.05	0.72	0.20	1.0	0.80	0.55	0.10	1.10
L18	0.50	0.5	0.05	0.23	0.10	1.0	0.05	1.80	0.10	3.30
L19	0.80	0.7	0.33	0.52	4.90	1.0	0.51	0.21	0.10	2.30
L20	0.60	0.51	0.18	0.34	1.09	0.95	1.37	0.92	0.74	1.57
Mean	0.29	0.32	0.27	0.41	2.22	1.25	0.76	0.81	0.34	2.63
Range	0.05-0.8	0.02-0.7	0.05-0.66	0.17-0.75	0.1-4.9	0.3-6.9	0.05-1.65	0.21-1.8	0.10-1.04	0.5-5.7
WHO	0.01	0.7	0.003	0.05	2	-	0.4	0.02	0.01	3
NIS	0.01	0.7	0.003	0.05	1	0.3	0.2	0.02	0.01	3

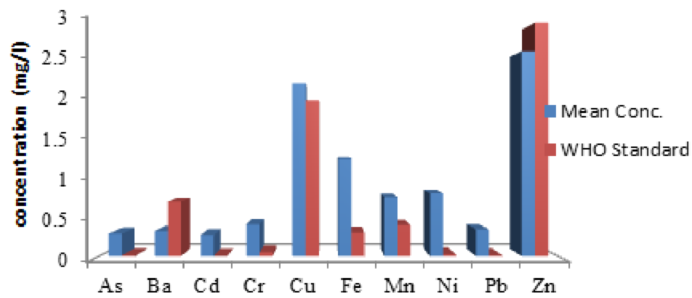

Fig.11: Each heavy metal's mean concentration vis-à-vis WHO prescribed limit for potable water

The concentration of As in all the samples is greater 0.01mg/l. The highest concentration of As occurs at the dumpsite, from where the concentration begins an approximately radial outward decrease (Fig.12). The lowest concentration of As exists within the zone where groundwater flow converges, at approximately 1Km south-westwards of the dumpsite.

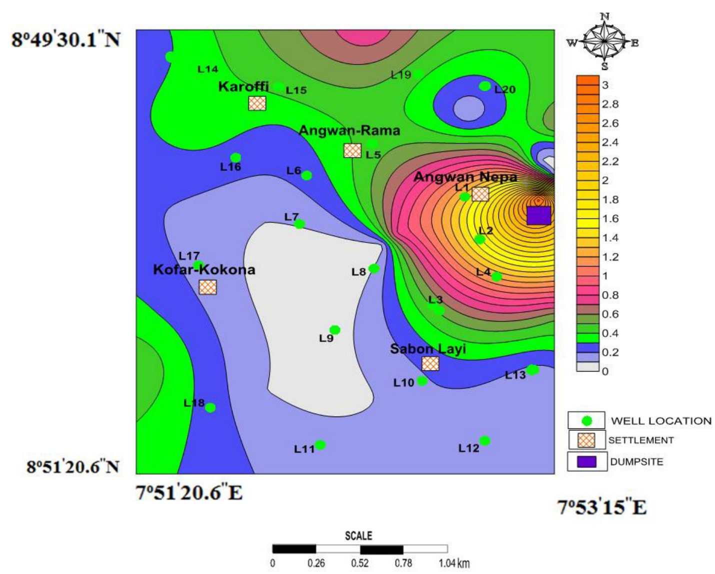

Fig. 12: Ionic concentration map for arsenic within Angwan-Nepa dumpsite and its vicinity

Spatial distribution of Cd concentration (Fig.13) follows the concentration pattern of As. However, a reversal occurs at about 0.5Km south of the dumpsite (on the NE of Sabon Layi) where a concentration syncline (or depression) exists. The concentration syncline is a probable geo-accumulation effect produced when regolith particles adsorb Cd ions from solution onto their surface, in response to decreasing regolith permeability and hydraulic conductivity. Solubility and concentration of Cd ions increased again southerly towards L3 due to improvement in regolith permeability along this direction.

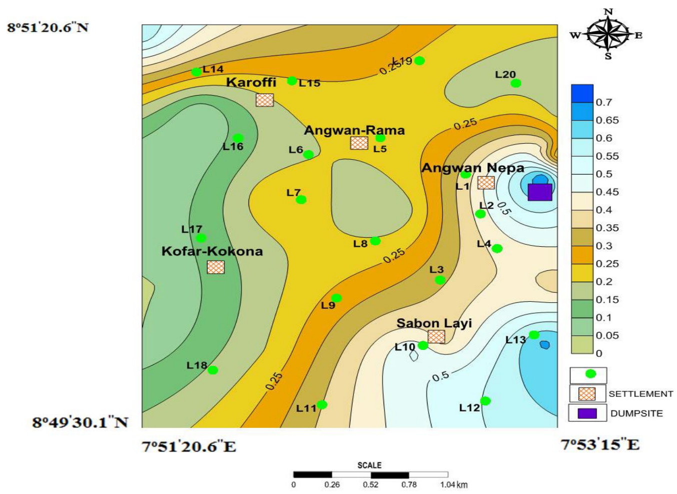

Fig. 13: Concentration map for cadmium within Angwan-Nepa dumpsite and its vicinity

Concentration of Cr ions in all the water samples is higher than the 0.05 mg/l healthy limit advised by WHO (2011). Concentration of Cr ions decreases in outward radial pattern from its plume at the dumpsite (Fig.14), in similarity with Cd. The absence of mafic and ultramafic rocks in the area indicates that the high concentration of Cr ions is attributable to the dumpsite leachate, and thus anthropogenic. The concentration of Ni exceeds the permissible limit of 0.02mg/l in all the samples. Highest Ni concentration occurs at the dumpsite and then the concentration decreases outward (Fig.15). Concentration reversal SW of Kofar Kokona is likely due to increased concentration arising from probable presence of nickel sulphide minerals within relict veins in the weathered schist in the area. On the other hand, the concentration of Pb exceeds the WHO (2011) prescribed limit of 0.01mg/l in all the water samples, with the concentration plume occurring at the dumpsite and decreasing outward from there (Fig.16).

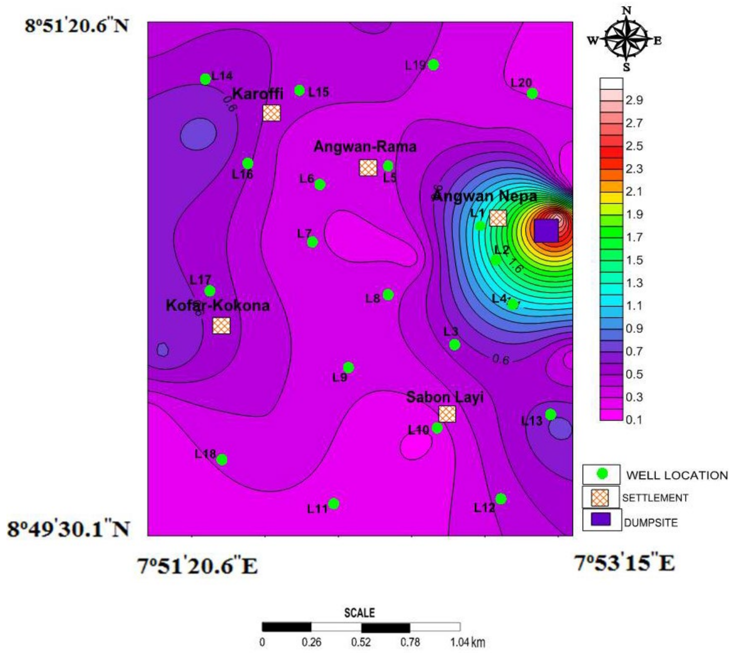

Fig. 14: Concentration map for chromium within Angwan-Nepa dumpsite and its vicinity

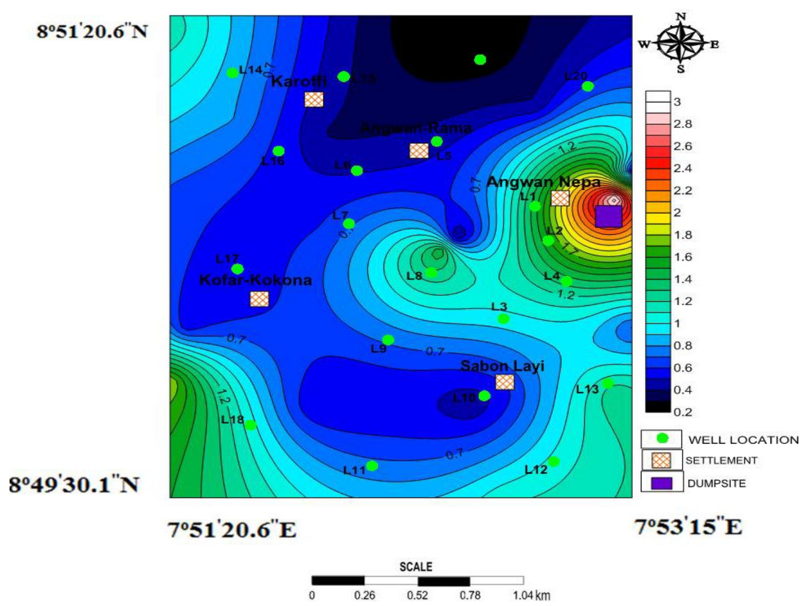

Fig. 15: Concentration map for nickel within Angwan-Nepa dumpsite and its vicinity

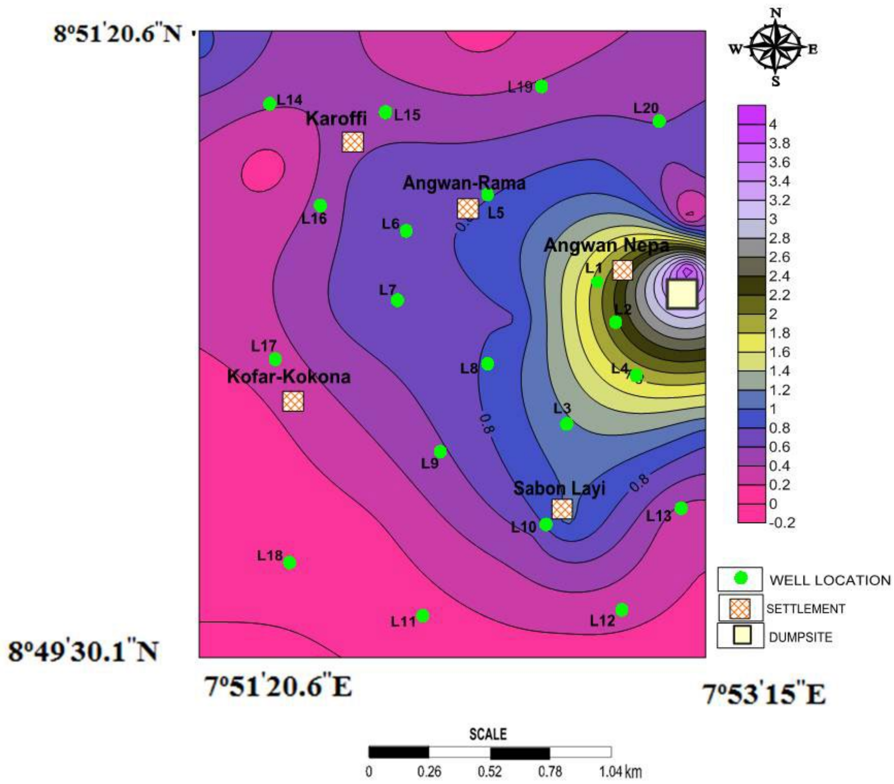

Fig. 16: Concentration for lead within Angwan-Nepa dumpsite and its vicinity

Concentration of Mn exceeds the WHO (2011) prescribed limit of 0.4mg/l in all the water samples. It is highest at the dumpsite, and then decreases south-westward and southward as a result of dilution associated with groundwater flow (Fig.17). The reversal in concentration trend on the SSE of Kofar Kokona is probably due to the presence of magnetite in relict mineralised veins within the weathered schist in this area.

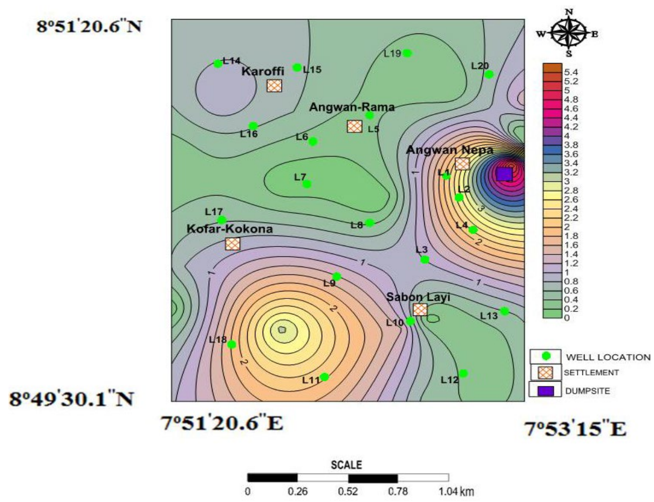

Fig. 17: Concentration map for manganese within Angwan-Nepa dumpsite and its vicinity

Spatial concentration map for Cu (Fig.18), Fe (Fig. 19), Zn (Fig. 20) and Ba (Fig. 21) all reveal a concentration plume at the dumpsite, and a radial outward concentration decrease due concentration attenuation related to dilution in direction of groundwater flow.

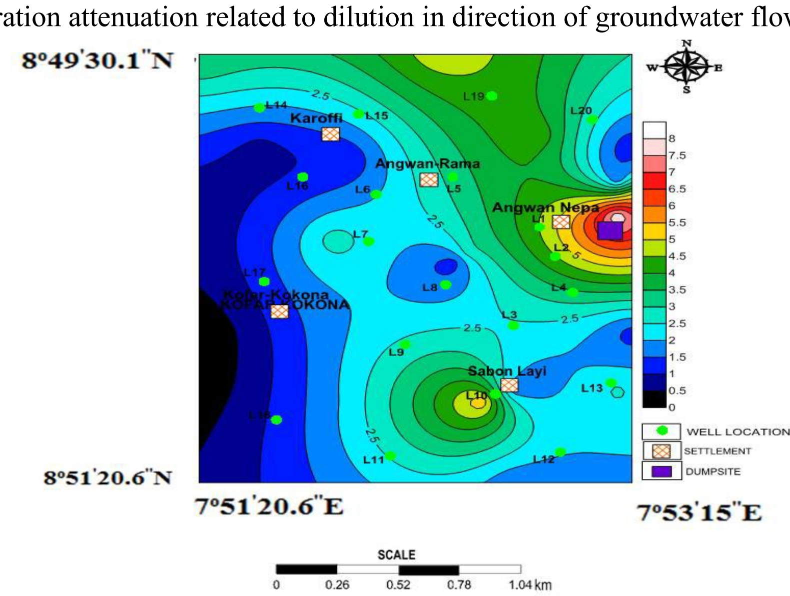

Fig. 18: Concentration map for copper within Angwan-Nepa and itsvicinity

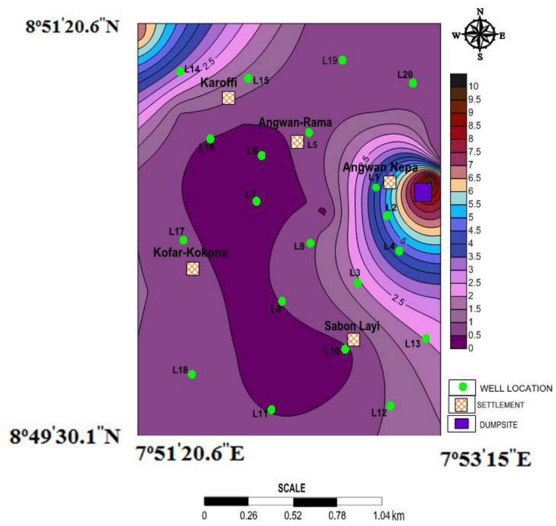

Fig. 19: Concentration map for iron within Angwan-Nepa dumpsite and its vicinity

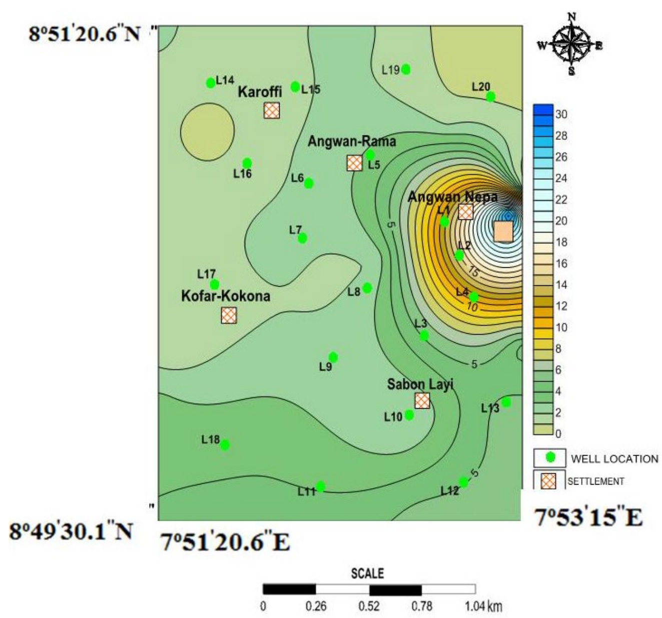

Fig. 20: Concentration map for zinc within Angwan-Nepa dumpsite and its vicinity

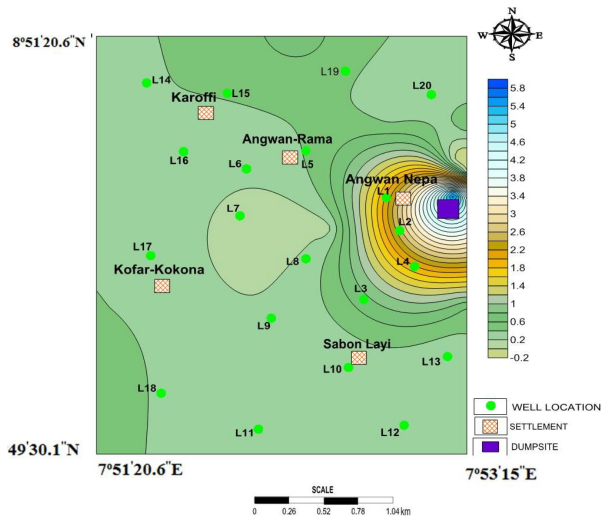

Fig.21: Concentration map for barium in Angwan-Nepa dumpsite and its vicinity

The computed contamination factor (CF) and pollution load index (PLI) for samples L0-L10 and L11 – L20 are given in Table 3. The mean concentration for each of the heavy metals in all the water samples and their average concentration in world rock (employed in the computations) are given in Table 4.

The CF for As reflects mild contamination level from As at the dumpsite (L0). The CF for Cd and Cu shows mild and very high contamination levels respectively at the dumpsite. The PLI value is less than 1.00 in the area and this implies that the overall contamination attributable to the aggregate effects of the heavy metals is negligible in the area. The computed metal pollution index (MPI) value for the area is given in Table 5. The MPI value is lower than 1.00 (approximately 0.6) and this indicates that the study area is yet to suffer anthropogenic pollution from heavy metals, though some contamination has occurred, especially at the dumpsite. I_{geo} value for each of the metals is given in Table 6. It reveals mild accumulation of As at the dumpsite. It also reveals geoaccumulation of Cd at the dumpsite and at L10, L12, L13, and L14.

