FEDERAL UNIVERSITY OF TECHNOLOGY MINNA

SUSTAINABLE WATER RESOURCES MANAGEMENT IN NIGERIA

By

PROF. ONEMAYIN DAVID JIMOH

B.Eng. (Ilorin), M.Sc (ABU), Ph.D (Birmingham), MNSE, R.Eng (COREN)

Professor of Civil Engineering

INAUGURAL LECTURE SERIES 18

11TH NOVEMBER, 2010

FEDERAL UNIVERSITY OF TECHNOLOGY
MINNA

SUSTAINABLE WATER RESOURCES MANAGEMENT IN NIGERIA

By

PROF. ONEMAYIN DAVID JIMOH

B.Eng. (Ilorin), M.Sc (ABU), Ph.D (Birmingham), MNSE, R.Eng (COREN)

Professor of Civil Engineering

INAUGURAL LECTURE SERIES 18

11TH NOVEMBER, 2010

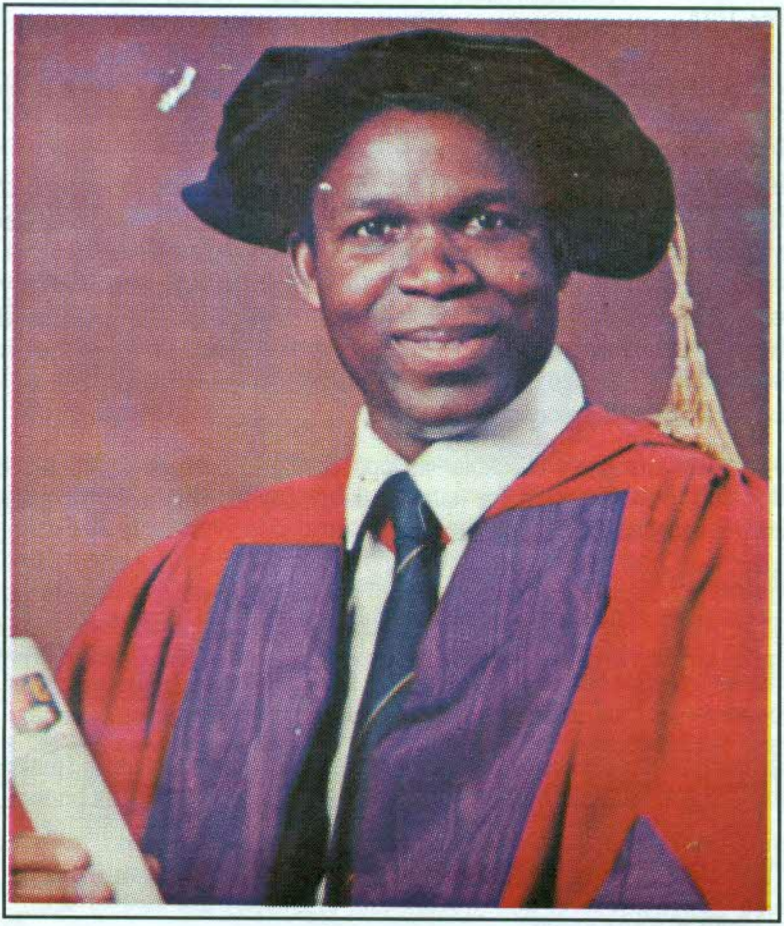
This 18th Inaugural Lecture was delivered under the Chairmanship of:

The Vice-Chancellor,
Prof. M. S. Audu, FMAN

Published by:
University Seminar and Colloquium Committee,
Federal University of Technology, Minna.

November, 2010

Design + Print:
Global Links Communications, Nigeria
✆: 08056074844, 07036446818, 08080255301



ONEMAYIN DAVID JIMOH

B.Eng. (Ilorin), M.Sc (ABU), Ph.D (Birmingham), MNSE, R.Eng (COREN)

Professor of Civil Engineering

SUSTAINABLE WATER RESOURCES MANAGEMENT IN NIGERIA

I would like to begin this lecture with a quote from Rutherford Aris (September 15, 1929 – November 2, 2005) a British born Mathematician and Chemical Engineer who was Regents Professor Emeritus of Chemical Engineering at the University of Minnesota, USA.

"If you don't do the best with what you have happened to have got, you will never do the best with what you should have had".

This quote forms the basis of dynamic programming, a method for solving complex problems by breaking them down into simpler steps. Life is complex and only God gives grace to follow it step by step. This has been my experience for the past 19 years when I joined the University. I did not know that after 17 years, including four and a half years of study fellowship I will be recommended for promotion to the full professorial rank. Encouragement, frustration and disappointment were experienced during the period. To come thus far therefore calls for thanksgiving to God for guidance, protection, wisdom and love. To Him be all the glory.

An Inaugural Lecture gives a scholar an opportunity to present his contributions to knowledge and their relevance for national development. This lecture highlights my contribution to knowledge on the chosen theme.

1. INTRODUCTION

It is with a great sense of humility that I stand this day, the 11th November, 2010 to present the 18th Inaugural Lecture of the Federal University of Technology, Minna titled: 'Sustainable Water Resources Management in Nigeria'. This is the first inaugural lecture in the Department of Civil Engineering, Federal University of Technology, Minna.

Civil engineering is a profession that deals with the design, construction and maintenance of the physical and naturally built environment, including works such as bridges, roads, canals, dams and buildings. It is the oldest engineering discipline after military engineering. The sub-disciplines of civil engineering are:-

- Structural Engineering
- Highway Engineering
- Water Resources Engineering
- Environmental Engineering
- Construction Engineering
- Coastal Engineering

The role of water resources engineer entails estimating the amount of water available, design physical and non-physical infrastructure needed to meet water needs, operate and manage the infrastructure. Water resources engineers are required in the following services:

(a) Water Distribution System;
(b) Wastewater and Storm Water Sewer Systems and Analysis;
(c) Irrigation Engineering and Drainage Canals;
(d) Hydraulic Structures (reservoir, floodway, dam, spillway and channel);
(e) Groundwater and Well design, Surface run-off Analysis;
(f) Extreme Event Planning and Analysis

Hydrology is an earth science studying the circulation and distribution of global water. Initially, the observers of the hydrological phenomena were few and made up of scientists who were engaged in studying the natural phenomena. This stage was considered as the Geographical Hydrology stage. With the progressive demand for water for human society and the progress of science and technology, the ability to control and manage water in the natural world was increasing. Then the appearance of hydraulic engineering structures stimulated engineers to study hydrological phenomena not only for description and characterization, but also for quantitative estimation and prediction. This was referred to as "Applied Hydrology" or "Engineering Hydrology". Now, Hydrology encompasses elements of other disciplines, such as geology, geophysics, meteorology and climatology, ecology and engineering.

Engineering Hydrology, which is a subject of water resources engineering, grew rapidly due to the need to control water, and is occupying a principal position in hydrology, bringing with it the development of hydrometric networks and techniques. It established the different kinds of empirical correlations, formulae, models and approaches with primitively genetic and inferential ideas. Together with the application of mathematical and statistical methods in hydrological analysis, all these ideas were aimed at planning, design, construction and operation of water projects and this turned hydrology into a technical science (Jiaqi, 1987).

Water is the lifeblood of our planet. It is fundamental to the biochemistry of all living organisms. The planet's ecosystems are linked and maintained by water, and it drives plant growth, provides a permanent habitat or breeding ground for many species. Water is also a universal solvent and provides the major pathway for the flow of sediment, nutrients and pollutants. Through erosion, transportation and deposition by rivers, glaciers, and ice sheets, water shapes the landscape and through evaporation it drives the energy exchange between land and the atmosphere, thus controlling the Earth's climate. Water is an essential resource for life and environment (Acreman, 1998). We need water for domestic activities and plants need the right quantity of water at the right time, we also need water for navigation and hydroelectric power generation`. The loss of 20% of body water can cause death. It is possible to survive for various weeks without food, but it is not possible to survive more than a few days without water. Water is life. Access to safe and affordable water is critical to a nation's development. A short dry spell during the growing season can devastate crops in the world's poorest regions, while floods threaten infrastructure and exacerbate disease.

The 20th century has witnessed unprecedented rises in human populations, from 2.8 billion in 1955 to 5.3 billion in 1990 and is expected to reach between 7.9 and 9.1 billion by 2025 (Engelman and LeRoy, 1993). Consequently, human demands for water, for domestic, industrial and agricultural purposes, are also increasing rapidly. The amount of water that people use varies, but tends to rise with living standards. In the United States, each individual typically uses 560 litres per day for domestic tasks (drinking, cooking and washing), whilst in France, it is 280 litres pay, UK has 150 litres per day, Senegal, the average use is 29 litres per day and in Nigeria, it is 35 litres per day (UNDP, 2006).

The increase in the world population and the economic and social progress of various countries has put serious pressures on water, which has led to a very serious situation of water crisis and water poverty. Some 1.1 billion people (18% of the world population) do not have access to safe drinking water, and some 2.2 Million people (most of them children, 1.8 millions) die of waterborne diseases yearly. It is also estimated that 50% world population is subjected to water stress and in the year 2025 this figure will be 65%. More than 800 million people suffer hunger and malnutrition (Falkenmark, 1989). Loss of lives and properties due to flooding is an annual occurrence in many parts of the world. Thus, there is a water crisis. The crisis is not only about having too little water to satisfy our needs, but managing water so badly that millions of people and the environment suffer badly.

The United Nations General Assembly at its 58th session in December 2003 proclaimed the years 2005 to 2015 as "Water for Life Decade". The declaration which focused on undertaking real and effective measures to meet the millennium targets included reduction by half the population that is currently completely lacking in the essential water supply and sanitation services, and energy. On 28th July 2010; the UN declared access to water as a human right. It is defined as the right to equal and non-discriminatory access to a sufficient amount of safe drinking water for personal and domestic uses (drinking, personal sanitation, washing of clothes, food preparation and personal and household hygiene) to sustain life and health. It further declared that States should prioritize these personal and domestic uses over other water uses and should take steps to ensure that this sufficient amount is of good quality, affordable for all and can be collected within a reasonable distance from a person's home. We are now at the middle of the Decade. What have we achieved? Are we prepared for the UN 2010 declaration?

This lecture provides a review of water resources potential and demand in the country, the status of water resources development and the challenges militating against sustainable delivery of the resource to users in Nigeria. The lecture also highlights my focus in research with case studies, contribution to knowledge in the field of water resources management, and proffer suggestions on how to attain sustainable water resources management in Nigeria.

2. THE ESSENCE OF WATER

Water is essential to life and permeates all our activities. We need water to drink, to wash our hands, to cook and to water plants. Without water, the plants would die and people and animals would go thirsty. We also need water for navigation and hydropower generation. Water is the most abundant liquid on Earth. It covers more than 70% of the earth's surface, and the total amount of water on Earth, in the form of oceans, lakes, rivers, clouds, polar ice, etc. is 1.260×10^{21} litres. The water is constantly being recycled (Figure 1). It is evaporated from the oceans by the sun and is given off by the forests. The vapour condenses into clouds, which rain out onto the land. The land water runs off into the lakes and rivers, which then run back to the seas, and the cycle is complete (http://science.jrank.org/pages/7301/Water.html).

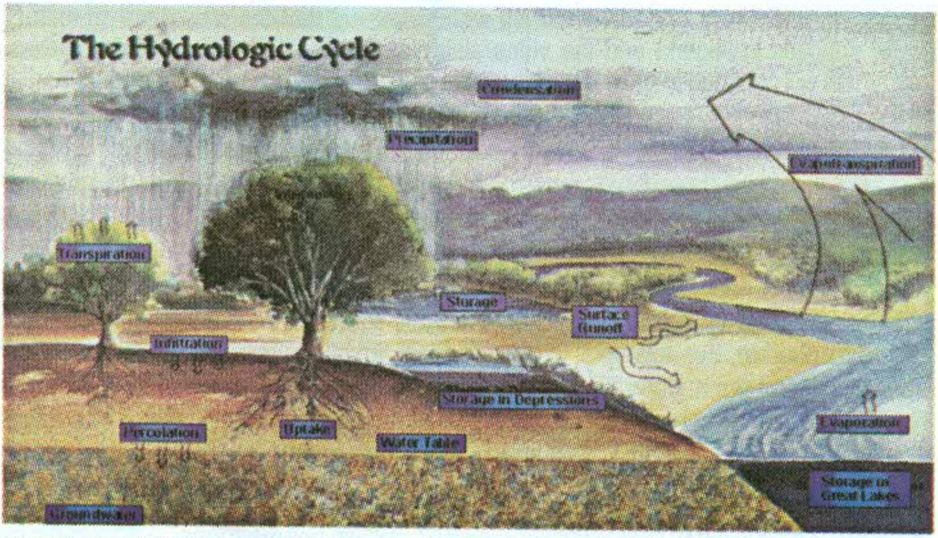


Figure 1: The Hydrologic Cycle (http://iwr.msu.edu/edmodule/water/cycle.htm)

Water as a resource is quantifiable and it is limited. Ninety-eight percent of the water on the planet is in the oceans, and therefore is **unusable** for drinking because of the salt content. About 2 percent of the water on the planet is fresh, but 1.6 percent of the water is locked up in the polar ice caps and glaciers. Another 0.36 percent is found underground in aquifers and wells. Only about 0.036 percent of the total water on the planet is found in lakes and rivers. That is still a very small amount compared to all the water available. The rest of the water on the planet is either floating in the air as clouds and water vapour or is locked up in plants and animals which includes human beings, since our body is 65 percent water (http://science.howstuffworks.com/question157.htm).

Freshwater resources are unevenly distributed, with much of the water located far from human populations. Many of the world's largest river basins (a basin is a land and water area drained by a water course and its tributaries) run through thinly populated regions. There are an estimated 263 major international river basins in the world, covering approximately 231,059,898 km^2 or 45.3% of the Earth's land surface area (excluding

Antarctica). Groundwater represents about 90% of the world's readily available freshwater resources, and some 1.5 billion people depend upon groundwater for their drinking water. Agricultural water use accounts for about 75% of total global consumption, mainly through crop irrigation, while industrial use accounts for about 20%, and the remaining 5% is used for domestic purposes. The availability of fresh water is one of the most critical environmental issues of our time, where the precipitation is highly variable. In addition, large changes in land cover, land use and water management practices including: removal of water from river systems for irrigation and consumption, degradation of forage land by over-grazing, deforestation, replacing natural ecosystems with mono-cultures, and construction of dams, have taken place during the last 50 years. The relatively large population and delicate ecosystems therefore, depend on water resources that vary greatly due to climate fluctuations and human induced changes. With increasing population and development we can expect that the pressures on existing water supplies in Nigeria and the vulnerability of the population depending on these resources will continue to grow. Therefore, it is crucial that we improve our understanding of the variability of terrestrial hydrologic systems, and the management of the resources (Coe *et al*, 2002, GIWA, 2004).

A study conducted by Loucks and van Beek (2005) among 67 urban centres in 29 African nations (including most of the continents largest cities), showed that in the 1990s, 58% were using at least rivers 25 kilometres away, and just over half of the urban centres that relied on rivers depended on inter-basin transfers. Furthermore, about 85% of water withdrawals in Africa are for agriculture, but this figure varies considerably from one region to another. For example, in Arid regions, irrigation plays an important role in agriculture, and the regions have the highest level of water withdrawal for agriculture. North Africa alone represents more than half of the continents agricultural withdrawal. The humid regions show the lowest agricultural withdrawals, 62% for the Gulf of Guinea and 43% for the Central region.

Around 2.2 million die of basic hygiene related diseases, like diarrhoea, every year in the world. The great majority are children in developing countries. In Nigeria, much of the water available for communities is unsafe (Enabor *et al*, 1998, Oloruntoba *et al*, 2006; Oloruntoba and Sridhar, 2007) and may contribute to water-borne or water related infections. The water-borne infections, typhoid, gastroenteritis and cholera, are those where an enteric micro organism enters the water source through faecal contamination and transmission occurs by ingestion of such waters. For decades, universal access to safe water and sanitation has been promoted as an essential step in reducing this preventable disease burden. The "Millennium Declaration" established the lesser but still ambitious goal of halving the proportion of people without access to safe water by 2015. Achieving "universal access" is an important long-term goal. How to accelerate health gains against this long-term backdrop and especially amongst the most affected populations is an important challenge (WHO, 2002, Sridhar and Oloruntoba, 2008).

The Global Water Supply and Sanitation 2000 Assessment (WHO/UNICEF, 2000) shows that 1.1 billion people lack access to improved water supply and 2.4 billion to improved sanitation. The study estimated that two out of every three people will live in water stressed areas by the year 2025. In Africa alone, it is estimated that 25 countries will be experiencing water stress (below 1,700 m^3 per capita per year) by 2025. Today, 450 million people in 29 countries suffer from water shortages. Clean water supplies and sanitation remain major problems in many parts of the world, with 20% of the global population lacking access to safe drinking water. Waterborne diseases from fecal pollution of surface waters continue to be a major cause of illness in developing countries. Polluted water is estimated to affect the health of 1.2 billion people, and contributes to the death of 15 million children annually. In 2010, Nigeria still recorded cholera outbreak affecting 9 States (Katsina, Bauchi, Borno, Adamawa, Gombe, Yobe, Taraba, Jigawa, Kaduna, FCT). Over 3,000 cases were reported with 781 death cases (Nigerian Tribune, 2010); with Katsina State recording the highest number of casualties (175 deaths and 310 reported cases).

Water has been found to be available in excess quantity at the place and the time it is required. This situation is referred to as flood. A flood is an overflow of an expanse of water that submerges land. It is a deluge (Haddow *et al*, 2004). *The* great Universal Deluge and its destructive power are described in Genesis 7 verses 6 to 12. In the sense of "flowing water", the word is applied to the inflow of the tide, as opposed to the outflow or "ebb". It is usually due to the volume of water within a body of water, such as a river or lake, exceeding the total capacity of the body, and as a result some of the water flows or sits outside of the normal perimeter of the body. It can also occur in rivers, when the strength of the river is so high it flows right out of the river channel, usually at corners or meanders.

Flooding of urban areas, agricultural land and highways is an annual phenomenon in Nigeria. Jimoh (1999a) recorded that the unusual rains in 1999 caused one of the highest recorded disaster in Nigeria. Most of the deaths were caused at night, when it may be harder to notice high waters and more confusing for the victim. A number of flooding cases were reported in Sokoto, Kebbi, Zamfara, Kano and Niger, Kogi and Kwara States, Nigeria in 2010. Some of the flooding was attributed to operation problem. For example, the gates of Kainji, Jebba and Shiroro dams are often opened at the peak of rainy season (September) to cope with high inflow to the reservoir. The consequent effect is loss of lives, properties, agricultural land and historical centres. It is often difficult or impossible to obtain insurance policies which cover destruction of property due to flooding. Table 1 shows a summary of flooding phenomena in Nigeria.

The annual flooding of the Mekong River and Tonle Sap Lake (Cambodia) is essential for agriculture, but the unpredictability of the flooding damaged infrastructure, agriculture and livelihoods. Between 2000 and 2002, flood phenomena affected 3.4million people and destroyed 7086 houses in Cambodia (Danida, 2008). The recent flooding in Pakistan had been devastating, resulting in loss of lives and affecting over 1 million people.

There are many factors that can affect the way that floods develop. These include heavy rain, wet soil, high rivers and operation of reservoirs. If soil is already wet a large amount of water rising quickly does not allow the ground to absorb more water and excess water pours into rivers and stream, causing them to overflow. Rivers that are already full of water can overflow easily, which can flood areas around the river. A factor that affects all flood formation is heavy rainfall. Heavy rain combined with topography, soil condition and water cover can cause large areas to be covered in a layer of water that is dangerously high. Only 150 mm (six inches) of flood water can knock a person off his or her feet and only 600 mm (two feet) of water can lift most cars.