Table 3: Computed CF and PLI of heavy metals in Angwan-Nepa dumpsite and its environs

Sample No.	**CF**										**PLI**
	As	**Ba**	**Cd**	**Cr**	**Cu**	**Fe**	**Mn**	**Ni**	**Pb**	**Zn**	
L0	1.67	0.0014	3.50	0.30	8.00	0.0002	0.0058	0.04	0.21	0.43	0.098
L1	0.06	0.00005	2	0.004	0.031	0.00002	0.000042	0.018	0.011	0.05	0.004
L2	0.06	0.00009	1	0.003	0.089	0.00001	0.00021	0.006	0.068	0.02	0.006
L3	0.40	0.00021	0.80	0.002	0.050	0.00001	0.00022	0.005	0.06	0.05	0.007
L4	0.18	0.00094	2.55	0.003	0.028	0.00002	0.00052	0.003	0.0085	0.08	0.008
L5	0.10	0.00071	4.75	0.003	0.019	0.00001	0.00063	0.005	0.058	0.03	0.006
L6	0.06	0.00071	0.90	0.003	0.078	0.00001	0.00021	0.006	0.058	0.03	0.006
L7	0.05	0.00047	1.25	0.003	0.050	0.00001	0.000073	0.008	0.055	0.03	0.006
L8	0.03	0.00047	0.85	0.004	0.022	0.00002	0.000095	0.02	0.063	0.03	0.015
L9	0.06	0.00047	2.55	0.002	0.098	0.00001	0.0012	0.006	0.043	0.03	0.008
L10	0.13	0.00071	1.60	0.004	0.031	0.00001	0.00012	0.008	0.08	0.04	0.007
L11	0.05	0.00071	1.05	0.0039	0.035	0.000010	0.0032	0.0066	0.0076	0.052	0.0073
L12	0.06	0.00047	3.3	0.0075	0.047	1.000392	0.00053	0.0017	0.017	0.081	0.0230
L13	0.29	0.00014	1.85	0.0032	0.023	0.000064	0.0017	0.0091	0.066	0.052	0.0110
L14	0.21	0.00071	2.95	0.0044	0.062	0.000138	0.00064	0.016	0.065	0.030	0.0142
L15	0.21	0.00009	0.25	0.0075	0.015	0.000002	0.0010	0.011	0.0076	0.007	0.0038
L16	0.12	0.00009	0.25	0.0062	0.013	0.000002	0.00024	0.0093	0.0023	0.026	0.0030
L17	0.18	0.00009	0.25	0.0072	0.003	0.000002	0.00084	0.0073	0.00077	0.016	0.0026
L18	0.28	0.00012	0.25	0.0023	0.001	0.000002	0.000053	0.024	0.0076	0.047	0.0028
L19	0.44	0.00017	1.65	0.0052	0.089	0.000002	0.00054	0.0028	0.0076	0.033	0.0058
L20	0.33	0.0012	0.9	0.0034	0.019	0.000019	0.0014	0.012	0.057	0.022	0.0099

Table 4: Mean concentrations of Heavy metals in water samples and their World rock surface Average from Manson (1966)

Parameter (mg/l)	As	Ba	Cd	Cr	Cu	Fe	Mn	Ni	Pb	Zn
Mean Conc. (mg/l)	0.29	0.32	0.27	0.41	2.22	1.25	0.76	0.81	7.27	2.63
World Surface Rock Ave. (mg/l)	1.8	425	0.2	100	55	500000	950	75	13	70

Table 5: Calculated MPI for the study area

Metals	**average concentration x**	**Reference value Ref**	**x/ref**
As	0.29	0.01	0.0029
Ba	0.32	0.7	0.224
Cd	0.27	0.003	0.00081
Cr	0.41	0.05	0.021
Cu	2.22	1	2.22
Fe	1.25	0.3	0.375
Mn	0.76	0.2	0.152
Ni	0.81	0.02	0.016
Pb	7.27	0.01	0.073
Zn	2.63	3	0.89
		Σ	**3.97**
		MPI = log Σ	**0.598**

Table 6: Computed I_{geo} for the heavy metals in the study area

	Igeo									
	As	**Ba**	**Cd**	**Cr**	**Cu**	**Fe**	**Mn**	**Ni**	**Pb**	**Zn**
L0	0.15	- 10.10	1.23	- 8.38	- 3.38	- 12.91	- 8.00	- 5.21	- 2.29	- 1.81
L1	- 4.51	- 11.06	0.41	8.70	-5.77	- 19.35	- 15.61	- 6.38	- 7.14	- 5.06
L2	- 4.51	- 11.66	- 0.60	- 9.20	- 4.08	- 20.25	- 12.80	- 7.90	- 4.47	- 6.38
L3	- 1.76	10.06	- 0.92	- 9.38	- 4.92	- 17.40	- 12.80	- 8.20	- 4.64	- 5.01
L4	- 3.92	- 11.06	0.77	- 8.90	- 5.71	- 16.35	- 11.48	- 6.70	- 7.48	- 4.21
L5	- 3.43	10.63	- 0.67	- 8.83	- 6.38	- 17.21	- 11.22	- 8.16	- 4.72	- 5.80
L6	- 4.64	- 11.06	- 0.74	- 8.76	- 4.27	- 16.71	-12.80	-8.04	- 4.68	- 6.06
L7	- 4.76	- 11.66	- 4.92	- 8.76	- 4.92	- 17.53	- 14.32	- 7.59	- 4.76	- 5.44
L8	- 5.72	- 11.66	- 0.84	- 8.70	- 6.06	- 16.35	- 13.94	- 6.27	- 4.57	- 5.64
L9	- 4.51	- 11.66	- 0.77	- 9.83	- 3.92	- 17.93	-10.10	- 8.38	- 5.11	- 5.64
L10	- 3.56	- 11.06	0.34	- 8.76	- 5.57	- 16.93	- 13.54	- 7.67	- 4.24	- 5.44
L11	- 4.51	- 11.06	- 0.51	- 8.59	- 5.44	- 17.14	- 8.83	- 7.83	- 7.62	- 4.84
L12	- 4.51	- 11.66	1.14	- 7.64	-5.01	- 15.23	- 11.44	- 6.51	- 6.51	-4.21
L13	- 1.76	- 10.06	0.30	- 8.90	- 6.06	- 14.51	- 9.71	- 7.38	- 4.47	- 4.84
L14	- 3.92	- 11. 06	1	- 8.43	- 4.61	- 13.41	- 11.18	- 6.64	- 4.47	- 5.57
L15	- 3.44	- 10.63	- 2.56	- 7.64	- 6.70	- 16.23	- 10.68	- 7.14	- 7.61	- 7.70
L16	- 4.64	- 10.63	- 2.56	- 7.93	- 6.88	- 16.23	-12.61	- 7.33	- 6.06	- 5.88
L17	- 4.76	- 10.63	- 2.56	- 7.70	- 8.70	- 16.23	- 10.80	-7.70	- 10.94	- 6.74
L18	- 9.04	- 10.32	- 2.56	- 9.38	- 9.70	- 16.23	-14.80	- 5.97	- 10.94	-5.01
L19	- 4.51	- 9.83	- 2.56	- 8.16	- 4.06	- 16.23	- 11.48	- 9.12	- 10.94	- 5.51
L20	- 5.56	- 10.51	- 0.74	-8.76	-6.27	- 16.23	- 10.02	- 6.93	- 4.76	- 6.06

Conclusion

A groundwater divide that trends NNW-SSE was established in the northern vicinity of Agwan-Nepa dumpsite from static water table elevation data. The data revealed that groundwater flows north-northeast wards in the northern sector of the divide, and south-southwest wards on its southern region. The data also revealed a groundwater convergence zone within 2.5 Km SW and another convergence zone within 4 Km NW of the dumpsite. Hydro-geochemical data indicated that the groundwater flowing south-southwest wards of the divide contains dissolved As, Cd, Cr, Mn, Ni and Pb in toxic level concentrations on the WHO standard for potable water. Dilution at the groundwater convergence zones keeps the concentration of the dissolved metals within the WHO prescribed concentration range for potable water. The groundwater divide protects groundwater on its northern portion from the dumpsite leachates, and this keeps the groundwater there potable. Contamination indices data established moderate to very high level contamination of Cd, and Cu, and moderate level contamination of As at the dumpsite.

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Estimation of Groundwater Recharge in the Lower-Ogun River Basin using Two Independent Methods

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Abstract
This paper aims at estimating and comparing the groundwater recharge in the lower Ogun basin, South western, Nigeria using soil moisture analysis and water table fluctuation. Stream data at Abeokuta New Bridge gauge station and meteorological data of Ikeja and Abeokuta stations, as well as water level measurements in Twenty (20) wells in Abeokuta and ten (10) in Ewekoro were used. On the basis of soil-moisture balance method, more groundwater recharge occurs in the lower and more developed part of the basin, where there is high amount of annual rainfall, while there is reduction northwards towards Abeokuta as rainfall decreases. The percentage of annual rainfall that becomes groundwater recharge was found to range between 0.0% to 23.3% in Abeokuta, and 0.0% to 31.2% in Ikeja. The water table fluctuation method reveals similarities in the groundwater recharge in Abeokuta and Ewekoro. The groundwater recharge percent of rainfall in Abeokuta, (0.8% to 4.3%) is similar to that of Ewekoro (2.5% to 4.5%).

Keywords: groundwater recharges, rainfall, PET, soil moisture analysis, water table fluctuations,

Introduction
Groundwater recharge is the downward flow of water reaching the water table, forming an addition to the groundwater reservoir (Bakundukize *et al*., 2011). Recharge occurs when water flow past the groundwater level and infiltrates into the saturated zone (Yeh, 2009). Many factors influencing groundwater flow into the saturated zone include topography, lithology, geological structures, depth of weathering, extent of fractures, primary porosity, secondary porosity, slope, drainage patterns, landforms, land use/land cover, and climate

(Mukherjee 1996; Jaiswal *et al*., 2003). Assessment of groundwater recharge is one of the key challenges in determining the sustainable yield of aquifers. In Nigeria in particular, the growing need for reliable recharge estimation originated from a desire to manage its water resources. With the ever increasing population coupled with fast development rate and urbanization, there has been an increasing trend in water exploitation for domestic, agricultural and industrial uses. Already, extensive groundwater overuse threatens the long-term sustainability of this resource in many regions of the world (Gleick, 1998). However, quantifying recharge remains one of the seminal problems in hydrologic research and evaluation (Scanlon and Cook, 2002). Accurate recharge estimates are important for groundwater resource assessment, water quality protection, streamflow and riparian ecosystem management, aquifer replenishment, groundwater flow modelling, and contaminant transport, and are keys to wise development in rapidly expanding urban, industrial, and agricultural regions (Potter and Bowser, 1995; Lewis and Walker, 2002; de Vries and Simmers, 2002; Scanlon *et al*., 2002). Several scholars have carried out extensive recharge research at a different scales in Nigeria (Edmunds *et al*., 1988; Djoret and Travi, 2001; Ngatcha *et al*., 2001; Goni, 2006; Idowu and Martins, 2007; and Ufoegbune *et al*., 2011) especially in estimating recharge at Lake Chad basin, Hadejia Nguru basin, Oyan and Opeki basin, little attention has been paid to lower Ogun River Basins in particular.

The essence of this paper is to compute groundwater recharge in the lower part of Ogun river basin using soil moisture analysis and water table fluctuation. The lower part of Ogun basin is considered to be well developed in terms of population density, water use and impervious cover. The results were analyzed to determine the variation of the recharges in different areas within the lower Ogun basin.

Study area

The part of the Ogun river basin downstream of the Ogun - Oyan confluence is defined as the lower Ogun river basin. It is a narrow strip (Fig. 1); about 100 km long from north to south and average width of 24km. Its total area is approximately 2,400 square kilometers. The relief is generally low, with the gradient in north-south direction. The Ogun-River takes its source from the Iganran hills at an elevation of about 530 m above mean sea level and flows directly southwards over a distance of about 480 km, before it discharges into the Lagos lagoon (Martins, 1987). Two seasons are distinguishable in the basin, a dry season from November to March and a wet season between April and October. Mean annual rainfall ranges from 900 mm in the north to 2000 mm towards the south. The total annual potential evapotranspiration is estimated at between 1600 mm and 1900 mm. The two major vegetation zones that can be identified in the basin are the high forest vegetation in the central parts, and the swamp/mangrove forests that cover the southern coastal and floodplains, next to the lagoon. The geology of the upper part of the lower Ogun river basin is described as a rock sequence that comprises of the Precambrian Basement (Jones and Hockey, 1964) and which consists of quartzites and biotite schist, hornblende-biotite, granite and gneisses. The foliation and joints on these rocks control the course of the rivers, causing them to form a trellis drainage pattern, particularly to the north of the study area. The sedimentary rock sequences are from Cretaceous to Recent; the oldest of them, the Abeokuta formation, consists of grey sand intercalated with brown to dark grey clay. It is overlain by Ewekoro formation, which typically contains thick limestone layers at its base. About 9 km upstream of Abeokuta town, there is a sharp change in land gradient, changing the river morphology from fast flowing to slow moving and leading to the formation of alluvial deposits overlying the sedimentary formation of Ewekoro, Ilaro and Coastal plain sands, in sequence towards the Lagos lagoon.

Materials and Methods

Weather elements data comprising rainfall, wind speed, maximum and minimum temperature, sunshine duration and relative humidity were obtained from the Nigerian Meteorological Agency (NIMET), Oshodi, Lagos State and River Basin Development Authority (OORBDA) Abeokuta, Ogun State. Real-time data on water level were collected for a year (12 months) in Abeokuta (20 wells) and Ewekoro (10 wells), using water level indicator. Stream data were collected for Abeokuta New Bridge from Ogun Oshun River basin Authority, Alabata, Abeokuta. The methods employed in this research were soil moisture analysis, where the Penman-Monteith equation (Allen *et al*., 1998) was used for the estimation of reference evapotranspiration-and the groundwater table fluctuation analysis.

Soil-Moisture Balance Method

The different terms of the soil moisture budget were computed separately in an excel sheet. In this method, the concept of water balance of the unsaturated zone (Thornthwaite& Mather, 1957) was applied. It consisted of keeping track of the accumulated potential water loss (APWL) and the amount of water in the soil (SB). Calculations to determine SB and APWL were performed for each month using monthly precipitation (P) and potential evapotranspiration (PET) (Table 1).

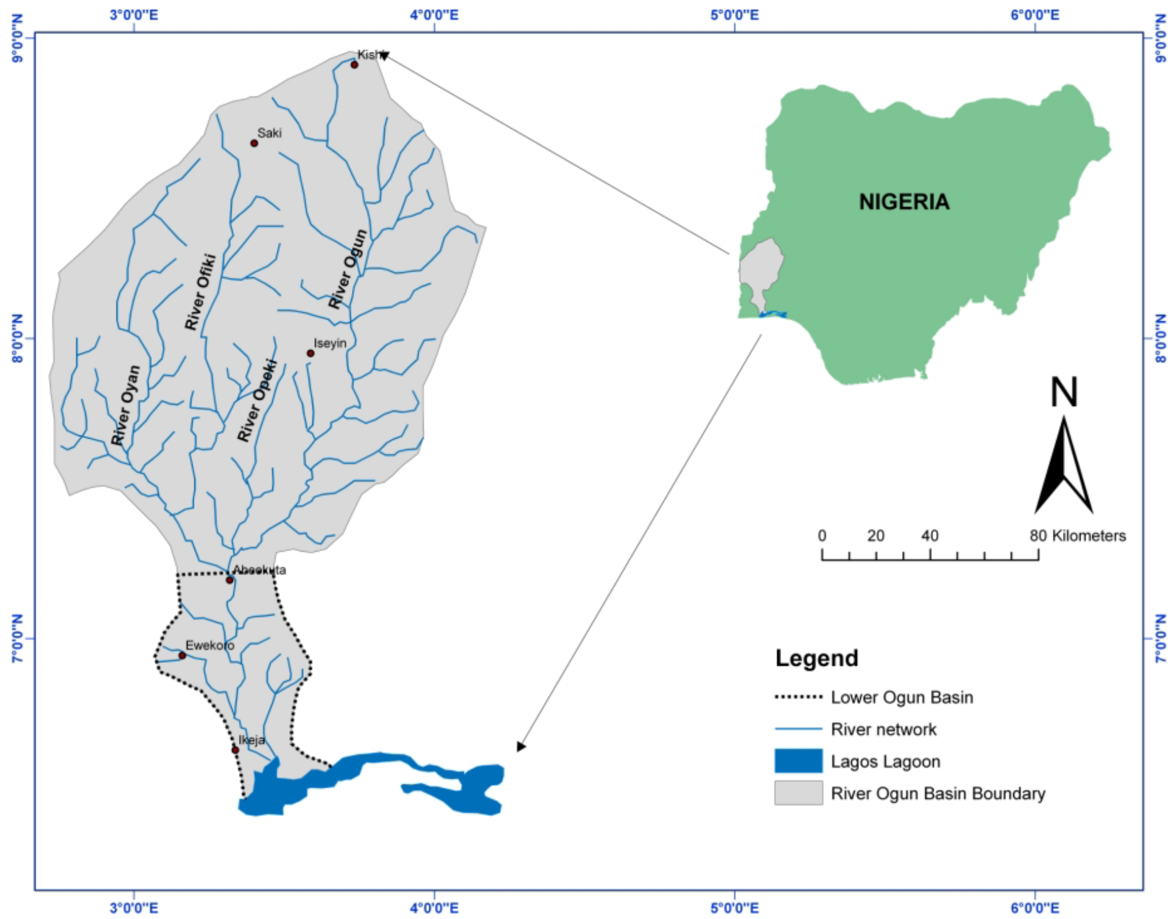

Fig. 1: Map of Ogun River Basin showing the Lower Ogun River Basin

Table 1: Annual soil-water budget calculations (Thornthwaite and Mather, 1957); (Bakundukize *et al*., 2011)

	WET SEASON SUR = (P-Ro) – PET > 0			DRY SEASON SUR = (P-Ro)-PET < 0
		S_B < CAP		
	S_B = CAP	(P-Ro)-PET ≤ CAP-S_B	(P-Ro)-PET > CAP-S_B	
S_B	CAP	S_B + (P-Ro)-PET	CAP	CAP*$e^{-APWL/CAP}$
R_N	(P-Ro) - PET	0	(P-Ro)-PET – (CAP-S_B)	0
AET	PET	PET	PET	(P-Ro) + ΔS_B
DEF	0	0	0	PET - AET

P = precipitation (mm); Ro = runoff (mm); PET = potential evapotranspiration (mm); APWL= accumulated potential water loss (mm) (PET – (P – RO)) accumulated for subsequent dry months; AET = actual evapotranspiration (mm); SB = water stored in soil: SB = CAP*e-APWL/CAP; CAP = soil capacity (mm): maximum water content of soil, without gravitational water (= average rooting depth (mm) * water content at field capacity (in volume %); ΔSB = change in SB; DEF = deficit (PET-AET) (mm); SUR = surplus ((P- Ro)-AET) (mm); RN = natural groundwater recharge (SUR-ΔSB) (mm)

The monthly climatic data, whenever available, were first rearranged into hydrologic years, a hydrologic year in south-west Nigeria starts in April, which is the beginning of the rainy season, and terminates at the end of March, i.e. the end of the dry season. This way of organizing data has the advantage of facilitating the computation of the change in soil moisture storage at the beginning of the hydrologic year, because the soil moisture storage at the end of the dry season, i.e. end of March, can be considered as completely depleted. Moreover, the concept of hydrologic year reflects the natural climatic reality in the sense that it commences with the start of the season of soil moisture recharge, includes the season of maximum groundwater recharge, if any, and terminates with the season of maximum soil moisture utilization (Ritter, 2006).

Penman-Monteith method

The standard Penman-Monteith method for estimating evapotranspiration can be mathematically expressed as follows (Allen *et al*., 1998):

$$PET = \frac{0.408\Delta(R_n - G) + \gamma \frac{900}{T+273} u_2 (e_s - e_a)}{\Delta + \gamma(1 + 0.34u_2)} \qquad (1)$$

where PET = reference potential evapotranspiration (mm day^{-1}), Rn = net radiation at the crop surface ($MJm^{-2}day^{-1}$), G = solar heat density ($MJm^{-2}day^{-1}$), γ = psychrometric constant (kPa°C^{-1}), T= mean air temperature (°C), U_2 = wind speed at 2 m height (ms^{-1}), e_s= saturation vapour pressure (kPa), e_a = actual vapour pressure (kPa), e_s - e_a = saturation vapour pressure deficit (kPa), and Δ= slope of the saturation vapour pressure curve (kPa°C^{-1}). Although the Penman-Monteith equation has proven to be the best method to estimate potential evapotranspiration worldwide, its major setback is that it requires a wide variety of weather data which are not always available in the developing world (Bakundukize *et al*., 2011).

Actual evapotranspiration (AET)

Actual evapotranspiration (AET) is an output of water that is dependent on moisture availability, temperature and humidity. Actual evapotranspiration increases with temperature as long as there is water to evaporate and for plants to transpire. The amount of actual evapotranspiration also depends on the amount of water available which in turn depends on the water holding capacity of the soil (CAP). Practically, the concept utilised to compute the AET could be summarized in the following way: (1) in wet months, when there is enough rain, i.e. when P-Ro > PET, the AET is at its maximum value, which is equal to the PET. (2) In dry months, when there is not enough rain, i.e. when P-Ro < PET, the precipitation is no longer able to meet the evapotranspiration demand. Therefore, the unmet amount of water required by the evapotranspiration demand is progressively taken from the soil moisture storage until it is completely depleted. Hence, even if there is not enough precipitation, the AET can still approach the PET when there is still enough water within the soil moisture storage.

Soil moisture storage

Soil moisture storage represents the total amount of water which is held within the plants root zone. The soil texture and crop rooting depth are the main determinant factors for this parameter. A deeper rooting zone means that there is a larger volume of water stored in the soil zone and therefore a reduced amount of water going to the groundwater reservoir as recharge. The maximum amount of water that can be held within the soil zone is referred to as the field capacity. At field capacity, the soil is holding all the water it can under the pull of gravity. This parameter is of capital importance in groundwater research as, conceptually, the recharge does not commence until when the moisture content exceeds field capacity. The soil water-holding capacity of the root zone is typically expressed in mm and can be obtained by multiplying the water content at field capacity by the effective depth of the root-zone. For instance, in our study area, soils deriving from the weathering of Precambrian meta-sediments and magmatic intrusions are predominantly clayey and the land cover is dominated by agricultural land with shallow rooted crops. Hence, assuming a uniform water-holding capacity of 30 % over the entire the root-zone and a rooting depth of 0.25 m for shallow rooted crops, the water capacity of the root zone becomes 75 mm (Table 2).

Table 2: Suggested values of water capacity for combinations of soil textures and vegetation types (Thornthwaite& Mather 1957, Bakundukize et al., 2011)

Vegetation	Soil texture	Water Content at field capacity	Rooting depth (m)	Water Capacity at the root zone (CAP)
Shallow rooted crops	Fine Sand	10	0.5	50
	Fine sandy loam	15	0.5	0.75
	Silt loam	20	0.62	125
Moderately rooted crops	Fine Sand	10	0.75	75
	Fine sandy loam	15	1.0	150
	Silt loam	20	1.0	200
Deep rooted crop	Fine Sand	10	1.00	100
	Fine sandy loam	15	1.00	150
	Silt loam	20	1.25	250

Runoff

Surface runoff (overland flow) is the fraction of precipitation, in mm, that flows on impervious surfaces or over the land surface into surface water bodies when the infiltration capacity is exceeded and any depression has been filled with water. Surface runoff is subtracted from the precipitation to compute the amount of remaining precipitation which participates into the further steps of the soil water balance process. The runoff factor for this preliminary study was taken as 23.64 percent of the precipitation as suggested by previous studies (Ayoade, 1975).

Change in soil moisture storage

The change in moisture storage is the amount of water, which is added to or removed from what is stored. The change in soil moisture storage fluctuates between 0 and the field capacity (Ritter, 2006). The change in soil moisture storage is computed, depending on the time scale used, as the difference between the current soil moisture and the previous one. Withdrawals of water from the moisture storage take place during the dry months (PET>P-Ro) wherein a certain amount is taken to meet the evapotranspiration demand. Water is added to the soil moisture storage during the wet months (PET<P-Ro) until the water capacity of the root-zone, i.e. 75 mm in our study area, is reached. The excess moisture is drained to the groundwater reservoir in the form of groundwater recharge.

Deficit

A soil moisture deficit occurs when the demand for water exceeds the amount which is actually available. Deficits occur when potential evapotranspiration exceeds actual evapotranspiration (PET>AET/ The amount of deficit is therefore calculated as the difference between potential and actual evapotranspiration *(*Ritter, 2006).

Surplus (S)

Surplus water occurs when P-Ro exceeds potential evapotranspiration, i.e. when there is more water than what is actually needed given the local environmental conditions. Surplus (SUR) is computed as the difference between P-Ro and the actual evapotranspiration (AET).The existence of surplus water indicates the possibility of groundwater recharge although the soil moisture storage must be brought to its field capacity at first.

Groundwater recharge (RN)

Groundwater recharge occurs when there is a surplus and the soil moisture is at its field capacity. It is calculated as the remaining surplus after the soil moisture has been brought to field capacity Table 3.

Table 3: Example of the Scheme Used for the Calculation of Recharge in Excel Sheet for Abeokuta

	Month	*P*	*Ro*	*P-Ro*	*PET*	*(P-Ro)-PET*	*PET-(P-Ro)*	*APWL*	*Sb*	*ΔSb*	*AET*	*DEF*	*SUR*	*Rn*
1982	Apr	193.3	45.70	147.60	114.07	33.53	-33.53	0.00	75	73.24	114.07	0	33.53	106.77
	May	159.6	37.73	121.87	83.39	38.48	-38.48	0.00	75	0	83.39	0	38.48	38.48
	June	131.4	31.06	100.34	148.71	-48.37	48.37	56.27	35.4	39.58	139.92	8.79	-39.58	0.00
	July	83.2	19.67	63.53	147.73	-84.20	84.20	132.57	12.8	22.61	86.14	61.59	-22.61	0.00
	Aug	6.8	1.61	5.19	142.27	-137.08	137.08	221.28	3.9	8.881	14.07	128.20	-8.88	0.00
	Sept	67.5	15.96	51.54	148.09	-96.55	96.55	233.62	3.3	0.596	52.14	95.95	-0.60	0.00
	Oct	96	22.69	73.31	145.26	-71.95	71.95	168.50	7.9	-4.6	68.70	76.56	4.60	0.00
	Nov	10.6	2.51	8.09	143.99	-135.90	135.90	207.85	4.7	3.238	11.33	132.66	-3.24	0.00
	Dec	0	0	0.00	139.16	-139.16	139.16	288.75	1.6	3.097	3.10	136.06	-3.10	0.00
1983	Jan	0	0	0.00	88.04	-88.04	88.04	227.20	3.6	-2.03	-2.03	90.07	2.03	0.00
	Feb	1.7	0.40	1.30	136.35	-135.05	135.05	223.09	3.8	-0.2	1.09	135.26	0.20	0.00
	Mar	3.6	0.85	2.75	149.1	-146.35	146.35	281.40	1.8	2.07	4.82	144.28	-2.07	0.00

P= Precipitation, Ro= Change in soil moisture content, PET= Potential evapotranspiration, Sb= Soil moisture balance, DEF=Deficit, SUR= Surplus, AET= Actual evapotranspiration; Rn= Recharge

The dominant soil types of the area (Fig 2) are based on the soil map from the Harmonized World Soil Database (HWSD-viewer).

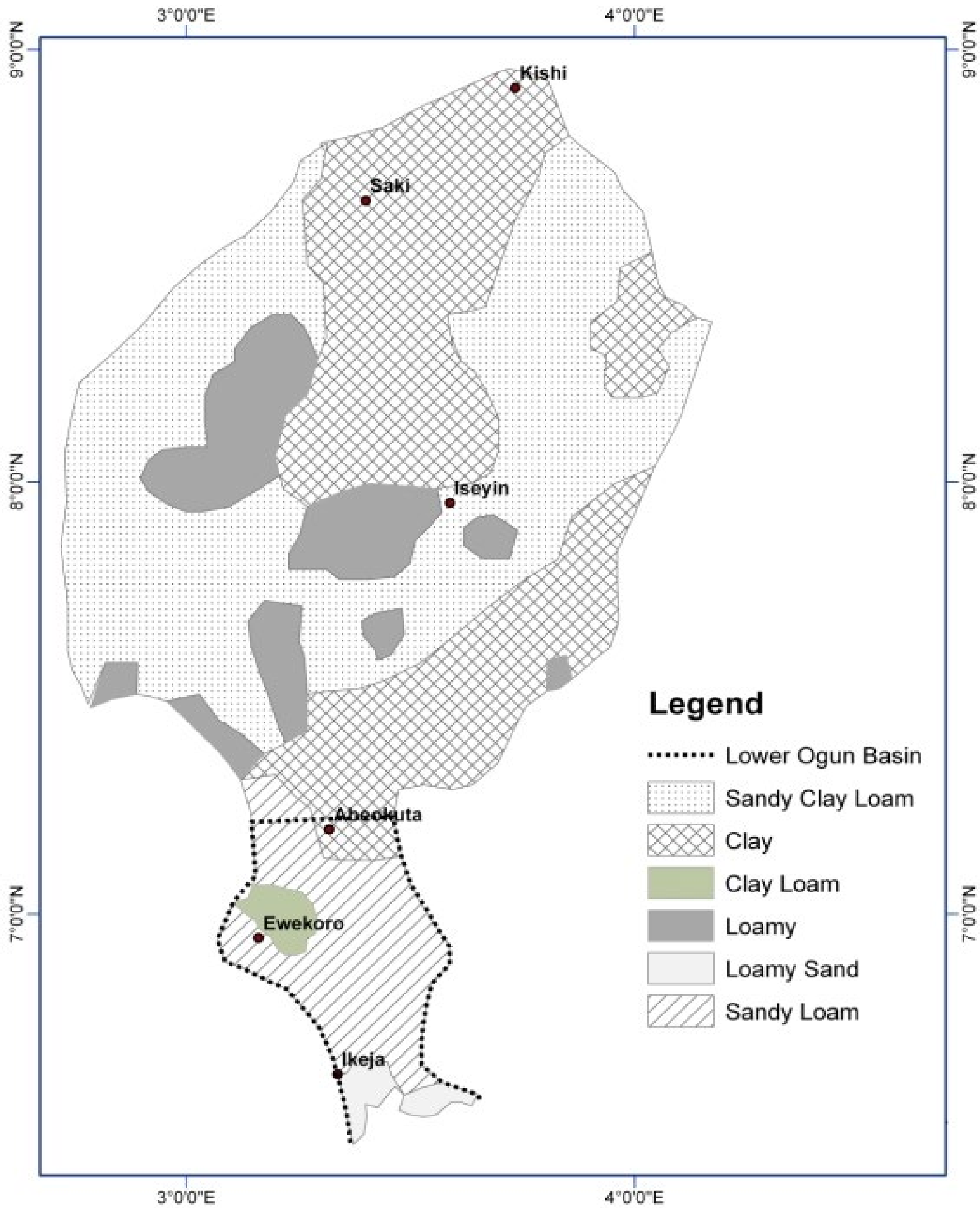

Fig. 2: Dominant Soil Textures in Lower Ogun River Basin

Water-table fluctuation method

The water-table fluctuation (WTF) method is based on the premise that rises in groundwater levels in unconfined aquifers are due to recharge water arriving at the water table. The WTF method has been used in various studies (Rasmussen and Andreasen 1959; Hall and Risser 1993). The method is best applied over short time periods in regions having shallow water tables that display sharp rises and declines in water levels. The technique can be useful for determining the magnitude of long-term changes in recharge caused by climate or land-use change. Difficulties in applying the method are related to determining a representative value for specific yield and ensuring that fluctuations in water levels are due to recharge and are not the result of changes in atmospheric pressure, the presence of entrapped air, or other phenomena, such as pumping. The method has been applied over a wide variety of climatic conditions. Recharge rates estimated by this technique range from 5 mm/year in the Tabalah Basin of Saudi Arabia (Abdulrazzak *et al*. 1989) to 247 mm/year in a small basin in a humid region of the eastern US (Rasmussen and Andreasen 1959). The area represented by the recharge rates ranges from tens of square meters to several hundred or thousand square meters. Time periods represented by the recharge estimates range from event scale to the length of the hydrographic record. Recharge is calculated as:

$$R(tj) = Sy*\Delta H(tj) \qquad (2)$$

where R(tj) (cm) is recharge occurring between times t_0 and tj, Sy is specific yield (dimensionless), and ΔH(tj) is the peak water-table rise attributed to the recharge period (cm).

Inherent assumptions include:

1. Sy is assumed in relation to the geologic properties of the area, and that is constant over the interval of the water-table fluctuation, for this study Sy was assumed to be 0.15% that is for weathered granite and gneiss as found in Abeokuta and 0.25% for Sedimentary zone of Ewekoro (CGWB, 2008);
2. The pre-recharge water-level can be extrapolated to determine ΔH(tj);

For this study the graphical approach of the water table fluctuation method (Delin *et al*., 2007) was used. The wells measured were highlighted in Fig. 3. ΔH (tj) is estimated as the difference between the peak of a water-level rise and the value of the extrapolated antecedent recession curve at the time of the peak. This recession curve is the trace that the well hydrograph would have followed had there been any precipitation.

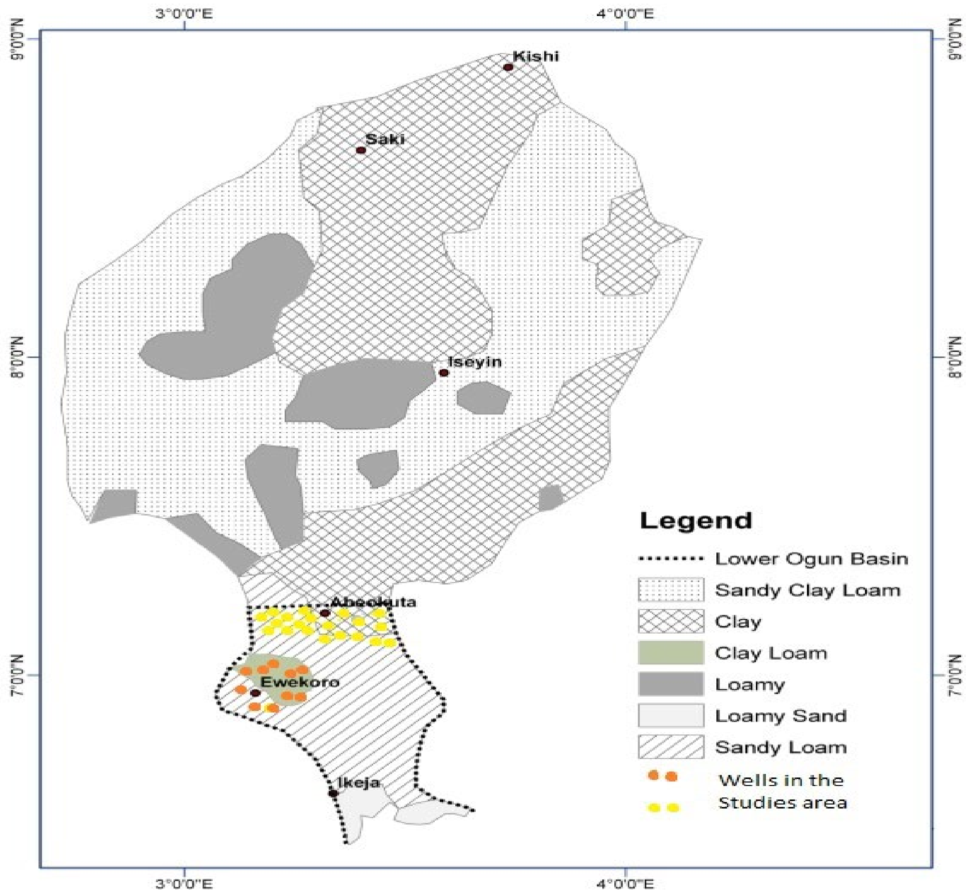

Fig. 3: Map Showing the Spatial Distribution of Wells in the Studies Area

Results and Discussions

Annual rainfall distributions

The average annual rainfall of Ikeja, computed from 28 years data, was 1482.72 mm, with a maximum and minimum value of 2007.7 mm, and 860.8 mm (these fell within the year 2002/2003 and 1983/1984 respectively). The average annual rainfall for Abeokuta is 1193.0mm, with a maximum and minimum value of 1876.4 mm and 753.7 mm (for the year 1982/1983, and 2007/2008, respectively). Twelve years rainfalls were above the average rainfall of 1482.7mm, which indicates that more rainfalls were witnessed in the 12 years within the 28 years of study, while decreased rainfall were experienced for 10 years in Ikeja (Fig. 4). The annual rainfall distribution in Abeokuta was contrary to Ikeja in that more rainfall were experienced in the 10 years where rainfall was above 1193.0 mm, while decreased rainfall was for 13 years within the span of study (Fig. 5). This goes to show that more rainfall above normal was experienced in Ikeja Area, a lower part of Ogun basin.