Table 1: Flooding Phenomena in Nigeria

Year	Name of Location	Number displaced	Lives Lost	Properties Lost
2004	Anambra	840		Farmland and Houses
	Adamawa (Song)	22,000	24	Farmland and Houses
	Taraba	8000	12	Buildings and Crops
2005	Imo	4100	4	Household Belongings
	Taraba (Jalingo)	4000	11	Buildings and Crops
	Edo (Oredo, Egor, Ikpoba			Household Belongings
	Katsina (Yanduna, Baure			15 houses destroyed
	Jalingo (Ringim, Jahun, Birinbawa			Crops and Houses
	Anambra	101		Houses and Roads
	Ikpalibe	60		Household Belongings
2006	Ekiti	750		Household Belongings
	Katsina Town, Faskari	4250		Household Belongings
	Birinin Kebbi	3010	5	House, Shop and Mosque
	Sokoto (Shagari)	1800		Houses, Farmland and Dam.
	Zamfara	1754		Houses, Farmland and Dam.
2007	Ogun	522		Buildings and Bridges
	Lagos	1420		Destruction of Properties
	Cross River	60		Destruction of Properties
	Akwa-Ibom (Uyo)	250		Destruction of Properties
	Bayelsa (Ekeremor			
	Damaturu	684	1	Houses and grains
	Yobe (Fune)	42		Houses and grains
	Bauchi (Alkaleri, Giade, Katagum	989		Houses, Bridges, Roads and Farmland.
	Adamawa (Demsa, Belwa, Michika	1300	7	Houses, Farmland, Foodstuff.
	Borno (Kaga, Chibok, Mobbar, Kusar	215		Household Belongings
	Borno (Jere)	210		Houses
	Gombe (Dukku, Akko Nafada, Shongom	671	8	Houses and Farmland
	Lagos (Ikosi-Isheri)	1420	1	Destruction of Properties.
	Ogun (Abekute N& S.Yelwa ,Sagamu	522		Houses, Bridges, Roads.
	Sokoto	1287		Household Belongings and Livestocks
	Kebbi	1464		
	Kano (Dambata, Gwazo, Gaya, Tofa	3,286		
	Niger (Wushishi, Mokwa)			Food Items, household materials.
	Kano	2898		Houses affected
	Kaduna	227		5 blocks of classroom and Mosque
	Kaduna			

(ECN, 2009)

Thus, the benefits of water management include the following:-

- Improve health through access to safe drinking water and sanitation
- Enhance food security by providing agriculture with water suitable for irrigation
- Protect against damage from floods
- Safeguard water supplies in times of drought
- Contribute to diet diversity by preserving freshwater fish habitats
- Offer employment opportunities if water quality allows fishing stocks to be maintained and other fishing enterprises to grow

3. SUSTAINABLE WATER RESOURCES MANAGEMENT

Surface water supplies are very limited and limited groundwater is available. The limited resource is not evenly distributed in space and time. The raw water quality is further impacted by urban development. In spite of these limitations, the demand is increasing (NWRMP, 1995 and Jimoh, 2010b). Management is a way of addressing the variability of the resource in space and time. This involves the use of structural and non-structural means. The structural means include dams and reservoir, borehole, dykes and canals, while non-structural steps include awareness and stakeholder participation. Water resources development and management need to be in a sustainable manner. Sustainability has been defined as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (The Brundtland Commission, 1987). This concept can be represented in seven key focal rings (Figure 2).

Figure 2: Concept of Management

Each ring represents one of the three systems that support our civilization: the economy, the environment, and our society. Each of these rings overlaps, that is, influences or is affected by the other two. For a community to be sustainable, each of these systems must be healthy and in balance with the others. The availability of fresh water is an important environmental issue of our time. Sustainable water resources systems are those designed and managed to best serve people living today and in the future. A water supply project is sustainable if it is managed in such a way that it meets the needs of the present without compromising the ability of future generations to meet own needs. Sustainability is achievable only if water is considered not only as a social good but also as an economic good.

Water resources are limited and highly variable. Pressures from population and development are increasing. Land use and land cover changes have been significant. Current or proposed future water management schemes are large in relation to the water resources. Management of water resources, both in terms of quality and quantity, therefore, requires an understanding of the interaction between water, the environment and man. Without such an understanding, management of water resources will be piecemeal. In carrying out this, the use of investigative and monitoring tools has proved very useful. Such techniques include the monitoring of water supply and demand, demographic factors, availability of surface or underground water and other hydro-climatological elements.

3.1 Water Resources Development

Nigeria has vast surface water resources, receiving very large part of her water from drainage arteries of West and Central Africa South of the Sahara. It is a well-drained country with a close network of rivers, lagoons, and streams most of which carry less water in the dry season (Figure 3). There is a noticeable decrease in the density of the drainage network from south to north; which has been attributed to the combined effect of hydro-climatic and geological factors. The perennial rivers of the Northern part of the country in particular have intermittent flows, occurring mainly during the short rainy season and are easily depleted during prolonged dry periods (Anukam, 1997).

The turning point for water resources development and management in Nigeria occurred after the severe drought of the 1960s. The response of the Government to the catastrophe was the initiation of strategies for coordinated and effective water resources development, which led to the creation of the Federal Ministry of Water Resources and the River Basin Development Authorities in the mid 1970s. The activities of these institutions were further strengthened in 1981 by the establishment of the National Committee on Water Resources, and by the Water Boards at the state level. These bodies were charged with taking an inventory, and ensuring rational and systematic planned management and conservation, of the country's water resources. Nigeria is divided into eight hydrological areas (Figure 4) and there are 63 large dams in operation throughout the country. The distribution of the resources all over the country is controlled by hydro-climatological and hydro-geological factors. The total numbers of existing and proposed dams in each of the hydrological areas are shown Table 2.

Table 2: Statistics of existing dams in Nigeria

Hydrological Area	States	Large dams	Small dams	Total
I	Katsina, Sokoto, Kebbi, Niger	9	11	20
II	Niger, Kwara, Kogi, Kaduna states, FCT	19	13	32
III	Borno, Plateau, Bauchi, Adamawa	12	9	21
IV	Plateau	4	9	13
V	Enugu, Anambra, Kogi, Edo, Delta	0	7	7
VI	Oyo, Ogun, Osun, Ondo	6	26	32
VII	Cross River	1	10	11
VIII	Kano	12	11	23
		63	96	159

(adapted from NWRMP, 1995)

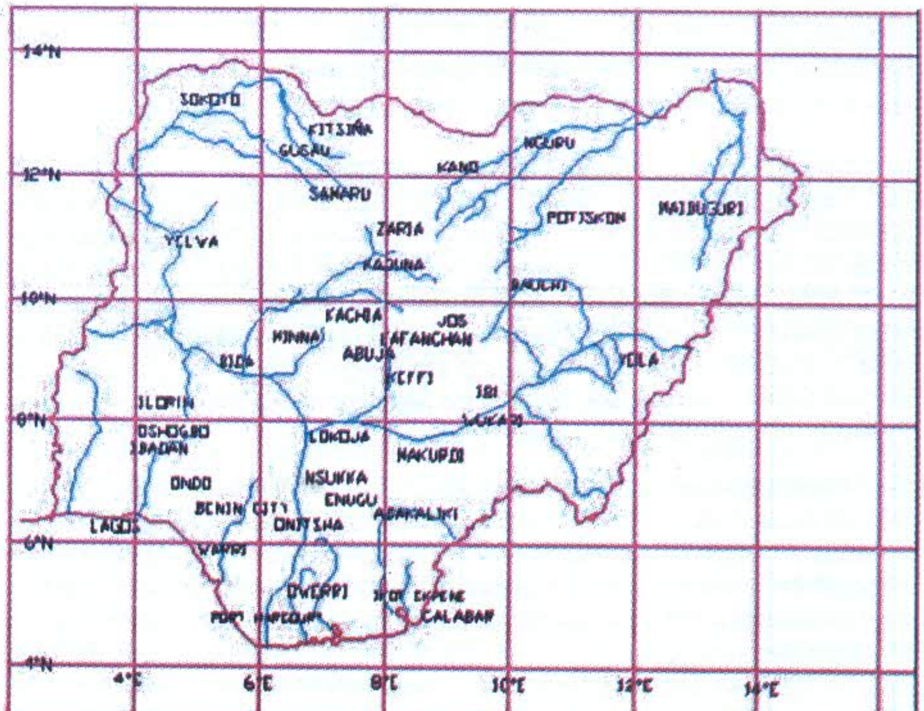


Figure 3: Major rivers in Nigeria (NWRMP, 1995)

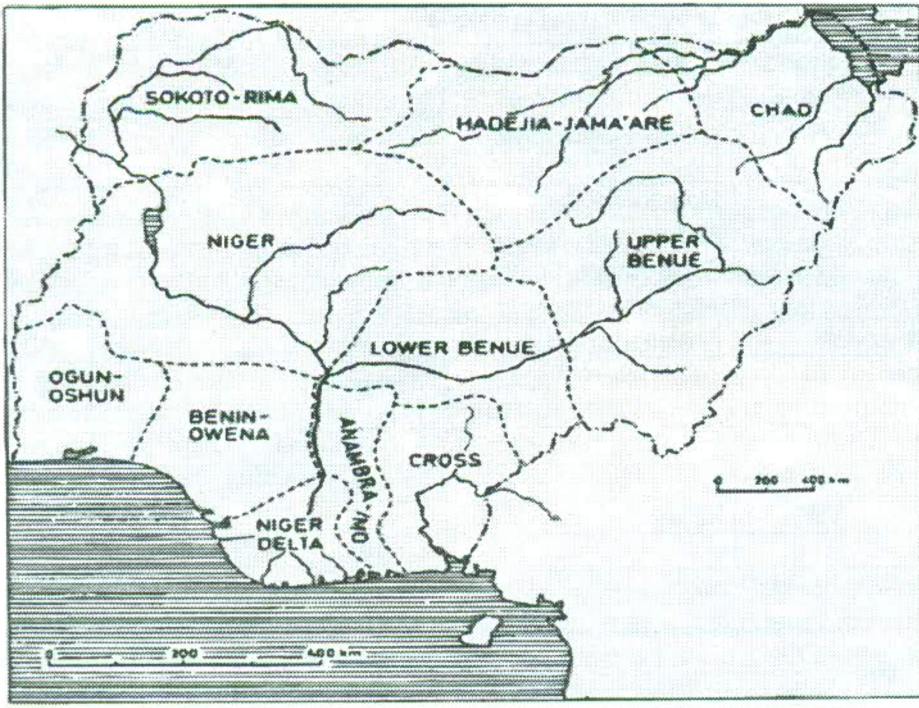


Figure 4: River Basin Authorities in Nigeria (adapted from Nwa, 1978)

The major surface water resources of Nigeria are those of: Niger River System, Lake Chad, Western Littoral and the rivers of Cross and Imo, in that order of importance. River Niger rises in Sierra Leone and Guinea from where it flows in North-East direction across the country, with its principal tributaries being the Benue, Kaduna, Gbako, Gurara and Sokoto-Rima Rivers. It drains an area of 575,000 km^2 in Nigeria. Its major tributary, the Benue, rises in the Republic of Cameroon and has a catchments area of about 233,000 km^2 in North-East Central Nigeria draining the Gongola, the Taraba, the Donga, the Katsina-Ala and the Mada rivers. Together the Niger and its principal tributary the Benue flow through nine countries (Afremedev, 1998).

Lake Chad is a shallow fresh water lake of about 15,540 km^2 in area, out of which about 4,800 km^2 lies at the North-East corner of Nigeria on the boundary with Republic of Chad, Cameroon and Niger. The Lake Chad Basin, located in the North-East Region of Nigeria, is drained by rivers Hadejia and Jama'are that originate from its west highlands, traversing through a vast wetland and discharging into the Lake Chad as the Komadugu-Yobe River. Nigerian portion of the Chad Basin area has three other minor rivers, the Ebeji, the Yedsarem, and the Ngadda Rivers. These four rivers however provide less than 10% of the lake inflow; while practically all of the remaining comes from the Chari River, which has its source in the Central African Republic.

The Cross River, which originates in Cameroon Highlands where the annual rainfall exceeds 4,000 mm, drains an area of about 44,030 km^2 in the South-East corner of Nigeria. The Western Littoral consisting mainly of the Ogun, the Oshun, the Owena and the Osse rivers drains the area lying to the south-west of the country between the River Niger and the Gulf of Guinea. Table 3 shows the potential surface and ground water resources from the hydrological basins.

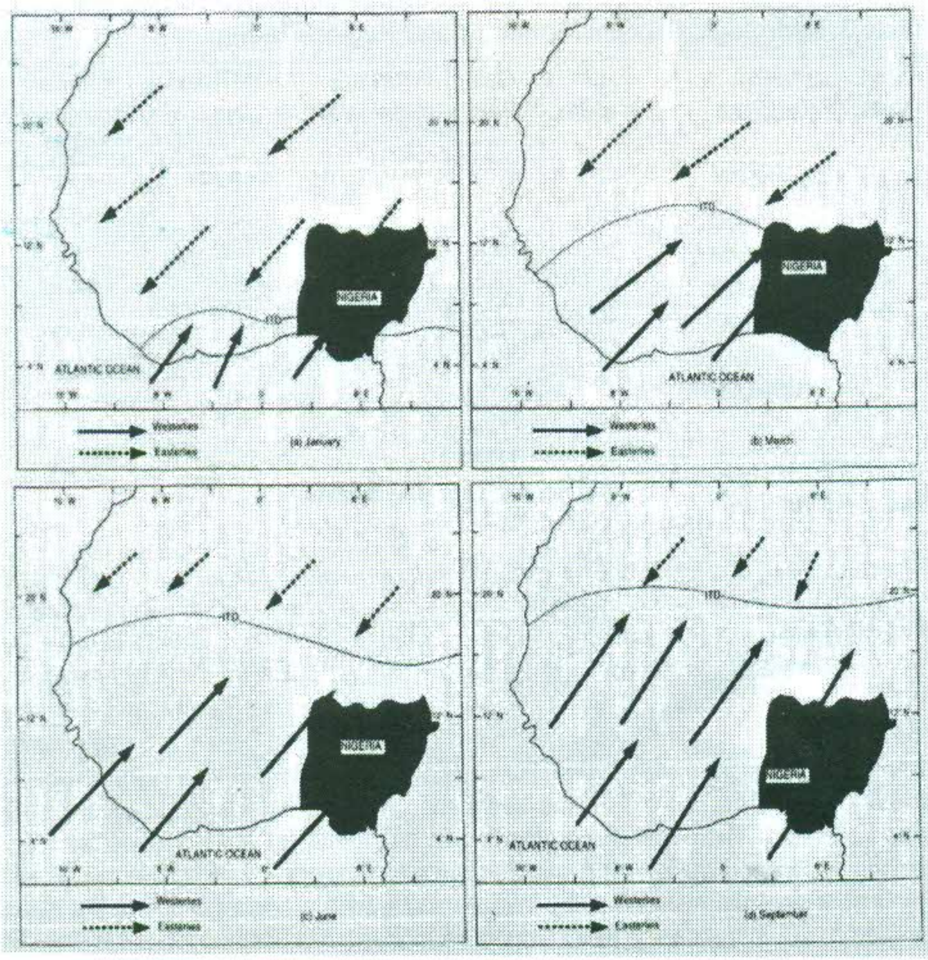
Table 3: Hydrological Basins/Surface Water Regions in Nigeria

Basin Code	Basin Designation	No. of Sub-basins	Area $10^3 km^2$	Percentage of total area	Annual Runoff $10^9 km^3$	Potential Groundwater $10^9 km^3$
1	Niger North	14	131.6	13.6	22.4	4.34
2	Niger Central	16	158.1	16.9	32.6	8.18
3	Upper Benue	14	158.9	16.9	55.0	6.99
4	Lower Benue	9	73.0	8.0	28.0	4.39
5	Niger South	5	53.9	5.9	20.0	7.15
6	Western Littoral	10	100.5	11.1	35.4	9.02
7	Eastern Littoral	7	59.8	6.5	65.7	6.28
8	Lake Chad	15	188.0	21.1	8.2	5.58
	Total	**90**	**923.8**	**100**	**267.3**	**51.93**

Source: NWRMP, 1995

The main source of water for the rivers and streams is rainfall and it is strongly influenced by the seasonal movement of Intertropical Convergence Zone (ITCZ). ITCZ is the zone of greatest convective activity and rain frequency, which lies between the north-easterly dry continental tropical airmass (cT) and the south-westerly tropical maritime moist airmass (mT). The dry and dusty continental airmass originates over the Sahara, and the warm and moist tropical maritime airmass originates over the Atlantic Ocean. In September for example, the westerly trade wind (mT) prevails over the entire country resulting in rainfall at every region of the country. On the other hand, only the coastal region is under the mT wind in January. Therefore, the coastal region has rainfall in January while the other regions of the country have no rainfall. The wet season occurs between July and September over the more northerly latitudes (12 - 14 N). Figure 5 shows the mean position of ITCZ in January, March, June and September. The length of wet season increases from three months at latitude 14 N to eight months (April to November) at the coastal region (4 - 8 N). Along the coast (4 - 8 N), the rainfall regime has two peaks. These peaks occur in May and October, and are separated by a short dry season in July or August. Annual rainfall varies from 3000 mm in the south-east to about 500 mm in the extreme north-east. Figure 6 shows the mean annual rainfall across the country (Adefolalu, 2002).

In summary, Nigeria's average annual rainfall is approximately 1080 mm, resulting in total mean annual rainfall volume of approximately 998 km^3 and surface water flowing from Nigeria to the sea is estimated as 263 km^3/year. The per capita domestic water consumption is 30 litres/day, approximately 11 m^3/year.Groundwater resources are estimated at around 87 km^3/year, of which great part (about 80 km^3) constitutes the base flow of major rivers.



January (top left), March (top right), June (bottom left), September (bottom right)

Figure 5: Seasonal movement of ITCZ over Nigeria

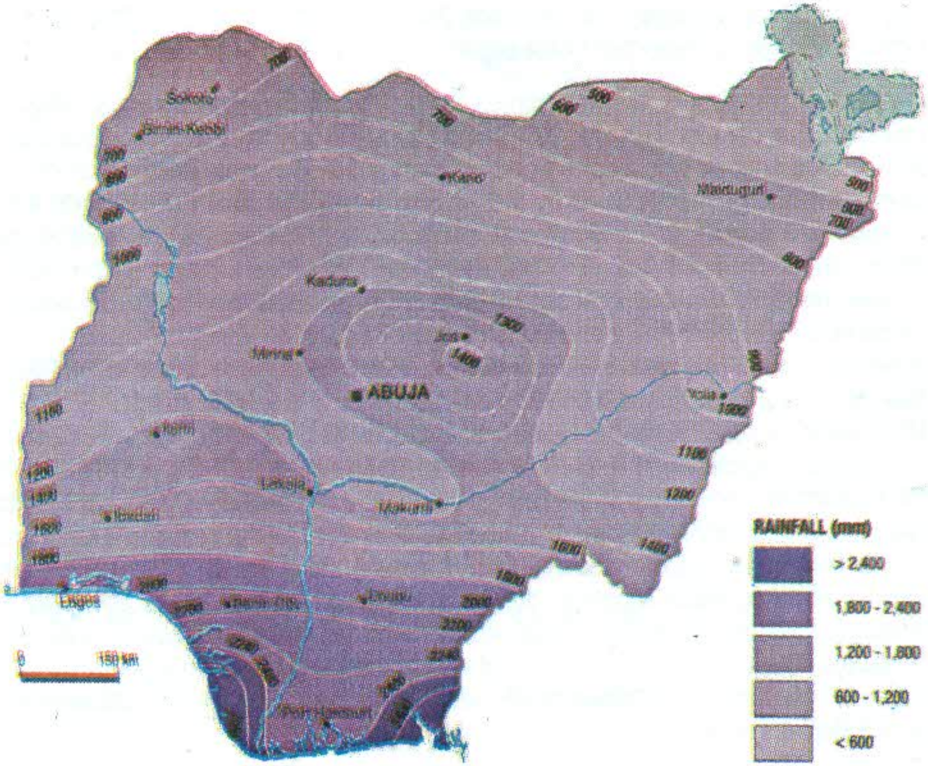


Figure 6: Mean annual rainfall in Nigeria (Adefolalu, 2002)

3.2 Water for Domestic and Agricultural Uses

An assessment (NWRMP, 1995) showed that the water consumption and demand in Nigeria would increase from 2,730 Mm^3 in 1995 to 24,140 Mm^3 (approximately nine fold increase) by 2020. It was also projected that only an average of about 8 per cent of both the potential surface and ground water resources will be consumed by 2020, with the notable exception of Lake Chad Basin where 35.6 percent of the surface water and 11 percent of the groundwater shall be consumed. It is therefore significant to stress the need for greater attention to water resources monitoring and more innovative water operations of projects. While the resource is finite, the demand is increasing at geometric rate.