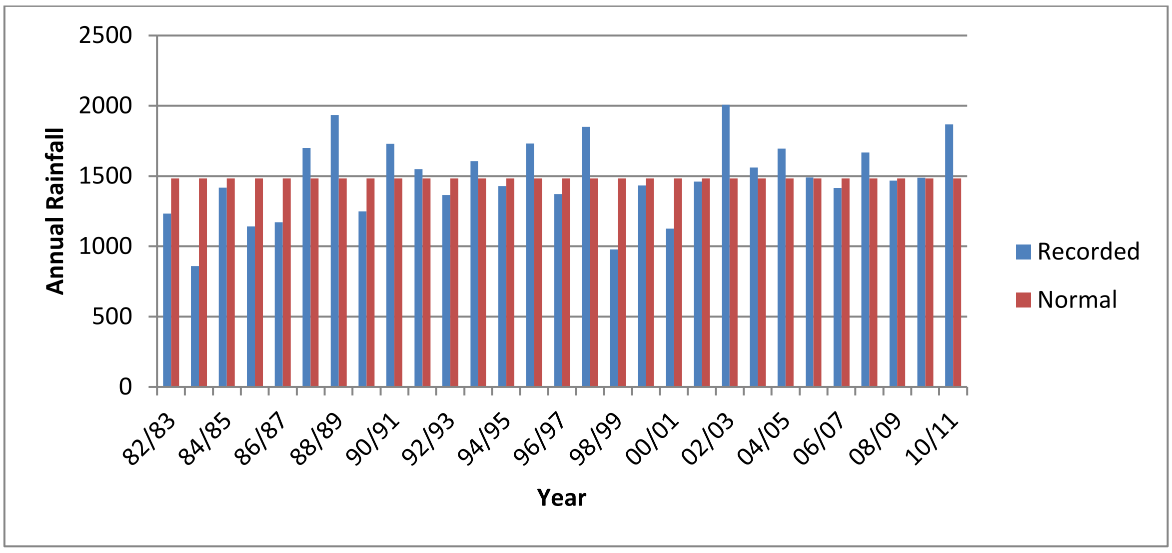

Fig. 4: Annual Rainfall Distribution of Ikeja

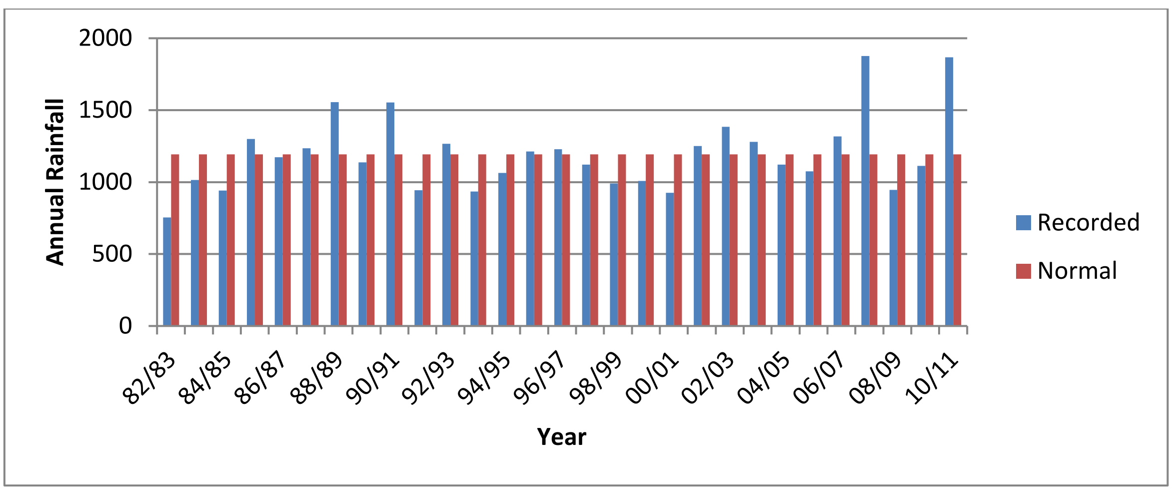

Fig. 5: Annual Rainfall Distribution of Abeokuta

Annual Potential Evapotranspiration

The annual evapotranspiration of the lower Ogun basin increases northward from 1444.1 mm in Ikeja to 1463.6 mm in Abeokuta. The maximum annual evapotranspiration within the lower Ogun basin ranges from 1826.8 mm to 2098.2 mm, while the minimum annual evapotranspiration ranges from 1043.7 mm to 1123.1 mm in Ikeja and Abeokuta stations, respectively (Fig. 6). This goes to show that was a northward water loss due to transpiration and evaporation in the Lower Ogun basin.

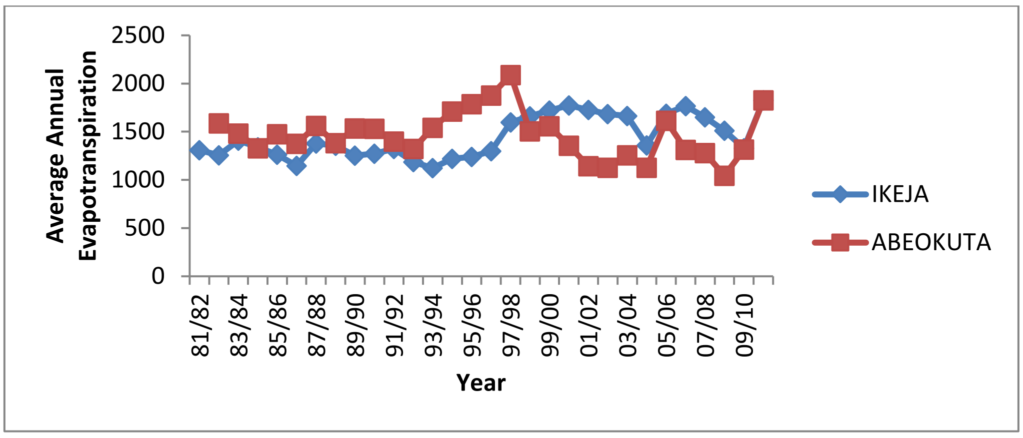

Fig. 6: Trend of Average Annual Evapotranspiration

Monthly Potential Evapotranspiration

As the average monthly evapotranspiration increases from the beginning of the raining season in April to September, there is a sharp decrease during the dry season starting from November to March (Fig. 7). Furthermore, it was observed that the potential evapotranspiration decreases northward in the lower Ogun basin in the wet season from Ikeja to Abeokuta, while the reverse is the case during the dry season when potential evapotranspiration decreases southward. This shows that monthly distribution of potential evapotranspiration correlates with quantity of water available.

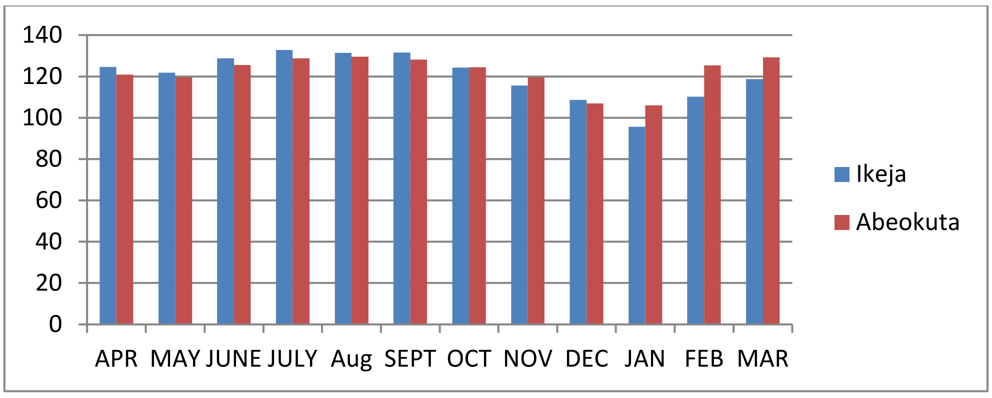

Fig. 7: Trend of Monthly Average Evapotranspiration

Soil-moisture balance method

Table 4 shows that the computed recharge for Abeokuta ranges from zero to 322.3mm/year, with the percentage groundwater recharge of rainfall ranges from 0.0% to 23.3%. The groundwater recharge estimated for Ikeja ranges from zero to 536.1mm/year, with the percentage of rainfall that becomes groundwater recharge ranges from 0.0 % to 31.6 %.

Table 4: Groundwater Recharge Computed From Soil-Moisture Balance Method

No	Hydrologic yr	Abeokuta			Ikeja		
	Year	P	Rn	%Rn	P	Rn	%Rn
1	82/83	753.7	145.3	19.3	1232.4	226.8	18.4
2	83/84	1014.5	19.3	1.9	860.8	131.7	15.3
3	84/85	941.2	21.0	2.2	1417	202.3	14.3
4	85/86	1299.7	115.1	8.9	1143	13.1	1.2
5	86/87	1172.4	123.2	10.5	1172.4	141.8	12.1
6	87/88	1235.5	133.9	10.8	1699.8	165.9	9.8
7	88/89	1557	337.3	21.7	1933.5	560.3	28.9
8	89/90	1138.2	70.9	6.2	1249.1	217.7	17.4
9	90/91	1552.7	154.2	9.9	1728.9	202.9	11.7
10	91/92	943	14.5	1.5	1549.3	385.4	24.9
11	92/93	1265.5	14.5	1.1	1364.4	173.9	12.8
12	93/94	934.7	0.0	0.0	1606.4	271.8	16.9
13	94/95	1063.9	0.0	0.0	1429.2	128.5	8.9
14	95/96	1213.5	0.0	0.0	1731.2	254.2	14.7
15	96/97	1229.7	55.6	4.5	1372.2	185	13.5
16	97/98	1122.3	0.0	0.0	1850.9	417.3	22.6
17	98/99	990.18	0.0	0.0	978.7	0	0
18	99/00	1009.2	98.6	9.8	1434.6	101.7	7.1
19	00/01	925.4	86.3	9.3	1125.2	76.9	6.8
20	2001/2002	1251.1	143.1	11.4	1459.8	10.4	0.7
21	2002/2003	1384.7	322.3	23.3	2007.7	344.7	17.2
22	2003/2004	1279.6	0.0	0.0	1560.1	158.3	10.2
23	2004/2005	1122.2	0.0	0.0	1695.6	536.1	31.6
24	2005/2006	1075.9	16.8	1.6	1489.3	146.2	9.8
25	2006/2007	1318.1	193.3	14.7	1416.3	117.6	8.3
26	2007/2008	1876.4	0.0	0.0	1669	218.4	13.1
27	2008/2009	944.9	0.0	0.0	1467.3	273	18.6
28	2009/2010	1112.6	41.2	3.7	1487.2	432.6	29.1
29	2010/2011	1867.7	196.1	10.5	1867.7	196.1	10.5
30	2011/2012	1217.4	79.8	6.56	1627.7	262.9	16.1
	AVRG	1193	115.1	9.3	1482.7	216.9	14.0

P = Precipitation, Rn = Recharge, %Rn Percentage Recharge

Water table fluctuations

Results computed from water table fluctuation method shows that the percentage of groundwater recharge ranges from 0.8 – 4.3 % in Abeokuta and 2.5% - 4.5% in Ewekoro (Table 5).

Table 5: Summary of Results Obtained From Water Table Fluctuations (2011)

Area	Wells (m)	ΔH (m)	SY	Max R (mm)	Min R (mm)	Rainfall (mm)	RAN-REGH (%)
Abeokuta	20	1.6-8.7	0.015	130.5	24.0	1868.0	0.8-4.3
Ewekoro	10	3.0-5.4	0.025	135.0	75.0	3023.0	2.5-4.5

ΔH = Change In Water Table Rise, Sy = Specific Yield, Max R =Maximum Recharge, Min R = Minimum Recharge, Ran-Regh = Range of % Recharge

Based on the twenty-eight years of study, it was posited that there was a sharp increase in the annual rainfall from the coastal region of Ikeja - Lagos state to Abeokuta in Ogun state, indicating a northward increase in the distribution of rainfall in the lower Ogun basin. For the study period, more wet years were experienced in the southern part of the lower Ogun basin. However, the northward decrease in normal annual evapotranspiration from suggests that potential evapotranspiration correlates positively with vegetation; as Ikeja and environs is well advanced in urbanization compared to Abeokuta. Groundwater recharge based on soil-moisture balance method carried out in Abeokuta and Ikeja revealed that the percentage of annual rainfall that becomes groundwater recharge was found to range between 0.0% to 23.3% in Abeokuta, and 0.0% to 31.2% in Ikeja. These results are similar to that of the work of Bakundukize *et al*. (2011), who extensively computed groundwater recharge in Bugesera region, Burundi where groundwater recharge ranges between a minimum 0 mm/year to 622.3mm/year for the 34 years of study. The possible explanation of the years where groundwater recharge was found to be zero is that those years were dry years while the years with considerable groundwater recharge are termed wet years. The result obtained from the water table fluctuation method shows that the percentage of rainfall that annually recharge the groundwater ranges from 0.8% to 4.3% in Abeokuta, and 2.5% to 4.5% in Ewekoro. This was found to be similar to that of Rasmussen and Andreasen (1959) where groundwater recharge is estimated to be 247 mm/year in a small basin in a humid region of the eastern US and Delin *et al*. (2006) who used the graphical approach for the water table fluctuations.

Relationship of Groundwater Recharge with Dominant Rock and Soil in Lower Ogun Basin

The groundwater recharge percent of rainfall in the Abeokuta, (0.8% to 4.3%) is relatively similar to of Ewekoro (2.5% to 4.5%) based on the study of water table fluctuations of wells in the areas (as in Table 6). While the soil-moisture balance method shows that groundwater recharge in the well-advanced urban center of Ikeja is greater than that of Abeokuta and Ewekoro. This could be in line with the recent findings of Sharp (2010) on the effect of urbanization on recharge where he argued that groundwater recharge is dependent on land uses, water uses, vegetative cover, and geologic condition. The results obtained in the three locations go in line with the work of Sharp (2010) who asserted that recharge rates might vary spatially and temporally but recharge generally increases within urban areas. Abeokuta, a developing urban center, had lesser values of groundwater recharge, which may be as a result of intense pumping in the areas and the geologic nature of the basement complex, despite its closeness to the river Ogun. The low range of groundwater recharge percent of rainfall in the rural area of Ewekoro may result from the geologic alignment, and the absence of impervious cover, resulting in increase of evapotranspiration from the dense vegetations in its rural area environment (Sharp, 2010). Although, water fluctuations of wells were not studied in Ikeja and environs, the soil-moisture balance method revealed that there was high groundwater recharge in the area. This was assumed to result from its closeness to the Atlantic Ocean, which influences its high rainfall distribution, its sedimentary nature of the soil and low vegetation covers despite the high potential evapotranspiration loss. Furthermore, detailed study of the three areas on demographic, water use and perception may reveal how urbanization impact groundwater recharges further.

Table 6: Summary of Groundwater Recharge Estimates

Urban area	Geology	Soil type	Groundwater recharge percent of rainfall	
			Water Table Fluctuation	Soil-Moisture Balance
Abeokuta	Basement	Clay	0.8% - 4.3%	0.0% - 23.3%
Ikeja	Sedimentary	Clay		0.0% - 31.6%
Ewekoro	Sedimentary	Sandy loam	2.5% - 4.5%	

Variation in rainfall and recharge in the Ogun Lower Basin

Looking closely on the variation that exists between the rainfall and recharge on ten years (decadal) basis for the two stations – Abeokuta and Ikeja for the hydrologic years, as in Table 4, it could be derived that the first decade starting from the year 1982/1983 to 1991/1992 witnessed lowest rainfall in 1991/92 in Abeokuta with the corresponding percentage recharge of 1.5, whereas Ikeja stations had considerable rainfall of 1549.3 and recharge percentage of 24.9%. A clear high rainfall was observed in Ikeja and Abeokuta within this decade, with the highest occurring in the 1988/89 hydrologic year and corresponding highest recharge percentage of 28.9. Abeokuta had 1557mm of rainfall and 21.7% became recharge. The lowest percentage of recharge of 1.2% in Ikeja occurred in the hydrologic year 1985/86 with rainfall of 1143 mm, at a time recharge was 8.9% in Abeokuta with considerable 1299.7 mm of rainfall.

The second decadal analysis between the hydrologic year 1992/93 to 2001/2002 shows that there is no recharge in the year 1993 to 1996 and 1997 to 1998 in Abeokuta station and 1998/99 in Ikeja station. These years are termed dry years. It was observed that scarcity of water was experienced in these years in the two cities at this material time. However, towards the end of the decade, the recharge percentage picked up from 9.3 % to 11.4 % in Abeokuta but it slides to 0.7 % in Ikeja from highest point of 22.6 %. The third decadal analysis between the hydrologic year 2002/2003 to 2011/2012 shows that there was continuation of drought immediately after the year 2002/2003 and 2007 to 2009 in Abeokuta station as against increase in recharge percentage value in Ikeja station from 17.2% to 31.6%. The recharge value however fluctuated towards the end of the decade in Ikeja. But the recharge of Abeokuta picked up from 3.7 to 10.5 % toward the end of the last decade. The general notion that rainfall determines the recharge is challenged by this decadal analysis results. This study is agreeing to the assertion that local climatic factor as well as other factors – topography, soil and geomorphic agents seems to be prevailing on the recharge of the Ogun lower basin.

Development of rainfall – recharge relationship for the basins

The relationships between average annual rainfall and groundwater recharge were carried out using linear regression analysis. The essence of this is to develop equations from the soil moisture analysis that give the best fit and which can be used for preliminary recharge estimations for the basins. Thus, based on soil moisture method, Abeokuta station had a linear equation of $R = 0.152P - 102.8$, with correlation coefficient of 0.18 (Fig. 8), which is not significant. Ikeja has a linear equation of R = 0.320P – 258.0, with correlation coefficient of 0.393 (Fig.9). The recharge is R and the annual rainfall is P.

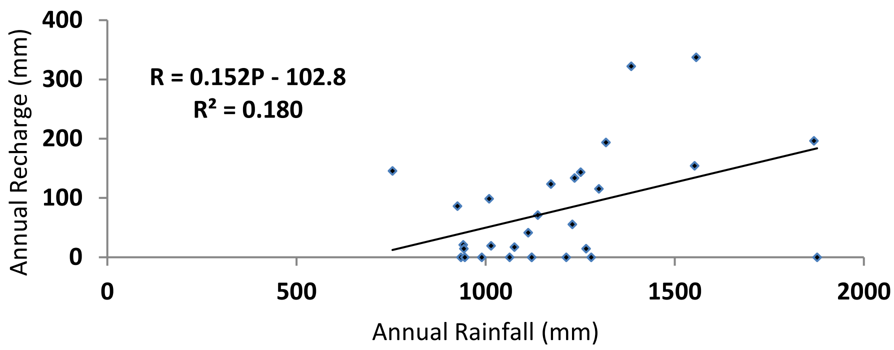

Fig. 8: Rainfall – recharge relationship at Abeokuta Station

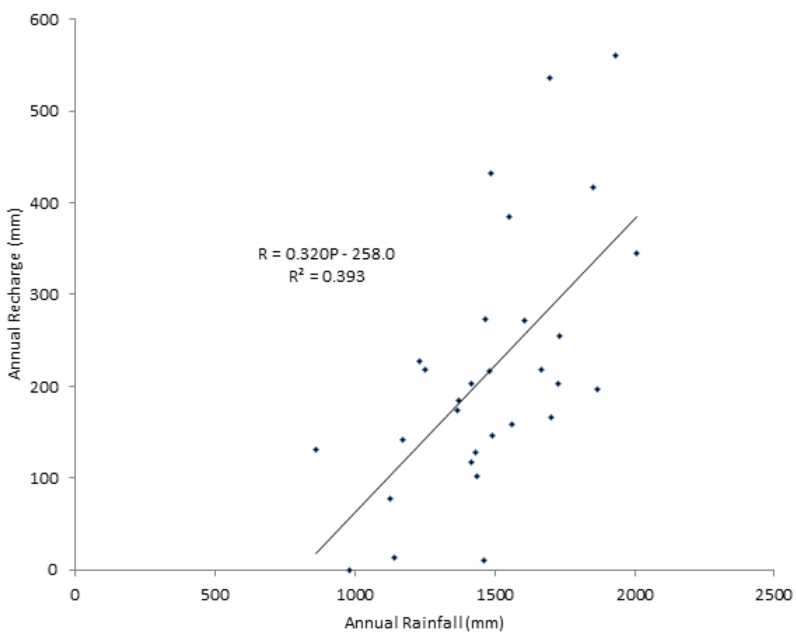

Fig. 9: Rainfall – recharge relationship at Ikeja

Conclusion

This study revealed that there was a northward decrease in the annual rainfall and evapotranspiration, from the coastal region of Ikeja to Abeokuta. The monthly distribution of the rainfall reveals that raining season begins in April to July; with a sharp decrease in August before the second wet season starts in September with a peak in October. The monthly evapotranspiration distribution in the lower Ogun basin reveals that evapotranspiration correlates with seasons, as there is an increase in southern part of the basin during wet season and an increase northern part during the dry season. The general notion that rainfall determines the recharge is challenged by decadal analysis results while the assertion that local climatic factor as well as other factors – topography, soil and geomorphic agents influenced recharge are supported by these results.

It can be concluded that based on soil-moisture balance method of groundwater recharge estimation, more groundwater recharge is found in the lower, well advanced urban part of the basin where there is high amount of annual rainfall, while there is reduction northward to Abeokuta as rainfall decreases. It is recommended that a detailed investigation and monitoring of discharges in the areas, as well as loss from mains, and pumping from boreholes will reveal further impacts of urbanization on the lower Ogun basin. It is also concluded that for preliminary recharge estimations for the lower Ogun basins, a linear equation of $R = 0.152P - 102.8$, with correlation coefficient of 0.18 can be used for Abeokuta station while for Ikeja station, a linear equation of $R = 0.320P - 258.0$, with correlation coefficient of 0.393 can be used. However, other methods of estimating recharge should be used and correlation of coefficient and determination determined to establish if same linear equation is obtained in other to achieve standardization of the preliminary recharge estimations equation for the basin.

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Determination of Pollution Status of River Benue at Makurdi Town, Nigeria

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Abstract
In this study, the pollution status of River Benue at Makurdi town was examined against the backdrop of its suitability for domestic uses. Physico-chemical and bacteriological concentrations in the river were used to determine the pollution status. Fifteen (15) composite water samples were collected across the 11km stretch of River Benue within Makurdi urban area in September, the peak of rainy season. Analysis was based on standard methods for water examination and level of concentration compared with WHO and Nigerian standards for drinking water. The results of analyses show turbidity, colour, cadmium, iron, copper and faecal coliform had elevated concentrations above the Nigerian standards. The average concentrations levels of these elements and the others studied exhibit variability with lowest at sampling station 1 upstream and increasing downstream at station 5. Consumers of raw water from River Benue stand the risks of contracting water and heavy metal related diseases such as typhoid, chlorea, diarrohoea, cancer, and brain damage problems. The source of this pollution is traced majorly to wastes both solid and liquid generated from residential, commercial and industrial establishments that find their way into water bodies. There is therefore need to monitor continuously the pollution level of River Benue and to regulate all activities capable of polluting the water sources. Indiscriminate dumping of wastes into water sources should be avoided. Industrial establishments should treat their wastes before they are discharged.
Keywords: River Benue, pollution, physico-chemical, concentration, status

Introduction
River Benue is the second largest river in Nigeria, a major tributary of the River Niger. The river rises from Adamawa plateau to the northern Cameroun and flows through States like Adamawa, Taraba and Benue before joining River Niger at Lokoja in Kogi State. The river has approximately a length of about 1,400km and has tributaries such as River Gongola, Mayo and Katsina-Ala (Udo,1981).River Benue is the main source of water supply for domestic, agricultural, industrial and recreational activities to inhabitants both rural and urban areas within the precinct of the river. Over the years, increase in population growth

coupled with urbanization characterized with concentration of socio-economic activities has placed greater toll on the quality and quantity of usable water. Makurdi town is one of the major towns being a state capital within the River Benue valley. Makurdi became a State capital following the creation of Benue State in 1976. Consequent upon the changing status Makurdi has continued to witne
ss greater in migration and concentration of socio-economic activities. The implication is that Makurdi town is faced with problems of acute water shortage, waste generation, environment pollution and degradation (Ocheri, 2006).

River Benue within Makurdi is a ready source for disposal of all kinds of waste from residential, industrial and commercial establishments. According to Hyland and Kupchella (1990) the discharge of industrial effluents and other wastes, solid or liquid of domestic origin into rivers and streams is an age long practice. For example Benue Brewery, Coca cola bottling company are located within the Benue River bank. Effluent from these industrial establishments drains into the river that has the capacity of compromising the natural quality of the water. Beside, stormwater runoff and occasional flooding of River Benue is tasking the quality of usable water which has implication on human health if such water is consumed directly without any form of treatment. This concern has attracted several studies on surface water quality in different parts of Nigeria urban areas (Ajayi and Osibanjo,1981;Olajire and Imekeoparia, 2001; Okpokwu, 2001; Bisong *et al.*, 2004; Okorie and Achlonu, 2003; Anyam *et al.*, 2004; Egborge,1991; Arimoro *et al.*, 2008; Emere and Nasiru, 2009; Amadi *et al.*, 2012a; Amad *et al.*, 2012; Eneji *et al.*, 2012). Consistent in their findings is that these surface water sources are polluted to some extent which has implications both on human and aquatic life. There is need, therefore to continuously monitor the quality of river water as quality expectation is required to protect drinking water resources, encourage activities and to provide good environment for fish and wildlife(Amadi *et al.*, 2010). Changes in water chemistry of rivers are usually anthropogenic via domestic, industrial and agricultural discharges which may in turn result to degradation of aquatic ecosystem (Amadi, 2010). The urban aquatic ecosystem are strongly influenced by long term discharge of untreated domestic and industrial wastewater, stormwater runoff, accidental spills(Sarika and Chandranohankanner, 2008) and direct waste dumping cause pollution which has great ecological impact on the river water quality and its surrounding food web (Abhishek and Mishra, 2008; Hejabi and Belagali, 2009).

All natural water is considered to be polluted when dissolved substances are present in amounts that make water unfit or undesirable for specific use (Drever, 1982). According to Tulley (1966) pollution is the alteration of natural environment, water, and soil which render them offensive or deleterious to aesthetic sense or for man's uses or for animal, fish and crop which man wish to preserve. But such alteration may not be considered as pollution until it reaches a limit of tolerance. In this study attempt is made to determine the pollution level of River Benue in Makurdi town. The concentration of physico-chemical and bacteriological elements in the river based on the WHO and Nigerian Drinking water standards were used to determine the pollution level of River Benue.

Materials and Methods

River Benue divide Makurdi town into Makurdi North and Makurdi South which lies between Lat.7^0 44N and Long.8^0 54N and is located within the floodplain of the lower River Benue valley(Fig.1).Makurdi town is drained principally by River Benue. Other minor rivers that drain Makurdi town and empty their water into River Benue include Idye, Genebe, Urudu, Kpege and Kereke. Occassionally, Makurdi town experiences river and flash floods accentuated by the general low physiography of the area (Ocheri, 2012).The flow pattern of most rivers in the tropics is detected by the climatic variability reflected in the swelling and the reduction in size or drying up during rainy and wet seasons (Ifabiyi, 2008).The warm moist southerly airmass and the dry northerly airmass is responsible for wet and dry season in Makurdi town. The mean annual rainfall is 1190mm and ranges from 775-1792mm.Temperatures are generally high throughout the year, with February and March occurring as the hottest months. Temperature in Makurdi varies from a minimum of 22.5^0C to a maximum of 40^0C (Ologunorisa and Tersoo, 2006). Makurdi is underlain by a geological formation that is cretaceous which is mainly of fluvio-deltaic sediments with well-bedded sandstone which are of hydrogeological significance in terms of groundwater yield and exploitation. Generally, groundwater table is high as such can be tapped at shallow depths even at 1m (Kogbe *et al.*, 1978; Ocheri *et al.*, 2010).

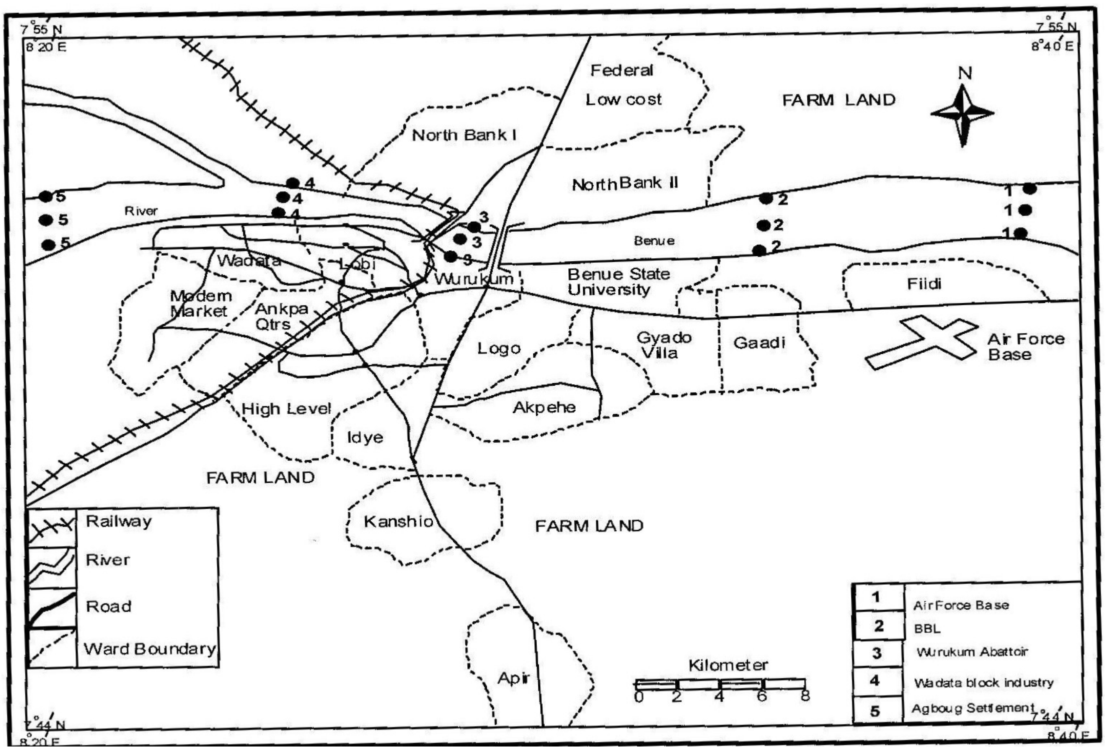

Fig.1: Map of Makurdi Town showing the sampling stations

Data for this study were obtained from analyses of water samples collected at designated points along the 11km stretch of River Benue within Makurdi town. Fifteen (15) composite water samples in all were collected from River Benue at five stations designated as stations 1, 2, 3, 4, and 5 at interval of 2km representing upstream to downstream stretch. For each of the station, three water samples were collected across the river using a canoe, one on the either side toward the bank of the river and in the middle. These stations were selected to reflect different landuses that can contribute to pollution of the water. These include residential, industrial and abattoir. Water samples were collected in the month of September being peak of rainy season vulnerability of pollution water sources is expected. This is confirmed in Eneji *et al.* (2012) study on heavy metals loading of river Benue. The collection, transportation, preservation and analyses of water samples were carried out as prescribed in the standard methods for water examination (APHA, 1985) and interpreted based on the Nigerian Drinking Water Quality Standards. The concentrations of the physico-chemical and bacteriological constituents as they affect the quality of drinking water were used to determine the pollution level of River Benue. Both field based and laboratory analyses were used in the study. Parameters examined in this study include pH, colour, temperature, turbidity, electrical conductivity, total dissolved solids, alkalinity, chloride, iron, chromium, cadmium, lead, copper, zinc and total coliform. For parameters like pH, temperature, electrical conductivity, turbidity calibrated meters were used in the analyses. For other parameters like alkalinity, total dissolved solids, chloride different laboratory titration techniques were used in their determination. Heavy metals such as iron, chromium, cadmium, lead, copper, zinc were analysed using atomic absorption spectrophotomectric techniques. While total and faecal coliform were determined using multiple fermentation and most probable number(MPN) techniques using media such as nutrient agar and macConkey agar.

Results and Discussion

The results of physico-chemical and bacteriological analyses of water samples from River Benue is presented in Table 1.

Table1: Results of physico-chemical characteristics of River Benue at Makurdi Town

Parameter/station	**1**	**2**	**3**	**4**	**5**	Allowable Limit (NSDWQ, 2007)
Temp. (^{0}C)	26.400	30.433	25.333	27.389	27.719	-
PH	6.633	7.600	7.567	7.267	7.478	6.5-8.5
Colour (TCU)	175.667	271.333	332.667	259.889	287.963	15
Turbidity (NTU)	52.333	68.667	75.333	65.444	69.815	5
TDS (mg/l)	43.500	48.067	50.467	47.344	48.626	500
EC (μS/CM^{-1})	67.400	86.867	89.400	81.222	85.830	-
Alkalinity (mg/l)	20.933	44.020	59.760	41.571	48.450	100
Chloride (mg/l)	21.193	29.850	32.487	27.843	30.060	250
Iron (mg/l)	0.133	0.193	0.210	0.179	0.194	0.3
Chromium (mg/l)	0.033	0.053	0.057	0.048	0.053	0.05
Cadmium (mg/l)	0.001	0.011	0.002	0.005	0.006	0.003
Lead (mg/l)	0.004	0.005	0.005	0.005	0.005	0.01
Copper (mg/l)	0.693	0.907	0.907	0.836	0.883	1.0
Zinc (mg/l)	1.200	1.647	1.980	1.609	1.745	3.0
TCC (MPN/100l)	350.000	783.333	3433.333	1522.222	1912.963	0/100

Table 2: Descriptive Statistics of Water Samples along River Benue within Makurdi.

Parameters	Minimum	Maximum	Mean	Standard deviation	CV%
Temperature (^{0}C)	25	32	27.88	3.140	0.122
pH	6.4	7.7	7.42	0.422	0.057
Colour (TCU)	170	398	256.06	60.76	0.237
Turbidity (NTU)	48	78	62.86	10.78	0.172
TDS (mg/l)	41.6	52	46.82	2.95	0.063
Electrical conduct. (μS/cm $^{-1}$)	64	91	77.96	9.168	0.118
Alkalinity (mg/l)	19.8	68.42	45.10	17.68	0.392
Chloride (mg/l)	19.8	41.79	31.43	6.693	0.218
Iron	0.12	0.28	0.191	0.043	0.224
Chromium (mg/l)	0.03	0.06	0.046	0.012	0.237
Cadmium (mg/l)	0.001	0.008	0.004	0.004	1.057
Lead(mg/l)	0.003	0.008	0.005	0.0046	0.679
Copper (mg/l)	0.64	1.02	0.860	0.255	0.296
Zinc (mg/l)	1.0	2.41	1.78	0.401	0.225
Total coli form count (MPN/100ml)	275	7800	1273.3	19.12	0.017

Temperature

The rate of biological and chemical reaction depends to large extent on temperature. The discharge of water from cooling processes such as electric stations, steel rolling mills, breweries into river raises temperature of such bodies. This disrupts aquatic ecosystem, as it results to depletion of dissolved oxygen and increase vapour pressure of volatile trace compounds in water and may induce odour. A rise in temperature of even 10^{0}C due to discharge of large volume of used cooling water can have several consequences (Webber, 1964; Martins, 1968).Temperature of water sample analysed ranged from 25 to 31^{0}C with a mean and coefficient of variation (CV) of 27.8 and 0.123%.The highest temperature of 32^{0}C was recorded in station 2 where Benue Brewery and Coca Cola bottling company is located. The effluent discharged from these industries may have accounted for high temperature as they find their way into River Benue. This is consistent with Bisong *et al.* (2004) findings of brewery industrial effluents into Ikpoba River in Benin City. The temperature variability does not exhibit a particular trend from upstream to downstream stretch. The highest temperature average of 30.4^{0}C was recorded in station 2, lowest of 25.3^{0}C in station 3, while stations 1, 4 and 5 had 26.4^{0}C 27.3^{0}C and 27.7^{0}C, respectively. This may be attributed to river flow dynamics.

pH

pH of water is an important parameter in describing the quality of water as the dissolution of mineral ions depends on it. It is very important in that it may affect the solubility and toxicity of metals in aquatic system (Efe *et al.*, 2005). pH of water samples analysed ranged from 6.4-7.7 with a mean and CV of 7.42 and 0.057%.The CV suggests that the pH of River Benue is almost the same throughout all the sampled stations. The River Benue water is alkaline and is within the NSDWQ recommended limit for drinking water. Apart from station1 upstream that had an average pH of 6.6 which is slightly acidic, all other stations maintained their alkalinity downstream.

Colour

Colour affects the aesthetic quality of water and also an indication of dissolved elements which may have health implications. According to WHO (2006) consumers to a large extent have no means of judging the safety of water themselves, but their attitude towards drinking water supplies will be affected to a considerable extent by the aspects of the water quality they able to perceive with their senses. It is natural for consumers to regard with suspicion water that appear dirty or coloured or has unpleasant taste or smell even though these characteristics may not in themselves be of direct consequence to health. Polluted water is not just dirty, but it is also deadly (NAS, 2009). Colour concentrations in the water samples ranged from 170-398 TCU having a mean of 256.1 and CV of 0.237%. Although the concentration of colour in the river varies with stations, the highest concentration is recorded in station 3 which is the abattoir. This probably may be traced to wastes both liquid and solid which are discharged into River Benue as the abattoir is located directly at the bank of the river. The colour concentration in River Benue is far above the NSDWQ set limit of 15TCU for drinking water. The average colour variability among the stations reveal station 1 has the lowest of 175.6 TCU upstream, and station 3 with the highest of 332.6 TCU.While stations 4 and 5 at downstream had 259.9 TCU and 287.9, respectively.

Turbidity

Water is said to be turbid when it lacks transparency as result of dissolved elements an indication of pollution. For drinking water NSDWQ set a limit of 5 TNC.The results of analyses show that all water samples from the stations have turbidity concentrations far above the NSDWQ guide limit for drinking water. Turbidity in water samples ranged from 48-78 NTU with a mean and CV of 62.86 NTU and 0.172%. Station 3 has the highest mean turbidity of 75.33 NTU at the abattoir station and lowest at station 1 NAF base. Abattoir wastes may have contributed to turbid nature of the River Benue. All the stations sampled for turbid concentrations in the river far exceeded the standard set for drinking water. The turbidity of the River Benue may be traced to all kinds of wastes generated from the residential, commercial and industrial establishments coupled with run off stormwater discharge into the river. On the variability of turbidity among the stations, station1 had an average of 52.3 NTU at upstream, while the highest of 75 NTU was recorded in station 3. The concentrations of turbidity at downstream section, stations 4 and 5 were 65.4 NTU and 69.8 NTU, respectively.