It is estimated that out of a total arable land area of 71.2 million hectares (total area 92,377million hectares) in Nigeria, less than half is actually cultivated. This is largely due to lack of effective agricultural implement and non availability of water when and where it is required. NWRMP (1995) reported that 39% of the land mass is potentially suitable for agriculture and out of this between 4.0 and 4.5 million ha (approximately 4.5 to 5.0%of the land) are judged suitable for irrigated agriculture but only 1.1 million ha can be supported fully by the water available, the remaining 3.4 million ha being fadama. The need to increase agricultural production for the populace is stressing the water demand.

In a study on water supply and sanitation in Nigeria (African Development Bank, 2004), it was found that between 60% and 70% of the population is without water or wastewater services. Most people who receive piped water are supplied by state water corporations, all of which are currently owned by the governments of the states within which they operate. In rural areas, about 49 percent of the population have access to safe water and 30 percent to improved sanitation facilities. About 72% of the urban population have access to reliable water supply of acceptable quality: sanitation coverage is estimated at 48 percent. Except for Abuja and limited areas of Lagos, no urban community has a sewerage system (African Development Bank, 2004). Leakage rates are around 50% and the proportion lost to wastage and illegal connections is actually rising (Hall, 2006). Many water agencies lack capacity and financial resources and so are finding it difficult to meet the existing demand for safe water and sanitation within their respective areas. In the far north and southwest of the country there are water shortages, and in the Delta region, and near major cities, there is insufficient control of water pollution and serious erosion (African Development Bank, 2004). In another study, Jimoh and Wojuola (2009) found that public water supply to the Federal Capital Territory (FCT) of Nigeria is inadequate and an alternative source of water includes streams, hand-dug wells and boreholes. The study showed that 41% of the territory uses hand-dug wells, while 23% depends on boreholes and 16% depends on streams. This implies that 57% of the people draw water from unhygienic sources.

The quality of available resource is also altered by users. In a study on farming practices at Tunga Kawo irrigation scheme in Niger State, Jimoh et al (2003) found that the quantity of fertilizer applied by the farmers was below the quantity required for optimum yield. Despite this, excess chemicals were identified in the surface and groundwater in the downstream end of the scheme. The presence of excess chemical in the water bodies was attributed to the techniques and timing of application of fertilizer in the irrigated plots. The magnitude of these impacts can be reduced by efficient application of input.

3.3 Water for Electricity Generation

Before 1960, coal was the main source of fuel for thermal power production in Nigeria. Construction activities on the first hydropower station in Nigeria commenced in 1964 at Kainji on River Niger. The dam was commissioned in 1968 with an installed capacity of 320 MW, and by 1978, the station had 8 plants with capacity of 760 MW. Later on, the tail water from Kainji Dam was utilized to generate 540 MW at Jebba Dam, 97km downstream of Kainji Dam. The third hydro-electric power (HEP) station, the Shiroro Dam was commissioned in 1990 with an installed capacity of 600 MW bringing the total installed capacity of HEP in Nigeria to 1900 MW. Thermal plants were also installed during this period so as to address the increase in power demand in the nation. Table 4 shows the capacity of the thermal and hydro-electric power stations in 1997. The Table shows that the installed capacity of HEP stations accounts for 32% of the 6000 MW installed capacity. By late 1990, the available installed capacity of both thermal and HEP stations was about 2500 MW (Adeleye, 1997) indicating availability factor of only 0.46. HEP stations account for about 51% of the 2500 MW. The availability factors for the HEP stations were reported to be better than those of thermal stations.

Hydroelectric energy is a renewable energy source which relies on the natural water cycle, and the flow of water due to gravity. It is beneficial to Nigeria and could be harnessed to address the shortage of energy because there are many rivers that are appropriate for HEP dam. Currently, Nigeria has developed 23% of her feasible hydropower. This is very low compared to other African countries such as Lesotho (50%); Bukina Faso (46%) and Kenya (34%). About half of the Nigerian population remains literally in the dark without access to electricity. The majority of these numbers are in the rural areas. The crises in the Niger Delta region, shortage of gas and low water level at the HEP reservoirs, are reasons always given to explain the inability of government to provide electricity for the people. While misappropriation of funds is the order of the day at the government level, in NEPA/PHCN the name of the game is fraud, corruption and inefficiency.

Table 4: Installed Capacity of Power Stations in Nigeria

Power Station	Installed Capacity (MW)	No of units	Fuel
Afam Thermal	700.9	18	Gas
Delta Thermal	812	20	Gas
Egbin Thermal	1320	6	Steam
Ijora Thermal	66.7	3	Gas
Sapele Thermal	1020	10	Steam(6 units) Gas (4 units)
Jebba Hydroelectric	540	6	Water
Kainji Hydroelectric	760	5	Water
Shiroro Hydroelectric	600	4	Water
Oji River Power Station	30	4	Coal
Isolated Power	10.3		

(Source: Adeleye, 1997)

Nigeria has considerable hydro potential sources exemplified by her large rivers, small rivers and stream and the various river basins being developed. Nigerian rivers are distributed all over the country with potential sites for hydropower scheme which can serve the urban, rural and isolated communities. Studies (Opanefe and Owolabi, 2002 and Zarma, 2006) have shown that potential sites exist in virtually all parts of Nigeria (Table 5). The total potential was estimated as 734.3 MW. So far about eight (8) small hydropower stations with aggregate capacity of 37.0 MW have been installed in Nigeria by private companies and the government. These include 3 MW plant in Bagel, 8 MW plant in Kura and 8 MW in Lere, and 2 MW Station at Kwall fall on N'Gell river (River Kaduna).

There has been consistent public outcry bordering on the poor and depreciating quality of services rendered by the Authority. For instance, Ilori (2004) reported that the energy generation availability in Nigeria declined to 1600 MW in 1999 from 5,876 MW installed capacity with only 19 functioning out of the 79 generating units. The current generation capacity is still below 2000 MW. Nigeria is a signatory to the Millennium Development Goal, and before then to several other international protocols on water resources development and management. A significant proportion of dam construction in the country took place in the late 1970s and in the 1980s. A total of 63 large dams and 96 small dams have been built so far. The water allocation from the reservoirs into the three main users is presented in Table 6. Irrigation activity accounts for the highest proportion of consumptive use of water in the country. The non-consumptive water for hydropower generation could be re-utilised downstream. There is a need to utilise the run-off from the

Table 5: Potential Hydro Power Sites in Nigeria

Location	River	Average Discharge (m^3/s)	Max. Head (m)	Installed Capacity (pf=0.5) MW
Donko	Niger	1650	17	225
Zungeru II	Kaduna	343	97.50	450
Zungeru I	Kaduna	343	100.60	500
Zurubu	Kaduna	55	40.0	20
Gwaram	Jamaare	75	50	30
Izom	Gurara	55	30	10
Gudi	Mada	41.5	100	40
Kafanchan	Kongum	2.2	100	5
Kurra II	Sanga	5.5	430	25
Kurra I	Sanga	5.0	290	15
Richa II	Daffo	4.0	480	25
Richa I	Mosari	6.5	400	36
Mistakuku	Kurra	2.0	670	20
Kombo	Gongola	128	37	35
Kiri	Gongola	154	30.50	40
Kramti	Kam	80	100	115
Beli	Taraba	266	79.2	240
Garin Dali	Taraba	323	36.60	135
Sarkin	Suntai	20	180	46
Danko	Donga	45	200	130
Gembu	Katsina Ala	170	45	30
Kasimbila	Katsina ala	740	49	260
Katsina Ala	Benue	3185	25.90	600
Makurdi	Niger	6253	31.40	1950
Lokoja	Niger	6635	15.25	750
Onitsha	Osse	80	50	30
Ifon	Cross	759	47	400
Ikom	Cross	1621	15.5	180
Afikpo	Cross	1704	10	180

(Source: Zarma, 2006)

Table 6: Allocation of water to principal users

No	User	Amount (proportion)	Comment
1	Irrigation	10.9 km^3 (36%)	Consumptive use
2	Water supply	0.8 km^3 (3%)	Consumptive use
3	Hydropower	13.6 km^3 (61%)	Non-consumptive use

(Source: FAO, 1993)

There is a general agreement that the utility services in Nigeria, including electricity, telephone, water, and transport, are failing to provide and develop the services and the infrastructure required for social and political development. The electricity and water supply systems are unreliable and under-developed. The Structural Adjustment Program (SAP) of the 1980s has increased prices but not performance, which has contributed substantially to lowering the quality of life and well-being of the average Nigerian who has become more and more impoverished (Ariyo and Jerome, 2004).

Water resources management in Nigeria is faced with a lot of problems which slowed down the development of the resource. Some of these problems included (Anukam, 1997):

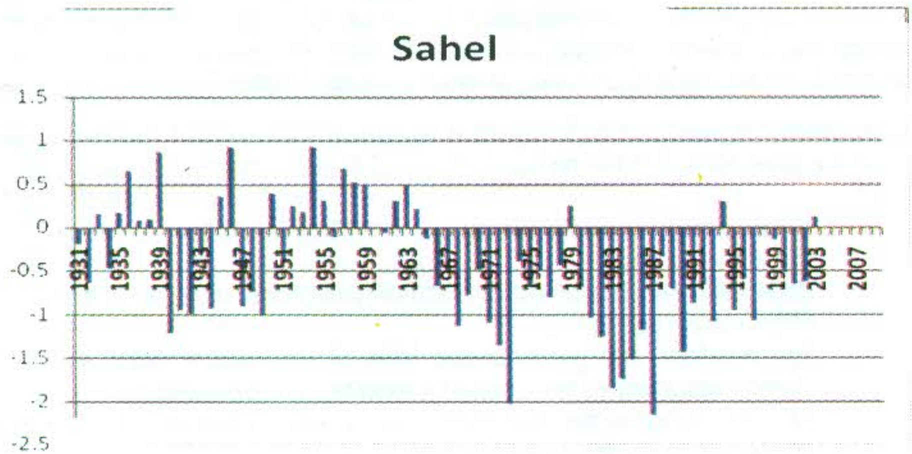
- The finite resource with increasing and competing demands
- Climatic variations.
- Unnecessary duplication and overlap in organisations, structures and functions of the relevant bodies.
- The ill-defined and uncoordinated roles of the Federal, State and Local Government agencies responsible for water resources development.
- Failure to recognise the inter-relationship between surface and ground waters, and between water resources and land use.

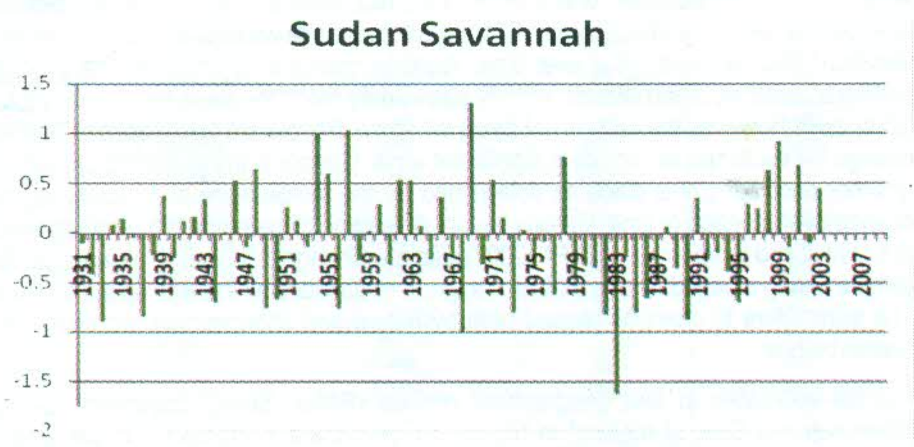
4. CHANGING HYDROLOGY

Weather is the temperature, precipitation (rain, hail, sleet and snow) and wind, which change hour by hour and day by day. Climate is the average weather and the nature of its variations that we experience over time. Weather changes all the time. The average pattern of weather, called climate, usually stays pretty much the same for centuries if it is left to itself. However, the earth is not being left alone. People are taking actions that can change the earth and its climate in significant ways. Climate is the prevailing or average weather conditions of a place as determined by the temperature and meteorological change over a period of time. Various factors determine climate and the most important are rainfall and temperature (NAPA, 2007).Climate Change is a change occurring in the climate during a period of time that can range from decades all the way up to centuries. The term refers to changes caused both by nature and changes that are caused by human beings.

Rainfall anomalies in four geographical regions (Sahel, Sudan Savannah, Guinea Savannah and Coastal regions) in Nigeria are presented in Figure 6. A quantitative assessment of the series showed linear trend was not significant during the period 1931-

1960 in the four regions (Jimoh and Webster, 1996); indicating stationary rainfall. However, Sudan Savannah and Sahel regions experienced declining trend during the period 1961-1990. There was a slight recovery in rainfall in the Sudan Savannah in the 1990s but declining trend persists in the Sahel regions. The situation in the Guinea Savannah was similar to that of Sudan Savannah. The Coastal region experienced a declining trend between 1961 and 1990, but the rate of reduction in rainfall was not as high as that of the Sahel region. It was observed that there was more instantaneous high rainfall in the Coastal region during the period. The downward trend in the annual rainfall corresponds to the period with the Sahelian drought especially in 1972, 1973, and 1981-1983 (Nicholson, 1981; Hulme, 1992).





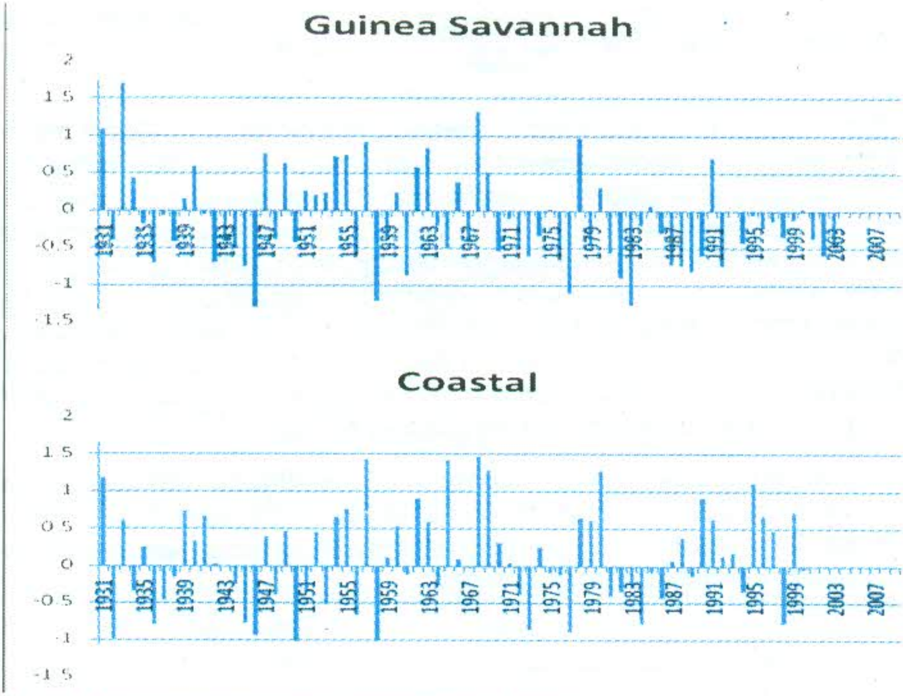


Figure 6: Rainfall anomalies of some synoptic stations in Nigeria

Although, the annual rainfall in each region was lower than the long term average in the 1990s, the number of flooding (urban and river plains) cases increased during the period. Jimoh and Webster (1996 and1998), Adefolalu, *et al* (2006) and Jimoh (2007) showed that while rainfall depth is decreasing, characteristics of rainfall such as start of rainy day, start of planting season, intensity of rainfall, frequency of wet and dry spells decrease and sometimes increase at a different proportion. This has considerable effect on urban flooding (Jimoh, 1999a) and crop yield (Ilesanmi, 1971, Benoit, 1977, and Olaniran and Sumner, 1989). Jimoh and Egharevba (2003) studied the start of planting season from 1931 to 2000 in Minna and found high inter-annual variation in the start of planting season. They also reported that there is no significant relationship between start of planting season and amount of rainfall. In addition, crop yield depends on start of planting season and dry spell within the growing period. The flooding phenomena were exacerbated by un-coordinated urban development, and indiscriminate dumping on flood plains (Jimoh, 1999a).

4.1 Effect of climate change on hydropower generation

Hydropower generation is the energy source most likely to be affected by climate change. It is sensitive to the amount, timing, and geographical pattern of precipitation, as well as temperature. There is the potential for more intense rainfall events (which would require more conservative water storage strategies to prevent flood damage), greater probability of drought (less hydroelectric production), and less precipitation (less water available during warm months); all of which point to less hydroelectric capacity at current powerhouses.

Reduced flows in rivers and higher temperatures reduce the capabilities of thermal electric generation. Higher temperatures also reduce transmission capabilities. Hydropower generation will be affected by increased run-off (and consequent siltation). Excessive drought will lead to higher evapo-transpiration, which adversely affects water volume, and will thus reduce hydroelectric capacity (Jimoh, 2010a). Climate change-induced extreme weather events such as windstorms, floods and tornadoes (which can topple transmission towers and hundreds of kilometres of power lines) will exacerbate the rate of failure of transmission systems of electric utilities. The cost implications are prohibitive. Yet demands for both space-cooling and space-heating can only increase, placing further dependence on this already burdened industry.

Figure 7 shows the inflow into Kainji Reservoir for the past 40 years. The inflow has been noisy. There was a declining inflow for the first 15 years of the reservoir. Jimoh (2007, 2008 and 2010a) showed the effect of the phenomena on the hydropower generation on the three large hydropower reservoirs in Nigeria.