Total Dissolved Solids

Drinking water with high concentrations of total dissolved solids makes the water not potable and constitutes an unfavourable physiological problem when consumed. The amount of dissolved matter in water is approximately proportional to its electrical conductivity (Nikoladze *et al.*, 1989).Total dissolved solids ranges between 41.6-52 mg/l, having a mean of 46.8 and CV of 0.063%. TDS concentrations in all the stations are within the NSDWQ limit for drinking water. However, on TDS variability, an average of 43.5 mg/l being the lowest was recorded in station 1 upstream and the highest of 50.4 mg/l in station 3 mid stream. Stations 4 and 4 downstream had 47.3 mg/l and 48.0 mg/l respectively.

Electrical conductivity

The electrical conductivity of the water samples from Benue are all within the NSDWQ prescribed limit for drinking water although the concentration varies among the stations. Electrical conductivity ranges from 64 to 91 uS/cm, mean of 77.96 and CV of 0.118%. The highest electrical conductivity is recorded in the station C which is the abattoir. Discharge of wastes from the abattoir may have contributed to the concentrations in electrical conductivity in this station. The average electrical conductivity among the stations reveal station1 with the lowest of 67.4 $\mu S/cm^{-1}$ upstream and with the highest of 89.0 $\mu S/cm^{-1}$ at station 3 mid stream. At downstream section, stations 4 and 5 had 81.0 $\mu S/cm^{-1}$ and 85.0 $\mu S/cm^{-1}$, respectively.

Total alkalinity

The concentrations of alkalinity of the River Benue are within the NSDWQ allowable limit of 100-500 mg/l for drinking water. The alkalinity ranged between 19.8-68.42 mg/l with a mean of 45.1 and CV of 0.392%. On the average variation in concentration among the stations, station 1 had the lowest of 20.9 mg/l and the highest of 59.7 mg/l at station 3 mid stream. Stations 4 and 5 at downstream section had 41.5 mg/l and 48.4 mg/l, respectively.

Chloride

Chlorides mostly sodium, calcium and magnesium are present in all kinds of natural waters. The solubility of sodium chloride is 360mg/l and that of magnesium chloride is 545 mg/l. If chlorides are present in water in substantial concentrations, water becomes aggressive to concrete. Chloride concentrations ranged from 19.8 to 41.79 mg/l, with a mean and CV of 31.4 and 0.218%. They are all within the NSDWQ guide limit for drinking water quality. However, on the average variability among the stations, station 1 upstream had the lowest of 21.2 mg/l, and a highest of 32.4 mg/l was recorded in station 3 midstream. Chloride concentrations of 27.8 mg/l and 30.0 mg/l were recorded in stations 4 and 5, respectively.

Iron

The iron concentration ranged from 0.12 -0.28 mg/l with a mean and CV of 0.19 and 0.224%. Although variation exists in the concentration of iron among the water samples, the concentration of all the samples are however above the NSDWQ limit for drinking water. The highest iron concentration is recorded in station 4 which is Wadata/New Garage where sand harvesting, block molding and automobile repairs go on. This may have contributed to the increased iron concentration in this station. However, on the average variability among sampling stations, station 1 recorded the lowest of 0.13 mg/l and the highest 0.21 mg/l in station 3 mid stream. Stations 4 and 5 had 0.17 mg/l and 0.19 mg/l, respectively. Excessive iron concentrations in water bodies can cause damage to cells of gastrointestinal tract and may also cause damage to the cells in the heart and liver (Adraino, 2001).

Chromium

Chromium is essential for sugar metabolism l in plants and animals; it is involved in the role the insulin plays in cells in the transport of glycolysis, the first step in adenosine triphosphate production. Chromium salts can be toxic to organisms at higher oxidation states (Eneji *et al.*, 2012). Chromium concentration in River Benue ranged from 0.03 to 0.07 mg/l with a mean of 0.05 and CV of 0.237%. Stations 2, 3 and 4 had elevated chromium concentrations above the NDWQS limit of 0.05 mg/l. The stations are Benue Brewery/Coca Cola bottling company, abattoir and Wadata/New Garage areas. The cause of elevated concentrations in these stations may be associated with wastes both liquid and solid that eventually find their way into the water bodies. According to Eneji *et al.* (2012), the source of chromium in River Benue may be from surface run offs and leachates associated with municipal solid wastes dumps, fireworks and discharges from small scale local tanneries. Similar findings were noted in River Warri in the Niger Delta by Egborge (1991). On the average variability among the sampling stations, station 1 upstream has the lowest 0.033 mg/l and the highest of 0.057 mg/l at station 3 mid stream. Stations 4 and 5 had concentrations of 0.048 mg/l and 0.053 mg/l, respectively.

Cadmium

Cadmium enters into aquatic ecosystems from the wastewaters of electroplating, chemical industries, hazardous wastes and fireworks and in Makurdi metropolitan area, the major sources of cadmium may linked with poorly managed solid wastes and frequent use of fireworks (Sha'Ato *et al.,* 2007; Eneji *et al.*, 2012). Cadmium in the study ranged 0.001-0.008 mg/l a mean of 0.004 mg/l and CV of 1.057%. Cadmium concentrations in River Benue is generally low except for few stations in station B that had concentrations above the NDWQS guide limit of 0.003 mg/l. The average cadmium lowest concentration of 0.001 mg/l was recorded in station 1 upstream with the highest of 0.011 mg/l at station 2. Stations 4 and 5 had 0.005mg/l and 0.006mg/l respectively.

Lead

Lead concentrations in water samples from River Benue ranges between 0.003-0.008 mg/l with a mean and CV of 0.005 mg/l and CV of 0.679% .The lead concentrations in all the sampling stations analysed were below the NDWQS of 0.1mg/l for drinking water. This finding is however at variant with that of Ajayi and Osibanjo (1981), Eneji *et al.* (2012). High lead concentrations in aquatic body may result in metallic poisoning which may manifest in form of tiredness, lassitude, irritation, anaemia in children, and possible human carcinogen(WHO,1980;Bakare - Odunola,2005. On the average lead concentration among the sampling stations, station 1 has the lowest concentration of 0.004 mg/l and the concentration increases downstream with stations 3, 4 and 5 having 0.005 mg/l, 0.005 mg/l and 0.006 mg/l, respectively.

Copper

Copper is essential to human body but concentrations at objectionable level become toxic to man and animal when ingested in large volume (Pearson, 1976). This why WHO and NDWQS sets a limit of 2.0 and1.0 mg/l. Concentrations of copper ranged from 0.64-1.02 mg/l with a mean and CV of 0.86 and 0.296%. From the results of analyses copper concentrations in River Benue are within guide limits for drinking water. This finding agrees with that of Eneji *et al.* (2012). According to them, municipal effluents and leachates from solid waste dumps could contribute to copper level in water bodies. On the variability of copper concentrations among the sampling stations, station 1 upstream has the lowest of 0.693 mg/l with the highest of 0.907 mg/l for both stations 2 and 3, while stations 4 and 5 downstream had 0.886 mg/l and 0.88 mg/l, respectively.

Zinc

Concentrations of zinc in River Benue ranged between 1.0-2.41 mg/l with a mean of 1.78 and CV of 0.225%. The concentrations at sampling stations fall within the NDWQS set limit of 5.0 mg/l for drinking water. One of the sampling points in station 4 has the highest zinc concentrations of 2.34 mg/l. On the average zinc concentration among sampling stations, station 1 has the lowest of 1.200 mg/l and the highest of 1.980 mg/l at station 3 mid stream. Stations 4 and 5 had 1.609 mg/l and 1.745 mg/l, respectively. The low concentrations of zinc recorded in River Benue is consistent with the findings of Egboh and Emeshili (2007) for River Ethiope in Delta State and Eneji *et al.* (2012) for River Benue.

Total coliform

Coliform bacteria are always present in the digestive tracts of animals, humans and in wastes. Because of their harmful effects NDWQS set guide limit of 50/100 for drinking water. Total coliform ranged from 275-7800 MPN with a mean of 1273.3 and CV of 0.017%. From the analyses all the sampling points have coliform concentrations far above the recommended guide limit for drinking water. Station 3 was particularly noted to have the highest coliform concentration of 7800 MPN. This is obvious because abattoir is located within this station. Wastes generated from the abattoir finds their into River Benue thereby increasing the bacterial load of the river .This implies the consumers of raw water from River Benue stand a very high risk of water borne diseases .On the total coliform variability among the sampling stations, station I upstream recorded the lowest average concentrations of 350.0 MPN and the highest of 3,433 MPN at station 3 mid stream. The total coliform count at stations 4 and 5 were 1,522 MPN and 1,912 MPN, respectively.

Conclusion

From the investigation, River Benue is polluted with elements of health implications. River Benue is polluted with heavy metals especially iron, chromium, cadmium and copper which are toxic to human and animal health and bacteriological contamination with increasing concentrations downstream. The source of this pollution is traced majorly to wastes both solid and liquid generated from residential, commercial and industrial establishments that find their way into water bodies. There is therefore the need monitor continuously the pollution level of River Benue and to regulate all activities capable of polluting the water sources. Indiscriminate dumps of wastes into water sources should be avoided. Industrial establishment should treat their wastes before they are discharged.

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Inventory and Sanitary Status of Self Water Supply Systems in Abeokuta, Nigeria

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Abstract
The research centered on self-supply systems in parts of Abeokuta South Local Government Area of Ogun State, Nigeria. Self-supply systems are privately owned household water sources. Data, which includes the types and existing self – supply systems, was collected on house – house basis. Inventory of the systems was carried out to ascertain the number of existing self-supply water sources and assess their current conditions. Nearly all households within the study area rely on self-supply hand – dug wells for their water needs. A total of one thousand, seven hundred and twenty nine (1,729) self-supply systems consisting 1,610 hand-dug wells and 119 boreholes were located with an estimated 31,238 users and an average of 42 users per source. Larger percentages (68.92%) of the assessed hand – dug wells are categorized as semi-protected wells. The contamination risk of the wells is as high as 39%. Water abstracted from hand-dug wells are consumed directly by ingestion or used for laundry and bathing purposes. The water consumers in the environment have the perspective that the water abstracted from the systems is consumable as long as it is clear with denial on the effect of unsafe water on health. It is suggested that increased public awareness should be promoted for self-supply owners and users with respect to the danger of improper construction and maintenance of the systems. It is also recommended that an appropriate distance of at least 10m of self-supply system to any sanitary facility including a solid waste dump site should be maintained. A minimum of 30m is however advised for latrines.

Key words: Hand-dug wells, inventory, self-supply systems, sanitary status

Introduction
Self-supply systems are privately owned household water sources. The systems are generally perceived as playing a role in water service delivery to the rural poor but in reality it is a water supply strategy for the un-served in urban, rural and small towns (Sutton, 2004; Carter

2006, Oluwasanya, 2009; Oluwasanya *et al*., 2011a). The unserved are those with limited or no access to public water systems. Self-supply systems are strictly owner investment. The systems can be incrementally improved, and easily replicable with technologies, which are affordable to users. The improvements are led and financed by the asset owners. Hand-dug wells, privately owned deep wells and boreholes, and rainwater harvesting are typical examples of self-supply systems. Self-supply technologies may include household water treatment and household water supply construction or upgrade (RWSN, 2010). Self-supply, as a water supply option is widely practiced, but tends to be ignored by Governments and funding agencies. Self-supply water system is a self-help approach that should be complementary to conventional communal supply. Communal supplies are heavily subsidized water supply services, which are implemented by governments and others, but managed by communities (RWSN, 2010). In recent times, upgraded self-supply sources are increasingly promoted as formal service delivery models for pro-poor irrespective of location to help achieve universal access (Mekonta *et al*., 2015). It is also endorsed as group-based self-supply sources to reach improved service level targets in informal settlements in the urban and isolated areas (Mekonta *et al*., 2015; Gowing *et al*., 2016).

The total demand for urban services grows as the population in towns and cities rises, with new and higher requirements due to altered lifestyle choices (Jenny *et al*., 2010) resulting to an increase in water demand for numerous uses. Increasing population and urbanization, rapid industrialization, and the expansion and intensification of food production are all putting pressure on water resources, resulting in the discharge of polluted water within and beyond national borders. Pollution is occurring at a time when millions of people still lack access to even the most basic drinking water and billons lack basic sanitation (WHO/UNICEF, 2012). Equitable access to water supply and sanitation has dominated water related issues worldwide, whether this is measured between urban and rural areas, between slums and formal urban settlements, between men and women, or between disadvantaged groups and the general population (UN-Water, 2014). As countries develop and populations grow, the potential demand for water is projected to increase by 55% by 2050. Already by 2025, two thirds of the world’s population could be living in water-stressed countries if current consumption patterns continue (UN-Water, 2014). Approximately 40% of the world’s population lives in basins that comprise two or more countries, which account for about 60% of global freshwater flow with nearly 2 billion people worldwide dependent on groundwater (UN-Water, 2014).

Nigeria with a growth rate of 3.2% (NPC, 2010) is the largest country on the West coast of Africa with a projected population of about 192 million people in 2016, and with about 43% of the populace living in cities or urban areas (Richard and James, 2014, Charles, 2011). The rate of urbanization in Nigeria is alarming and the major cities are growing at rates between 10 to 15% yearly (Olukayode *et al*., 2011). Hence, the need to assess and document water supply approaches that would facilitate the realization of water for all or wider population, and progress towards meeting the relevant SDG target.

Description of the Study Area

Abeokuta South Local Government Area, ASLGA (Fig. 1) is usually referred to as the Premier Local Government in Ogun State, Nigeria, owing to the historic eminence of the geographical entity as the traditional seat of the Local or Native Authority in Egba since 1898. The Local Government has about 35km of tarred roads scattered within the boundary with a landed area of 71 km² and a population of 250,295 with an annual growth rate of 3.03% as at the 2006 census (NPC, 2010). This population is projected to be 337,357 in 2016. Occupations of the indigenes include: Pottery, Tie and dye, Wood carving, and Blacksmithing. The indigenes engage in the highlighted occupations on a large scale in anticipation of foreign investment opportunities. Abeokuta South Local Government is divided into 15 wards for the purpose of elections of councilors into the local government Board. The fifteen political wards and their various townships were categorized into five zones in this research (Table 1).

Table 1: Categorization of townships within Abeokuta South LGA, Ogun State, Nigeria

Zone	Ward	Township
A	1	Ake, Wasimi-Ake, Ibarapa, Isale-Ake, Eruwon, Iporo-Ake
	2	Asero Estate, Car wash-Adatan, Oke-Aregba, Abiola way, Obantoko, Ilupeju, Ire-akari
	3	Adatan, Lantoro, Oke-Ero, Isale-Abetu, Abule-Oloni, Oke-Lantoro
B	4	Aregba, Arinlese, Emere, Kugba, Keesi, Oke-efon, Shaje
	5	Ibon, Isale-Ijemo, Ijemo, Ijemo-Agbadu, Ita-Boyinbo, Odo-Oja, Oke-Ijemo,
	6	Isale-Itoko, Itoko, Oju-Agemo, Oke-Aleji
C	7	Ijaiye, Idi-Aba, Olorunsogo, Iyana Motuary, Kemta-Olokuta
	8	Erunbe, Ijako-Ilogbo, Oke-Ejigbo, Sokenu, NUD
	9	Ago-Ijesa, Ijeun-Titun, Leme, Ewang Estate, Olorombo
D	10	Oke-Itoku, Isale-Ijeun, Iporo-Sodeke
	11	Itoku, Oke-Bode, Odutolu,
	12	Isabo, Kuto, Amolaso, Igbehin, Isale-Igbehin, Imo
E	13	Igbore, Itori, Ago-Oba, Oke-Ikanna, Ogbe and Odo-Oyo.
	14	Panseke, Onikolobo, Sodubi, Abule-Olokemeji, Quarry road, Saraki and Adigbe
	15	Panseke, Onikolobo, Sodubi, Abule-Olokemeji, Quarry road, Saraki and Adigbe

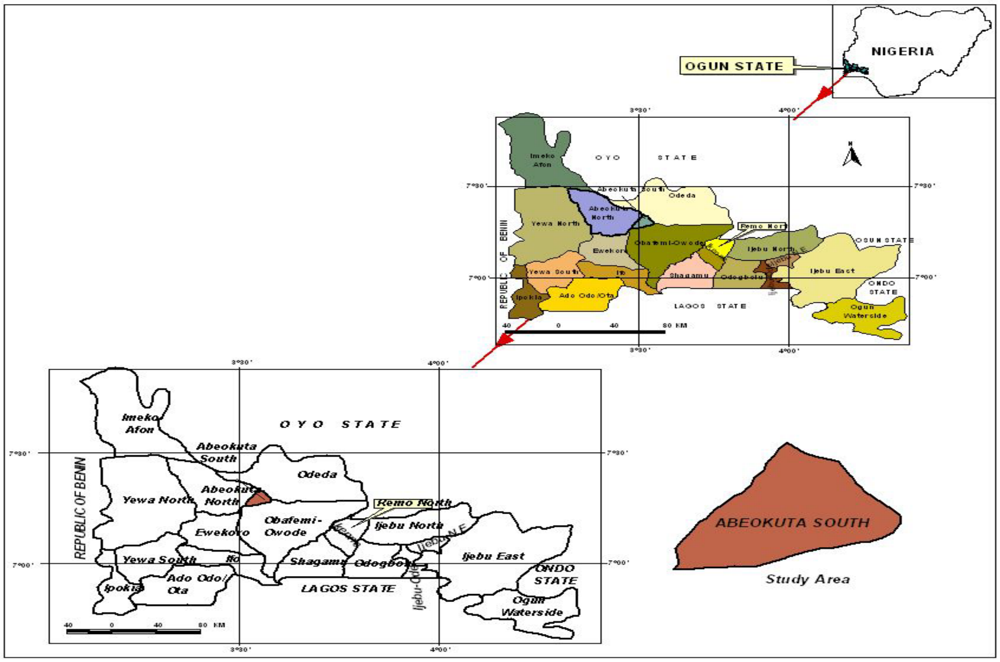

Fig. 1: Location map of Abeokuta South LGA, Ogun State, Nigeria

Methodology

The research field work took place from January – June in 2013. A data sheet was prepared for the collection of the on-site data (Appendix I). A column indicated well point codes for hand-dug wells identification. The coding was based on a short formatting of the Township's name with an assigned serial number (for instance, the third well located in Panseke was coded as `PAN 003'). Other information on the data sheet include date and time of visit, location, geographical coordinates (latitude, longitude and altitude), the well profile such as age of well, depth, static water level, presence or absence of lining, well head and its height, well cover and type, mode of operation, water uses, apron, and drainage. Other information include distances to sanitary facilities (latrine, burial site, solid waste dump, and animal breeding area) and information on the number of people accessing the self-supply system. Water quality indicator parameters such as pH, E.C and TDS were taken in-situ as a rapid water quality assessment. Samples were however collected randomly for bacteriological investigation; *Escherichia coli* counts in the dry season, on-set of rains and rainy season.