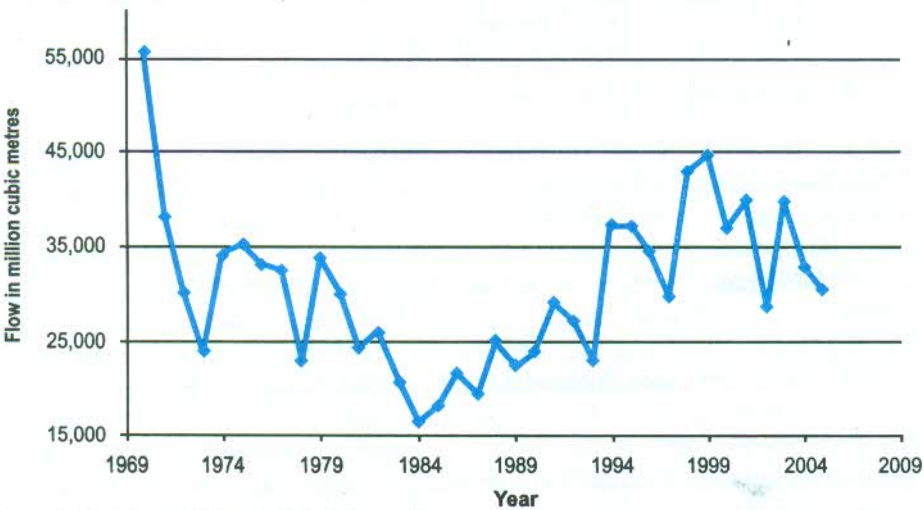


Figure 7: Variation of inflow to Kainji Reservoir

4.2 Effect of climate change on modelling

Time series of daily rainfall records are often required as input for water resources projects such as irrigation and small town water supply projects. The availability of such records is often constrained by economic, technical and personnel reasons. As an alternative, the rainfall records can be simulated using stochastic rainfall models (Haan *et al.*, 1976). This involves using the historical rainfall records to estimate the model parameters of an appropriate model, which may then be used to simulate the desired length of rainfall series. Stern (1980a,b), Garbutt *et al.* (1981) and Jackson (1981) reported that second or higher order Markov chain models are adequate for describing the occurrence of daily rainfall in Nigeria. The model parameters, expressed as transition probabilities, estimated at daily time scale increase geometrically with the order of model. Number of model parameter is 2^n (that is, number of parameters to be estimated is 1, 2, 4, and 8 for orders 0, 1, 2 and 3 respectively).

Jimoh and Webster (1996), however, showed that the order 1 Markov model is sufficient for representing the occurrence of daily rainfall in the country. This observation was based upon the ability of the model to reproduce the characteristics of the observed series, such as:

- Average monthly number of wet days.
- Frequency duration curve over 30 years for wet and dry events
- Average number of wet events.
- The first and last wet days over 30 years.

The study further showed that the required length of record for estimating parameters of first order Markov model depends on the 'period of record'. For a trend-free (stationary) period, there is no significant difference in the model performance for record lengths of 10, 20, or 30 years. This suggests that 10 year record in a trend-free period is adequate for estimating the model parameters. Non-stationary phenomenon which is reflected as 'trend' in rainfall series could be attributed to climate change. The root mean square error of estimating the mean monthly number of wet days in Nigeria during a non-stationary period could be as high as three times the value for the stationary period.

Rainfall series in Nigeria have been reported (Adefolalu, 1986; Jimoh and Webster, 1996) to show significant trend from the 1960s. The relationship between the rainfall anomalies and some ocean-atmospheric variables was investigated by Jimoh and Webster (1998). The work identified a system for forecasting the anomaly based upon preseason weather variables comprising sea surface temperatures and the position of the ITCZ (Figure 8). The position of the ITCZ has stronger influence on the rainfall in the Midland and Sahel regions of the country, while the sea surface temperature at the Gulf of Guinea has a stronger influence on rainfall in the Coastal and Guinea Savanna regions. It was also identified that the position of the ITCZ relative to individual station influences the depth of rainfall, especially for stations in the northern part.

The heat flux from the ocean into the atmosphere depends on the differences between sea and air temperatures, and on wind speed near the surface. Thus, a warm ocean and a strong wind enhance the transport of heat vapour into the atmosphere, and the heat flows into the atmosphere lowers the stability of the atmosphere and encourages deep convection (Cordery and Opoku-Ankomah, 1994). This mechanism justifies the relationship in the Coastal region of Nigeria. The ocean temperature for the mixed rainfall pattern, when the Coastal region has a high rainfall agrees with this hypothesis. This hypothesis does not, however, explain why low rainfall in the Sahel is associated with warm ocean. Perhaps it could be as a result of combined effect of ocean current and moisture contents of the atmosphere. That is the influence of ocean current on Sahel rainfall is low while those of moisture contents of movement of the south-west trade winds are high.

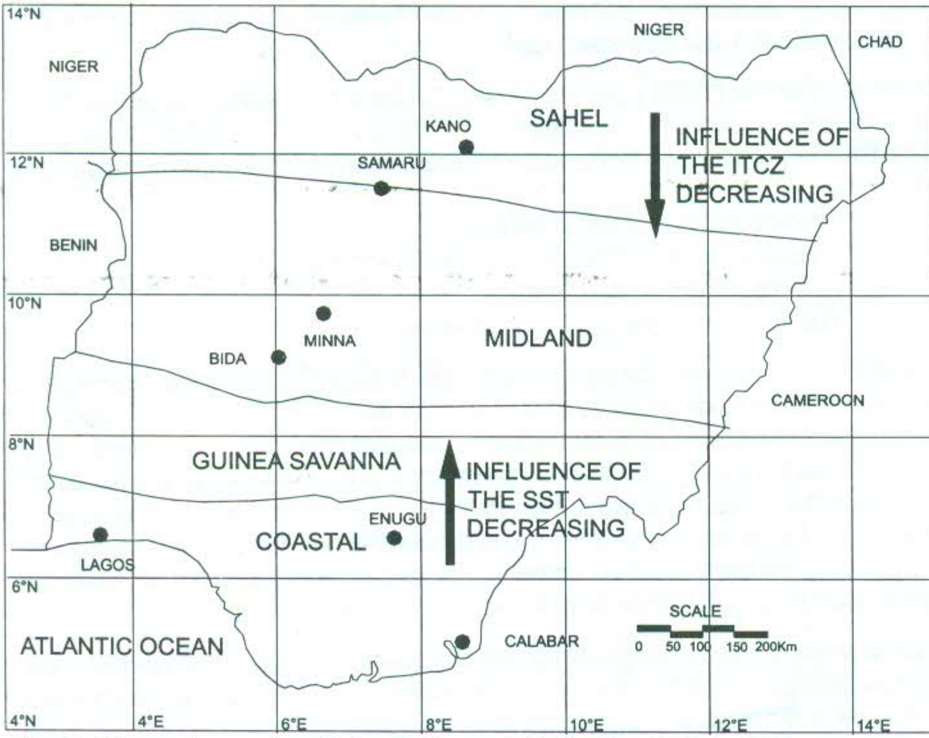


Figure 8: Influence of ocean-atmospheric variables on rainfall (Jimoh and Webster, 1998)

5. INADEQUATE HYDRO-METEOROLOGICAL DATA

Hydrological and meteorological data are required for planning, design and operation of water resources projects. The data include rainfall, temperature, relative humidity, wind speed, streamflow, etc). The collection and dissemination of rainfall data are the responsibility of the Federal Department of Meteorological Services (FDMS). Some organisations such as the River Basin Development Authorities (RBDAs) and Agricultural Development Projects (ADPs) supplement the work of the FDMS. Figure 9 shows the synoptic and some agro-meteorological stations in the country. The number of gauges in the country has increased from 11 in the 1900's to 368 in the 1990's (Mott MacDonald, 1992). The rain gauge density is approximately one gauge per 2500 km^2, which exceed the minimum requirement of one gauge per 750 km^2 (WMO, 1947). The density is not sufficient to monitor the special variation in the rainfall regime.

In addition, the gauges are not uniformly distributed across the country (Figure 9). There are more gauges in the south west region than the north east region of the country. Most stations are equipped with standard UK Meteorological office type II gauges for monitoring daily rainfall. Rainfall data from these stations is in cumulative depth over a period of 24 hours (8.00 a.m. to 8.00 a.m. the following day). There are recording gauges (tilting siphon type) at some of the synoptic stations (located at airports) for monitoring the intensity of rainfall at smaller time intervals. Rainfall stations over the country encounter problems such as replacement of damage of malfunctioning equipments and lack of consumables, such as pens and charts. This explains limitation in the design of urban and highway drainage systems in Nigeria.

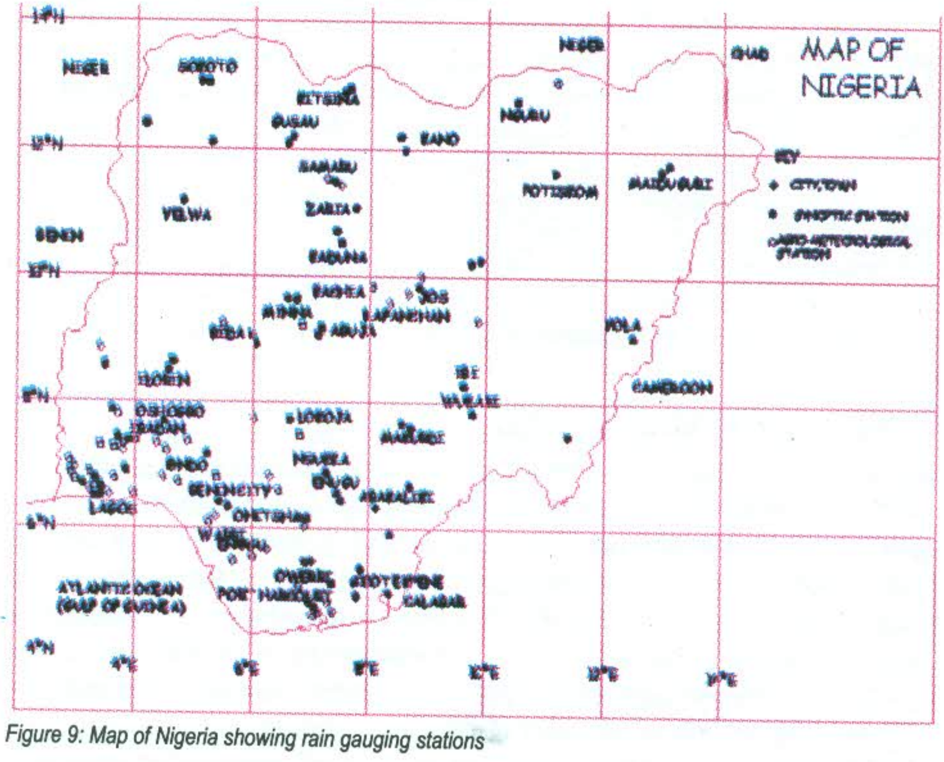


Figure 9: Map of Nigeria showing rain gauging stations

Jimoh and Webster (1996) reported that the sequences of wet and dry days generated with the unsmoothed model parameters are similar to the observed sequences. The study further illustrated that a smoothened model parameter will facilitate the modelling exercise. Jimoh and Webster (1999) stressed that it is essential that parameter sets be smoothed in order to facilitate comparison between different gauges and different periods of record. The comparative work has shown that the use of different techniques of smoothing based upon Fourier fitting and averaging are equally good in terms of reproducing the characteristics of the observed record. A Fourier series fitted to values of Markov model parameters at one day time step, where the values are obtained by 15-day averaging of historical parameters and the intermediate values at one day time step obtained by linear interpolation, was adjudged better in reproducing the start of the wet season and has been used in all subsequent analysis (Jimoh and Webster, 1999). This is clearly of importance in the use of models where limited observed data are available for parameter identification.

The dearth of hydrological data on rivers and streams in Nigeria was reported by Nwa (1978), Mcdonald (1992), Jimoh and Sule (1992) and NWRMP (1995). The reports showed that hydrological data are not adequate in terms of length of record, spatial coverage and consistency. The situation since 1995 has been worsened by bureaucracy, policy implementation, finance and technical problems. The situation has put a lot of stress on the managers and operators of water projects. Even in a country like the UK, where there are over 1,000 river flow measurement stations, the quantity of available water resources is still uncertain and considerable funds are being invested to develop methods of resource assessment for un-gauged rivers (Gustard *et al*, 1992). There are many rainfall-runoff models for addressing un-gauged basins, but estimating the model parameters is a critical problem. Jimoh and Sule (1992) found that a 9 parameter model is capable of reproducing the hydrologic characteristics of River Gurara Basin in North Central Nigeria. The model is capable of estimating seasonal flow in River Chanchaga, Minna.

6. OPERATION OF WATER FACILITIES

The frequency and intensity of a lot of hydrological events such as drought and flood continue to fluctuate due to climate change and nature or human causes. Thus, the existing reservoir operation rules need to change. The operation of reservoirs is a classical problem in water resources engineering with a long and distinguished history, spanning well over a century (USACE, 1991). One practical approach to this problem is combining the use of optimization modelling with simulation modelling techniques. Changing long-term reservoir operation policies to reflect changes in reservoir operating purposes often requires a rethinking of reservoirs operation strategies. Simulation modelling retains a central role in this process, but faces difficulties due to the enormous range of different operating policies which may be examined.

Simulation models (described as IF THEN statement to fairly complex mathematical functions), in most cases require explicit statement of operating rules. Optimization models do not require explicit statement of operating rules. The objectives for the reservoir operations are explicitly stated in the form of penalty functions. The representation of hydrologic uncertainty in optimization models has been developed from several different perspectives. The two important 'schools of thought' (USACE, 1996) on this subject are explicitly stochastic representation and implicitly stochastic representation. Explicit stochastic representation of hydrologic uncertainty and variability requires characterizing the hydrologic inputs to the system in explicit probabilistic terms, i.e., joint probability functions and time series correlations. These probability functions, disaggregated where more than one hydrologic input is important, are then typically formulated as a stochastic dynamic program and solved to derive an optimal operating policy (Stedinger, *et al.*, 1984; Tejada-Guibert *et al.*, 1990 and 1995; and USACE, 1996). This approach has significant computational inconvenience and requires often difficult specification of hydrologic input probability functions (Young, 1966).

The objective function in a reservoir optimisation model is expected to incorporate efficiency, survivability and sustainability (Labaide, 2004). Efficiency refers to the maximum current and future discounted welfare, while survivability is ensuring future welfare exceeds minimum subsistence level. Sustainability refers to the maximum cumulative improvement over time. The main interest of reservoir operators and planners is to get the best use of stored water. There are a number of studies on optimisation of reservoirs. There have been (Yeh, 1985 and Wurbs, 1993) a gap between theoretical developments and real-world implementations of application of optimization models to reservoir systems. Possible reasons (Labadie, 2004) for this disparity include: (1) many reservoir system operators are sceptical about models purporting to replace their judgment and prescribe solution strategies and feel more comfortable with use of existing simulation models; (2) computer hardware and software limitations in the past have required simplifications and approximations that operators are unwilling to accept; (3) optimization models are generally more mathematically complex than simulation models, and therefore more difficult to comprehend; (4) many optimization models are not conducive to incorporating risk and uncertainty; (5) the enormous range and varieties of optimization methods create confusion as to which to select for a particular application; (6) some optimization methods, such as dynamic programming, often require customized program development; and (7) many optimization methods can only produce optimal period-of-record solutions rather than more useful conditional operating rules.

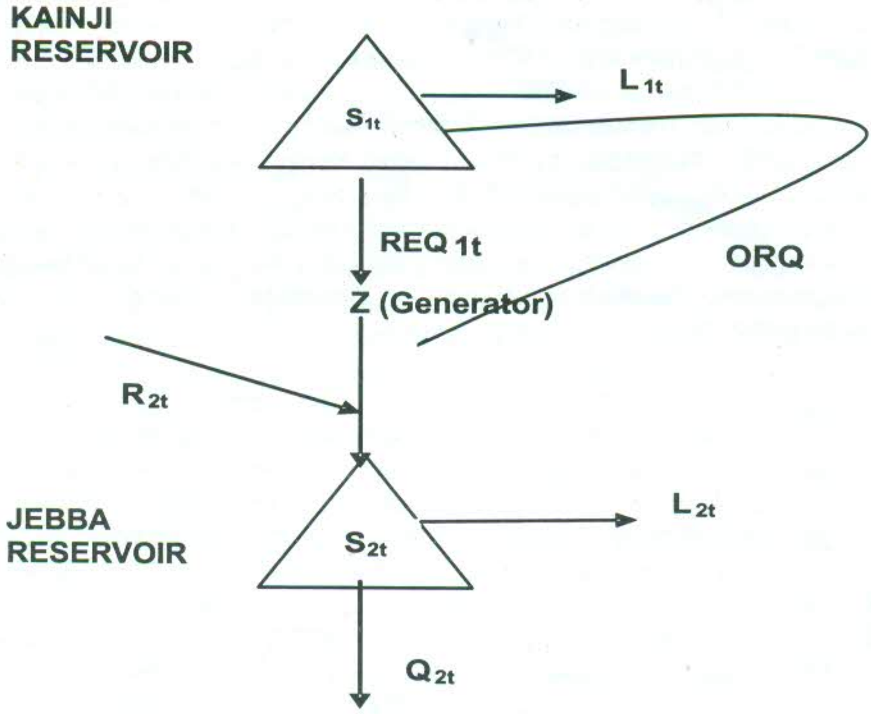
Many of the hindrances to optimization in reservoir system management are being overcome through ascendancy of the concept of decision support systems and dramatic advances in the power and affordability of desktop computing hardware and software. Several private and public organizations actively incorporate optimization models into reservoir system management through the use of decision support systems (Labadie et al. 1989). Incorporation of optimization into decision support systems has reduced resistance to their use by placing emphasis on optimization as a tool controlled by reservoir system managers who bear responsibility for the success or failure of the system to achieve its prescribed goals. This places the focus on providing support for the decision makers, rather than overly empowering computer programmers and modellers.

There are many types of optimisation models (Yeh, 1985). For hydro-power reservoir, the system is dynamic and the equations are nonlinear and non-convex. In addition, the unregulated inflows, net evaporation rates, hydrologic parameters, system dynamics and economic gain are treated as random variable. Thus we have large scale nonlinear system that can be represented by stochastic rather than discrete system. Optimization solution in hydropower system is also site specific. Jimoh (2008) reported that Stochastic Dynamic Programming (SDP), in a family of dynamic programming is suitable for addressing the Kainji-Jebba hydropower system. Dynamic Programming (DP) is based on Bellman's principle of optimality, which states that no matter what the initial stage and state of a Markov decision process, there exists an optimal policy from that stage and state to the end. DP is the calculation of flexible feedback of closed-loop optimal policies conditioned on the current system state. Except for optimal control theory, the development of optimal feedback policy is unique to DP. The main problem of DP is dimensionality difficulties, which is overcome by the use of digital computer.

6.1 Kainji-Jebba Hydropower system

The effective operation of a water reservoir depends on the storage capacity of the reservoir inflow and its outflow demand. The run off of river varies annually. Every flood frequency is determined by the inflow pattern for a particular hydrological season or sequence. The operation of the Kanji reservoir depends on the inflow and storage. The reservoir is to have its initial normal annual impoundment at about mid August based on the presence of substantial inflows from Niger white flood. Thus the excess inflow, if any, gives the rising stage of the reservoir. There are five curves meant for the filling operation, which is kept close to central curve. The inclination of the reservoir hydrograph to the left side of the central curve indicates excessive filling rate and could lead to over filling which can be catastrophic; while to the right of the central curve it indicates inadequate filling. There are six curves for the emptying stage. The central curve remains the control curve to be followed for the drawdown. The purpose of the drawdown is to create enough storage for the water of the incoming flood session. Any operation below the lowest curve indicate only a slim chance of filling the reservoir, unless with its high inflow or limited outflow (Oke, 1995). The limitation of the reservoir operation policy is that it is not flexible and has no inherent structure to handle the existing climate dynamic. Thus, Jimoh (2007 and 2008) showed that an operation policy based Stochastic Dynamic Programming (SDP) performs better than the existing policy, in terms of energy generation and flood control.

A schematic representation of the Kainji and Jebba Reservoirs system is presented in Figure 10.



Notation: I is inflow, Q is release, R is runoff into river between Kainji and Jebba, S is storage, L denotes losses including evaporation and seepage, REQ is the discharge through the turbine and ORQ represents other releases from the reservoir. The subscripts 1 and 2 denote Kainji and Jebba respectively, and t denotes time.

Figure 10: Schematic diagram of Kainji and Jebba Reservoir system

The objective function of the system is to maximize power generated at Kainji and release sufficient water for Jebba reservoir. The analysis is based on Bellman's principle which states that an optimal policy has the property that whatever the initial state and initial decisions are, the remaining decisions must constitute an optimal policy with regard to the state resulting from the first decision. The reservoir system operation is subject to a number of constraints such as continuity equation, storage constraints and obligatory release for Jebba Reservoir. The storage constraints are: (i) the storage in the reservoir is not less than a minimum value, and (ii) the storage does not exceed the reservoir capacity less a reserved storage for flood. The volume reserved for flood control varies with season, as illustrated in Figure 11 (Jimoh, 2007).

The optimisation study was carried out using the characteristics of the reservoir shown in Table 7 and evaluated with the operation policy between 1996 and 1999 (Jimoh, 2007).

Flooding of River Niger plain in September and October is an annual phenomenon. The 1999 event was severe, and according to the managers, the opening of the spillways at the dam during high inflow to avoid failure of the dam was a contributing factor. Figure 12 shows the inflow to the reservoir, the outflow and the optimized release policy under the hydrologic condition. The inflow to Kainji Reservoir during the 1999 black flood season did not differ significantly from the previous year record. However, the inflow during the 1999 white flood season differed significantly from the previous year record. The managers adopted the operation policy of the previous year for the 1999 season and the reservoir was not emptied in anticipation of the incoming high inflow, thus, the flooding of river plain was experienced. The result underscores the importance of operation policy and forecasting inflow series.

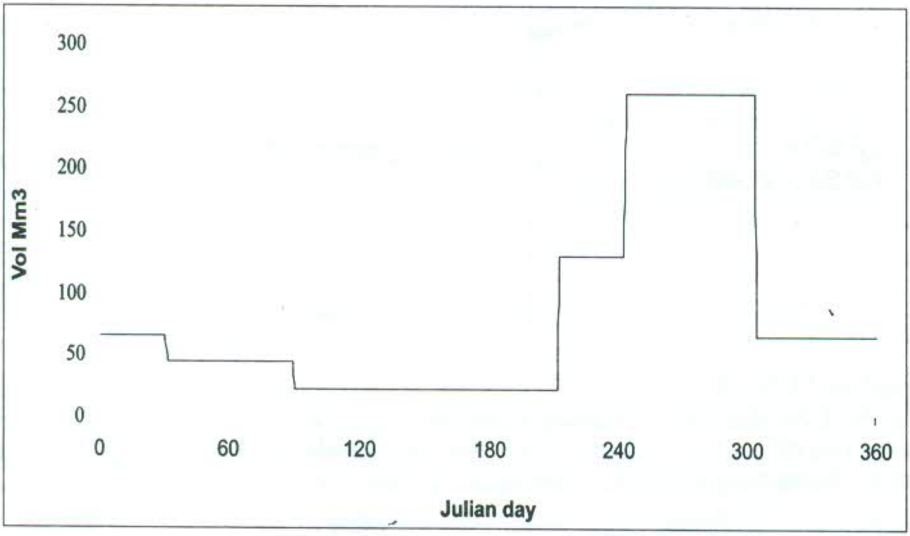


Table 7 : Characteristics of Kainji Reservoir

Parameter	Value
Maximum capacity	15000 M m^3
Minimum capacity	3500 M m^3
Optimum downstream requirement	1500 m^3/s
Minimum head on turbine	24 m
Maximum water surface elevation	141.9 m.a.s.l
Annual energy target	3000 GWh
Plant capacity	760 MW

There is no significant variation between the monthly inflows in November to July during the period 1996 to 1999. The monthly inflow in August, September or October varies with year. Significant difference is observed in September when peak rainfall occurs in the area within Nigeria that contributes to flow in River Niger. The highest monthly inflow occurred in 1999, followed by 1998 and the least value occurred in 1997.

The outflow from Kainji Reservoir includes turbine and other discharges. There is one-month lag between the outflow and inflow series. The outflow series has peak value in October, while inflow series has peak in September. An assessment of the storage level in Kainji Reservoir showed that the reservoir was within the full zone in September 1999 when high inflow arrived resulting in high spillage in September and October. Thus, there was high spillage so as to avoid structural failure of the dam. It was also observed that volume of water released from the reservoir remained high after the cessation of high inflow. In addition the release between December and February brings the reservoir to a low level between March and May without commensurate inflow to augment the reservoir water. Available water level in the reservoir is often below the desired level for energy generation. The outflow for Kainji Reservoir was higher than 2000 m^3/s in September and October during the period 1996 to 1999. The optimized release from the reservoir as presented in Figure 12 showed that the release could be maintained below 2000 m^3/s throughout the year. Under the optimized policy, the outflow from Kainji Reservoir would have: (i) maximized the impounded water for energy generation, (ii) met the requirements of Jebba Reservoir and other downstream users, and (iii) reduced the flooding of downstream plain. (Jimoh, 2007 and 2008). It is recommended that the managers should adopt an operation policy that could handle inter-annual variation in inflow to the reservoir.

Figure 13 shows the head available for generating electricity under an optimised operation policy. During the four years under study (1996 to 1999), the minimum operating head (24 m) was achievable in all seasons. It was found that the head available for energy generation varied with season and year. In 1999, the head above turbine exceeded 24 m in all season, except in July due to high inflow to the reservoir. On the other hand, the head above turbine was 24 m in five out of 12 months in 1997 and 1998 which was attributed to the inflow to the reservoir. Maintaining the operating head at minimum level in July in all year enabled the reservoir to satisfy its flood mitigation requirement. The implication of this phenomenon is that it is not possible to operate the system at a 'constant head' throughout the year. An alternative energy source is required during the low head period of the pre-high inflow season if we want steady energy throughout the year.

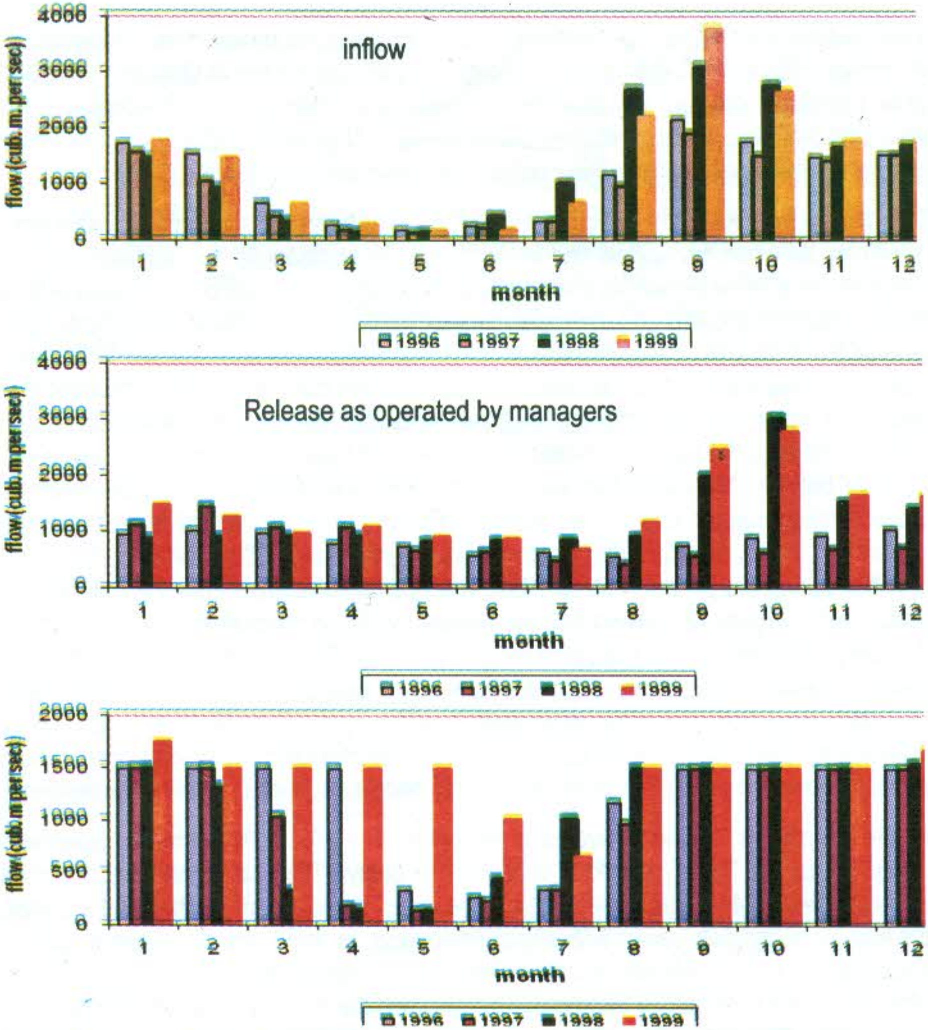


Figure 12: Operation of Kainji Reservoir between 1996 and 1999

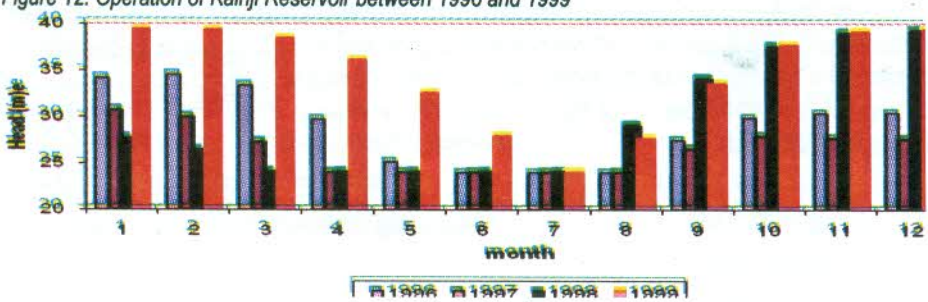


Figure 13: Optimised head of Kainji Reservoir

6.2 Tiga-Challawa Dam system

The Hadejia River is a part of the Yobe River basin in northern Nigeria. Two major dams were built in the upstream part of the Hadejia River. The dam on the main river connecting to the Yobe River is under development. By comparing discharge for the controlled and uncontrolled rivers it is shown that the first dam led to an average decrease of 33% in annual flow in the upstream part of the Hadejia River. The total annual flow in the Hadejia River further downstream, just above the Hadejia-Nguru Wetlands (HNW), was not significantly reduced as a result of the dams. This is related to a relatively small river flow reduction at lower flows in the upstream part of the Hadejia River. The major impact of the dams on the downstream part of the river is the change in regime from ephemeral to perennial. The introduced dry-season flows created favourable circumstances for the development of weed blockages in the HNW. Due to these blockages the Hadejia River stopped contributing to the Yobe River. Furthermore, after the completion of the dams the timing of the floods in the HNW became less predictable. Despite the decrease of total wet-season discharge relatively large flood extents are still experienced in wet years. This is explained by the fact that almost all the water entering the HNW through the Hadejia River now remains within the wetlands. (Goes, 2001)

Figure 14 represents the schematic diagram of the river system of the Komadugu-Yobe Basin (KYB). This study will focus on the upper section of the basin, up to Hadejia Valley Project. The competing demands on the impounded waters from both Tiga and Challawa George Reservoirs are summarized in Table 8.

Table 8: Competing Demands from Tiga and Challawa George Reservoirs

S/N	Tiga Reservoir	Challawa George Reservoir
1	Evaporation loss	Evaporation loss
2	Proportion of water demand for Kano City Water Supply (KCWS)	Proportion of water demand for Kano City Water Supply (KCWS)
3	Irrigation requirement for Kano River Irrigation Project (KRIP)	Irrigation requirement for Hadejia Valley Irrigation Project (HVIP)
4	Ecology requirement	Ecology requirement

The objective function is to maximize the area under irrigation subject to the constraints; - (i) storage level does not fall below a minimum level, (ii) obligatory requirement to Kano City Water Supply is satisfied, (iii) downstream ecological requirements are satisfied, and (iv) continuity and storage constraints are satisfied. The results of the optimisation for Tiga Reservoir by Jimoh and Offie (2009) for the following input (Table 9) are presented in Figures 14 to 19.

Table 9: Input parameter to Tiga Reservoir model

	Item	
1	Cropped area for rice	14,000 ha
2	Cropped area for wheat	400 ha
3	Cropped area for vegetable	2,000 ha
4	Cropped area for maize	200 ha
5	Overall irrigation efficiency	50%
6	Population of Kano City Water Supply (KCWS)	6,000,000
7	Per capita consumption	120 lcpd
8	Proportion of KCWS to be met by Tiga Reservoir	50%

The ultimate aim is to show that the impounded water at the end of September is sufficient to meet the irrigation requirement for the area specified for cropping. Sensitivity analyses showed that the minimum storage for Tiga Reservoir is 400 Mm^3 and 200 Mm^3 for Challawa Reservoir. For Tiga Reservoir, the current maximum release is adequate for KRIP phase 1 (22000 ha) and water demand for 3 million people. The capacity of the outlet at Tiga dam needs to be increased beyond 47 m^3/s to meet higher demand when the expansion of KRIP phases I and II would be completed.

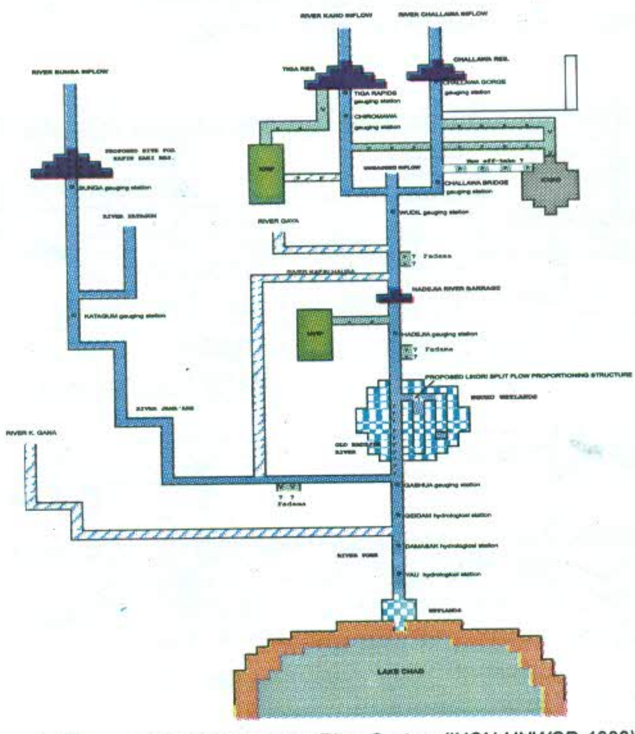


Figure 14: Schematic Diagram of Komadugu-Yobe River System (IUCN-HNWCP, 1999)

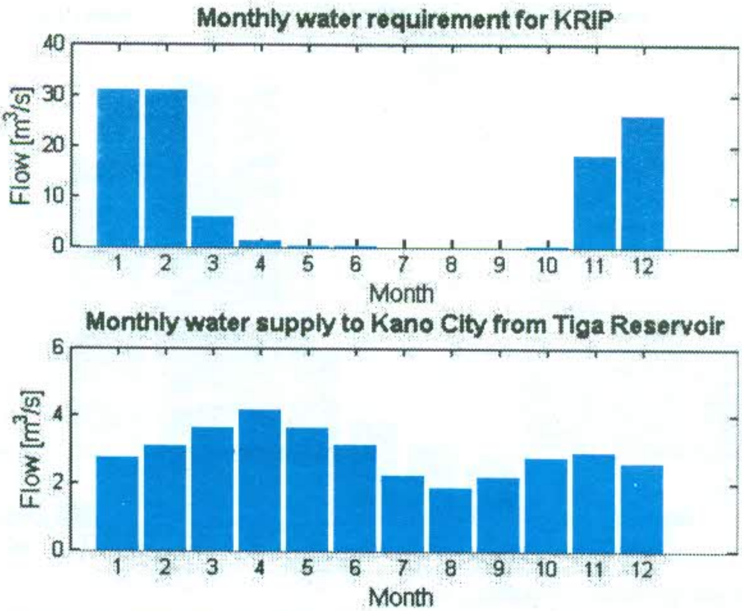


Figure 14: Monthly water requirement for KRIP (Kano River Irrigation Project) and Monthly water supply to Kano City from Tiga Reservoir

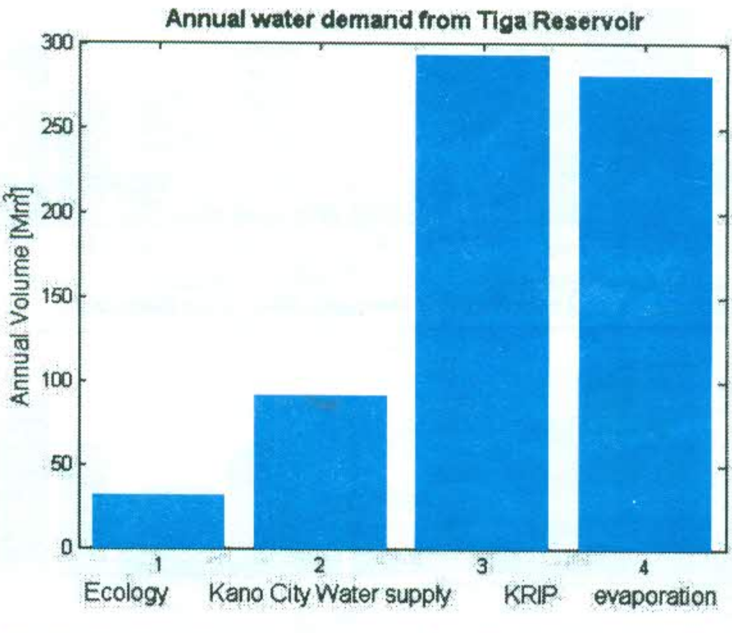


Figure 15: Annual water demand for ecology requirement, Kano City Water Supply from Tiga Reservoir, water requirement for KRIP, and annual evaporation losses