The static water level and the well depth were determined with the use of a 30m length measuring tape with a weight attached to the end of the tape. The weight served to indicate the well bottom. The geographical coordinates were determined with the use of a geographical positioning system (GARMIN GPS 12XL). The distance of the various sanitary facilities available at each of the sited wells were measured in meters with measuring tape. The age of wells, number of users and well uses were inquired through a semi-formal interview sessions with the well users during the on-site sanitary survey. Availability of apron, drainage path, well head, lining and well cover with its type were observed. A calibrated HANNA Portable Combo probe meter was used to test the pH, EC, TDS and temperature of the water. Water sample from each of the sources was poured into a beaker and the probe meter inserted for determination of the parameters.

Well classifications

The accessed wells were classified into three different categories based on the data derived from the well profiling. The categories include protected, semi-protected and unprotected wells based on Oluwasanya *et al.* (2011a).

- **Protected wells:** These comprise of wells, which are fully equipped with air-tight (no perforation) well cover, apron, drainage path, and a dedicated rope and bucket or pump for water abstraction (Fig. 2).
- **Semi-protected wells:** Are wells equipped with at least one of the features that made up protected wells (Fig.2).
- **Unprotected wells:** Are wells without any of the features listed for protected well (Fig. 2).

1. Examples of protected wells in ASLGA, Ogun State, Nigeria

IJJ 015 ONK 002

2. Examples of semi-protected wells in ASLGA, Ogun State, Nigeria

IJJ 010 ITE 010

3. Examples of unprotected wells in ASLGA, Ogun State, Nigeria

IJJ 007 IGR 020

Fig. 2: Examples of three classes of wells in Abeokuta South LGA, Ogun State, Nigeria

Sanitary Risk Score Assessment

A sanitary inspection form (Appendix II) developed by Oluwasanya *et al.* (2011b) was used for the assessment of the risk associated with located wells. Data collected during the sanitary survey and the well profiling were used to determine the risk scores. The form consists of eight questions with a minimum and maximum score of 1 and 5 respectively, which translates to a minimum possible risk score of 8 and a maximum possible risk score of 40. The generated scores were then used in risk ranking of wells into low, medium, high and very high risks categories.

Results and Discussion

Inventory

The result obtained from the inventory activities showed a total of 1,729 self-supply systems (hand-dug wells (1610) and boreholes (119)) in the study area. Of this total, 347 systems are within zone A, 309 in zone B, 302 in zone C, 315 in zone D and 456 in zone E. The 1,729 self-supply systems are classified into three groups based on their features with 371 (21.46%) systems as protected, 1212 (70.10%) systems as semi-protected and 146 (8.44%) systems as unprotected wells. A total number of 101 systems out of the 371 protected wells are in zone A, 46 systems in zone B, 97 systems in zone C, 54 systems in zone D and the remaining 73 systems are in zone E. In the class of semi-protected wells, 215 systems out of the 1,212 systems are in zone A, 161 systems in zone B, 205 systems in zone C, 252 systems in zone D and the remaining 379 systems are in zone E. A total number of 31 systems out of the 146 unprotected wells are within zone A, 102 systems in zone B, none in zone C, 9 systems in zone D and the remaining 4 systems in zone E. The spread showed that 29% of the sources evaluated in zone A are protected with 62% semi-protected and 9% unprotected. Fifteen percent of the evaluated systems in zone B are protected with 52% semi-protected and 33% unprotected. Similarly, 32% of the sources in zone C are protected with the remaining 68% as semi-protected. In zone D, 17% of the systems are protected with 80% semi-protected and 3% unprotected. In zone E, 16% of the sources are protected, 83% semi-protected and 1% unprotected. The result shows that the level of well construction and protection decreases from zone C to zone E to zone D to zone A, and to zone B (zone C > zone E > zone D > zone A > zone B) (Table 2 and Fig.3). Townships in Zone C are generally newer municipalities relative to the down-town zone B areas.

However due to owner receptivity and resultant accessibility issues, only 746 of the total located sources were available for profiling and sanitary survey. Water quality testing was further limited to 632 sources due to lack of water in some of the wells. The 746 sources comprises of 702 hand-dug wells and 38 boreholes. Of the 746 evaluated water sources, 133 systems are in zone A, 177 systems in zone B, 249 systems in zone C, 99 systems in zone D and 88 in zone E (Table 3). On the basis of well classifications, 153 (21.76%) systems are protected, 512 (68.92%) sources are semi-protected and 71 (9.32%) systems are classified as unprotected wells (Table 3).

Table 2: List of self-supply systems in Abeokuta South LGA, Ogun State, Nigeria

Segment		Hand-dug wells			
Zone	**Wards**	**Located**	**Protected**	**Semi-protected**	**Unprotected**
A	1, 2, 3	347	101	215	31
B	4, 5, 6	309	46	161	102
C	7, 8, 9	302	97	205	0
D	10, 11, 12	315	54	252	9
E	13, 14, 15	456	73	379	4
TOTAL		1729	371 (21.46%)	1212 (70.10%)	146 (8.44%)

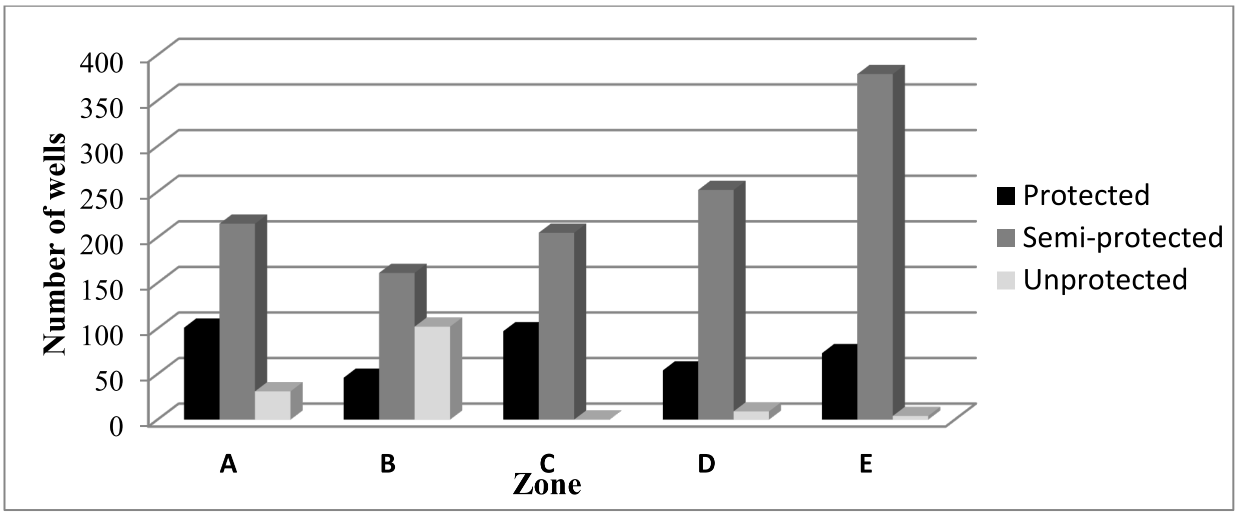

Fig. 3: Distribution of self-supply hand-dug wells in Abeokuta South LGA, Ogun State, Nigeria

Table 3: Inventory and classifications of Self-Supply wells in Abeokuta South LGA, Ogun State, Nigeria

Zone	Located	Assessed wells			
		Protected	**Semi-protected**	**Unprotected**	**Total**
A	347	39	82	12	133
B	309	27	97	55	177
C	302	75	174	0	249
D	315	7	89	3	99
E	456	15	72	1	88
TOTAL	1729	163 (22%)	512 (69%)	71 (9%)	746

Well age

Information on well age could only be gathered for 685 wells. The wells were classified into five age groups (Table 4). In the age class of 1-5 years, 250 (36%) wells were identified, 128 in the age class of 6-10 years, 155 in the age class of 11-20 years, 141 in the age class of 21-50 years, and 11 in the age class of more than 50 years (Table 4). This result implies that the age group 1-5 gives the total number of wells (250 wells) that was constructed after the study conducted by Oluwasanya *et al*. (2011a).

Table 4: Age classification of self-supply hand-dug wells in Abeokuta, Nigeria

	Age (years)				
	1-5	**6-10**	**11-20**	**21-50**	**> 50**
Hand-dug wells	250 (36%)	128 (19%)	155 (22%)	141 (21%)	11 (2%)

N = 685

Water Users and Uses

From the result of this research, a total number of 31,238 users are estimated to depend on the 746 self-supply systems with an average of 42 users to each of the sources. A total of 4,404 users are recorded in zone A, 12,477 users in zone B, 4,357 users in zone C, 5,845 users in zone D and 4,155 users in zone E (Table 5). About eighteen percent (18%) of the users are recorded to abstract water from protected wells, 79% draw from semi-protected wells and 3% draw water from unprotected wells (Fig. 4).

Table 5: Number of self-supply water users in Abeokuta, Nigeria

Zone	**A**	**B**	**C**	**D**	**E**	**Total**
Users	4,404	12,477	4,357	5,845	4,155	31,238

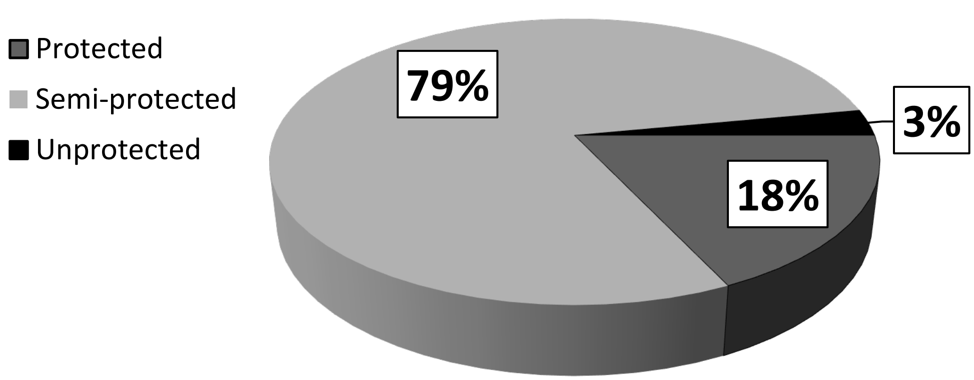

Fig. 4: Water users of self-supply hand-dug wells in ASLGA, Ogun State, Nigeria

Self-Supply Water is used for domestic purposes, but the types of domestic uses vary with the perception of the users on the quality of water abstracted from the well. Some of the users believed that any water abstracted from hand-dug wells is not suitable for drinking while some believed that as long as the water is clear and odourless, it is drinkable. The identified water uses are bathing, cooking, drinking and washing (dish washing, laundry and floor cleaning). Findings show that about twenty-two percent (21.8%) of the users claimed the water is used for domestic plus drinking purposes, 59.4% uses the water for domestic minus drinking purposes, 15.8% uses the water for domestic minus drinking and cooking while 3% used the water for laundry and/or household cleaning only (Fig. 5).

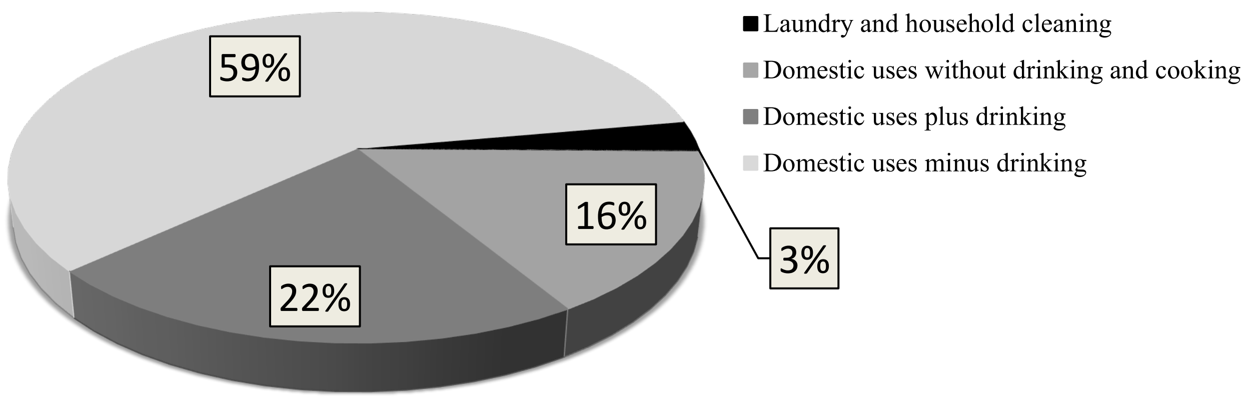

Fig. 5: Water uses of self-supply hand-dug wells in Abeokuta South LGA, Ogun State, Nigeria

Mode of Abstraction (Operation)

About seventy-two percent (84.95 %) of the self-supply hand-dug wells are operated with bucket and rope, 13.06 % with surface pump and 1.99 % are operated with both (Fig. 6). Depending on the hygiene of the source owners or users, the mode of operation based on bucket and rope is categorized into dedicated bucket and rope kept in the well or indoor and, the bucket and rope kept on/or around the well. The water quality abstracted is seen to vary with the type of operation, which could be a pump or a dedicated rope and bucket (kept in the well) having a quality better than that of rope and bucket kept outside the well.

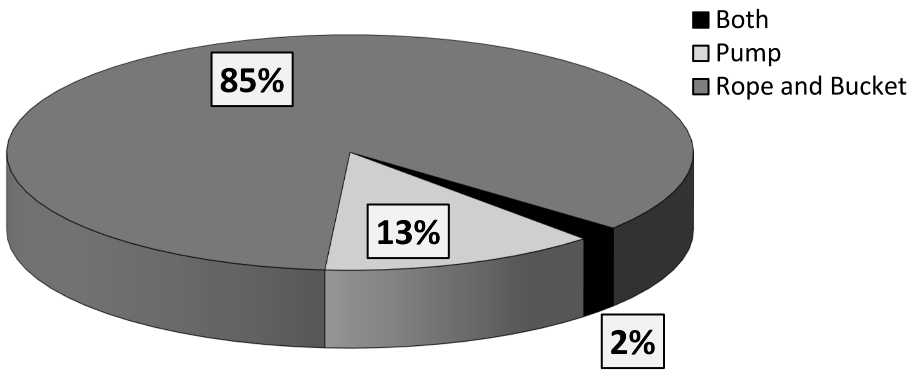

Fig. 6: Water abstraction methods (operation) of self-supply hand-dug wells in Abeokuta South LGA, Ogun State, Nigeria

Well Construction

Mode of construction of the identified water supply systems was also considered. Results showed that all the hand-dug wells located are constructed manually. Some are constructed with protective features while others are without appropriate features to prevent the wells from contaminations. The standard features considered for hand-dug wells include well head, well cover, apron, wall lining, cement floor and drainage (Fig. 7).

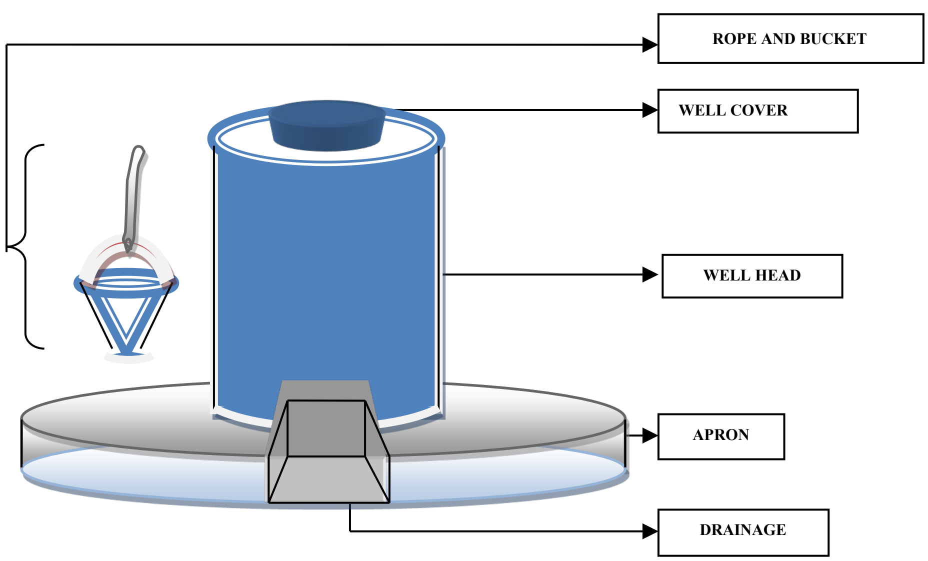

Fig. 7: Typical features of a hand-dug well

Water Saturation Level in Wells (Water Head)

The head of water in the well (i.e. depth from the static water level to the bottom of the well) is measured in meters (Fig. 8). Findings show that the saturated level is a function of the season, the yield of the well, and the total depth of the well from ground surface. The assessments of the water quality of some of the wells were not carried out due to the total dryness of the wells. Some of the dry wells include: AGO 002, IBA 002, IBA 006, IGR 020, IJJ 020, IYO 002, OLU 006, ONI 023, ONI 045, ONK 012 and PAN 006. The saturated water level of each of the assessed wells is estimated by deducting the static water level from the total depth of the well. The saturated water level ranged from 0.03m to 12.07m with a mean value of 1.51m (Table 6).

Table 6: Descriptive statistics of water saturation in the wells

	Minimum	Maximum	Mean	Std. Deviation
Depth (m)	0.90	16.87	5.61	2.412
Water level (m)	0.25	12.00	4.10	2.03
Water head (m)	0.03	12.07	1.51	1.27

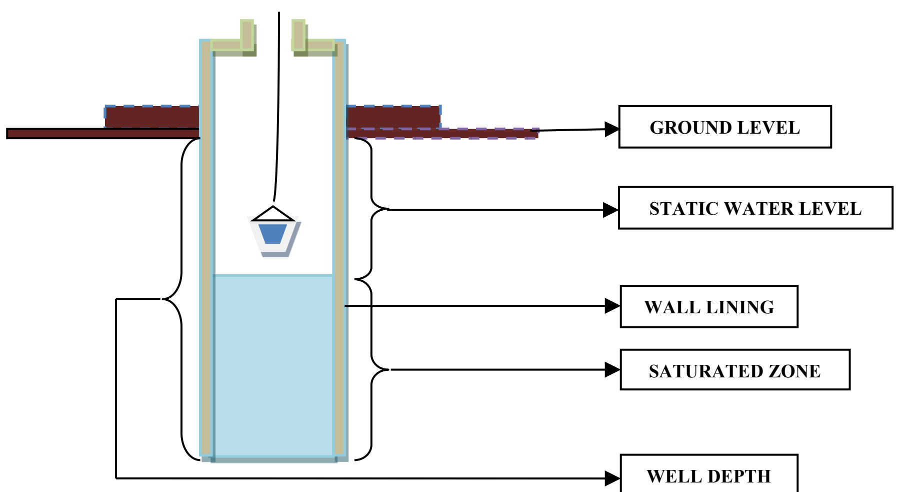

Fig. 8: Schematic layout of the internal structure of hand-dug well.

Sanitary Survey

Sanitary inspection forms were used to review and determine potential sources of contamination or existing risk factors. Sanitary score for all the located wells ranged from 9 to 40. The sanitary score in Zone A ranged from 9 to 40, 14 to 31 in Zone B, 14 to 32 in Zones C and D, and 18 – 40 in Zone E (Table 7). Poor well construction and proximity to latrine facilities, burial sites and solid waste sites including animal invasions are responsible for low sanitary score values. Risk ranking based on the sanitary inspection scores ranged from very high to low risk. A total number of 32 wells are categorized as wells with Very High contamination risk, 258 wells as wells with High contamination risk, 317 wells with Intermediate risk and 139 wells are seen as Low risk wells (Fig. 9).