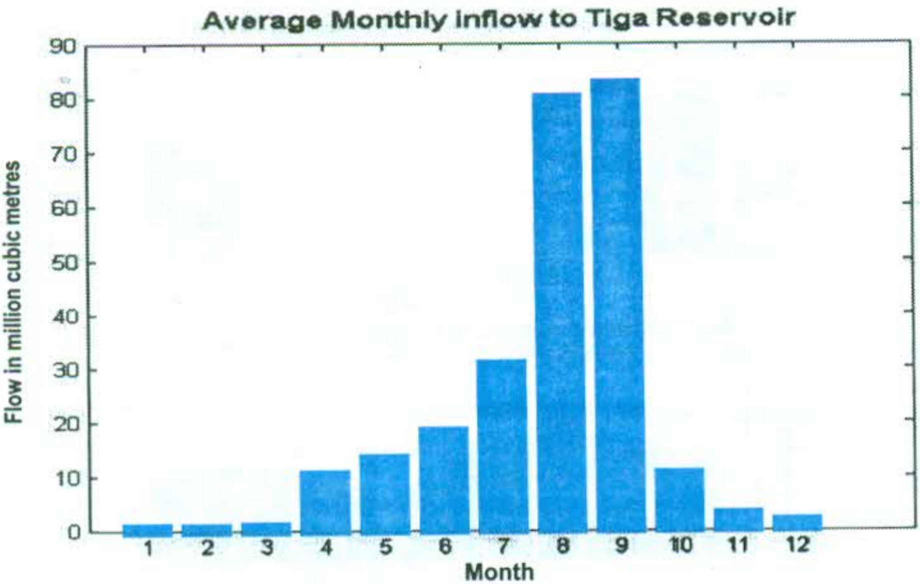


Figure 16: Average Monthly Inflow to Tiga Reservoir

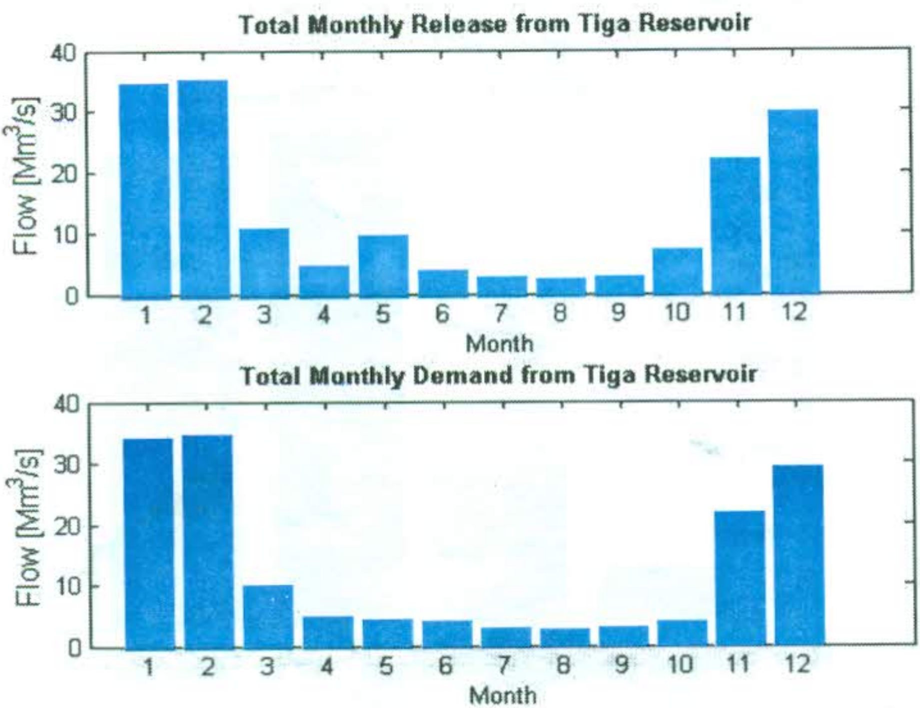


Figure 17: Monthly Demand and Release from Tiga Reservoir

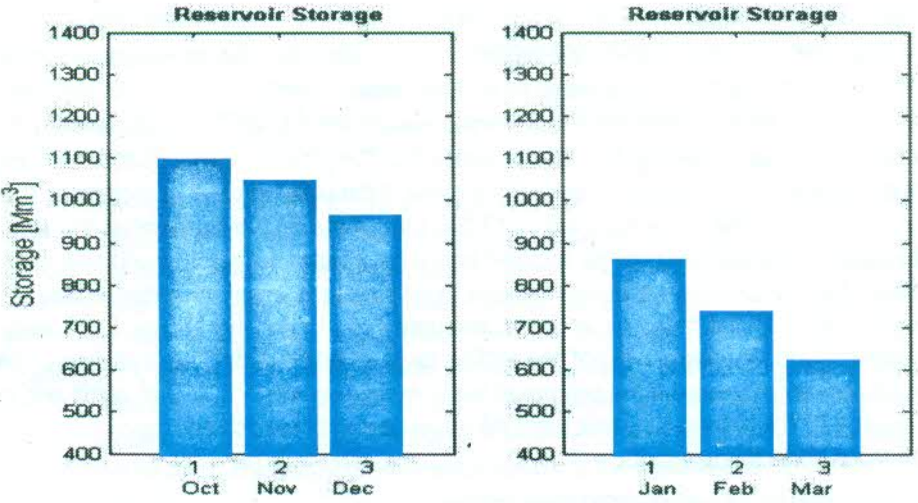


Figure 18: Reservoir Storage during dry season

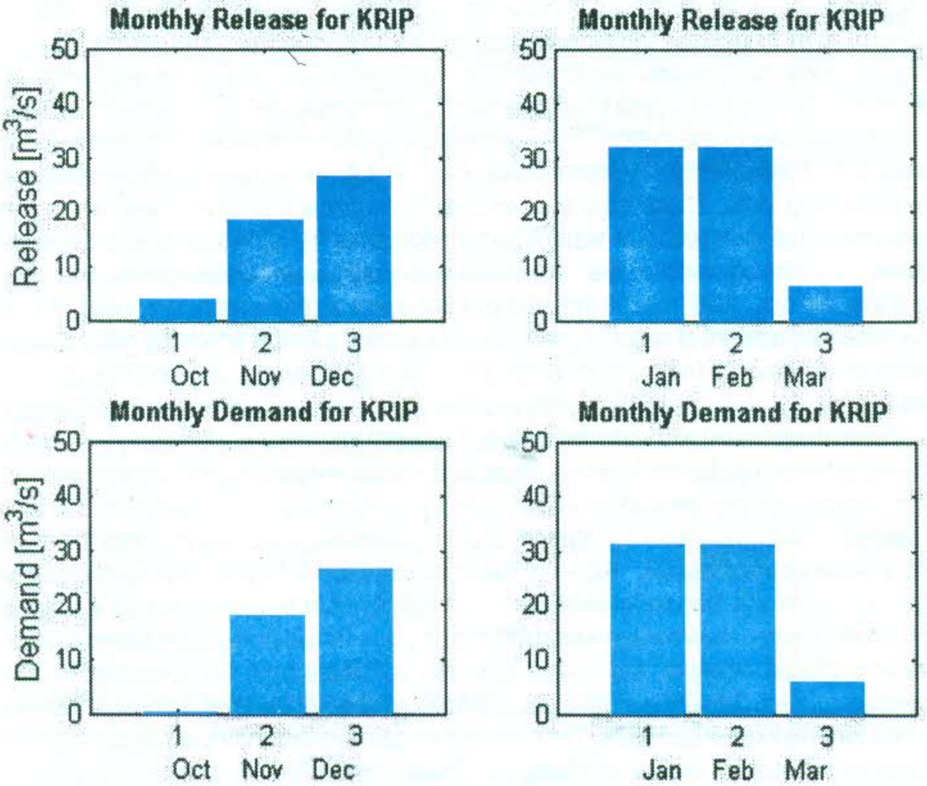


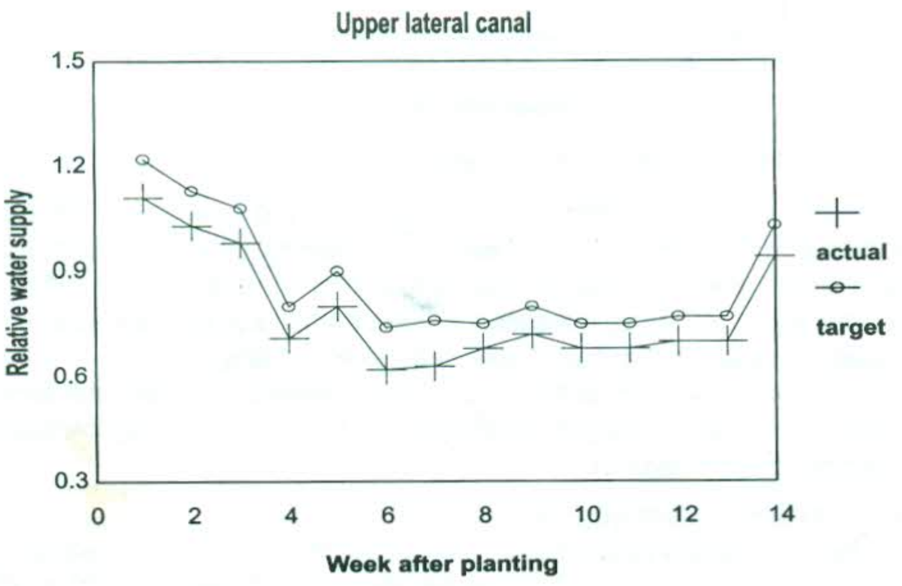
Figure 19: Monthly Demand and Release for KRIP

Jimoh and Offie (2009) further showed that if the total cropped area for rice under KRIP is increased from 14,000 ha to 40,000 ha, the requirement during the dry season would be above 47 m^3/s, the opening capacity of all Tiga outlets. Thus, the capacity of the outlet would need to be increased beyond the present limit (47 m^3/s) for the supply to meet the water requirement. Investigation also revealed that the present outlet capacity can only meet the demand for 22,000 ha area. In addition, if the outlet capacity is increased, and the volume of water in the reservoir is 13,000 Mm^3 at the end of September, the study showed Tiga Reservoir would be depleted below the minimum storage of 400 Mm^3 at the end of March, indicating that there must be a high inflow to the reservoir between May and September to fill the reservoir in the subsequent year. Under this scenario, the water requirement for farming would not be satisfied for two months during the dry season. The worst scenario occurred if the volume of water in reservoir is 11,000 Mm^3 at the end of September. The reservoir can not meet the water demand from domestic and agricultural purposes under this scenario.

7. MAINTENANCE OF WATER FACILITIES

A high proportion of arable land in Nigeria is not farmed due to non - availability of water when required. A lot of financial resources have been invested into various irrigation projects so as to increase the farmed area, and improve crop yield. The returns from the projects have not justified the investment. Management is the art of studying how decisions of all kinds and at all levels are made and how they are implemented to achieve stated objectives of the system. Management as applied to irrigation systems includes prediction of the quantity of water required, the time it is needed and its actual release to increase crop yield. These objectives include economical use of available water and ensuring equal distribution of water in time and space for economic crop production. Water utilisation efficiency is the marketable crop yield per unit water applied. It is often said that the crop yield from an irrigated plot increases as more water is applied. This is true when the amount of water applied does not exceed a limit at which the ground water becomes detrimental to the plant. When the level of groundwater exceeds this limit, the soil is said to be waterlogged. The area requires a well designed and maintained drainage system to drain the excess water from the soil. Despite this, there is a tendency for farmers to irrigate their crops beyond the limit because the water supplies to plots are not metered. The charges on the amount of water used by farmers are often based on the area irrigated. The farmers take this system of paying for water used as a privilege to use as much water as it is available. An equal distribution of water in time is essential to meet the continuous varying crop water requirement. A deficiency in the supply during a stage of growth like the vegetative stage would affect crop yield. Timing the delivery of the irrigation water is difficult wherever the source of supply is remote from the consumption. The operation of such delivery system is based on a fixed and reliable level, flexible or demand schedule (Replogle *et al*, 1983). The fixed and reliable system is common in our irrigation schemes because of its ease of operation. The control of the flow measuring facilities is important in achieving the stated objectives. An unequal distribution of water shows that the demands of parts of the area are satisfied at the expense of the others due to their positions along the distribution system. Farmers who receive sufficient water at their plots often over - irrigate their crops, resulting in water logging problems. Farmed areas are abandoned at other parts of the scheme due to inadequate supply of water (Maurya and Sachan, 1984, and Jimoh, 1992a).

Jimoh (1999b) showed that the roughness coefficient of irrigation canals in Kano River Irrigation Project was 70% higher than the designed value, while the hydraulic efficiency of canals was as low as 60% due to weed infestation and poor maintenance of the canals. In addition, the water delivery performance ratio of the water diversion structures as operated by the irrigators was found lower than the designed and attainable value, indicating poor operation of the structure. The study showed that the targeted relative water supply to the main canal of Kano River Irrigation Project was low due to conveyance losses in the canal, illegal lifting of water from the main canal and overtopping of the canal at a particular section. The actual relative water supply to the three lateral canals (Figure 20) rarely exceeded unity, confirming inadequate supply to the units. The reliability of meeting the crop water requirement of the area designed for cropping were 35.7%, 41.6% and 16.7% for the upper, middle and lower lateral canals respectively. The reliability of meeting the crop water requirement of the actual cropped area of the canals was 28.6%, 16.7% and 16.7% for the respective canals. Differences between the actual and targeted reliability were attributed to differences in cropped area. The difference between the reliability at the respective canals shows unequal distribution in the system. The targeted and the actual relative water supply vary with sectors, confirming inequality problem.



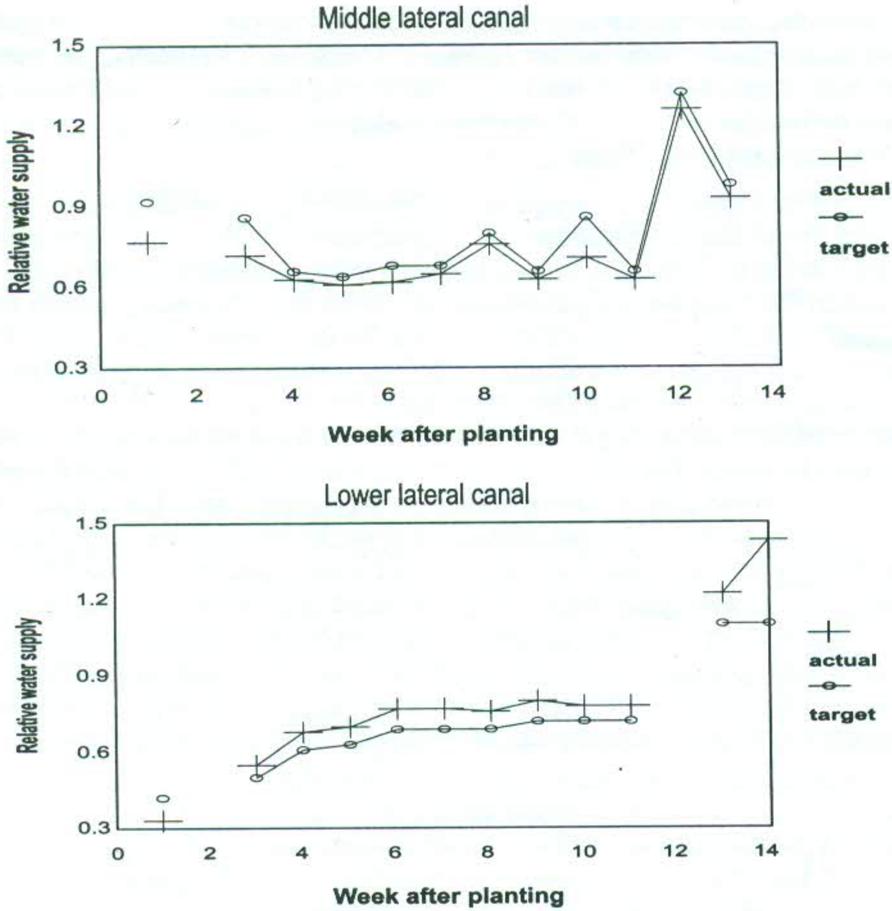


Figure 20: Actual and Targeted Relative Water Supply

The crop yield from such scheme is expected to be low, and explains why River Basin Authorities in the country have not been able to meet the target set for agricultural development. Steps that could be taken to reduce the identified problems include (i) training the irrigators for proper operation of hydraulic facilities, (ii) maintaining the canals (especially the unlined type) as at when due, (iii) encouraging farmers to form block associations and training the farmers on the danger of illegal lifting of water and damage to water distribution facilities, and (iii) supplying water to the canals on equitable basis to reflect the actual cropped area.

8. RESERVOIR SEDIMENTATION

The forest land covers about 15% of the entire land area of Nigeria. The land area is exposed to erosion activities. Some of the sediments are trapped by the existing reservoirs. Available records on sediment yield and water quality are of short length, and are records taken during the design and construction of major dams (NWRMP, 1995). For example, FMAWRRD (1986) stated that sediment yield in most rivers in the River Gurara Basin ranged between 1.0 and 2.0 g/l. Further studies, Jimoh (1992b) showed that the low value is adequate for estimate during the dry season, but the sediment yield during the rainy season is higher than 2 g/l. The high yield during the rainy season is due to human activities such as farming, bush burning and tree felling. These activities are increasing at an alarming rate (Geomatics International, 1998). Since sedimentation is inevitable, allowance are made in form of dead capacity in the design, but design based on low estimate of sediment yield will result in frequent filling of reservoir with sediment. Water level recorded for such reservoir is false head. Remediation procedure of reservoir has high tangible and intangible costs. For example, de-silting a water supply reservoir requires the provider to find an alternative water source for the community during the exercise, an operation that is expensive. Sometimes it is difficult to locate alternative source of water that will meet the needs of the users during the exercise. Existing dams in the country should have steps for measuring rate of sedimentation on a continuous basis. This will help in assessing the effect of land use pattern, and climate change on reservoir sedimentation.

9. RAPID RURAL-URBAN DRIFT

The population of Nigeria is currently above 140 million people, with 41% urban and 59% rural. Urban areas are cities or towns with population exceeding 20,000 and are characterized by higher population density. Urban areas are created and further developed by the process of urbanisation. In 1997, over 400 towns in the country were classified as urban area (Water Utilities Project, 2001). The rate of urbanization has been increasing. It was 10.6% in 1953, 20% in 1970, 38% 1993, and 41.2% in 1997 (Water Utilities Project, 2001). Consequently water demand for domestic activities has been increasing. The demand has further been increased by improve standard of living and technology. Less than 50% of the population has access to potable water supply and majority of these people are those living in urban and semi-urban areas. Various traditional means of obtaining water have been developed by individuals and communities for many centuries. The commonest and oldest is the use of hand-dug wells and collecting water direct from streams and ponds.

For example, the population of Abuja which became the Capital of Nigeria in 1991 has increased beyond projection. Development activities were divided into four phases and as at now, only the first phase and part of the second phase have been developed. However, the population of the Federal Capital Territory was estimated to be 1,300,000 in 1998 (WADSCO, 2005), but NPC (2006) reported that the population of the Territory as 778,567. The estimates are higher than the projected population for the city when all phases are developed. Development of public water supply system to the Territory has remained stagnant during the period. The water supply system depends on a 100 Mm^3 capacity Usuma Reservoir which was constructed in 1986. Initially, the system had a treatment plant of 5000 m^3/hr capacity, and it was proposed that the plant capacity would increase to 10,000 m^3/hr in 1992, 15,000 m^3/hr in 1997, and 30,000 m^3/hr in 2002 (Abuja Master Plan, 1979). However, the capacity of the plant remained at 10,000 m^3/hr in 2002. This means that only a third of the plant capacity designed for the Territory was provided. The implication is that if raw water is available in the reservoir, the existing plant can not provide adequate potable water to the territory. The water available in the reservoir was not sufficient to meet the domestic need of the Territory when fully developed (FMAWRRD, 1986). At present, people depend on water from streams, hand-dug well and borehole to meet their daily need. Jimoh and Wojuola (2008) confirmed that only 20% of the population depend on public water supply for domestic need and 21% depend on borehole, while 57% depend on unhygienic source (hand dug well and streams). The completion of the River Gurara Inter-basin Water Transfer Project for augmenting raw water supply to the Usuma Reservoir will increase the supply of potable water. Similarly, Minna the capital city of Niger State has been experiencing acute water shortage. A quantitative assessment of the water resources potential of Chanchaga River Basin was carried out. The existing source of water for the dam depends on Tagwai-Chanchaga Reservoir in the Chanchaga River Basin. The result showed that available surface water resource in the basin is adequate for the meeting the present domestic water demand of the town. One of the main causes of water scarcity is inability of the government to increase the capacity of the water infrastructures (reservoir, water distribution network and treatment plant) according to the growth in population.

10. UN-COORDINATED DEVELOPMENT IN HYDROLOGICAL BASINS

Nigeria is divided into 8 hydrological basins. Each basin is further divided into sub-basins. There are 63 large dams and 96 small dams in the basins. NWRMP (1995) showed more potential dam sites across the country. Water resources projects affect both upstream and downstream water users. For example, the water supply to Lake Chad is primarily from the Chari-Logone River, which provides approximately 95% of the total input and empties into the southern pool, and the Komadugu-Yobe River, which contributes less than 2.5% and is the only river flowing into the northern pool. The water balance of the Lake is highly variable resulting in fluctuating open surface waters that have exhibited dramatic expansion and contraction over geologic and recent history (Servant and Servant 1983). In the last decades the open water surface has reduced from approximately 25,000 km^2 in 1973, to less than 2,000 km^2 in the 1990s (Olivry *et al.* 1996, Grove 1996, Coe and Foley 2001). The northern pool has not contained permanent open waters for more than 25 years although recently there has been some flooding observed, associated with wet years in 1994 and 1999 (GIWA, 2004).

The Komadugu-Yobe Basin (KYB) is situated in the Sudan-Sahel zone of northeast Nigeria and southeast Niger. The Nigerian sector of the basin accounts for 95% of the water the basin contributes to Lake Chad. The basin is drained by the Yobe River (which is formed by the Hadejia and Jama'are tributaries, and creates the Hadejia-Nguru floodplain at their juncture) and the Komadugu Gana (or Missau River). There are two large dams, Tiga and Challawa Gorge Dams. One of the major water management problems in the basin is the fragmented, inequitable and uncoordinated management of surface water resources. In a Decision Support System (DSS) model developed (Jimoh, 2006 and KYBP, 2006) to handle equitable allocation of water resources in the basin, it was shown that the development in the basin is based on supply-management approach. The DSS is a predictive model with capability for predicting the flow pattern along the river system on weekly time step under six climate scenarios, namely, (i) Prolonged dry year, (ii) Very dry year, (iii) Dry year, (iv) Normal year, (v) Wet year, and (vi) Very wet year, considered in the study. The current annual demand in the basin is summarised in Table 10, while the regional distribution of the demand is presented in Figure 21.

Table 10: Summary of Current Annual Demand for KYB

Sub-basin	User	Annual demand Mm^3	Proportion %
Hadejia	Kano City Water Supply	215.36	43.8
	Kano River Irrigation Project	123.50	25.2
	Hadejia Valley Irrigation Project	24.16	4.9
	Others	24.25	4.9
	Hadejia Nguru Wetlands	87.73	17.9
Jama'are	Kawali Irrigation	0	0
Yobe	Others	16.17	3.3
	Total	**491.26**	**100**

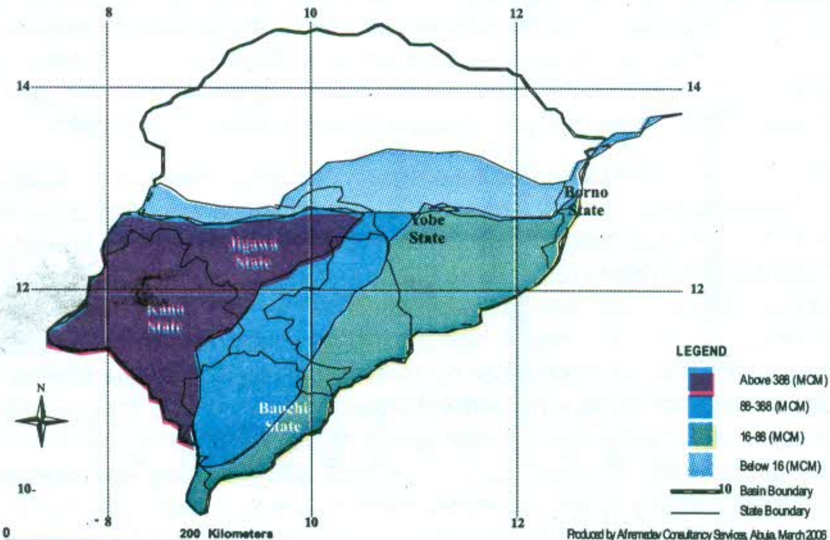


Figure 21: Regional variation in water demand at Komadugu Yobe Basin

The analysis showed that while the current water requirement of Hadejia sub-basin, excluding the requirement of Hadejia-Nguru Wetlands (HNWs), accounts for 80% of the annual demand of KYB; the sub-basin contributes 60% of water resources in KYB. The DSS can facilitate decision-making on equitable allocation of the available water resources. For example, it can be shown that in a normal year, neither the water requirement of the HNWs nor the irrigation requirement of HVIP can be satisfied during the first quarter of the year under the existing situation. This implies that the available surface water resources in the KYB, under the existing condition, are not sufficient to sustain the proposed Sugar Project in Jigawa State. The situation in a dry year is even worse. In addition, the water requirement of communities along the river system after Gashua could not be satisfied from January to April. This finding has implication on developing potential dam sites in the basin. In summary, there should be a much greater emphasis on water resource management and a shift of emphasis from supply to demand management of water resources in the basin.

11. INADEQUATE INVESTMENT

All over Nigeria, water supply is undertaken by the government. There is no distinct policy on the status of water supply, either as a social or economic good for rural and urban centres. In urban areas, public taps are provided where the poor can get water free of charge. The water utilities charge the State Governments or Local Authorities for the supply. State governments approved subsidies and cross subsidies in water tariffs to ensure that the charges are affordable to all the consumers. However, the intended subsidies sometimes ended up providing free or cheap water to those who can afford to pay higher prices. It is believed that raising water rates or charging for it where it has historically been free would hurt the poor or be "unfair" to them and could even lead to serious objection or social unrest. Consequently, there is reluctance to increase water rates, with the result that the water supply agencies suffered excessive financial losses. Against this background, the water supply delivery continues to deteriorate more especially in the urban poor and peri-urban areas (Water Utilities Project, 2001).

Mogbo and Jimoh (2001) assessed the adequacy of financial investment in water sector in the Federal Capital Territory between 1991 and 2004 and reported that the ratio of water budget to annual budget ranged between 0.008 and 0.33, with the highest ratio in 1991 and the lowest ratio in 1995. There was no systematic variation in the financial ratio. In addition, it was found that capital allocated to the FCT Water Board has been consistently low. The cost – benefit ratio of the water supply scheme was less than 1.0, except in 1995. This, the revenue can not meet the operation cost of the scheme. While the population as well as the water demand of the city was increasing, the investment into water supply remained constant. Other causes of the low performance of the scheme were:- (i) increase in water demand without corresponding development, (ii) inappropriate metering system, (iii) cheap prices offered to consumers by the authority, (iv) non-payment of water rate by consumer, (v) inefficient collection of revenues, and (vi) high level of bureaucratic bottlenecks.

Similarly, the proportion of Niger State annual budget allocated to the State Water Board was found to be low: 24% in 1991, 24% in 2008, 18% in 2009 and less than 10% in other years (Figure 22). Consequently, the water distribution system is over-stressed resulting in frequent break down and high hydraulic losses. Hydraulic loss on water distribution system in the state is higher than 40% (Niger State Water Board, 2006). Comparing the water revenue with the annual water budget (Figure 23), 70% of the annual water budget was recorded as water revenue in 1999 and 2003, while the revenue for other years was less than 30% of the State Water Budget.

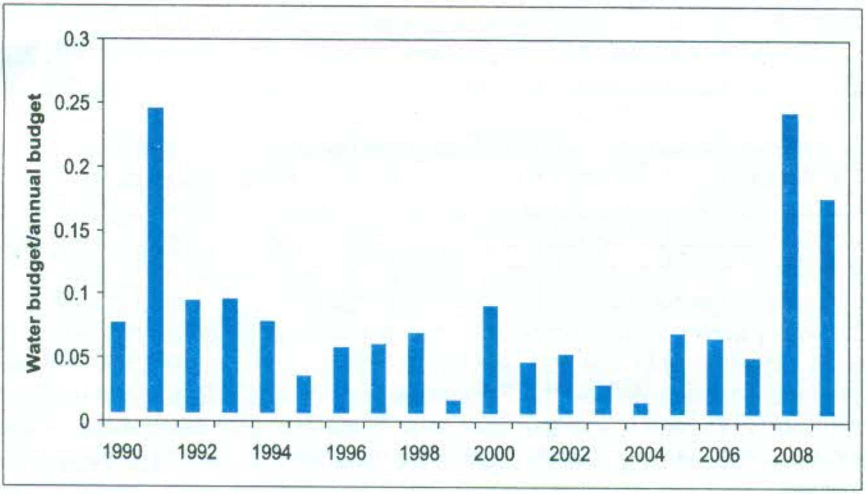


Figure 22: Ratio of Niger State water budget to the state annual budget

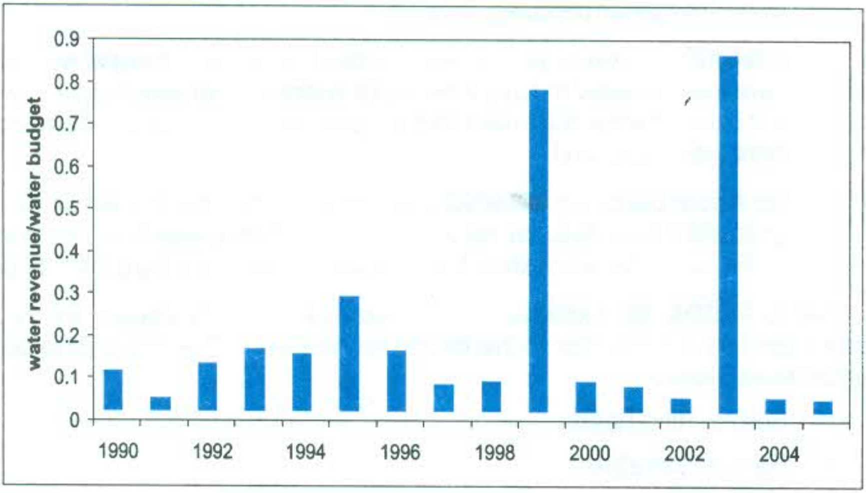


Figure 23: Niger state water revenue versus water budget

12. POLICY ON WATER RESOURCES DEVELOPMENT

The National Water Supply Policy: The center-piece of the policy is the provision of potable water in sufficient quantity to all by the year 2015 which is to be achieved through improvement of the present inadequate level of services to cover 50% of the population by the year 2000 and 80% by the year 2010 and to all by the year 2015. It will raise the per capita service level to 120 litres for urban areas. The policy will also promote community and private sector and NGO participation and supplement the National health care programs of the Nation. The instruments for the operation of the policy shall be the various Federal, State, and Local Government laws and bye-laws establishing the River Basin Development Authorities, State and Local Government Water Agencies and their respective water supply regulations and water quantity standards. If this policy is successfully implemented, the major problem facing the urban poor with regards to water supply would be surmounted.

The policy for the regulation of Water Resources Development in Nigeria, is reflected in the Water Resources Decree 101 of 1993 (Fed. Govt. Gazette Extraordinary No. 27 Vol. 80 of 1st Sept. 1993.). This decree recognizes the various sources of Water in Nigeria for domestic, industrial and agricultural purposes. It also sought to, among others; promote the optimum planning, development and use of water resources in the country. It recognizes the water resources as comprising "all surface and ground water, and all water in any water course affecting more than one State as described in Schedule to this Decree, together with the bed and banks thereof...." It confers on the Federal Government represented by the Federal Ministry of Water Resources (FMWR) the responsibility for controlling the use of both surface and groundwater resources traversing more than one state throughout the Federation. It is based on three important principles:

a) a link between the right to use water and the ownership of land adjacent to that water (the riparian principle),

b) a separation between private (water drawn from small streams or wells which gave too little water to have potential for communal benefit) and public water; and between water in the rivers that are restricted to a state and those traversing more than a state, and

c) the African customary law which saw rivers and the water in them as common good which belongs to the nation as a whole and are available for common use by all citizens, but which should be controlled by the state in the public interest.

In other to facilitate the execution of the tasks set out in the decree, the Federal government had in 1976, prior to this decree set up Eleven River Basin Development Authorities as follows:-

i) Sokoto - Rima Basin

ii) Hadejia - Jema'are

iii) Lake Chad

iv) Upper Benue Basin

v) Lower Benue Basin

vi) Cross River Basin

vii) Anambra - Imo River Basin

viii) Niger Basins

ix) Ogun - Oshun Basin

x) Benin Basin

xi) Niger Delta.

The Niger Basin is now operating under two River Basin Development Authorities (The Lower and Upper Niger River Basins). The persistent merging and de-merging of the ministries and departments on water management is not favourable for good policy formulation and management. Table 11 shows the record of merging and de-merging exercises. Federal Ministry of Water Resources was merged with Federal Ministry of Agriculture two years after it was created, and two years after, the ministry was de-merged. In summary, Federal Ministry of Water Resources was merged with Federal Ministry of Agriculture four times (1977, 1984, 1992 and 2006) and de-merged four times (1979, 1989, 1994 and 2010) after its creation in 1975. The River Basin Development has also had a number of administrative changes during the period. The effects of these changes are lack of continuity in policy, inconsistency and stagnation. A vibrant agency to implement policy is required to achieve sustainability of water resources development and management.

Table 11: History of Water Resources Related Institutional Changes

Period	Development
1959	Creation of the Inland Waterways Division of the Federal Ministry of Communications based in Lokoja with responsibility for monitoring levels in the Niger/Benue system
1960 - 1966	Formation of Hydrological Unit under the First Republic
1960s	Creation of Water Resources Division in the Ministry of Agriculture and Formation of the Geological Survey Department of the Federal Ministry of Mines and Power
1970s	Creation of State Water Boards or Corporations
1970s	Creation of Kainji Lake Development Commission and the Chad Basin and Sokoto Rima River Basin Development Authorities in the Second National Development Plan
1975	Creation of the Federal Ministry of Water Resources (FMWR)
1976	A further nine (9) RBDAs were established (3rd National Development Plan)
1977	FMWR disbanded and absorbed into Federal Ministry of Agriculture
1979	Re-creation of the Federal Ministry of Water Resources
1984	FMWR merged with the FMA&NR to form Federal Ministry of Agriculture, Water Resources and Rural Development
1984	Creation of 18 RBDAs , and change of name to River Basin and Rural Development Authorities (RBRDAs) with one for each State except Ogun and Lagos that shared one
1987	Mergers of 18 RBRDAs to the former 11 and the name reverted to RBDA with reduction of functions to only provision of water for multipurpose usage
1989	Re-creation of FMWR
1990	Partial Commercialization of RBRDAs by Technical Committee on Privatisation and Commercialisation (now Bureau of Public Enterprises (BPE))
1992	Re-merger of FMWR with FMARD
1994	Re-creation of FMWR which was merged with Directorate of Food Road and Rural Infrastructure (DFFRI) thus renamed FMWR&RD
1994	Change of the name from River Basin Development Authorities to River Basin and Rural Development Authorities and creation of Upper and Lower Niger RBRDAs out of Niger RBRDA
2006	Re-merger of FMWR and FMANR
2010	Re-creation of FMWR

13. CONCLUDING REMARK

There is an increased pressure on water resources in the country as a result of the growing water demand, combined with decreased water availability due to climate change and variability. The traditional management technique is supply-oriented. This has led to the overexploitation and depletion of freshwater resources, and inequality in supply. The situation is worsened by inappropriate policy, inadequate fund, improper operation and maintenance, and un-coordinated development. Management of this finite resource should include supply and demand aspects, policy implementation, and participatory planning. The issue is to integrate demand management into water supply planning to achieve rational balance between supply and demand of water resources. In summary, sustainable water management in the country need to adopt the Integrated Water Resources Management (IWRM) approach, as stated in the Dublin principles (UN, 1992), which assert that:

1) Fresh water is a finite and vulnerable resource, essential to sustain life, development and the environment. Its, effective management demands a holistic approach, linking social and economic development with protection of natural ecosystems.

2) Water development and management should be based on a participatory approach, involving users, planners and policy-makers at all levels. The participatory approach entails raising awareness of the importance of water among policy-makers and the general public. It means that decisions are taken at the lowest appropriate level, with full public consultation and involvement of users in the planning and implementation of water projects.

3) Women play a central part in the provision, management and safeguarding of water. This pivotal role of women as providers and users of water and guardians of the living environment has seldom been reflected in institutional arrangements for the development and management of water resources.

4) Water has an economic value in all its competing uses and should be recognized as an economic good. Within this principle, it is vital to recognize first the basic right of all human beings to have access to clean water and sanitation at an affordable price. Failure to recognize the economic value of water has led to wasteful and environmentally damaging uses of the resource. Managing water as an economic good is an important way of achieving efficient and equitable use, and of encouraging conservation and protection of water resources.

14. RECOMMENDATION

In order to achieve sustainable water resources management in Nigeria, it is recommended that:-

a) Planning, design, development and operation of water projects require hydrological, meteorological, hydro-geological and operational data. Availability of hydrological, hydro-geological and operational data has been a major obstacle in water resources management. Wherever the data exist, they are either, inadequate in length, inconsistent, incomplete, or unreliable. There is a need to rehabilitate the non-functioning gauges and establish new ones. The gauge stations must have automatic recording meters to capture high, low and night flows. There is also a need to develop the capacity of personnel engaged in collection, collation and archiving of the data.

b) Reservoir sedimentation is inevitable, but the rate at which the reservoir is filled can be monitored and even reduced. There is a need to assess the status of sediment trapped in the reservoirs, establish stations for monitoring rate of inflow to the lakes, and design appropriate de-silting procedure and land use practices.

c) The climate is dynamic which means the operation of water projects must be dynamic. Policies that are flexible to climate change and variability are the result of continuous research. Proper reservoir operation requires knowledge of quantity and timing of flow (that is, flow forecasting). This could be achieved using appropriate time series and physical models. This is the starting point of an effective flood and drought management. Real time forecasting is the output of continuous monitoring, analysis and modelling. The government and private institutions need to encourage research activities in the field of water resources.

d) Sustainable water management requires appropriate agencies to formulate, implement and monitor water policy. Merging of water management departments should be discouraged. The institutions must be allowed to grow.

e) The Federal Executive Council of Nigeria recently created an agency responsible for actualizing Integrated Water Resources Management (IWRM) principle. This is encouraging, but the National Assembly needs to pass the IWRM bill, this will empower the agency to function effectively.

f) The government as well as private sector should invest into development and operation of water projects appropriately. The level of investment should not lag behind increase in water demand.

g) Most river basins contain a variety of landscapes, land uses, habitats, industry, communities, laws and traditions. Implementation of IWRM requires the establishment of interdisciplinary teams including hydrologists, water engineers, geologists, biologists, physicists, soil scientists, planners, human and animal health experts, ecologists, sociologists, demographers, legal experts, and agro-foresters. The teams are to address a wide range of sectoral and cross-sectoral topics including population dynamics, water quality modeling, irrigation, health problems, water weeds, fish, herding, legislation, training, participatory rural appraisal, development of a geographical information system, equitable allocation of resources, development of community participation, establishment and running of authorities to coordinate planning and management.

ACKNOWLEDGEMENT

To God be the glory for His mercy and favour. He is the fountain of Knowledge and Wisdom. In His mercy, I have been able to achieve this feat from a humble beginning. When I graduated in 1986 from University Ilorin, though with an outstanding grade, I did not want to register immediately for a higher degree due to financial reasons. In His divine way, I received financial assistance at every crucial stage of my career. I am grateful to Him for ordering my step through the rough and hard road to this position.

My wife, Mrs. Mary Aduke Jimoh, thank you for your understanding, love and support. You are a blessing and a wonderful wife. My children, Ayodeji, Tolulope, Olufunmilayo and Adeoluwa, I appreciate you.

To my father and mother (Elder Joseph Jimoh Megbehingbe and Mrs Abigail Megbehingbe), despite your poverty level, you struggled to train me, Thank you for giving me the opportunity. I am grateful for your care, support and love. I am glad that you witness this day. Tribute to my late uncle, Pa Jonathan Osebeyo Megbehingbe under whom I had my primary school education.

I do recognize the unique contribution of my teachers, lecturers and mentors. My colleagues in the Department and the University, I appreciate your understanding and the good working relationship. I do acknowledge the role played by my past students, especially the research students.

I would like to recognise the role played by The Commonwealth Scholarship Commission in United Kingdom for financing my PhD research at the University of Birmingham, UK and later, a six-month research fellowship at the same university. It is a privilege to enjoin the prestigious award twice in a career.