The water temperature of all the located wells ranged from 20.5°C to 32.7°C with a mean value of 29.3°C (Table 8). The pH of all the located wells ranged from 4.05 to 9.95 with a mean value of 7.43 (Table 8). The lowest and highest pH values of the wells are outside the standard range prescribed by the World Health Organization (WHO), although the mean pH value of all the wells fall within the prescribed range of 6.5-8.5. High pH values are due to low concentration of hydrogen ion [H^+] in water, this may be as a result of dirty environments and free movement of particles into the wells resulting from absent of well cover. Low pH values in water are due to high concentration of hydrogen ion [H^+].

The actual electrical conductivity (EC) of water in each of the located wells is converted to standard values related to temperature at 25°C for comparativeness. It is observed that the electrical conductivity of water in all the wells ranged from 172µS/cm to 2732µS/cm with a mean value of 841.83µS/cm (Table 8). Although the mean EC value is below the maximum desirable value of 1000 µS/cm prescribed by WHO, it is discovered that the highest EC value is above the maximum desirable standard. High EC values are due to high amount of dissolved ions in the water, which may have resulted from free movement of particles into the well via usage of bucket and rope, and by direct ingress as a result of lack of well cover or perforated covers. Total dissolved solids (TDS) of all the wells ranged from 82mg/l to 1324mg/l with a mean value of 444.28mg/l (Table 8). The electrical conductivity (EC) measured from each of the hand-dug wells is almost twice its total dissolved solids (TDS) at the varied temperature of each of the wells with a derived equation of $\boldsymbol{y = 1.67 \times x}$, where $\boldsymbol{y}$ and $\boldsymbol{x}$ represent EC and TDS, respectively (Fig. 10). The result shows a significant correlation at 0.01 level between temperature and electrical conductivity, pH and electrical conductivity, electrical conductivity and well depth, electrical conductivity and water head. A significant correlation at 0.05 level for pH and depth, and no significant correlation at both 0.01 and 0.05 level for temperature and pH, temperature and well depth, temperature and water head in all the assessed wells (Table 9).

The correlation (r = 0.236) between pH and electrical conductivity in all the assessed wells is a positive but weak relationship (Table 9). This shows that, ideally, an increase in any of the two parameters may result in the increase of the other. The correlation (r = 0.542) between the well depth and water head in all the assessed wells is a positive intermediate correlation (Table 9). It implies that, an increase in well depth may expectedly indicate more water head. The correlation (r = -0.301) between the well depth and pH in all the assessed wells is a negative weak correlation (Table 9). Directionally, the value of pH may decrease with an increase in the well depth.

Table 7: Range of Sanitary scores of self-supply wells in Abeokuta, Nigeria

Zone	Minimum score	Maximum score
A	9	40
B	14	31
C	18	32
D	14	32
E	18	40

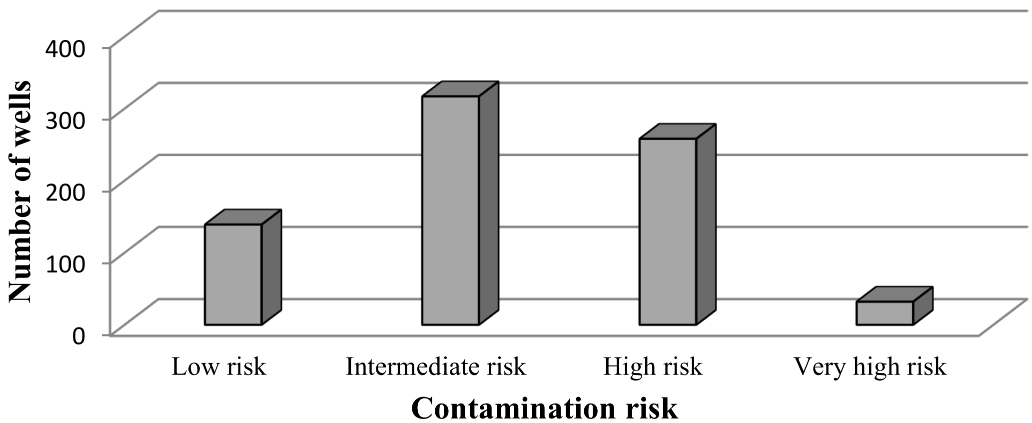

Fig. 9: Contamination risk variation of self-supply hand-dug wells in Abeokuta South LGA, Ogun State, Nigeria

Table 8: Descriptive statics for water quality analysis

	Minimum	Maximum	Mean	Std. Deviation
E.C (µS/cm)	172	2732	841.83	388.00
pH	4.05	9.95	7.43	0.80
TDS (mg/L)	82	1530	447.04	213.25
Temperature (ºC)	20.5	32.7	29.3	1.25

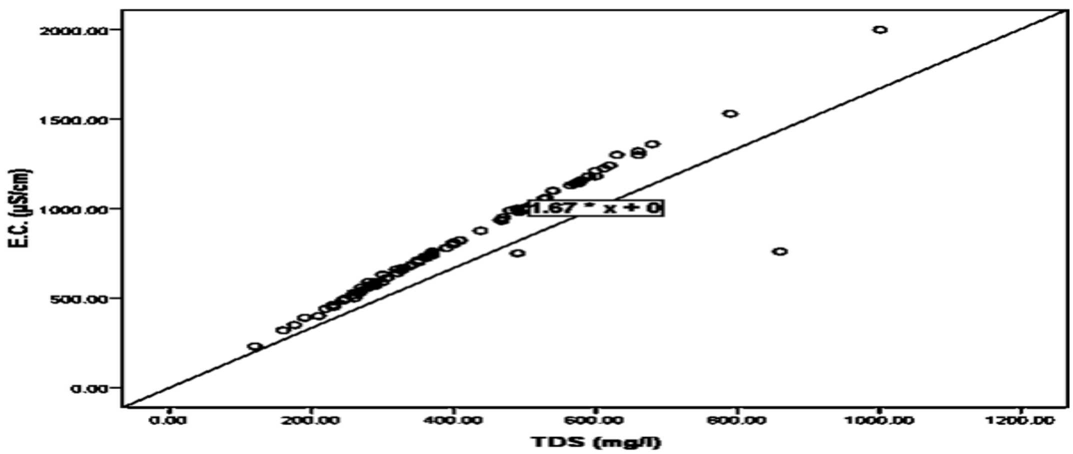

Fig. 10: Graph of Electrical Conductivity against Total Dissolved Solid

Table 9: Correlation matrix for water quality parameters and well depth

	Temperature (ºC)	E.C. (μS/cm)	pH	Depth (m)	Water head (m)
Temperature (ºC)	1	-0.104**	0.022	-0.059	0.069
E.C. (μS/cm)		1	0.236**	-0.193**	-0.163**
pH			1	-0.301**	-0.088*
Depth (m)				1	0.542**
Water head (m)					1

**. Correlation is significant at the 0.01 level (2-tailed).
*. Correlation is significant at the 0.05 level (2-tailed).

Table 10: Correlation matrix for well age and water quality

	Temperature (ºC)	**T.D.S (mg/L)**	**E.C (μS/cm)**	**pH**
Well age	-0.052	0.215**	0.230**	0.087*

**. Correlation is significant at the 0.01 level (2tailed).
*. Correlation is significant at the 0.05 level (2-tailed).

There is no correlation between well age and temperature at both 0.01 and 0.05 significant level (Table 10).

Bacteriological Analysis

The average *E. coli* growth of the three water samples collected from each of the fifty sample points ranged from 0 to 283.33 CFU/100ml of water (Table 11). The mean value of *E. coli* growth present in the wells for the dry season (first set of analysis) is seen to be the highest with a value of 78 CFU/100ml of water, this mean value dropped to 52 CFU/100ml of water at the onset of rainfall (second set) and dropped again to 34 CFU/100ml of water in the raining season (third set). From this result, the growth of

E. coli appears to decrease with increase in the volume of available water as the mean growth of *E. coli* dropped down from dry to rainy season (Table 11). The drop in *E. coli* count may have occurred due to the high rate of sub-surface flow, which could in turn dissolve and move contents of sanitary facilities into the wells. It is however mandatory for safe water source to be free of *E. coli* (WHO, 2014). Apart from the *E. coli* growth detected in some of the fifty analyzed wells, bacteria like (Streptococci, Coliform Bacilli, Staphylococcus Spp., and Pseudomonas Spp.), which can cause serious illness to human beings are also detected in many of the wells.

The correlation between Faecal coliform in the samples collected and sanitary scores of the sampled wells shows a weak negative relationship of r = -0.334. This shows that a higher sanitary score may depict a lower *E .coli* growth in the well. The correlation between Faecal coliform and sanitary score in the first set of samples collected shows a weak negative relationship of r = -0.148. The correlation between these two parameters in the second set of samples collected is also a weak negative correlation of r = -0.412. The correlation between these two parameters in the third set of samples collected as well gives a weak negative correlation of r = -0.140. The results show that expectedly the status of the wells in terms of protection, state and distance to sanitary facilities may impact on its *E. coli* content (Table 12). But the correlation or relationships between faecal coliform and sanitary inspection are hardly ever significant.

Table 11: Bacteriological water quality status of self-supply hand-dug wells in Abeokuta, Nigeria

	Minimum	Maximum	Mean	Std. Deviation
DRY (CFU/100ml)	0	800	78.53	146.80
ONSET OF WET (CFU/100ml)	0	850	52.38	147.07
WET (CFU/100ml)	0	385	34.90	89.65
AVERAGE (CFU/100ml)	0	283.33	55.27	72.53

N = 50 sources

Table 12: Correlation matrix for Faecal coliform and sanitary scores

	Dry season (CFU/100ml)	**Onset of Wet season** (CFU/100ml)	**Wet season** (CFU/100ml)	**Average *E. Coli*** (CFU/100ml)	**Sanitary scores**
Dry season (CFU/100ml)	1	-0.110	0.040	0.617	-0.148
Onset of wet season (CFU/100ml)		1	-0.007	0.599	-0.412
Wet season (CFU/100ml)			1	0.434	-0.140
Average *E. Coli* (CFU/100ml)				1	-0.334
Sanitary score					1

Discussion

Self-Supply systems in Abeokuta, Nigeria: Trend, Challenges and Opportunities

The result of this research is compared with a previous research conducted by Oluwasanya *et al.* (2011a). A total of 2,280 dug wells in 2011 was located in an earlier study, which is more than the number of wells

(1,729) recorded in this study. The difference in the number of wells between these two studies can be traced to the difference in the total area covered, since this research covered less area compared to the previous study in 2011. Based on findings from the age of the identified self-supply wells in this research, there is an evidence of 36% increase in the number of available wells since the time the previous study was conducted (Table 4). With consideration on the mode of operation, it is discovered that about 85% of the wells were operated with bucket and rope. A lot of time and energy is consumed by this operation technique, and is less convenient especially for the vulnerable user group like the elderly and pregnant women (Oluwasanya *et al.*, 2011a; Workneh *et al.*, 2009). There is a need for an intervention towards the upgrade of this operation technique so as to make the abstraction of water from this source easy and convenient. The large number of available wells operated with bucket and rope technique is an indication that Abeokuta metropolis is a good market for the sales of advance water lifting technologies. Oluwasanya *et al*. (2011a) and Workeh *et al*. (2009) encouraged the introduction of pulley-windlass and rope pumps as a form of upgrade of the operation technique in areas like Abeokuta metropolis. This upgrade will serve as an avenue for Private sector participation in the development of local and affordable water lifting equipment and a benefit to the users by saving time and making water abstraction more convenient. However, the need for improvement in design and quality of well construction in the study area is also emphasized.

The role of regulation in Self-Supply Systems and water safety

Oluwasanya *et al*. (2011a) observed that water supply strategies had traditionally been a two way linear approach; public and communal water supply. The public water systems option is usually favoured for urban water supply while the communal water systems are generally restricted for use at the rural areas. However, Oluwasanya *et al*. (2011a) argued that Abeokuta, a developing urban city, had about half of its population not served with treated public water but rely on self-supply water initiatives for their water needs. Hence, self-supply water initiatives feature among the unserved in the urban area, and are consequently not restricted to rural areas. Recognizing the role of self-supply systems as the third key player in water supply management is thus necessary, such that self-supply systems would be upgraded and main-streamed into water supply management. Mainstreaming self-supply systems as an important water supply management strategy would also spotlight the systems for appropriate source and water safety regulations. As water safety regulation is key to ensuring safe water production of any system type, it is necessary to set up a monitoring and regulatory team so as to continually assess the hygiene status and practices of the water sources and the corresponding users. Findings showed that most of the source owners do not consider the influence and impacts of sanitary facilities on water wells when allocating spaces on their piece of lands for various household facilities. Although this has reduced over the years as most of the wells constructed in the past five years are seen to be constructed with considerations for sanitary facilities and burial sites. The poor water quality in some of the wells can however be traced to the proximity of the wells to sanitary facilities.

Conclusion

As water is said to be ubiquitous in our environment, its availability for abstraction is of great concern when its quality satisfies the intended use. The main self-supply systems within the study area is found to include hand-dug wells and boreholes, with the former taking the larger percentage (about 93%). Almost

(70%) of the located hand-dug wells are semi-protected, that is, lacking one or more of the necessary protective features. Although a larger percentage (about 78%) of the consumers do not consume the water directly, but still make use of the water for cooking, bathing, laundry and floor cleaning. Some of the self-supply wells are well managed and protected but found to be highly contaminated due to limiting house spacing. In such instances, the neighbouring houses have sanitary facilities in close proximity to self-supply system in another building. Although fenced, the untreated wastewater from neighbouring toilets finds its way into self-supply systems through sub-surface flow with a consequent negative effect on the quality of water abstracted from such water sources.

Similarly, some of the located self-supply wells are hand-dug to a very shallow depth (e.g. 1m) usually during wet season. Well construction during the wet season creates an initial good yield but lower future yields. The study suggests that:

1. Source owners and users should be advised as to the danger of improper construction and maintenance of self-supply systems.
2. Standard mode, time of construction and design should be stipulated so that the system can be fully protected from the time of construction.
3. Appropriate distance of at least 30m is recommended for self-supply system from any sanitary facilities including a solid waste site. Adequate fencing of the sources from animal invasions should also be provided.
4. Consideration of potential sources of contamination particularly toilet facilities on neighbouring compounds should be factored before locating water sources on owned landed properties.
5. Since most of the houses built have limiting spaces, considerations should be made by the community to provide communal water supply sources rather than individual supply systems that makes most of the systems to be constructed in close proximity to sanitary facilities.
6. Source owners are encouraged to adopt dedicated bucket and rope if dedicated pump is considered prohibitive to reduce the contamination risk of the system.
7. Since Abeokuta metropolis is noted to be a good market for the sales of advance water lifting technologies (such as pulley-windlass and rope pumps) as a form of upgrade of the currently available operation technique, the participation of Private sectors in the development of local and affordable water lifting equipment would be highly welcomed.
8. Self-Supply systems should be regulated.

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APPENDIX I:DATA COLLECTION SHEET

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DEPARTMENT OF WATER RESOURCES MANAGEMENT AND AGROMETEOROLOGY

A RESEARCH ON THE INVENTORY OF SELF-SUPPLY SYSTEMS IN ABEOKUTA METROPOLIS

Page 1

SN	WELL CODE	LOCATION	GEO-REFERENCING			WELL ANALYSIS						WELL PROFILE					
			Latitude (ºN)	Longitude (ºE)	Altitude (m)	pH	Temp. (C)	E.C (µS/cm)	Nitrate (mg/L)	Turbidity (mg/L)	E.Coli (count/100 ml)	Age	Depth (m)	Water level (m)	Lining	Well head	Operation

Page 2

SN	Date DD/MM/YR	Time of the day	WELL PROFILE (continuation)							
			Uses	Apron	Drainage	Well cover & type	Distance to latrine (m)	Distance to burial site (m)	Distance to dump site (m)	Animal breeding (m)

APPENDIX II:SANITARY INSPECTION FORM FOR SELF SUPPLY HAND-DUG WELLS

I. Type of facility:**Self supply hand-dug well (protected/unprotected)**

1. General information
   - LGA: ....
   - Location: ....
2. Cluster group number: ....
3. Date of visit: .... Weather at time of visit: ....

   Water sample taken? .... Sample No.: .... Faecal Coliform/100ml

II. Specific Diagnostic Information for Assessment

SN	Questions	Risk scoring systems	1	2	3	4	5
1	Is there a latrine within 10m of the well?						
2	Is there burial basement(s) within 10m of the well?						
3	Is there any solid waste dump within 10m of the well?						
4	Is there well head protection?						
5	Is there animal breeding and animal waste within 10m of the well?						
6	Is a bucket also in use and left in a place where it could be contaminated?						
7	Is there a well cover?						
8	Is there a well wall lining (cement or ring)?						

Total per unit scores

SI score = Sum of total per unit scores: ..../40

Contamination risk scores: 8-16 = Very high; 17–24 = High; 25-32 = Intermediate; 33-40 = Low; Scale of scoring: 1 = poor: 5 = good

Remediation action: ....

Risk scoring criteria per question:

Q1&2

1. latrine/soak away distance of< 5m and on higher ground than well
2. latrine/soak away distance of< 10m and on equivalent ground level with well
3. latrine/soak away distance of< 10m and on lower ground level than well
4. latrine/soak away distance of 10m and on equivalent ground level with well
5. latrine/soak away distance of> 10m and on lower ground level than well/no burial site

Q3

1. High heap solid waste distance of< 5m
2. High heap solid waste distance of< 10m
3. Moderate solid waste heap distance of 10m
4. Low heap solid waste distance of> 10m
5. No solid waste

Q4

1. No cement apron, floor and drainage around well head with ponding
2. Well head with apron, but no cement flooring and drainage with ponding
3. Well head with apron, crack in cement flooring and poor drainage
4. Well head apron, crack in cement flooring with good drainage
5. Adequate well head apron with cement flooring and good drainage

Q5No fence, gate and well head protection with very likely animal invasion

1. No fence, incomplete well head protection with likely animal invasion
2. No fence and gate, moderate well head protection with less likely animal invasion
3. Low fence and gate, good well head protection and not likely animal inversion
4. Adequate well fencing and gate, well head protection and not likely animal inversion

Q6

1. Users use bucket and rope kept on the floor around well
2. Users come with bucket and rope
3. Users use owners' bucket and rope kept on well
4. Users use owners' bucket and rope kept indoor
5. Use of bucket and rope kept permanent within the well

Q7

1. Open well
2. Well cover with large opening and without lock and key
3. Well cover with little openings and with lock and key
4. Airtight well cover without lock and key
5. Airtight well cover with lock and key

Q8

1. No wall lining
2. Well lining made with blocks and within < 3m of depth
3. Well lining with rings or cement and within 3m of depth
4. Well lining with rings from apron to > 3m of depth
5. Well lining with rings from apron to bottom

Source: Oluwasanya *et al.* (2011b)