The support of my Chaplain, Dr Michael Onimole and Pastor Eli Alasan, and members of Chapel of Grace, Federal University of Technology, Minna has been wonderful and rewarding.

Finally, I am grateful to the University Administration (past and present) for giving me the opportunity to learn and contribute to knowledge. Thank you for the arrangements made for this lecture.

My relatives, friends and all present today, thank you for the moral support. It is wonderful.

Thank you, and may God bless you.

REFERENCES

Abuja Master Plan. (1979). The Master Plan for Abuja the New Federal Capital Territory. International Planning Associates, New York, USA.

Acreman, M. (1998). Overviews: Principles of Water Management for People and the Environment. In. de Sherbinin, A., and Dompka, V. (Eds.) Water and Population Dynamics: Case Studies and Policy Implications. International Union for Conservation of Nature (IUCN)

Adefolalu, D. O. (1986). Rainfall trends in Nigeria. Theor. and Appl. Climatol., vol. 37, pp. 205 – 219,

Adefolalu, D. O. (2002). Climate of Nigeria. In: Africa Atlases, Les Editions J.A., 62–65.

Adeleye, E. A. (1997). The problem of power supply in Nigeria. Proc. of Quarterly Lectures of the Nigerian Society of Engineers (Minna Branch), Part 1: 49 – 71.

Afremedev Consultancy Services Limited (1998). Regional Land and Water Resources Development Planning Study, Vol. 2 – Integrated Catchment Management Strategy – Report R2/2: Institutional and Human Resource Arrangements for integrated natural resources management. Petroleum (Special) Trust Fund (PTF), Abuja, Nigeria

African Development Bank (2004). Federal Republic of Nigeria Country Strategy Paper 2005-2009

Anukam, L. C. (1997). Case Study IV- Nigeria. In Helmer, R. and Hespanhol (Eds). Water Pollution Control - A Guide to the Use of Water Quality Management Principles. In Published on behalf of the United Nations Environment Programme, the Water Supply & Sanitation Collaborative Council and the World Health Organization by E. & F. Spon. WHO/UNEP.

Ariyo, A and Jerome, A (2004). Utility privatisation and the poor: Nigeria in focus. HBS Global Issues papers NO.12 JULY 2004 www.boell.de

Benoit, P. (1977). The start of growing season in Northern Nigeria. Agricultural Meteorology, vol. 18, pp. 91 - 99.

Coe, M.T. and Foley, J. A. (2001). Human and natural impacts on the water resources of the Lake Chad basin. Journal of Geophysical Research, 106:3349-3356.

Coe, M.T. Ramankutty, N and Birkett, C (2002). Climate and Human Impacts on Water Resources in Africa University of Wisconsin-Madison. Retrieved July 2003 from: http://lcluc.gsfc.nasa.gov/products/pdfs/Abstract-Coe2001.pdf.

Cordery, I., and Opoku-Ankomah, Y. (1994). Atlantic sea surface temperatures and rainfall variability in Ghana. J. Climate, 7(4): 551 - 558.

Danida (2008). Climate Change Screening of Danish Development Cooperation with Cambodia.

Enabor, B., Sridhar, M. K. C., and Olaseha, I. O. (1998). Integrated water management by urban poor women: A Nigerian slum experience, Water Resources Development, 14: No. 4, 505-512.

ECN (2009). Impact of climate crisis on energy management contingency. A study Messrs Eshrun Nigeria Ltd , Energy Commission of Nigeria, The Presidency, Abuja.

Engelman, R. and LeRoy, P., (1993). Sustaining Water-Population and the Future of Renewable Water Supplies. Washington D.C.: Population Action International.

Falkenmark, M., (1989). The massive water scarcity now threatening Africa: why isn't it being addressed? Ambio, Vol. 18, No 2; 112-118.

Food and Agriculture Organisation – FAO (1993): Integrated Rural Water Management – Proceedings of the Technical Consultation on Integrated Rural Water Management 15-19 March 1993, FAO, Rome.

FMAWRRD (1986). Gurara Interbasin Water Transfer Scheme. Federal Ministry of Agriculture, Water Resources and Rural Development. Planning Report. University of Ilorin Consultancy Services, University of Ilorin, Nigeria.

Garbutt, D. J.; Stern, R. D.; Dennett, M. D. and Elston, J. (1981). A comparison of the rainfall climate of eleven places in West Africa using a two-part model for daily rainfall. Arch. Met. Geophy. Biokl., Ser. B. 29: 137 - 155.

Geomatics International Inc. (1998). The Assessment of Vegetation and Land Changes in Nigeria Between 1976/78 and 1993/95, Federal Department of Forestry (FDF), The Forestry Management Evaluation and Coordinating Unit (FORMECU), Abuja.

GIWA (2004). Global International Waters Assessment Regional assessment 43: Lake Chad Basin. Published by the University of Kalmar on behalf of United Nations Environment Programme.

Goes, B.J.M (2001). Regional Management of Water Resources (Proceedings of a symposium held during the Sixth IAHS Scientific Assembly at Maastricht, The Netherlands, July 2001). IAHS Publ. no. 268, 2001.

Grove, A.T. (1996). African river discharges and lake levels in the twentieth century. In: Johnson, T.C. and Odada, E. (eds), Liminology, Climatology, and Palaeoclimatology of the East African lakes. Gordan and Breach, Newark, N.J, p 95-100.

Haddow, G.D.; Jane A. and Bullock (2004). Introduction to Emergency Management. Amsterdam, Butterworth-Heinmann ISBN 0-7506-7689-2.

Hall, D. (2006). Water and Electricity in Nigeria. Public Services International Research Unit (PSIRU), Business School, University of Greenwhich, Park Row, London.

Haan, C. T.; Allen, D. M. and Street, J. O. (1976) A Markov chain model of daily rainfall. Water Resources, Res., 12(3): 443 - 449.

Hulme, M. (1992) Rainfall changes in Africa: 1931 - 1960 to 1961 - 1990. Int. J. Climatol., 12: 685 - 699.

http://iwr.msu.edu/edmodule/water/cycle.htm. The Hydrologic Cylcle.

http://science.jrank.org/pages/7301/Water.html Water - What Is Water?, An Unusual Liquid.

http://science.howstuffworks.com/question157.htm How much water is there on Earth?

Ilesanmi, O. O. (1971). An empirical formulation of an ITD rainfall model for the tropics: A case study of Nigeria. J. Appl. Meteor., 10: 882 - 891.

Ilori, B. (2004). The role of government in the development of basic infrastructure. www.cenbank.org/out/publications/ocasionalpapers/RD/2004/Jos-02-3

IUCN-HNWCP (1999). Water Management Options for the Hadejia-Jama'are-Yobe River Basin. International Union for Conservation of Nature-Hadejia-Nguru Wetlands Conservation Project, Nigeria.

Jackson, I. J. (1981). Dependence of wet and dry days in the tropics. Arch. Met. Geophy. Biokl., Ser. B. 29: 167 - 179.

Jiaqi, C. (1987). The new stage of development of hydrology - Water Resources Hydrology. Water for the Future: Hydrology in Perspective (Proceedings of the Rome Symposium, April 1987). IAHS Publ. no. 164, 1987

Jimoh, O. D. (2010a). Impact of Climate Change on Hydropower Generation in Nigeria. A Paper presented at National Workshop on Energy Efficiency and Modern Bio-Fuels for Climate Change Mitigation in Nigeria, held at Hydro Hotels, Minna Niger State between 20th and 21st July 2010

Jimoh, O. D. (2010b) Urban Water Supply System in Nigeria. Key note paper delivered at the International Conference on Sustainable Urban Water Supply in Developing Countries, held between 26th and 28th July 2010 at Main Auditorium, University of Ilorin, Nigeria

Jimoh, O. D. and Offie, M. O. (2009). Development of Reservoir Operation Model for Tiga and Challawa George Reservoirs. Department of Dams and Irrigation, Federal Ministry of Agriculture and Water Resources, Abuja, Nigeria

Jimoh, O. D. and Wojuola, O. A. (2009). Shallow aquifer resources of Federal Capital Territory, Nigeria. Water and Environment Journal, (Journal of the Chartered Institution of Water and Environmental Management, Vol. 23, no. 1: 41 – 45

Jimoh, O. D. (2008). Operation of Kainji Reservoir in a changing hydrology. Nigerian Journal of Engineering, Ahmadu Bello University, Zaria, Vol. 14, no. 1: 53 - 60

Jimoh, O. D. (2007). Operation of Kainji and Jebba reservoirs for steady energy production in Nigeria. A paper presented at the 1st Annual Conference of Nigerian Committee on Large Dams (NICOLD) Chelsea Hotel, Abuja, Nigeria

Jimoh, O. D. (2006). Water Audit and Decision Support System for the Komadugu Yobe Basin. Stakeholder Workshop of the Komadugu Yobe Basin to showcase results of Knowledge-base studies on the catchment Management Plan for the Basin held at the National Water Resources Institute, Kaduna from 15th to 17th May, 2006. A FMWR and IUCN Catchment Management Programme.

Jimoh, O. D., Ayodeji, M. A. and Mohammed, B. (2003). Effect of agro-chemicals on surface and ground waters in Tunga-Kawo (Nigeria) irrigation scheme. Hydrological Science Journal, Vol. 48, no 6: 1013 – 1023.

Jimoh, O. D. and Egharevba, N. A. (2003). Effect of rainfall pattern on maize yield in Minna (Northern Nigeria). Journal of Science, Technology and Mathematics Education (JOSTMED), Vol. 6, No. 1: 106 - 111.

Jimoh, O. D. (1999a). Causes of urban flooding in Niger State: A case study of Bida and Minna Towns. Journal of National Association of Technological Teachers, Vol. 3, No. 1: 231 – 239.

Jimoh, O. D. (1999b). Performance of water distribution system in an irrigation project: A case study of Kano River Irrigation Project. Proc. of the International Seminar on Performance of Large and Small Scale Irrigation Schemes in Africa (Abuja: 15 - 19 November): p. 162 - 179.

Jimoh, O. D. and Webster, P. (1999). Stochastic modelling of daily rainfall in Nigeria: Intra-annual variation of model parameters. Journal of Hydrology, Vol. 222: 1 – 17.

Jimoh, O. D. and Webster, P. (1998) Weather-conditioned Markov model for the occurrence of daily rainfall in Nigeria. In. Hydrology in a Changing Environment, Vol. I Wheater, H. and Kirby, C. (Eds.). Proc. of the First International Conf. of the British Hydrological Society: p. 71 – 80.

Jimoh, O. D. and Webster, P. (1996) Optimum order of Markov chain for daily rainfall in Nigeria. Journal of Hydrology, Vol. 185: 45 – 69.

Jimoh, O. D. (1992a) On equity of water distribution system to Kano River Project. Proc. of the 16th Annual Conf. of Nigerian Society of Agricultural Engineers, Minna: p.8 - 13.

Jimoh, O. D. (1992b). Hydrology. In: Sikoki, F. D. (Ed.) Rapid Inventory Survey of Shiroro Lake Watershed and Fisheries, Chapter 3, p. 31 - 47. A Consultancy handled by FUTMIN Consult, Federal University of Technology, Minna for The Presidency, Natural Resources and Environmental Conservation, Abuja.

Jimoh, O. D. and Sule, B. F. (1992) Hydrological analysis of water balance in the Gurara River basin catchment (Nigeria). Proc. of 4th Int. Conf. of Hydraulic Software, Valencia, Spain: p. 39 - 49.

KYBP 2006. Komadugu Yobe Basin Water Audit Report. A Report by Afremedev Consultancy Services Limited for FMWR-IUCN-NCF Komadugu Yobe Basin Project, Kano, Nigeria.

Labaide, J. W. (2004) Optimal operation of multireservoir systems: state-of-the-art revie., " J. Water Resour. Plan. Manage., 130(2), 93-111.

Labadie, J., Brazil, L., Corbu, I., and Johnson, L., eds. (1989). Computerized decision support systems for water managers, ASCE, Reston, Va

Loucks, D. P. and van Beek, E. (2005). Water Resources Systems Planning and Management. An Introduction to Methods, Models and Applications. with contributions from Stedinger, J. R., Dijkman, J. P. M and Villars, M. T. Studies and Reports in Hydrology, Delft Hydraulics, UNESCO Publication.

Maurya, P. R. and Sachan, R. S. (1984). Large – and small scale irrigation systems in Nigeria. A comparative study. Lecture given at African Regional Symposium on Small Holder irrigation, Harare, Zimbabwe, September.

Mogbo, T. C. and Jimoh, O. D. (2001) The management of water supply in Nigeria: A case study of the Federal Capital Territory. Proc. of the 3rd Annual Engineering

Conference of the School of Engineering and Engineering Technology, Federal University of Technology, Minna: p. 90 – 97.

MottMacdonald International (1992). Sub-Saharan Africa Hydrological Assessment West African Countries. Coutry report: Nigeria. The World Bank United Nations Development Programme. MottMacdonald International, Cambridge, U.K. in association with BCEOM Montferrier-Sur Lez, France and SOGREAH Grenoble, France.

NAPA. (2007). National Adaptation Program of Action on Climate Change in Uganda

National Population Commission (2006): 'Preliminary Report on 2006 National Population and Housing Census', No.2, Vol. 96 printed and published by The Federal Government Printer. Abuja, Nigeria

Nicholson, S. E. (1981) Rainfall and atmospheric circulation during drought periods and wetter years in West Africa. Mon. Wea. Rev., 109: 2191 - 2208.

Niger State Water Board (2006), Progress report on the board achievement.

Nigerian Tribune (2010). Cholera death toll now 781. Nigerian Tribune Wednesday, 08 September 2010.

Nwa, E. U. (1978) Water resources development, utilisation and management for agricultural production in Nigeria. Samaru Conference Paper 16. Zaria, Nigeria: Institute of Agricultural

NWRMP (1995). The National Water Resources Master Plan. The report of a study carried out by Japan International Cooperation Agency (JICA) with National Water Resources Master Plan (NWRMP) team for Federal Ministry of Water Resources and Rural Development, Federal Republic of Nigeria. Sector Report, vol 2, part 2. Prepared by Sanyu Consultants Inc and Sumiko Consultants Co., Ltd.

Oke, V. O. (1995) Status of reservoir management and operation in Nigeria in view of climate change. In. Global Climate Change- Impact on energy development, Umolu, J. C. (Ed.): 107 – 114.

Olaniran, O. J. and Sumner, G. N. (1989) A study of climatic variability in Nigeria based on the onset, retreat, and length of the rainy season. Int. J. Climatol. 9: 253-269.

Olivry, J.C., Chouret, G., Vuillaume, G., Lemoalle, J. and Bricquet, J.P. (1996). Hydrologie du Lac Tchad, ORSTOM, Monographies Hydrologiques, 12:266. Paris, France.

Oloruntoba, E. O. and Sridhar, M. K. C. (2007). Bacteriological quality of drinking water from source to household in Ibadan, Nigeria, African Journal of Medicine and Medical Sciences, Vol 36, 169-175

Oloruntoba, E. O., Agbede, O. A. and Sridhar, M. K. C. (2006). Seasonal variation in Physiochemical quality of household drinking water in Ibadan, Nigeria, ASSET-An International Journal, Series B, Vol. 5 (1), 70-81

Okpanefe, P. E. and Owolabi, S. (2002). Small hydropower in Nigeria. 2001 TCDC Training Workshop on SHP. SHP News, Spring 2002.

Replogle, J. R., Mariam J. L. Swarmer, L. R., and Phenan, J. T. (1983). Farm water delivery systems. In. Jensen, M. E. (ed.) . Design and Operation of Farm Irrigation Systems. A.S.A.E. Monograph No. 3.

Servant, M. and Servant, S. (1983). Paleolimnology of an upper quaternary endorheic lake in Chad basin. In: Carmouze, J.P., Durand, J.R. and Leveque, C. (eds), Lake Chad. Monographiae Biologica 53: 11-26.

Sridhar, M. K. C. and E. O. Oloruntoba (2008).Water, Development, Health and the Nigerian Millennium Development Goals, Chapter 5, in Environmental Planning and Health in Nigeria, Essays in honour of Professor Timothy Olayiwola Egunjobi, Edited by Tunde Agbola,

Stedinger, J., Sule, B., and Loucks, D. (1984). Stochastic dynamic programming models for reservoir operation optimization. *Water Resour. Res.*, 20(11), 1499-1505.

Stern, R. D. (1980a) Analysis of daily rainfall at Samaru, Nigeria, using a simple two-part model. Arch. Met. Geophy. Biokl. Ser. B. 28: 123 - 135.

Stern, R. D. (1980b) The calculation of probability distribution for models of daily precipitation. Arch. Met. Geophy. Biokl. Ser. B. 28: 137 - 147.

Tejada-Guibert, J., Stedinger, J., and Staschus, K. (1990). Optimization of the value of CVP's hydropower production. J. Water Resour. Plan. Manage., 116(1), 52-70.

Tejada-Guibert, J., Johnson, S., and Stedinger, J. (1995). The value of hydrologic information in stochastic dynamic programming models of a multireservoir system. Water Resour. Res., 31(10), 2571-2579.

The Brundtland Commission (1987). Sustainable Development. The United Nations World Commission on Environment and Development.

UN (1992). The Dublin Statement on Water and Sustainable Development. International Conference on Water and the Environment (ICWE) in Dublin, Ireland, on 26-31 January 1992.

United Nations Development program (2006). Human Development Report http://www.data360.org/dsg.aspx?data_set_group_id=757

USACE (1991). Optimization of multipurpose reservoir system operations: A review of modelling and analysis approaches, Research Document No 34, US Army Corps of Engineers. Hydrologic Engineering Center, Davis, CA.

USACE (1996). Developing seasonal and long-term reservoir system operation plans using HEC-PRM. US Army Corps of Engineers. Hydrologic Engineering Center. Davis, CA. www.hec.usace.army.mil

WADSCO. (2005) Development of the Gurara water transfer project. By Water and Dam Services Company Workshop on Federal Ministry of Water Resources Gurara water transfer to FCT, Paper 1, 12 pp.

Water Utilities Project (2001). Water Utilities Project No. 5 - Strengthening the Capacity of Water Utilities to Deliver Water and Sanitation Services, Environmental Health and Hygiene to Low Income Communities. Case Study for Kano (town), Nigeria Context and Practices. Lead Consultant: Engr. Mohammed H. Iliyas. Water Utility Partnership for Capacity Building in Africa

WHO (2002). Managing Water in the Home: Accelerated Health Gains from Improved Water Supply. Geneva.WHO/SDE/WSH/02.07 prepared by Sobsey, M.D. http://www.who.int/water_sanitation_health.

WHO/UNICEF (2000) Global Water Supply and Sanitation 2000 Assessment Report. World Health Organisation and United Nation's Children Fund Joint Monitoring Programme for Water Supply and Sanitation. WHO, Geneva.

WMO (1947). Guide to Hydrometeorological Practices. Third edition, World Meteorological Organization, WMO No 168 Technical paper 82

Wurbs, R. (1993). 'Reservoir-system simulation and optimization models. J. Water Resour. Plan. Manage, 119(4), 455-472.

Yeh, W. (1985). "Reservoir management and operations models: A state-of-the-art review." Water Resources. Res., 21(12), 1797-1818.

Young, G. K. (1966). Techniques for finding operating rules, Ph.D. Thesis, Harvard University, Cambridge, MA, 100p; a derivative work was published as 'Finding reservoir operating rule', Journal of the Hydraulics Division, ASCE, vol. 93, No HY6, November, pp. 297 – 319.

Zarma, I. H. (2006). Hydro Power Resources in Nigeria. Being a country position paper presented at 2nd Hydro Power for Today Conference International Centre on Small Hydro Power (IC-SHP), Hangzhou, China 2006